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F8b

CD-0010-22

December 15, 2023

Appendix B: Works Cited

Works Cited

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CDFW 1998
Species Accounts for Western Red Bat
and Pallid Bat provided

TERRESTRIAL MAMMAL SPECIES OF SPECIAL CONCERN IN CALIFORNIA

Edited by
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Report prepared for
CALIFORNIA DEPARTMENT OF FISH AND GAME
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Submitted May 1998

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CALIFORNIA DEPARTMENT OF FISH AND GAME

Pallid bat, *Antrozous pallidus*

Elizabeth D. Pierson & William E. Rainey

Description: *Antrozous pallidus* is a large (forearm = 45-60 mm), long-eared vespertilionid bat. It can be readily distinguished from all other California bat species by a combination of large size, large eyes, large ears, light tan coloration, a pig-like snout, and a distinctive skunk-like odor. Although color varies from very light, almost blonde, in desert populations, to tan along the coast and farther north, the overall impression is of a light colored bat. No other species has fur this light. It lacks the nose-leaf found in *Macrotus californicus* and the bilateral nose lumps found in *Corynorhinus townsendii*. *Myotis evotis* is much smaller and has dark, rather than pale colored, ears. *Euderma maculatum*, which also has light ears, can be distinguished by its unique pelage coloration -- black with three large, white dorsal spots.

Pallid bats sometimes leave characteristic sign. Remains of scorpions, Jerusalem crickets, sphinx moth wings, and/or long-horned beetles in association with bat guano, indicate the presence of pallid bats. It is possible, however, to find pallid bat guano deposits that do not have culled insect parts.

Taxonomic Remarks: *A. pallidus*, a member of the Family Vespertilionidae, was first described in 1856 from a specimen collected in El Paso, Texas (LeConte 1856). The first record of *A. pallidus* for California was from Old Fort Tejon, Kern County (Merriam 1897). Based on morphometric analyses, there are six currently recognized subspecies of *A. pallidus*, with three (*A. p. pacificus*, *A. p. pallidus*, and *A. p. minor*) occurring in California (Martin and Schmidly 1982). The primary characteristic used to separate subspecies is size. Since genetic analyses have not been conducted on California populations, geographic boundaries between the subspecies have not been clearly delineated, and specimens for most localities have not been examined, we treat all California *Antrozous* as *A. pallidus*. Koopman (1993) recognizes two species of *Antrozous*, *A. pallidus* and *A. dubiaquercus*, whereas others (Engstrom and Wilson 1981, Engstrom et al. 1987) place the latter species in a separate genus, *Bauerus*.

Distribution: Pallid bats are known from Cuba, Mexico and Baja California, through the southwestern and western United States, into southern British Columbia. They occur as far east as Kansas, Oklahoma, and Texas, and throughout much of the United States west of the Rocky Mountains (Hall 1981, Martin and Schmidly 1982). In California, the species occurs throughout the state in a variety of habitats including low desert, oak woodland and coastal redwood forests, extending up to 3,000 m elevation in the Sierra Nevada.

According to Martin and Schmidly (1982), *A. p. pacificus*, the largest subspecies, occurs along the coast and in the coast ranges west of the Central Valley. *A. p. minor*, the smallest subspecies, occurs in the Colorado River basin and adjacent mountain ranges. *A. p. pallidus* occurs throughout the rest of the state (including western San Diego County, the Central Valley, all of the Sierra Nevada and areas east of the crest, and, farther north, all areas east of the coast ranges). Martin and Schmidly (1982) describe an area of intergradation in the Klamath Mountains between *A. p. pacificus* and *A. p. pallidus*. According to Hall (1981), *A. p. pallidus* is confined to the area east of the Sierra Nevada crest, south of Lake Tahoe. The subspecific status of *A. pallidus* populations in California warrants further investigation.

Life History: Pallid bats are colonial, with a typical colony containing 30-70 animals, although colonies of several hundred have been found. Colonies form in the spring (March-May), and stay together until October (Barbour and Davis 1969). These colonies can be bachelor groups, but usually consist of adult females and their young. Pallid bats mate in the fall or winter, but, as is typical of northern hemisphere vespertilionids, the females do not actually become pregnant until the spring. They give birth to one or two young in early summer (Orr 1954). Young are born in an altricial state, dependent on their mothers for at least 6 weeks. They are deaf at birth and begin to respond to low frequency vocal communications at about 6 days of age, and have hearing equivalent to that of an adult by 12 days of age (Brown 1976, Brown et al. 1978). The young accompany their mothers when first learning to fly and forage (Brown and Grinnell 1980). Although they are weaned at 6-8 weeks, the young are not self-sufficient until the fall when colonies disperse. Recapture data from the upper Sacramento River drainage suggest that females in that part of California do not reproduce until they are two years old (Rainey and Pierson 1996). Lewis (1993) showed that reproductive success was positively correlated with temperature for a pallid bat population in Oregon. Pallid bats are not known to migrate, and are presumed to spend the winter hibernating close to their summer roosts. No wintering aggregations have been found, although hibernating individuals have been detected close to or in the same structures as the summer roosts (Barbour and Davis 1969, C. Scott pers. comm.).

Pallid bats forage primarily on large (20-70 mm) arthropods, caught on the ground or gleaned off vegetation. Prey items include flightless arthropods, such as scorpions (Vejoridae), ground crickets (Gryllacrididae), solpugids (Solpugidae), and darkling ground beetles (Tenebrionidae); largely ground-roving forms, including scarab beetles (Scarabeidae), predacious ground beetles (Carabidae), carrion beetles (Silphidae), and short-horned grasshoppers (Acrididae); and vegetation-dwelling insects, including cicadas (Cicadidae), katydids (Tettigoniidae), praying mantids (Mantidae), long-horned beetles (Cerambycidae) and sphingid moths (Sphingidae) (Hatt 1923, Borell 1942, Barbour and Davis 1969, Hermanson and O'Shea 1983).

Radiotelemetry (P. Brown pers. comm.) and the known behavior of favored prey items suggest pallid bats fly close to the ground, and land on the ground to capture prey. Light-tagging studies have also documented animals feeding on the wing, 10-20 ft (3-6 m) off the ground (pers. obs.). Discarded large arthropod remains most commonly found in pallid bat roosts in California are Jerusalem crickets, cicadas, long-horned beetles, and scorpions (D. Pierson and W. Rainey pers. obs.). Although pallid bats use echolocation to assess habitat, they apparently locate prey primarily by listening (Bell 1982). Pallid bats have also been reported as visitors to fruits and flowers (Barbour and Davis 1969, Howell 1980). Although they are presumably feeding on insects associated with these plants, they also appear to serve as pollinators of some desert plants (Herrera et al. 1993).

Habitat: Although pallid bats are frequently associated with desert areas and the Sonoran Life Zone (Barbour and Davis 1969, Hermanson and O’Shea 1983), Orr (1954), who studied this species extensively in California, described the species as occurring in a number of habitats, including coniferous forests, nonconiferous woodlands, brushy terrain, rocky canyons, open farm land, and desert. In our observations (D. Pierson and W. Rainey) in northern California, this species is associated with oak habitat, particularly lower elevation oak savannah. It is also found in association with coast redwoods, and mid- to higher elevation coniferous forest (Orr 1954, Rainey et al. 1992). It is, for example, one of the species most frequently observed in Giant Sequoia groves at ca. 2,000 m (Pierson and Heady 1996).

Pallid bats are primarily a crevice roosting species, and select daytime roosting sites where they can retreat from view. Common roost sites are rock crevices, old buildings, bridges, caves, mines, and hollow trees (Barbour and Davis 1969, Hermanson and O’Shea 1983). Recent radiotracking efforts in the west, including California, suggest that pallid bats are far more dependent on tree roosts than was previously realized. They have been located in tree cavities in oak, Ponderosa pine, coast redwood and giant Sequoia (Rainey et al. 1992, Cross and Clayton 1995, Pierson and Heady 1996).

On Santa Cruz Island, however, radio-tagged animals selected rock crevices and buildings, despite abundant oak woodland (Brown et al. 1984). Pallid bats are also one of the species most predictably associated with bridges. They sometimes roost in expansion joints by day, but more commonly are found night roosting, particularly under concrete girder structures (Lewis 1994, Pierson et al. 1996). They are also often associated with buildings, ranging from collapsing barns and historically significant sites (e.g., some of the missions) to some relatively recent structures.

Roost temperature may be a limiting factor in roost selection. Cliff-roosting pallid bats in Arizona selected crevices that remained warm and stable (ca. 30^{o} C) in the summer, and tracked ambient temperature fluctuations in spring and fall (Vaughan and O'Shea 1976). Pallid bats are intolerant of roost temperatures above 40^{o} C (Licht and Leitner 1967), and often occupy roosts that offer a varied temperature regime. In attic settings, the animals emerge from crevices to roost on open rafters when roof temperatures become excessive. Pallid bats are very sensitive to disturbance at the roost. When disturbed, they generally retreat into crevices, and with repeated disturbance, may abandon the roost. Their response time is slow, however, making them vulnerable to shooting and other forms of vandalism, and their loyalty to a chosen roost (particularly buildings, mines, bridges) is generally high.

In central coastal California, pallid bats are most frequently found foraging in open oak woodland, but also feed in forested canyons (E. Pierson and W. Rainey pers. obs.). Radiotracking studies have shown that animals generally feed within 6-8 km of their roost, and have regularly occupied feeding areas (E. Pierson and B. Rainey unpubl. data; P. Brown pers. comm.).

Status: Class II. Although the status of *A. pallidus* has not been investigated, bat biologists have noted a definite decline in populations in recent years in California (P. Brown pers. comm.; E. Pierson and W. Rainey pers. obs.). For example, in 1980, four substantial pallid bat roosts were known in Napa County, and two in southern Sonoma County. Only one of these is still occupied, and when last checked, had many fewer animals than in 1980. This decline may be due to the conversion of oak woodlands to vineyards in the Napa Valley. This species, although it will coexist with humans in rural settings, appears to be intolerant of suburban and urban development. In the San Francisco Bay area, there are museum records for pallid bats from the Stanford University campus for 1895-1951, for San Francisco in 1948-1950, and for Berkeley from 1883-1945. Available data suggest this species is extirpated from all these localities. Recent surveys of the Presidio in San Francisco found no pallid bats despite the persistence of small remnant patches of suitable oak habitat (Pierson and Rainey 1995). Although there have been numerous records of bats on the UC Berkeley campus in the past 20 years, none have been pallid bats. The species does persist in the more rural eastern portions of Alameda and Contra Costa counties, and in parts of Marin County, particularly in the vicinity of Point Reyes National Seashore and in proximity to oak woodland.

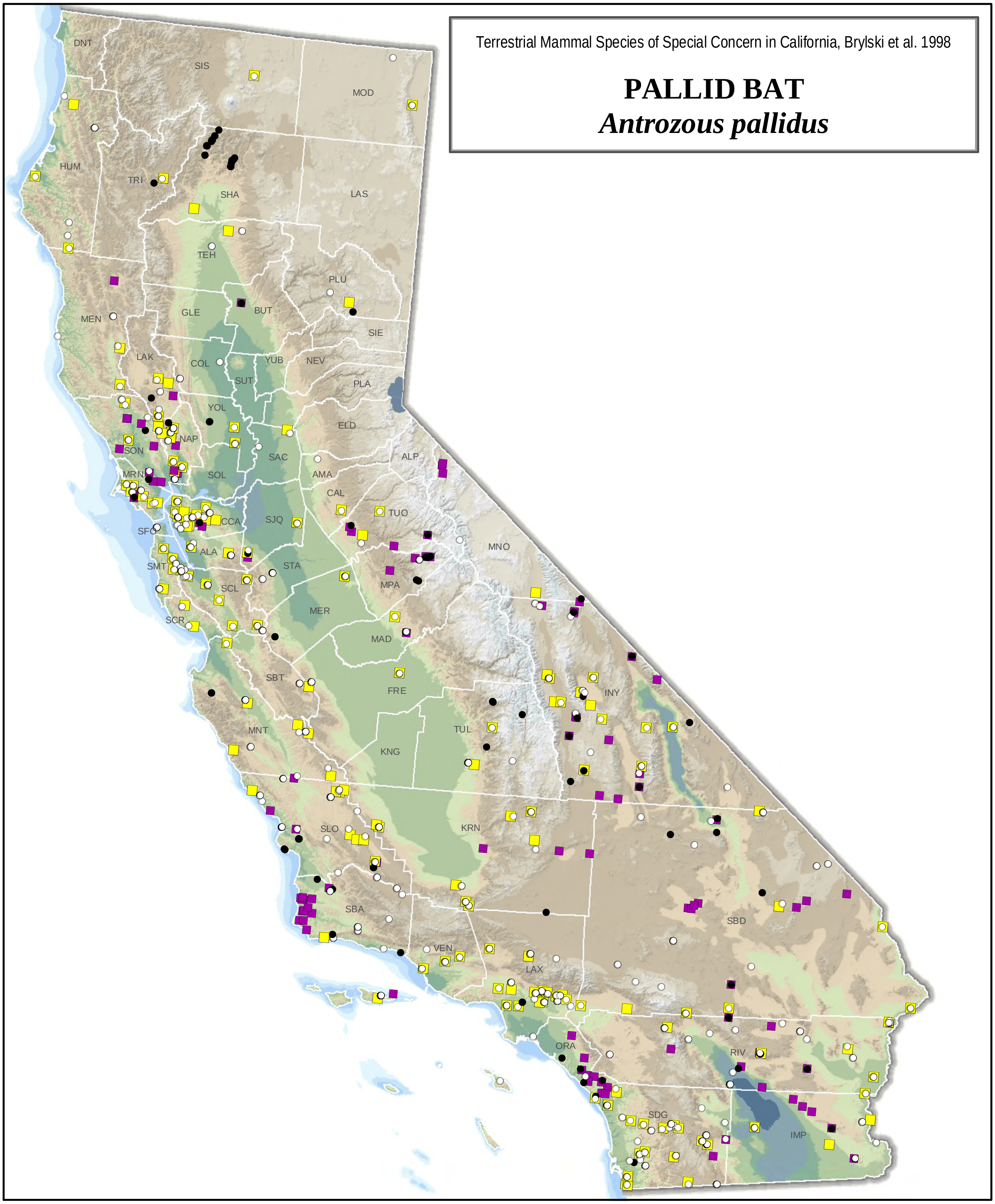
P. Brown (pers. comm.) has noted precipitous declines in populations in coastal southern California since the 1970s. Yet, at that time, only one of 12 roost sites documented by Krutzsch (1948) in the 1940s was still occupied (P. Brown pers. comm.). Destruction of buildings and urban expansion likely account for observed declines in Los Angeles, Orange, and San Diego counties.

Current timber harvest practices, particularly the selective removal of hardwoods and large Ponderosa pine snags, likely pose a serious threat to pallid bat populations in forested areas. Additionally, at lower elevations, oak habitat is being lost to suburban expansion and agricultural conversion. The rapidly growing human population of the Sierra foothills is a case in point. Because pallid bats frequently roost in buildings, they often are excluded by renovations or by the desire of property owners to be rid of them. Because their roosting sites are often highly visible (e.g., open rafters) and the animals display considerable roost loyalty, they are often targeted by pest control operators and vandals. This species is often associated with historic buildings in which their presence is typically viewed as a hazard by property managers. Pallid bats colonies could also be impacted by bridge modifications and/or replacements, inappropriate mine/cave closures, and human induced alterations of rock features (e.g., blasting of cliffs for road construction or inundation for water impoundment).

Management Recommendations: Status surveys are necessary, particularly in areas where apparent declines have occurred or where habitat conversion is most intense. More information is needed on the habitat requirements of pallid bats, particularly in forested settings. Genetic studies, using non-lethal sampling techniques, should be conducted to resolve subspecies issues.

Terrestrial Mammal Species of Special Concern in California, Brylski et al. 1998

PALLID BAT
Antrozous pallidus



Locations verified by authors
(captures, observations, museum records)

● Post - 1978

○ 1978 and before

■ CNDDB post-1978

🟨 CNDDB 1978 and before

1:4,880,000
Wildlife Branch:KFien12109

Red bat, *Lasiurus blossevillii*

Elizabeth D. Pierson & William E. Rainey

Description: *Lasiurus blossevillii* is a medium sized bat with a short rostrum, short rounded ears, and a heavily furred interfemoral membrane (Barbour and Davis 1969, Shump and Shump 1982). It can generally be distinguished by the brick-red color of its fur. The color, however, can vary from intense red to yellow-brown. It can, nevertheless, be distinguished from the other *Lasiurus* species with which it could be most readily confused based on size. *L. blossevillii* has a forearm of 35-45 mm. *Lasiurus xanthinus*, which generally has more yellow fur, is larger, with a forearm of 45-48 mm. *Lasiurus cinereus* is considerably larger, with a forearm of 46-58 mm. The pelage of *L. cinereus* is generally dark grey, with frosted white tips, a yellow face, and ears rimmed in black. Although *L. blossevillii* can appear somewhat frosted and have a yellowish tinge to its fur, it is never as dark, nor as frosted, as *L. cinereus*.

Taxonomic Remarks: The red bat is generally included in the genus *Lasiurus* (Family Vespertilionidae) as *L. borealis* (Koopman 1993). Hall (1981), who reverted to an earlier generic name, *Nycteris*, mapped the distribution of six subspecies, with all California animals referred to *N. borealis teliotis*. Genetic studies (Baker et al. 1988, Morales and Bickham 1995) support the separation of red bats into four separate species, with all animals in the western United States, Mexico, Central America, and South America referable to *L. blossevillii*.

Distribution: *L. blossevillii* has a very broad distribution reaching from southern British Columbia, through much of the western United States, through Mexico and Central America, reaching as far south in South America as Argentina and Chile (Hall 1981, Shump and Shump 1982).

In California, the majority of records are from the coastal areas from the San Francisco Bay area south, plus the Central Valley and surrounding foothills, with a limited number of records from southern California, extending as far east as western Riverside and central San Diego counties. Red bats have been captured or seen on three occasions on Santa Cruz Island (P. Brown pers. comm.). There are no records from the lower desert, from higher elevations in any of the mountain ranges, nor from the east side of the Sierra Nevada. Red bats have been captured in Nevada, however, just a mile east of California and the White Mountains (J. Szewczak pers.comm.). Currently, the most northern locality in California is from the upper Sacramento River near Dunsmuir, Siskiyou County (Rainey and Pierson 1996).

There are multiple records for red bats in the San Francisco Bay area in the spring, fall, and winter months, including records from Golden Gate Park in San Francisco (Grinnell 1918, Orr 1950, Constantine 1959). Although reproductive females and young do occur in coastal California in the summer (Constantine 1959, C. Scott and P. Winters pers. comm.), they are more likely to be located inland, particularly in the Central Valley, where they can find the desired summer temperatures of 80-95°F (Constantine 1959). Immature animals from several localities in eastern Contra Costa County have been turned in to rehabilitation facilities during June and July in recent years (C. Scott pers. comm.).

Life History: Reproductive patterns in red bats are summarized by Shump and Shump (1982). Whereas most vespertilionid bats have a single young per year, red bats have litters of up to five. No information is available on *L. blossevillii*, but *L. borealis* has a mean litter size of 3.2 young (Shump and Shump 1982). In the midwest, *L. borealis* are born around the middle of June. In California, two young about 2 weeks old were found in Contra Costa County on July 1 (C. Scott pers. comm.). Young are born at about 0.5 g. each, and can fly at 3-6 weeks of age. This species mates in the late summer or early fall. Females become pregnant in spring and have a pregnancy of 80-90 days.

Red bats forage on a number of insect taxa, flying at both canopy height and low over the ground (Shump and Shump 1982). The limited dietary information has all come from *L.borealis* in the eastern U.S. No information is available on the diet of *L. blossevillii* in California. In a study conducted in Indiana, Whitaker (1972) found that red bats ate 26% moths. Other studies (summarized in Shump and Shump 1982) have also found Homoptera, Coleoptera, Hymenoptera, and Diptera in the diet.

Red bats are migratory, and there are records of them on the east coast being found a considerable distance out to sea (Norton 1921, Carter 1950). The most striking account of migration comes from Mearns (1898), who describes "great flights of them the whole day."

Habitat: *L. blossevillii* roosts in the foliage of trees and shrubs, predominantly in edge habitats adjacent to streams and open fields (Shump and Shump 1982). Constantine (1959) found the species roosting in fruit trees (apricot and orange) in the Central Valley of California. An analysis of these roost sites by Constantine (1959) suggested the bats selected trees that were well-pruned and 4.5-6.0 m in height, with roost sites typically located 2.6 m above the ground. The trees had rigid branches and short stems which resisted the wind, a spreading canopy, and lacked lower limbs that might provide perches for predatory birds. The roosting site was usually dark, well sheltered from above, with open exposure for free flight below. Dalquest (1945) noted daytime roosting sites for *L. blossevillii* in tamarisk windbreaks along irrigation ditches in California's Central Valley. Although *L. borealis* has been reported roosting in caves in Kentucky and Missouri (Quay and Miller 1955, Myers 1960), this behavior has never been seen in *L. blossevillii*.

Although they have been observed foraging around lights in urban areas (e.g., Shump and Shump 1982), Constantine (1959) found red bats primarily in areas distant from human habitation. In Canada, Furlonger et al. (1987) found they foraged around lights in towns and rural areas, more than in urban areas. The animals studied by Orr (1950) in Golden Gate Park in San Francisco were roosting in *Sparmannia africana*, a large-leafed, exotic, evergreen plant commonly planted in gardens in the Bay area. On Santa Cruz Island, red bats were observed foraging among native oaks and ironwood trees (Brown et al. 1994). Winter behavior of this species is not well understood. Saugey et al. (1994) recently documented, through a radiotracking study in Arkansas, that when temperatures dropped, some individuals moved from trees to hibernate in the leaf litter. Red bats apparently arouse from hibernation on warm days to feed (Shump and Shump 1982), and Orr's observations suggest that this species forages periodically during the winter in the San Francisco Bay area (Orr 1950).

Status: Class II. The status of this species in California is not currently known, although it occurs relatively rarely in net captures, in Department of Health Services records, and at rehabilitation facilities (D. Constantine pers. comm., C. Scott pers. comm., W. Rainey and E. Pierson unpubl. records)

Given what is known of the distribution and habitat needs of this species in California, it is possible to identify a number of threats, and hypothesize population declines and extirpations in certain areas, as follows:

<u>Predation</u>: Predation, other than human disturbance, is rarely an issue for bat species which seek cryptic and protected diurnal retreats (e.g., crevices). It can, however, be a factor for the foliage dwelling lasiurines. There are a number of reports in the literature of red bats being attacked and

killed by birds, particularly jays (Allan 1947, Downing and Baldwin 1961, Wilks and Laughlin 1961, Elwell 1962, Hoffmeister and Downes 1964, Horsley 1991). There is also a record of red bats being eaten by an opossum (*Didelphis virginiana*) (Sperry 1933). Since both jays and opossums thrive as commensals with humans, it is likely that predation from these species has increased for red bats. Additionally, a significant proportion of the red bats turned in to rehabilitation facilities has been retrieved from domestic cats.

Agricultural Conversion of Riparian Zones: Past records have shown a close association between red bats and riparian corridors. Particularly important are those associated with the major river systems that drain the Sierra Nevada. Agricultural conversion has led to significant loss of riparian corridors in the Central Valley, and thus has reduced both roosting and foraging habitat for *L. blossevillii*.

Storage Reservoirs: Storage reservoirs occur on most of the major rivers draining the Sierra Nevada, and are particularly prevalent at lower elevations, at ca. 200-600 m. A significant amount of riparian vegetation has been submerged by these reservoirs. Mist netting surveys in the Los Banos Creek drainage, at the site of a proposed reservoir, documented an association between *L. blossevillii* and the large stand of mature sycamores in that drainage. Additionally, the changes in downstream flooding regimes resulting from dam construction lead to altered riparian vegetation.

Pesticides: Constantine (1959) documented that *L. blossevillii* roosts in fruit trees in the Central Valley. Many fruit orchards are subjected to particularly intense pesticide treatments. Although the effects of aerially sprayed organophosphates on *L. blossevillii* have not been specifically examined, documentation of negative impacts on raptors (Wilson et al. 1991) suggests potential problems for bats.

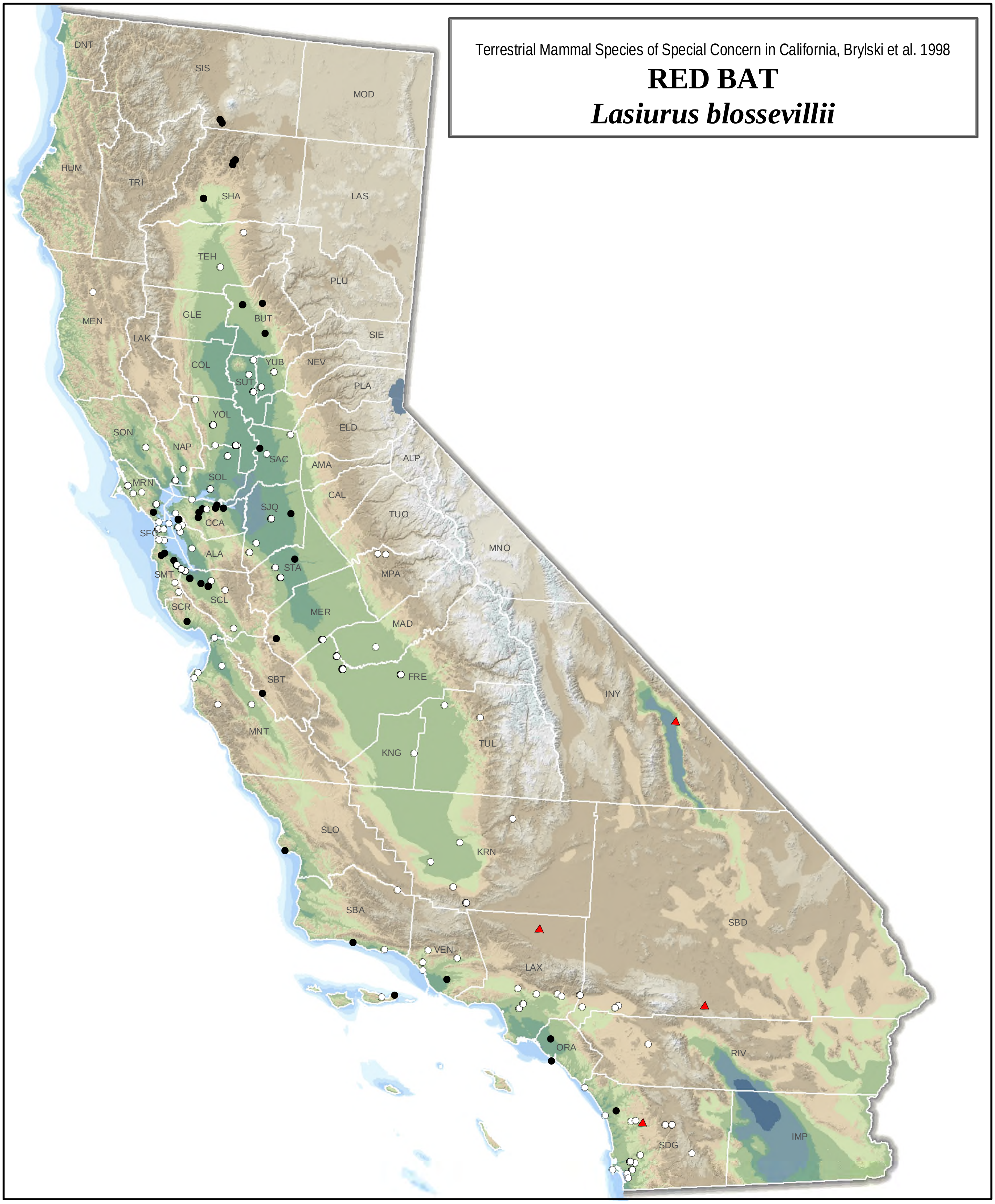
Fire: The finding of Saugey et al. (1994) that red bats may move down to the leaf litter when temperatures drop raises questions regarding potential impacts from fire, particularly controlled burns which are conducted in either the spring or fall.

Management Recommendations: Given the high association of this species with agricultural and riparian areas, a status review, particularly in the Central Valley and surrounding foothills, is urgently needed. Radiotracking should be conducted to characterize roost sites and foraging habitat. It is likely that the species would benefit from any reduction in pesticide use, and restoration of riparian habitat.

Terrestrial Mammal Species of Special Concern in California, Brylski et al. 1998

RED BAT

Lasiurus blossevillii



Locations verified by authors
(captures, observations, museum records)

● Post - 1978

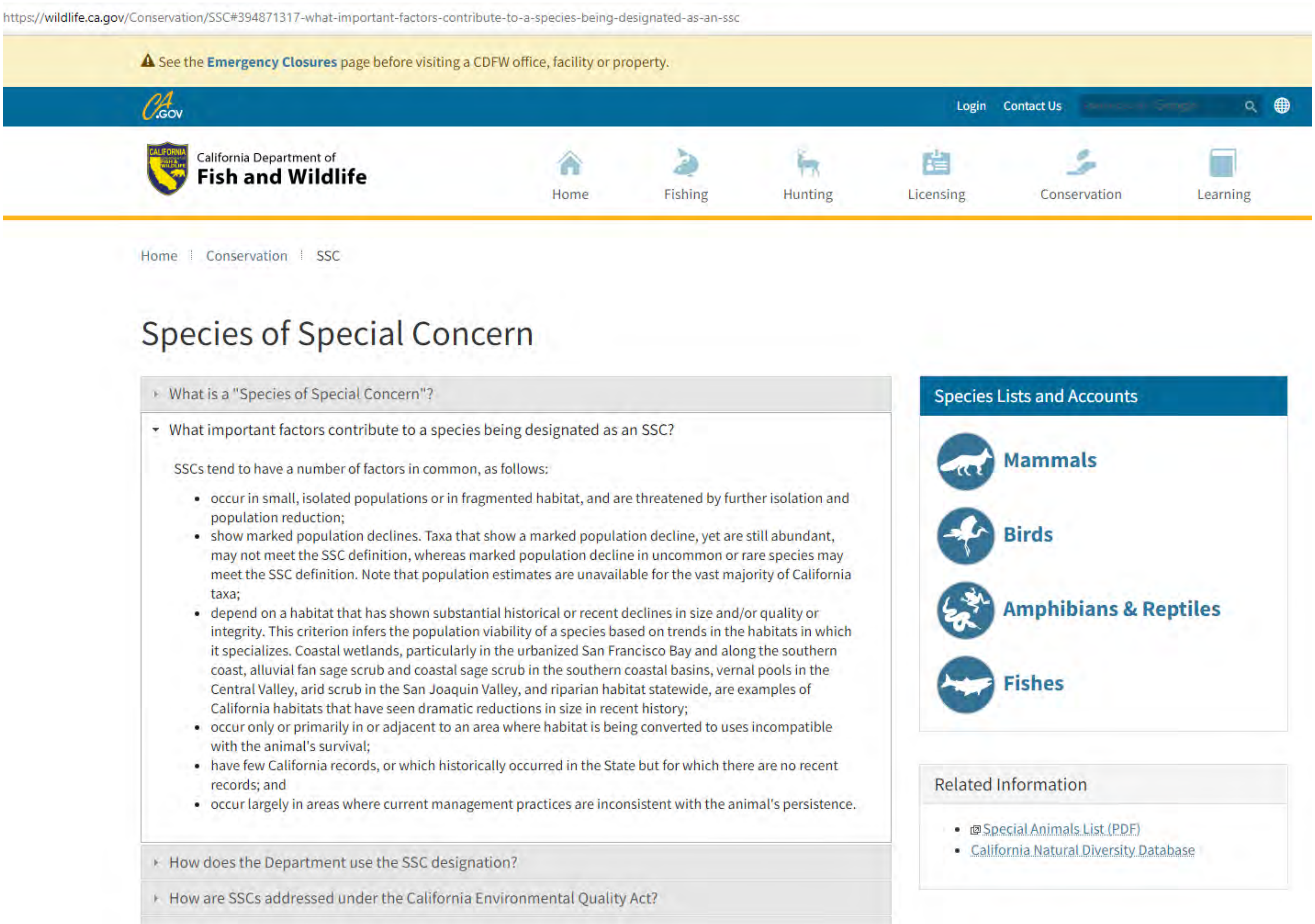
○ 1978 and before

▲ Constantine 1998

No CNDDB records

1:4,880,000
Wildlife Branch:KFien12109

CDFW 2023



https://wildlife.ca.gov/Conservation/SSC#394871317-what-important-factors-contribute-to-a-species-being-designated-as-an-ssc

⚠ See the **Emergency Closures** page before visiting a CDFW office, facility or property.

California Department of
Fish and Wildlife

Home ⁝ Conservation ⁝ SSC

Species of Special Concern

▸ What is a "Species of Special Concern"?

▾ What important factors contribute to a species being designated as an SSC?

SSCs tend to have a number of factors in common, as follows:

- occur in small, isolated populations or in fragmented habitat, and are threatened by further isolation and population reduction;
- show marked population declines. Taxa that show a marked population decline, yet are still abundant, may not meet the SSC definition, whereas marked population decline in uncommon or rare species may meet the SSC definition. Note that population estimates are unavailable for the vast majority of California taxa;
- depend on a habitat that has shown substantial historical or recent declines in size and/or quality or integrity. This criterion infers the population viability of a species based on trends in the habitats in which it specializes. Coastal wetlands, particularly in the urbanized San Francisco Bay and along the southern coast, alluvial fan sage scrub and coastal sage scrub in the southern coastal basins, vernal pools in the Central Valley, arid scrub in the San Joaquin Valley, and riparian habitat statewide, are examples of California habitats that have seen dramatic reductions in size in recent history;
- occur only or primarily in or adjacent to an area where habitat is being converted to uses incompatible with the animal's survival;
- have few California records, or which historically occurred in the State but for which there are no recent records; and
- occur largely in areas where current management practices are inconsistent with the animal's persistence.

▸ How does the Department use the SSC designation?

▸ How are SSCs addressed under the California Environmental Quality Act?

Species Lists and Accounts

Mammals

Birds

Amphibians & Reptiles

Fishes

Related Information

- Special Animals List (PDF)
- California Natural Diversity Database

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CORRECTION

Recovery of otoacoustic emissions after high-level noise exposure in the American bullfrog

Dwayne D. Simmons, Rachel Lohr, Helena Wotring, Miriam D. Burton, Rebecca A. Hooper and Richard A. Baird

There was an error published in *J. Exp. Biol.* **217**, pp. 1626-1636.

In Fig. 3, panel A has a duplicated line graph and the keys in panels B and D are incorrect. The correct figure is printed below.

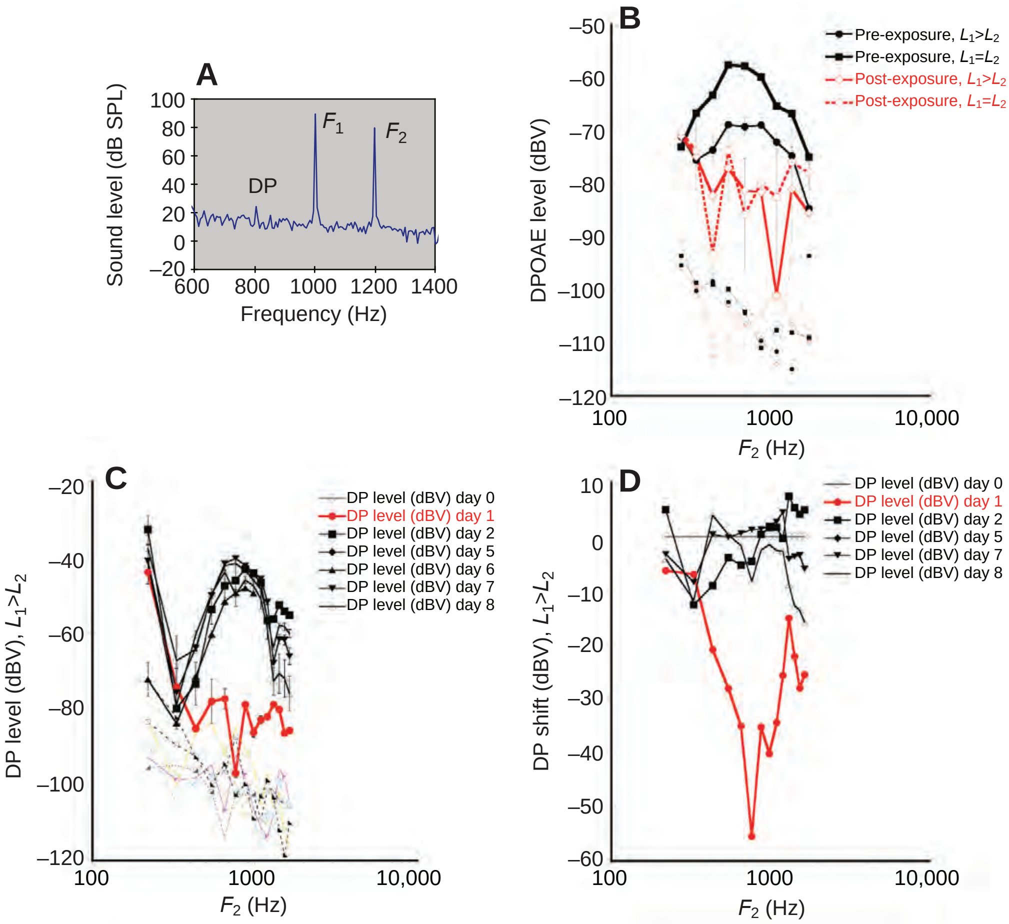

Fig. 3. Cubic distortion products recorded before and after noise exposure in adult bullfrogs. (A) The cubic distortion product (DP) $2f_1$–f_2 recorded from the bullfrog ear with primary f_1 and secondary f_2 frequencies as shown. In this example, secondary levels are 10 dB lower than primary levels. (B) Plot of cubic distortion product otoacoustic emission (DPOAE) levels from the right ear (ipsilateral) versus secondary frequency (f_2). DPOAE levels are in decibels relative to 1 V rms (dBV). The plot depicts DPOAE levels recorded before (solid symbols) and 24 h after (open symbols) 150 dB SPL broad-band noise exposure. Filled and open squares represent corresponding pre- and post-noise levels, respectively. At each frequency, the primary stimulus was held constant at 80 dB SPL and the secondary stimulus level was presented at equal strength (solid squares, L_1=L_2) and then with secondary levels 10 dB lower than primary levels (solid circles, L_1>L_2). Noise level measurements were taken and averaged on either side of the peak DPOAE level immediately before and after noise exposure, with each ear tested and averaged over three presentations. Dashed lines represent noise floor. (C) Cubic DPOAEs (L_1>L_2) from the right ear were tested before (day 0) and 1, 2, 5, 6, 7 and 8 days after noise exposure. Dashed lines represent noise floor. (D) Plot of the DPOAE shifts at each frequency tested before (0 days) and following (1, 2, 5, 6, 7 and 8 days) a 20 h noise exposure. The DPOAE shift was calculated as the difference in pre-exposure and post-exposure DPOAE levels.

We apologise to the authors and readers for this omission.

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RESEARCH ARTICLE

Recovery of otoacoustic emissions after high-level noise exposure in the American bullfrog

Dwayne D. Simmons[1,*], Rachel Lohr[2], Helena Wotring[2], Miriam D. Burton[2], Rebecca A. Hooper[2] and Richard A. Baird[2]

ABSTRACT

The American bullfrog (*Rana catesbeiana*) has an amphibian papilla (AP) that senses airborne, low-frequency sound and generates distortion product otoacoustic emissions (DPOAEs) similar to other vertebrate species. Although ranid frogs are typically found in noisy environments, the effects of noise on the AP have not been studied. First, we determined the noise levels that diminished DPOAE at $2f_1–f_2$ using an f_2 stimulus level at 80 dB SPL and that also produced morphological damage of the sensory epithelium. Second, we compared DPOAE ($2f_1–f_2$) responses with histopathologic changes occurring in bullfrogs after noise exposure. Consistent morphological damage, such as fragmented hair cells and missing bundles, as well as elimination of DPOAE responses were seen only after very high-level (>150 dB SPL) sound exposures. The morphological response of hair cells to noise differed along the mediolateral AP axis: medial hair cells were sensitive to noise and lateral hair cells were relatively insensitive to noise. Renewed or repaired hair cells were not observed until 9 days post-exposure. Following noise exposure, DPOAE responses disappeared within 24 h and then recovered to normal pre-exposure levels within 3–4 days. Our results suggest that DPOAEs in the bullfrog are sensitive to the initial period of hair cell damage. After noise-induced damage, the bullfrog AP has functional recovery mechanisms that do not depend on substantial hair cell regeneration or repair. Thus, the bullfrog auditory system might serve as an interesting model for investigation of ways to prevent noise damage.

KEY WORDS: Hearing loss, Hair Cells, Regeneration, Cubic distortion product, Active amplification

INTRODUCTION

Anuran amphibians (frogs and toads) live in environments that are inherently noisy at low frequencies, and in which many other frogs of the same species are calling in competition. The sound intensities of frog calls can reach up to 110 dB sound pressure level (SPL) within 50 cm of a calling male frog (Narins and Hurley, 1982). Thus, frogs and toads may have adaptations of their auditory system that facilitate some measure of immunity from the effects of intense sounds and noise-induced hearing loss. Like other vertebrates, the anuran inner ear is a highly sensitive, frequency analyzer. Within the bullfrog inner ear, the amphibian papilla (AP) is a sensor of airborne, low-frequency sound. The AP contains mechanosensitive hair cells that, like the mammalian cochlea, are contacted by the terminal arbors of both afferent and efferent neurons, are tonotopically organized, and generate otoacoustic emissions (OAEs) when tones are given to the ear (reviewed in Simmons et al., 2007). As the by-product of an active amplification process, OAEs in mammals reflect a fundamental property of normal hearing (Kemp, 1978; Kemp, 2002) and provide a non-invasive means of monitoring the active amplification processes necessary for hearing sensitivity (Kössl and Boyan, 1998; Kössl and Vater, 1996; Maison et al., 2007; Shera and Guinan, 1999). One type of OAE that is easily recorded is the distortion product OAE (DPOAE), in which two pure tone stimuli (f_1 and f_2) are presented to the ear and a third difference tone (f_3) is recorded as the cubic distortion product ($2f_1–f_2$). DPOAEs are a sensitive indicator of inner ear integrity and are used routinely for diagnostic screening of inner ear function (Brown et al., 2000; Lonsbury-Martin et al., 1993; Ohlms et al., 1991; Prieve, 2002; Shera and Guinan, 1999). Although DPOAEs initially were thought to be absent in the amphibian ear (Baker et al., 1989), they are now believed to be present in most anuran amphibians (van Dijk and Manley, 2001; Simmons et al., 2007). Some studies suggest that anurans may have both passive and active mechanisms responsible for the generation of DPOAEs (Meenderink and van Dijk, 2006; van Dijk et al., 2011).

In the American bullfrog, *Rana catesbeiana* (*Lithobates catesbeianus*, Shaw 1809), there have been no studies of hair cells after damaging noise levels and no studies of how DPOAEs are affected by noise. The peripheral auditory system of the frog appears designed to minimize the detrimental effects of noisy environments (Carey and Zelick, 1993; Zelick and Narins, 1985; Narins and Zelick, 1988). The bullfrog AP presumably undergoes sensory hair cell repair and regeneration similar to other inner ear organs in the bullfrog (Baird et al., 2000; Gale et al., 2002). If the bullfrog AP does exhibit noise damage, then we would expect the AP to show frequency-specific hair cell loss.

We hypothesized that hair cells in the AP are susceptible to narrow-band noise exposures and should show DPOAE responses that correlate with morphological damage and recovery. Our first goal was to investigate whether the cubic DPOAE ($2f_1–f_2$) was sensitive to noise overexposure. Our second goal was to determine the temporal course of hair cell damage and recovery. This being the first such study of noise-induced hearing loss in the bullfrog, a more detailed understanding of normal AP morphology was also necessitated.

RESULTS

Normal morphology and innervation of the bullfrog AP

In order to assess the effects of noise-induced trauma, we first characterized the normal morphology of the bullfrog AP sensory epithelia. As shown in Fig. 1A, the bullfrog AP has a triangle-shaped, rostral head and a narrower caudal extension. The AP nerve branch approached the sensory epithelium from the lateral side,

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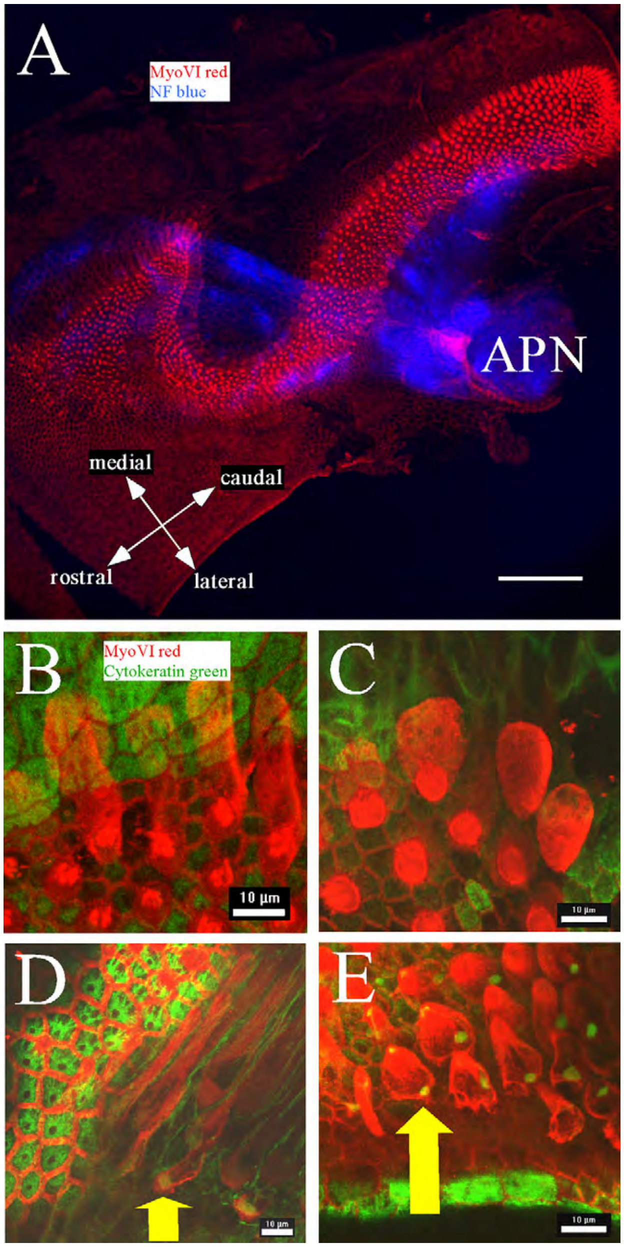

Fig. 1. Overview of bullfrog amphibian papilla. (A) Low-magnification *Z*-projection of a confocal stack of an amphibian papilla nerve branchlet (APN, blue), indicating its bifurcation and approach to the rostral (left) and caudal (right) amphibian papilla (AP). Myosin VI-labeled (MyoVI, red) hair cells extend throughout the rostral and caudal AP. (B–E) *Z*-projections of high-magnification confocal stacks of myosin VI-labeled (red) hair cells and cytokeratin-labeled (green) supporting cells in the rostral (B,D) and caudal (C,E) AP regions. Hair cells located on the medial (B,C) and lateral (D,E) margins of the AP have distinct morphologies. Lateral hair cells (D,E) co-express both myosin VI and cytokeratin (yellow arrows). Scale bars: A, 100 µm; B–E, 10 µm.

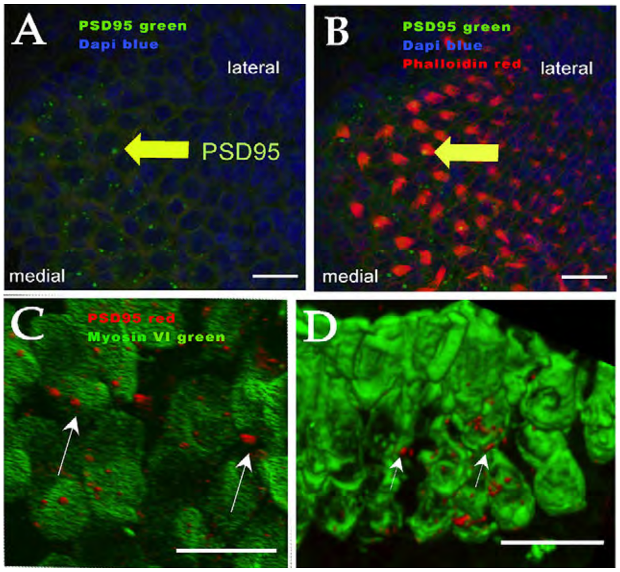

Fig. 2. Immunolabeling of the AP with antibodies against PSD-95. The panels show PSD-95-labeled puncta surrounding hair cells. (A) Low-magnification confocal image showing PSD-95 immunolabeling (green) with DAPI-stained hair cell nuclei (blue). Yellow arrows identify the same PSD-95-labeled puncta in A and B. In both rostral and caudal AP regions, PSD-95 immunoreactivity was especially robust among mature hair cells (on the medial AP margin). (B) Same image as in A except with phalloidin-stained hair bundles (red) to identify hair cells. (C) Higher magnification projection of confocal images of the medial hair cells showing myosin VI-labeled hair cells (green) in caudal medial AP regions. White arrows identify PSD-95-labeled puncta (red) on medial hair cells. (D) Higher magnification reconstruction of myosin VI-labeled hair cells in rostral medial regions of the AP. White arrows identify PSD-95-labeled puncta (red) on medial hair cells. Scale bars represent 10 µm.

bifurcating into two nerve branchlets that pass under and around the sensory epithelium before turning back to innervate hair cells in the rostral or caudal region. Hair cells were homogeneously labeled with myosin VI and supporting cells were labeled with cytokeratin (Fig. 1) (Cyr and Hudspeth, 2000; Cyr et al., 2000). We observed both rostrocaudal and mediolateral morphological differences similar to distinctions previously reported (Lewis, 1976; Lewis, 1984; Lewis and Li, 1975; Shofner and Feng, 1983; Smotherman and Narins, 2000). In all APs examined (*N*=20), hair cells along the medial margin had round apical surfaces with uniform hair bundles emerging from circular cuticular plates, and nuclei in the basal third of the sensory epithelium. Rostral hair cells had larger apical surfaces and more elongated cell bodies than hair cells in the caudal extension (Fig. 1B,C). In all cases, hair cells along the lateral edge of both rostral and caudal regions were morphologically distinct. Lateral hair cells had smaller apical surfaces, more lateral hair bundles, and more elongated cell bodies than medial hair cells. We found that these lateral hair cells were also immunocytochemically distinct from hair cells in more medial regions. Hair cells along the lateral margin had myosin VI immunoreactivity but, unlike their more medial counterparts, also expressed cytokeratin in discrete subnuclear clusters (Fig. 1D,E). Three-dimensional reconstructions of lateral hair cells (not shown) clearly demonstrated that cytokeratin labeling was within the hair cell and not in nearby or invading supporting cell processes.

We also immunolabeled excitatory postsynaptic contacts with antibodies against PSD-95. At excitatory synapses, PSD-95 binds NMDA and non-NMDA receptors as well as potassium channels (Craven et al., 1999; Davies et al., 2001; Kornau et al., 1995). Reconstructed confocal images of PSD-95 immunoreactivity surrounding hair cells are shown in Fig. 2. In general, caudal hair cells were contacted by a small number (~5) of large, closely spaced synaptic contacts whereas rostral hair cells were contacted by a greater number (~10) of smaller synaptic contacts. In both rostral and caudal AP regions, PSD-95 immunoreactivity was especially robust among medial hair cells (Fig. 2A,C,D). This immunoreactivity is punctate in appearance, forming bead-like plaques that encircle the basolateral portion of the hair cell (Fig. 2A,C,D). Consistent with the presence of afferent terminals on hair cells, PSD-95 immunoreactivity is contained mostly within the subnuclear region of the hair cell and is concentrated at the synaptic terminal region of the hair cell (Fig. 2C,D).

DPOAEs pre- and post-noise exposure

Our goal was to use DPOAEs to monitor both hearing loss and functional recovery and then to compare the recovery of DPOAE levels with morphological recovery. The $2f_1–f_2$ cubic DPOAE was recorded using an earphone and microphone system sealed around the rim of the tympanic membrane (Fig. 3A). In all frogs investigated, DPOAEs at $2f_1–f_2$ (with an f_2/f_1 ratio of 1.2) had stable amplitudes and low variances between re-tests. The f_2 stimulus level was held constant at 80 dB SPL. Equal primary and secondary levels (i.e. $L_1=L_2$) gave the most robust DPOAEs with geometric mean frequencies near 1000 Hz (Fig. 3B). With this stimulus paradigm, DPOAEs above the noise floor could be recorded over a range of secondary (f_2) frequencies from roughly 300 to 1400 Hz. Peak DPOAE amplitudes typically occurred around 800–900 Hz. These DPOAE audiograms had steep DPOAE growth rates on both low- and high-frequency sides. When secondary stimulus levels were 10 dB lower than primary levels (i.e. $L_1 > L_2$), DPOAE audiograms differed from those obtained with equal stimulus levels (Fig. 3B). In such cases, DPOAEs above the noise floor were observed over a narrower range of secondary (f_2) frequencies, typically from 500 to 1100 Hz, and peak DPOAE amplitudes were typically 10 dB less for a given f_2 frequency. No DPOAEs were recorded in frogs that died either during the experiment (*N*=4) or after lethal injections, suggesting that DPOAEs recorded in these frogs are strictly associated with some type of active metabolic processes within the ear.

The biggest differences between equal and unequal stimulus levels occurred in response to noise exposures. Within 24 h of exposure to high-level (>150 dB SPL), 1/3-octave noise bands centered at 800 Hz, equal primary and secondary stimulus levels showed a drop of 10–20 dB in DPOAE amplitude that typically occurred between 500 and 100 Hz (Fig. 3B). Following noise exposure, DPOAE amplitudes were highly variable. This increased variability could be dependent on the depth of anesthesia post-exposure as our goal was frog

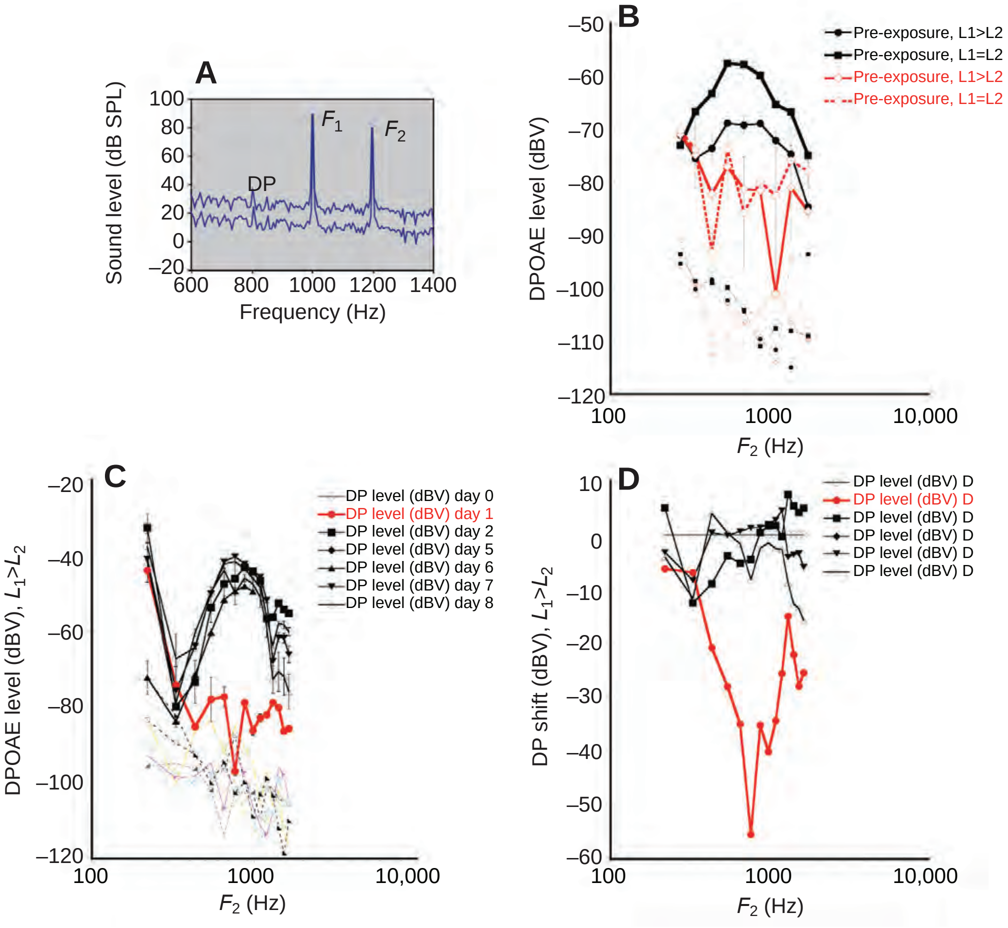

Fig. 3. Cubic distortion products recorded before and after noise exposure in adult bullfrogs. (A) The cubic distortion product (DP) $2f_1–f_2$ recorded from the bullfrog ear with primary f_1 and secondary f_2 frequencies as shown. In this example, secondary levels are 10 dB lower than primary levels. (B) Plot of cubic distortion product otoacoustic emission (DPOAE) levels from the right ear (ipsilateral) versus secondary frequency (f_2). DPOAE levels are in decibels relative to 1 V rms (dBV). The plot depicts DPOAE levels recorded before (solid symbols) and 24 h after (open symbols) 150 dB SPL broad-band noise exposure. Filled and open squares represent corresponding pre- and post-noise levels, respectively. At each frequency, the primary stimulus was held constant at 80 dB SPL and the secondary stimulus level was presented at equal strength (solid squares, $L_1=L_2$) and then with secondary levels 10 dB lower than primary levels (solid circles, $L_1>L_2$). Noise level measurements were taken and averaged on either side of the peak DPOAE level immediately before and after noise exposure, with each ear tested and averaged over three presentations. Dashed lines represent noise floor. (C) Cubic DPOAEs ($L_1>L_2$) from the right ear were tested before (day 0) and 1, 2, 5, 6, 7 and 8 days after noise exposure. Dashed lines represent noise floor. (D) Plot of the DPOAE shifts at each frequency tested before (0 days) and following (1, 2, 5, 6, 7 and 8 days) a 20 h noise exposure. The DPOAE shift was calculated as the difference in pre-exposure and post-exposure DPOAE levels.

recovery (van Dijk and Manley, 2001). With unequal primary and secondary stimulus levels (i.e. $L_1 > L_2$), there was a consistent, robust drop of at least 20–30 dB with an f_2 frequency between 700 and 1100 Hz (Fig. 3C). This drop in DPOAE amplitude was at or near noise floor levels and demonstrated less variability than those associated with equal primary and secondary levels.

For all subsequent $2f_1–f_2$ DPOAE testing, we used L_2 levels that were 10 dB lower than L_1. We followed DPOAE amplitudes for up to 9 days after intense, high-level, 1/3-octave band noise exposures for 4–24 h. Animals were tested immediately before noise exposure and at varying times following noise exposures. No changes in DPOAE levels occurred with noise exposures that were less than 12 h duration. After longer duration (20–24 h) exposures, DPOAE levels were mostly absent; that is, near the noise floor at an f_2 frequency near 800–1000 Hz (Fig. 3C). Within 3–5 days of exposure, DPOAE levels had recovered to approximate pre-exposure levels (Fig. 3B,C). To compare the changes in DPOAE levels after noise exposure, we calculated the DPOAE shift, i.e. the relative change in DPOAE amplitudes compared with pre-exposure DPOAE amplitudes (Fig. 3D). DPOAE shifts in the exposed (ipsilateral) ear were significantly greater than in the contralateral ear, and the ipsilateral DPOAE amplitude was usually near or at background noise levels. In the contralateral (non-exposed) ear, DPOAE shifts were also present, but highly variable (data not shown). Thus, the contralateral ears could not be used as control ears. In nearly all cases, the maximum DPOAE shift occurred within the first 24–36 h period, suggesting that hair cell function associated with active processes was compromised within that period. DPOAE shifts measured within the first 12 h following noise exposure, although more variable, demonstrated some hypersensitivity before giving a maximum DPOAE shift by 24 h. DPOAE shifts typically returned to pre-exposure levels, suggesting that some type of hair cell recovery occurred within the observed time frame.

We also investigated the relationship between the period of DPOAE recovery and the maximal change in DPOAE amplitude relative to the pre-exposure DPOAE amplitude (maximal DPOAE shift). A plot of the number of animals demonstrating a maximum DPOAE shift (N=11) and recovered DPOAE amplitude (N=16) is shown in Fig. 4A. At 24 h post-exposure, five of 11 animals had a maximal DPOAE shift and none had a recovered DPOAE. By 48 h, nine of 11 animals showed maximal DPOAE shifts and six had recovered DPOAE levels. By 72 h, the remaining two animals had undergone a maximal DPOAE shift and another six animals had recovered. By 96 h, all 16 animals tested had recovered DPOAE amplitudes.

The results presented thus far do not show whether the f_2 frequency input threshold changes after noise exposure. To assess possible changes in the threshold of the f_2 frequency input, the input–output relationship of DPOAE amplitude to f_2 threshold level was determined for five animals. The lowest f_2 level with a recordable DPOAE was taken as the DPOAE threshold. A plot of the relative f_2 threshold and the relative DPOAE threshold is shown in Fig. 4B. When comparing f_2 threshold levels to the pre-exposure f_2 threshold level, four out of five frogs showed an increase in the relative DPOAE threshold level within 12–24 h of noise exposure. By 48 h post-noise exposure all frogs had an f_2 threshold level that intersected with the point at which distortion was measured in our system and, therefore, was not measurable. By 72 h post-noise exposure all five frogs exhibited f_2 threshold levels nearly matching their pre-exposure thresholds. These results suggest that the threshold DPOAE requires increasingly higher stimulus input levels after noise exposure, but recovers relatively quickly after any disruptive effects of the noise have ceased (i.e. by 72 h).

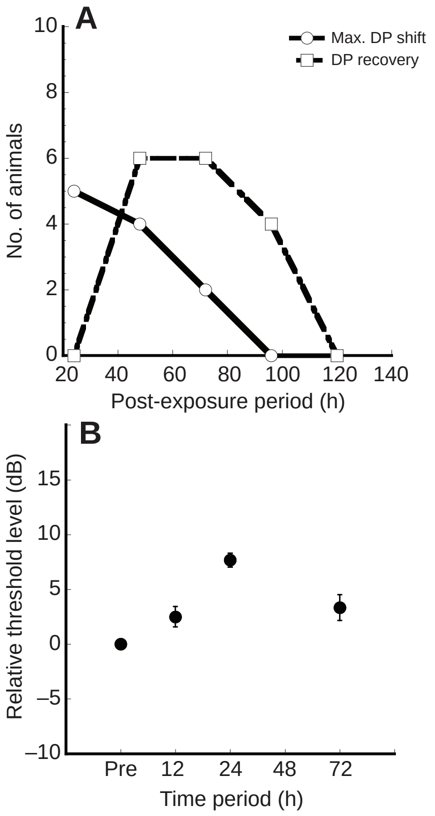

Fig. 4. DPOAE recovery. (A) Plot of the number of animals that have a maximum DPOAE shift (solid line) or have a recovered DP (dashed line) versus the post-exposure period. (B) Plot of the mean relative f_2 threshold level versus time period. The lowest f_2 level with a recordable DPOAE was taken as the threshold and subtracted from the pre-exposure f_2 level threshold. The pre-exposure time period was collected immediately before the noise exposure.

Hair cell damage and recovery

We used pure tone or 1/3-octave frequency bands to investigate whether hair cell damage would be limited to specific regions and to understand the relationship between morphological and functional recovery. After 1/3-octave band noise exposures, we found that noise levels up to 134 dB SPL for durations as long as 24 h were insufficient to cause any significant signs of morphological damage to hair cells (Fig. 5A). Even short duration (4 h) noise exposures up to 150 dB SPL were ineffective at producing observable morphological damage between 12 and 48 h after exposure. However, noise levels of at least 150 dB SPL for 20–24 h caused reproducible damage to hair cells in the bullfrog AP immediately following exposure (Fig. 5B). We therefore exposed the right ears of 33 bullfrogs for 20 h to 150 dB SPL noise bands centered at 800 Hz, and harvested inner ears at 1 day (N=5), 3 days (N=12), 7 days (N=4), 9 days (N=8) or 14 days (N=4) after noise exposure. We observed that hair cells in the caudal AP were severely damaged or lost within 3 days of noise exposure (Fig. 5B). Although there were differences between ipsilaterally exposed ears and contralateral ears, it was clear that caudal hair cells in contralateral ears demonstrated the most hair cell damage. In both ipsilateral and contralateral ears, the most severe damage was always found along the medial margin. We found little, if any, damage to hair cells in lateral AP regions of either ipsilateral or contralateral ears.

Within the first 12–24 h of noise exposure, we observed hair cell damage that included fragmenting hair cells, missing hair cells,

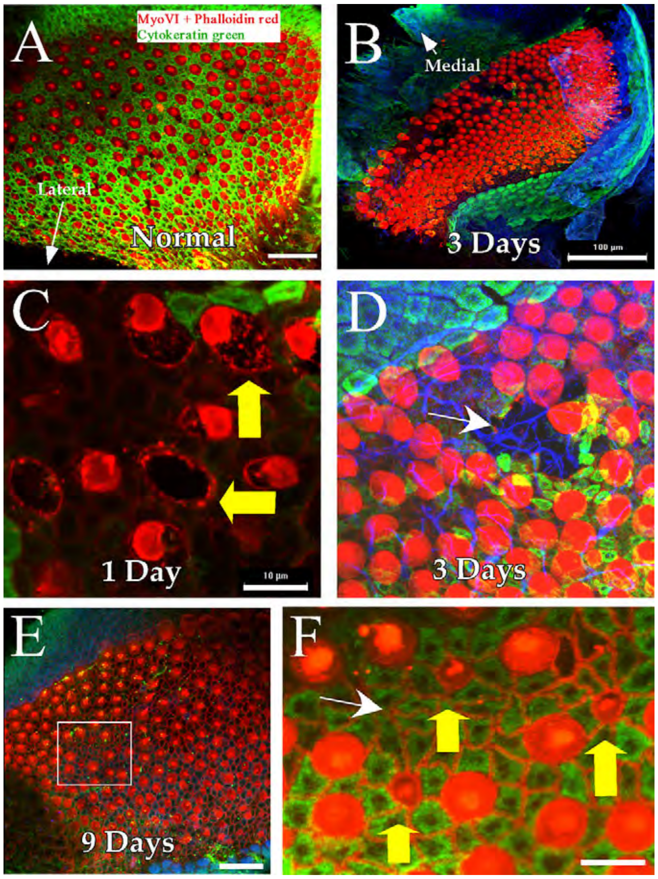

Fig. 5. Noise-damaged AP hair cells. (A–E) Myosin VI-labeled (red) hair cells and cytokeratin-labeled (green) supporting cells in the AP after exposure to noise levels up to 134 dB SPL for 20 h (A) and noise levels at 150 dB SPL for 20 h (B–E). In all panels, the lateral edge is as indicated in A and the medial margin is as indicated in B. Fragmenting hair cells (yellow arrows, C) and epithelial holes (white arrow, D), seen 1 and 3 days after noise exposure, were confined to a narrow region along the medial margin of the caudal region (B). (D–F) Myosin VI- and phalloidin-labeled (red) hair cells and cytokeratin-labeled (green) supporting cells, 3 and 9 days after noise exposure, showing epithelial scar formations (white arrow, F), restoration of intercellular junctions, and the appearance of regenerating hair cells (yellow vertical arrows, F). The box in E is shown at higher magnification in F. Scale bars: 30 µm (A,E); 100 µm (B); 10 µm (C,F). Scale is the same in C and D.

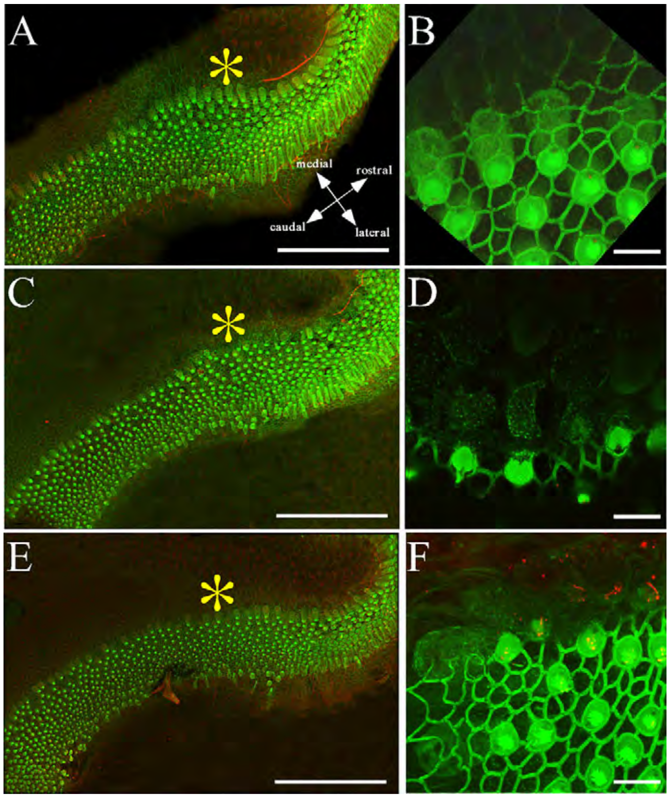

Fig. 6. Hair cell loss in damaged AP regions. Low-magnification (A,C,E) and high-magnification (B,D,F) images of caudal hair cells from normal (A,B) and noise-exposed ears 3 days (C,D) and 9 days (E,F) post-exposure to a high-intensity, 800 Hz tone. Myosin VI and phalloidin are both labeled green. Neurofilament is labeled red. The asterisks represent the same region in each AP as measured from the caudal tail. Regions of epithelial scar formations (S) are also shown. Scale bars: 100 µm (A,C,E) and 10 µm (B,D,F).

reduced cytokeratin labeling in supporting cells and disrupted intercellular junctions (Fig. 5C). We also occasionally observed cytokeratin labeling in hair cells (not shown). Fragmented or spot-like myosin VI labeling was also characteristic of damaged regions 24–72 h after noise exposure (see also Fig. 6D, Fig. 8C,D). In all cases with 1/3-octave band noise, the most dramatic hair cell damage was mostly confined to the medial margin of the caudal extension (roughly 800–1000 Hz region) while moderate damage extended toward the rostral region up to the caudal tail neck region (roughly the 500–600 Hz region) but was never seen in the rostral head. Missing hair cells were replaced by epithelial scar formations within 72 h (Fig. 5D). Scar formations consisted of an actin mesh network of four to eight polygonal epithelial cells. These formations are likely created by the expansion of the apical projections of neighboring epithelial cells into the epithelial spaces vacated by hair cells (Baird et al., 2000). Hair cells located in more lateral regions adjacent to the lateral margin sometimes had splayed hair bundles but no obvious signs of missing or otherwise damaged hair cells, suggesting that they were more resilient to noise damage. Recovery was evident along the medial margin 9 days after noise exposure, which included, for example, the restoration of intercellular junctions (Fig. 5E). At 9 days, numerous repairing or regenerating hair cells had immature hair bundles (Fig. 5F).

We documented hair cell loss in response to a pure tone in five normal (unexposed) ears and seven experimental ears following 20 h exposure to an 800 Hz stimulus at 150 dB SPL. As revealed by anti-myosin VI and phalloidin staining (both green) in Fig. 6A, unexposed ears had little evidence of hair cell loss as defined by the absence of a cuticular plate or disruption to the regularly arrayed (polygonal) mesh network interspersed between myosin VI-labeled hair cells. Fig. 6C,D and 6E,F show AP organs 3 and 9 days following noise exposure. In general, 800 Hz exposures produced regions of damage that were more narrowly confined than 1/3-octave band noise exposures. At 3 days, many hair cells within the region of damage had swollen and/or fragmented cell bodies, abnormal apical surfaces and some missing cuticular plates (Fig. 6D). There was also an increase in the presence of epithelial scar formations. At 9 days, hair cells in the damaged regions had nearly normal myosin VI immunolabeling, normal appearing cuticular plates and hair bundles of varying sizes. Unlike the normal AP, damaged regions had increased scar formations (Fig. 6F) that gave rise to the appearance of a lower density of hair cells, suggesting evidence of hair cell loss.

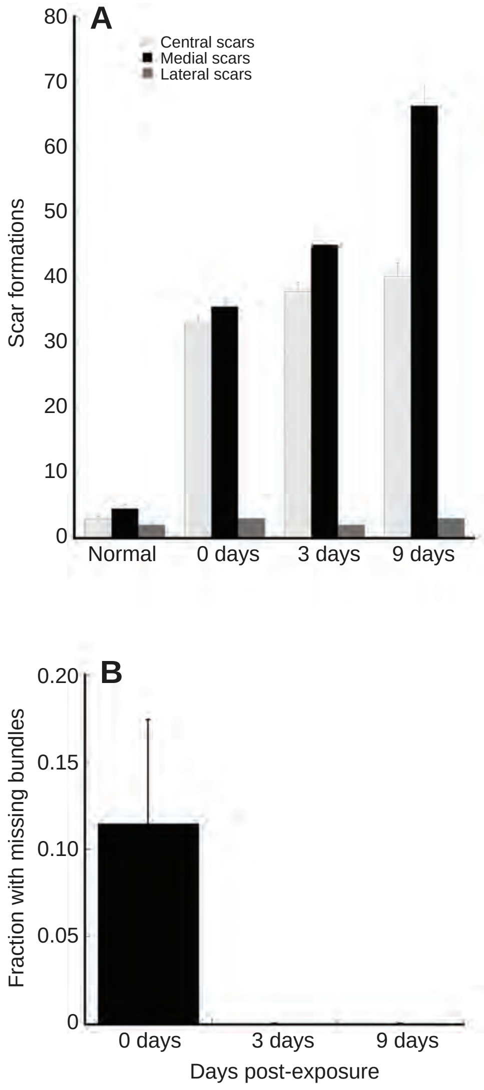

Fig. 7. Epithelial scars and missing hair bundles. (A) The number of epithelial scars was plotted in normal ears and exposed ears after 0, 3 and 9 days. Epithelial scars were counted in 100 µm distance bins from the end (tip) of the caudal extension of an exposed ear and non-exposed ear from the same animal. (B) The fraction of hair cells with missing bundles was plotted in exposed ears after 0, 3 and 9 days. Only mature hair cells in exposed ears showed a significant number of missing stereocilia bundles.

It was difficult to assess directly hair cell loss at different periods of recovery because of their irregular organization. We divided the caudal AP into 100 µm distance bins along the rostrocaudal axis. Furthermore, we divided hair cells into three radial groups – medial, central and lateral – primarily on the basis of location but also because of other characteristics such as cell body and bundle morphology. The number of missing medial and central hair cells was then approximated by counting the number of medial margin, central and lateral scar formations in the 100 µm distance rostrocaudal bins of normal control (*N*=5) ears and exposed ears within the first 12–24 h (0 days, *N*=9), 3 days (72 h, *N*=4), and 9 days (*N*=3) of noise exposure. As expected from our observations of hair cell damage, the number of medial scars was highest and the number of lateral scars lowest and virtually unchanged in exposed ears compared with control normal ears (Fig. 7A). At 0 days after exposure, the number of medial scars was not much different from the number of central scars, but both were greater than in control ears. At 3 days after exposure, the number of scars increased, with a slightly higher number in medial margin regions. By 9 days after exposure, the number of medial scars was highest. There were no other obvious signs of damage apart from a few splayed hair bundles in lateral hair cells.

As active processes in non-mammalian vertebrates may involve the hair bundle, the number of hair cells with missing bundles was also plotted against caudal extension position for medial margin hair cells (Fig. 7B). We did not observe any central or lateral hair cells with missing hair bundles; therefore, our data are restricted to medial margin hair cells. In control ears, no medial hair cells were found with missing hair bundles. Twenty-four hours after noise exposure, hair cells with missing hair bundles were found in about half of the experimental cases and these hair cells were limited to the medial margin throughout the caudal extension. However, the number of medial hair cells with missing hair bundles was highly variable across animals. By 3 days after noise exposure, no medial margin hair cells were found with missing bundles anywhere in the caudal extension. There are at least two explanations for the absence of hair cells with missing bundles: either these hair cells repaired or re-grew their hair bundles or the hair cells without bundles were no longer present.

Qualitative observations on synaptic recovery

We made qualitative observations as to the extent of synaptic recovery after 0, 1, 3, 9 or 14 days post-exposure survival. First, three bullfrogs, were given high-intensity (150 dB SPL), 1/3-octave band (cf. 800 Hz), short duration (4 h) noise exposures in one ear. Compared with the contralateral ear (Fig. 8A), the right exposed ears all demonstrated an increase in PSD-95 immunoreactive puncta within the first 24 h (Fig. 8B). Longer (20–24 h) high-intensity noise exposures produced secondary, severe morphological disruption to neurofilament-labeled fibers, resulting in fewer PSD-95 immunoreactive puncta in the damaged regions (Fig. 8C). At 3 days post-exposure, although myosin VI-labeled hair cells were missing in damaged regions, PSD-95 labeled profiles were observed that co-localized with myosin VI fragments representative of this post-exposure stage (Fig. 8D). Such myosin VI and PSD-95 fragments were not associated with synaptic endings, suggesting that many synaptic connections were disrupted by the noise stimulus. At 9 days post-exposure, the luminal surface was completely repaired with newly generated hair cells present (Fig. 8E). Although afferent re-innervation of the damaged region was not complete by 9 days, a decrease in isolated PSD-95 and co-localized myosin VI and PSD-95 fragments were seen (Fig. 8F). By 14 days after sound exposure, regenerating medial hair cells in the damaged region were contacted by thin neurofilament-labeled fibers and had small PSD-95-labeled puncta (Fig. 8G–I).

DISCUSSION

The present study is the first to investigate high-intensity noise exposure in the bullfrog. The bullfrog AP requires long-term (20–24 h), high-level (>150 dB SPL) noise exposures in order to produce consistent damage of the sensory epithelium and maximal DPOAE shifts. Significantly, we found that morphological recovery and physiological recovery from overexposure to noise are not synchronized. Additionally, our results not only extend previous findings of morphological differences across the bullfrog AP mediolateral axis but also suggest that these morphological differences correlate with differences in sensitivity to acoustic trauma. High-intensity, narrow-band sound produces morphological damage concentrated along the medial margin of the bullfrog caudal

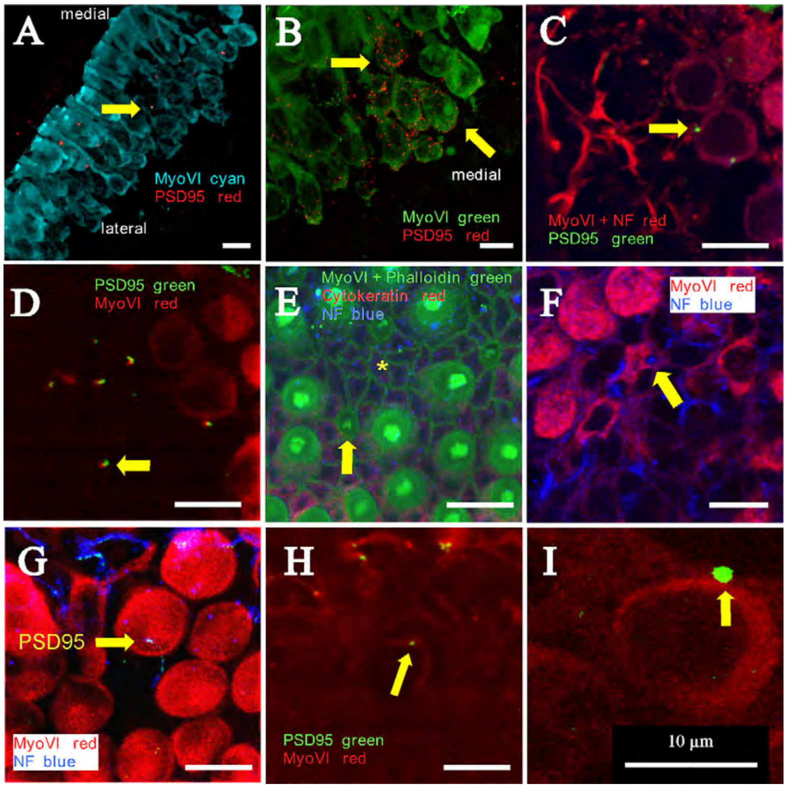

Fig. 8. PSD-95 and neurofilament labeling after noise exposure. (A) An unexposed control AP labeled with myosin VI (blue) and PSD-95 (red). PSD-95 puncta (yellow arrow) are found on medial hair cells and not lateral hair cells. (B) After a short (4 h) noise exposure (150 dB SPL), PSD-95 immunoreactivity (red) dramatically increases on medial hair cells. AP hair cells are labeled with myosin VI (green). Yellow arrows identify PSD-95 puncta surrounding the basolateral portions of hair cells. (C) Myosin VI-labeled hair cells (red), PSD-95 labeled puncta (green) and neurofilament (NF) labeled fibers (red) 1 day after a 20 h noise exposure. Yellow arrow identifies PSD-95 puncta apposed to a myosin VI-labeled medial hair cell. (D) Myosin VI-labeled hair cells (red) and PSD-95 labeled puncta (green) 3 days after a 20 h noise exposure. Yellow arrow shows PSD-95 puncta overlapping with myosin VI-labeled fragment. (E) Luminal surface view of myosin VI- and phalloidin-labeled hair cells (green) 9 days after a 20 h sound exposure, showing restoration of scars and intercellular junctions (asterisk), and the appearance of regenerating hair cells (yellow arrow). (F) A view near the basement membrane of a sound-exposed caudal AP 9 days after sound exposure. Myosin VI-labeled hair cells (red) are contacted by neurofilament-labeled (blue) fibers (yellow arrow). (G) Recovered hair cells 14 days after sound exposure. This region of the AP has new connections from neurofilament-labeled (blue) auditory neurons (yellow arrow). (H) At 14 days after sound exposure, punctate PSD-95 immunoreactivity (yellow arrow) was also seen closer to the basement membrane within scar formations. (I) Higher magnification image of a myosin VI-labeled hair cell (red) from H showing punctate PSD-95 immunoreactivity (green; yellow arrow) by 14 days post-sound exposure. All scale bars represent 10 µm.

AP. The finding that the bullfrog AP regenerates hair cells following acoustic trauma could make it an attractive model in which to study noise damage after high-level noise exposures.

Our results confirm that the most robust DPOAEs at $2f_1$–f_2 are near 800 Hz. The greatest DPOAE shift following noise exposure was located in regions consistent with maximal $2f_1$–f_2 responses. The complete abolishment of the DPOAE required the delivery of a very intense signal (≥150 dB SPL) to the ear for 20 h. Our data suggest that in the bullfrog, DPOAE levels are sensitive to hair cell damage. However, DPOAEs showed partial, if not full, recovery of their original amplitude as early as 72 h after noise exposure. Although DPOAEs recover within 3–5 days of sound exposure, morphological recovery was not complete until after 9 days. The time course between DPOAE and morphological recovery illustrates a potentially significant dissonance between these morphological and physiological parameters. If the high stimulus level DPOAE used in this study is generated from passive non-linear responses from the caudal AP (Meenderink and van Dijk, 2004), it may explain the observation that they return to normal levels before full morphological recovery of the caudal hair cells. Although the recorded DPOAEs may be passively generated, the observations that they were sensitive to animal viability also suggests that they are associated with some type of active metabolic process.

Our data raise the possibility that there may be multiple functional populations of hair cells in bullfrogs reminiscent of the hair cell dichotomy seen in the bird and mammal cochlea. Hair cells along the medial margin of the caudal AP not only are more susceptible to noise trauma but also receive an afferent innervation characterized by PSD-95 immunoreactivity and lack any cytokeratin immunoreactivity. Amphibian papillar hair cells in more lateral locations are less sensitive to noise trauma, have little PSD-95 immunoreactivity and show cytokeratin immunoreactivity. Intense, but relative short duration, noise stimulation in the bullfrog does not produce any severe morphological trauma but does increase the amount of PSD-95 immunoreactivity observed in medial hair cells. Longer duration traumatic noise stimulation obliterates myosin VI labeling of medial hair cells and disrupts cytokeratin labeling in supporting cells reminiscent of recent studies after noxious insult in the bullfrog sacculus (Hordichok and Steyger, 2007). Previous studies suggest that cytokeratin expression may be downregulated during hair cell differentiation (Cyr et al., 2000). In the present study, however, cytokeratin regulation may be associated with mechanisms of cell death and/or sensory repair in which the sensory epithelium is attempting or preparing for recovery (Hordichok and Steyger, 2007). PSD-95 fragments also remain associated with myosin VI-labeled fragments of hair cells in damaged regions. Even after major hair cell damage, afferent nerve terminals may still be present and may be ready to re-innervate new hair cells. At least one other study has shown that levels of PSD-95 are associated with sound-evoked activity (Bao et al., 2004).

There have been surprisingly few studies of the afferent innervation of regenerated hair cells (Duckert and Rubel, 1990; Duckert and Rubel, 1993; Haque et al., 2009; Ryals and Westbrook, 1994; Xiang et al., 2000; Zakir and Dickman, 2006). New synaptic endings are seen on repairing and regenerating hair cells soon after their appearance, but normal innervation is not restored for much longer periods (Haque et al., 2009; Ryals and Westbrook, 1994; Whitlon and Sobkowicz, 1991; Zakir and Dickman, 2006). Rapid functional recovery after sound trauma may be associated with processes involving the surviving hair cells – rather than with the regeneration of lost hair cells (Reng et al., 2001). This idea would be consistent with the present results in the bullfrog. However, in the bird cochlea, after ototoxic trauma, functional recovery is typically slower and parallels the structural regeneration more closely. The completeness of functional recovery also differs according to frequency, with regions of higher frequencies demonstrating more incomplete functional recovery (Cotanche, 1999).

OAEs and hair bundles

Our study is the first to investigate DPOAE shifts in response to noise exposure in the frog. Previous studies of the effects of noise on the auditory system of frogs have been limited mostly to observations of temporary threshold shifts of auditory nerve responses (e.g. Zelick and Narins, 1985). The DPOAEs recorded in this study displayed sensitivity and amplitude patterns consistent with the findings of other researchers. van Dijk and Manley recorded DPOAE amplitudes ranging from ~5 to 15 dB SPL (van Dijk and Manley, 2001), similar to the findings of Meenderink et al., who reported average DPOAE amplitudes of ~5 dB SPL (Meenderink et al., 2005). Maximum DPOAE amplitudes were recorded at DPOAE frequencies ranging from ~600 to 1000 Hz, corresponding to our finding that an f_2 frequency of 800–1200 Hz elicits the most robust response (Meenderink et al., 2005; Simmons et al., 2007; van Dijk and Manley, 2001; Vassilakis et al., 2004).

Based on theoretical and experimental work in mammals and humans, it is widely accepted that the DPOAE at $2f_2$–f_1 can be interpreted as the sum of two frequency components: a distortion component originating close to f_2 and a reflection component originating at the site of the distortion product, $2f_2$–f_1 (Shera and Guinan, 1999; Mauermann and Kollmeier, 2004). In mammals, the DPOAE input/output function can be used to characterize changes in cochlear non-linearity or for the prediction of thresholds (Mauermann and Kollmeier, 2004; Mills, 2004). In five frogs, we observed that the f_2 levels necessary to obtain a DPOAE threshold increased following noise exposure similar to predictions in mammals with hearing loss. Increasing f_2 levels could be indicative of damage to the distortion component, and consistent with DPOAEs in the frog also having two frequency components.

In amphibians, reptiles and birds, the best candidate for an active process may be the active motility of mechanically sensitive hair bundles (Bozovic and Hudspeth, 2003; Fettiplace, 2006; Hudspeth et al., 2000). In the present study, DPOAE recovery in bullfrogs is better correlated with the number of intact hair bundles than with the number of repairing/regenerating hair cells, suggesting that DPOAEs require intact hair bundles and may be linked to hair bundle micromechanics. Many studies have shown that repairing and regenerating hair cells develop normal-appearing hair bundles and seem functional. The first suggestion that damaged hair cells could repair their bundles was based on observations of hair cell recovery in cultures of neonatal mice organ of Corti (Sobkowicz et al., 1993). Laser-damaged hair cells also appear to re-grow their stereociliary bundles once they regain contact with the luminal surface (Sobkowicz et al., 1997). Hair cells in damaged vestibular organs appear to restore their hair bundles through a process of self-repair (Gale et al., 2004; Zheng et al., 1999).

The suggestion that intact hair bundles may be associated with the presence or absence DPOAEs is also consistent with studies of the mammalian cochlea using prestin-null mice (Cheatham et al., 2004; Dallos et al., 2008; Liberman et al., 2004). Without prestin, outer hair cells are incapable of electromotility, thus eliminating outer hair cell somatic motility as a dominant source of DPOAE generation. Liberman et al. (Liberman et al., 2004) attributed the continued presence of DPOAEs at high stimulus levels to the fast adaptation of outer hair cell stereocilia bundles as they appeared to be the only non-linearity left within the organ of Corti. In mice and chinchillas, damage to supporting cells and the uncoupling of stereocilia are also better predictors of DPOAE shift than the presence of outer hair cells (Harding and Bohne, 2004a; Harding and Bohne, 2004b). There is increasing evidence that in non-mammalian vertebrates, active movements of hair bundles are necessary for amplification and thus the generation of otoacoustic emissions (Fettiplace, 2006; Peng and Ricci, 2011).

In this study, we measured DPOAEs using relatively high-level stimuli (80 dB SPL). Previous investigations in the frog have interpreted DPOAEs resulting from such high-level stimuli as representing a passive non-linearity in the frog's auditory epithelia. This interpretation is based on the fact that these high-level components are insensitive to body temperature changes (Meenderink and van Dijk, 2006) and persist post mortem (van Dijk et al., 2003). The observation that these DPOAEs were abolished over a similar time course to morphological damage argues that they are associated somehow with the morphological integrity of the AP and, in particular, caudal hair bundles. Furthermore, the DPOAEs recorded in this study did not persist post mortem. Therefore, our data are consistent with the idea that the source of DPOAEs produced at high stimulus levels prior to noise exposure may be associated with the non-linear mechanics of the stereocilia bundle in active hair cells and noise disrupts this function. However, our data do not address whether the source of the recovered DPOAEs is associated with active or passive mechanics of the hair bundle. As mentioned previously, the apparent dissociation between DPOAE recovery and morphological recovery suggests that the recovered DPOAE is not dependent on total hair cell recovery. It is tempting to speculate that the recovered DPOAE is generated from the hair bundles associated with either more lateral hair cells or remaining undamaged medial hair cells.

In conclusion, frogs typically are located in environments with intense, broad spectrum, ambient noises and therefore have derived multiple solutions to maximize audible signal throughput (Feng et al., 2006; Narins and Wagner, 1989; Narins et al., 1988). We had to use extremely high-intensity sound levels to induce hearing loss. Our results indicate that the processes that generate the $2f_1$–f_2 DPOAE at high stimulus levels are highly resilient to high-intensity noise, and that the $2f_1$–f_2 DPOAE recovers much faster than the parameters typically associated with morphological recovery would suggest. We speculate that the $2f_1$–f_2 DPOAE is capable of being generated from multiple sources across the sensory epithelium that allow it to return quickly after traumatic insult.

MATERIALS AND METHODS

Animals

Adult bullfrogs, *R. catesbeiana* (measuring 102 mm, snout to vent length), were obtained from Carolina Biological Supply (www.carolina.com) and housed in fresh, de-chlorinated water in large recirculating aquaria according to published standards of the US Public Health Service. Bullfrogs were anesthetized for a minimum of 20 min in 0.2% tricaine methanesulfonate (MS-222) for all *in vivo* procedures, and killed by decapitation. For sound experiments, a single intramuscular dose of sodium pentobarbital (50 mg kg^{-1} body mass) was given. All experimental procedures were approved by the animal committees at Washington University School of Medicine and the University of California, Los Angeles.

In vivo sound exposure

Noise stimuli were delivered via a closed acoustic system. After 20 min in 0.2% MS-222, either left or right ears of bullfrogs were exposed for 4 or 20 h to high-intensity (150–160 dB) pure tone at 800 Hz or 1/3-octave noise bands centered at 800 Hz to eliminate DPOAEs and damage hair cells in the caudal amphibian papilla. To prevent dehydration, animals were kept moist by constant application of Ringer's solution with 0.1% MS-222. An Altec 802D horn driver with a flexible 3/8 in (9.5 mm) i.d. hard wall vinyl tube delivered low-frequency pure tones or 1/3-octave noise bands centered at 800 Hz to the bullfrog ear tympanic membrane [~1/4 in (6.4 mm) diameter] using a pure tone generator and 60 W power amplifier. We continuously measured the driver output at a side tube extension of the horn driver with a 4134 Bruel and Kjaer microphone. In order to not damage the tympanic

Table 1. Antibody inventory used to investigate hair cells and synapses in the amphibian papilla

Target	Manufacturer (product no.)	Immunogen	Host	Working dilution	Positive control	Negative control
Myosin VI	Sigma (KA-15)	Human myosin VI (C-terminal)	Rabbit	1:100	Manufacturer's immunoblotting	Omission of 1° Ab
Myosin VI	Proteus (25-6791)	Porcine myosin VI (aa 1049–1254)	Rabbit	1:100	{Hasson:1997tx}	Omission of 1° Ab
Calbindin	Swant (CB38)	Recombinant rat calbindin D-28k	Rabbit	1:250	Immunohistochemistry on cerebellum sections	Omission of 1° Ab
Calbindin	Swant (300)	Calbindin D-28k, purified from chicken gut	Mouse (mAb)	1:250	Immunohistochemistry on cerebellum sections	Omission of 1° Ab
Cytokeratin	Gift from Dr J. Cyr, University of West Virginia School of Medicine	Bactiophage antibody fragment library of bullfrog inner ear proteins	Mouse (mAb)	1:20	{Cyr:2000jz}	Omission of 1° Ab
PSD-95	BD Transduction Laboratories (610495)	Rat PSD-95 (aa 353–504)	Mouse (mAb)	1:100	Manufacturer's western blot rat brain	Omission of 1° Ab

1° Ab, primary antibody; mAb, monoclonal antibody; aa, amino acids.

membrane or impede sound transmission, a latex rubber tip was loosely sealed with silicone onto the rim of the tympanic membrane.

Sound exposures lasted 20–24 h in order to produce consistent damage. With this setup we delivered ~150–160 dB SPL without significant distortion between 600 and 1600 Hz. A driver output of 158.0 dB SPL at 800 Hz produced 159.8 dB SPL at the latex rubber tip. Right and left ears were acoustically decoupled to minimize intra-oral interactions.

DPOAE measurements

Equipment was calibrated using a 2231 type Bruel and Kjaer sound level meter with a 0.5 in (12.7 mm) pressure microphone in a Zwislocki coupler. Stimulus intensities were calibrated in a 0.5 cc cavity using a sound level meter (A-weighting frequency filter). Stimulus responses were averaged 100–200 times. The biologic signal was amplified (×100,000) and notch filtered at 60 Hz with a DB4 Digital Biological Amplifier (Tucker-Davis Technologies, TDT, Alachua, FL, USA) during data collection. The signal was band-pass filtered below 30 Hz and above 3000 Hz after collection using the TDT BioSig program. Cubic DPOAEs at $2f_1–f_2$ were recorded through a low-noise ER10C earphone (Etymotic Research, Elk Grove, IL, USA) and microphone system placed around the bullfrog's tympanic membrane using TDT hardware and software to generate stimulus tones. DPOAE levels were expressed in decibels relative to 1 V rms (dBV). The primary (f_1) and secondary (f_2) stimulus frequencies were determined from geometric mean frequencies (Hz) centered at 250, 311, 394, 494, 628, 794, 994, 1239 and 1589 Hz with the frequency ratio (f_2/f_1) set to 1.2. At each frequency, stimulus levels were first presented with constant (80 dB SPL) equal primary and secondary levels (i.e. L_1=L_2) and then with secondary levels being 10 dB lower than the primary level (i.e. L_1=90 dB SPL and L_2=80 dB SPL). Noise level measurements were taken and averaged on either side of the peak DPOAE level immediately before and after noise exposure, with each ear tested and averaged over three presentations.

DPOAE measurements were taken immediately before noise exposure and 12, 24, 48 and 72 h post-noise exposure, or until DPOAE recovery. Using an f_2 stimulus level at 80 dB SPL, three measurements were averaged at each frequency. We also recorded the lowest f_2 level with a recordable DPOAE, which was taken as the DPOAE threshold. Once DPOAE recovery was observed at $2f_1–f_2$, the animal was killed and the ears were collected and prepared for confocal microscopy. To determine the non-linear distortion of the recording system, the probe was placed against a solid surface after each measurement session. No distortion was noted at any of the threshold levels where a DPOAE was recorded. This process was crosschecked by performing pre- and post-death DPOAE measurements on a frog. No non-linear distortion was noted where DPOAEs had been recorded pre-death.

Dissection of the bullfrog AP

After an appropriate post-exposure survival period (0, 1, 3, 9 or 14 days), we re-anesthetized and decapitated noise-exposed bullfrogs, dissecting their APs in chilled, oxygenated Hepes-buffered saline (HBS) containing (mmol l^{-1}): 110 Na^+, 2 K^+, 4 Ca^{2+}, 120 Cl^-, 3 D-glucose and 5 Hepes, pH 7.25. We then transferred APs to amphibian phosphate-buffered saline (PBS) for subsequent experiments. For immunocytochemistry, AP tissues were fixed in 4% paraformaldehyde, permeabilized in 0.5% Triton X-100 in PBS to enhance antisera penetration, and incubated in a blocking solution consisting of 3% normal horse serum and 1% BSA in PBS to reduce non-specific labeling. Some ears were embedded in gelatin–agarose and sectioned at 200 µm on a Vibratome.

Immunocytochemistry

The antibodies used to characterize hair cells, support cells, nerve fibers and synapses are listed in Table 1. Included in this table are the specifications for the immunogen, the host in which it was raised, and controls. Tissues were immunolabeled with various combinations of antisera against either myosin VI or calbindin D-28k to label hair cells, inner ear cytokeratin to label supporting cells and PSD-95 to label synapses. We confirmed myosin VI and calbindin D-28k immunolabeling by comparing cellular labeling using two different primary antisera. For double- and triple-immunolabeling experiments, primary antisera from different species were often incubated together. APs were incubated overnight at 4°C in a primary antisera cocktail diluted in PBS. APs were then incubated in fluorescently conjugated secondary antisera [such as CY5-conjugated GAR IgG (Americium, GE Health Sciences, Piscataway, NJ, USA), biotinylated HAM IgG (Vector Laboratories, Burlingame, CA, USA) or Alexa 594 streptavidin (Molecular Probes, Life Technologies, Carlsbad, CA, USA)]. After secondary antibody labeling, tissues were stained with DAPI to label cell nuclei and Alexa-conjugated phalloidin (0.2%) to label hair bundles. Tissue was then mounted in Fluoromount (Southern Biotechnology, Birmingham, AL, USA) and examined with confocal microscopy. Negative controls, including the omission of primary antisera and substitution of normal serum for primary antisera were used. We pre-tested all antisera for specificity and sensitivity in single labeling experiments before using them in multiple labeling experiments.

Confocal microscopy

We used green (Alexa 488), red (Alexa 594) and far-red (Alexa 647/660) fluorophores, a combination that minimized spectral bleed-through between adjacent channels, to triple-label APs. Using a laser scanning confocal microscope (Zeiss LSM 5 or Bio-Rad Radiance 2000 AGR-3, Thornton, NY, USA) and a ×60 water-immersion (NA=1.20) objective (Plan Apochromat, Nikon), inner ear sensory organs were visualized and reconstructed. Fluorescent emissions were simultaneously acquired with appropriate blocking and emission filters, scanned at slow (25–50 lines s^{-1}) scan speeds for maximum resolution, and independently detected with either 8- or 12-bit accuracy by photomultiplier tubes. 3D images of serially reconstructed image stacks from the confocal microscope were rendered using Velocity (v4.xx; Improvision, PerkinElmer, Shelton, CT, USA). *Z*-projections of images were routinely performed.

Single confocal images were de-convolved to remove out-of-focus information and median filtered to eliminate image noise, and gray levels were adjusted from the stack histogram to maximize brightness and contrast (MicroTome, VayTek, Fairfield, IA, USA; Velocity, PerkinElmer). We applied a constrained iterative deconvolution algorithm with a measured point-spread function to confocal image stacks. We then reconstructed and rendered hair cells in de-convolved image stacks using 3D image rendering programs (Volocity, PerkinElmer; NeuroLucida, MicroBrightField, Williston, VT, USA).

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Competing interests

The authors declare no competing financial interests.

Author contributions

D.D.S. designed experiments, assisted with hearing tests, performed immunocytochemical experiments, did confocal microscopy, analysed data, and wrote and edited the manuscript. R.L. performed hearing tests, analysed data, and helped write the manuscript. H.W. performed hearing tests and helped with data analysis. M.D.B. helped with experimental design, performed immunocytochemical experiments and did confocal microscopy. R.A.H. performed immunocytochemistry and image analysis. R.A.B. helped with experimental design and helped write the manuscript.

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Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects

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This publication is dedicated with great respect and admiration to Dr. Jeanette Thomas who was an original panel member, valued colleague, and dear friend. Jeanette was a champion of marine mammal science who set higher standards for all in terms of scholarship, integrity, and professionalism. She was a stellar role model, particularly for young women in science; an insightful editor; and a dedicated professor and mentor. She will ever continue to inspire us.

Abstract

This article evaluates Southall et al. (2007) in light of subsequent scientific findings and proposes revised noise exposure criteria to predict the onset of auditory effects in marine mammals. Estimated audiograms, weighting functions, and underwater noise exposure criteria for temporary and permanent auditory effects of noise are presented for six species groupings, including all marine mammal species. In-air criteria are also provided for amphibious species. Earlier marine mammal hearing groupings were reviewed and modified based on phylogenetic relationships and a comprehensive review of studies on hearing, auditory anatomy, and sound production. Auditory weighting functions are derived for each group; those proposed here are less flattened and closer to audiograms than the Southall et al. M-weightings. As in Southall et al., noise sources are categorized as either impulsive or non-impulsive, and criteria use multiple exposure metrics to account for different aspects of exposure. For continuous (non-impulsive) noise sources, exposure criteria are given in frequency-weighted sound exposure level (SEL, given in units relative to 1 μPa^2-s or (20 μPa^2)-s for water and air, respectively). Dual exposure metrics are provided for impulsive noise criteria, including frequency-weighted SEL and unweighted peak sound pressure level (SPL, given in units relative to 1 μPa or 20 μPa for water and air, respectively). Exposures exceeding the specified respective criteria level for any exposure metric are interpreted as resulting in predicted temporary threshold shift (TTS) or permanent threshold shift (PTS) onset. Scientific findings in the last decade provide substantial new insight but also underscore remaining challenges in deriving simple, broadly applicable quantitative exposure criteria for such diverse taxa. These criteria should be considered with regard to relevant caveats, recommended research, and with the expectation of subsequent revision.

Key Words: hearing, marine mammals, noise exposure, TTS, PTS, weighting, criteria

Introduction and Overview

Scientific evaluation of how anthropogenic (human-generated) noise influences marine mammals extends back nearly half a century (Payne & Webb, 1971). Increasing knowledge and concern for animal welfare have led regulators and industry to consider what noise exposure levels from specific human activities are likely to harm marine animals, especially the marine mammals (cetaceans, pinnipeds, other marine carnivores, and sirenians) which are the focus herein (e.g., National Marine Fisheries Service [NMFS], 1995; High Energy Seismic Survey [HESS], 1999; for a more detailed review, see Houser et al., 2017). Scientific advisory organizations have also reviewed and evaluated the available science in terms of its implications (and limitations) for regulatory policies for ocean noise (e.g., National Research Council [NRC], 1994, 2000, 2003, 2005; International Council for the Exploration of the Sea [ICES], 2005). These efforts stimulated substantial scientific research and increased appreciation for the complexity of the underlying issues that had to be addressed to broadly predict the potential effects of noise. Verboom & Kastelein (2005) proposed hearing-weighted exposure thresholds for discomfort, temporary threshold shift, and hearing injury for exposure to continuous sounds for harbor seals and harbor porpoises. However, prior to 2007 and largely because of limited data, noise exposure criteria had not been formulated or broadly proposed for different types of marine mammals and different types of anthropogenic noise sources.

In 2002, the U.S. National Marine Fisheries Service (NMFS) Ocean Acoustics Program assembled a panel of scientists to address this challenging task. They reviewed all available information and developed methods to evaluate and quantify noise exposure levels for different anthropogenic sources expected to cause (1) behavioral responses of varying severity and (2) reductions in auditory sensitivity changes, including both temporary threshold shifts (TTS) and permanent threshold shifts (PTS). This resulted in the auditory exposure criteria described in Southall et al. (2007). The purpose of the present article is to advance and update these criteria to better predict the risk of TTS and PTS onset from noise exposure in marine mammals.

Southall et al. (2007) acknowledged the limitations of their approach given the limited underlying data and the need to extrapolate findings from terrestrial to marine mammals. Their focus was limited to marine mammals under the jurisdiction of the NMFS, resulting in the inclusion of cetaceans (whales, dolphins, and porpoises) and most pinnipeds (seals and sea lions), but the exclusion of walrus, polar bears, sea otters, and sirenians (manatees and dugongs). Despite these limitations, the initial process was an important step, providing specific scientific recommendations to inform regulatory decision-making and serving as a foundation for future criteria.

Elements of Southall et al. (2007) were derived from approaches used to develop damage risk criteria for human hearing (Kryter et al., 1966; Kerr et al., 2017). Historically, this research on hearing damage focused on laboratory animal species as models for human hearing and hearing damage, particularly for PTS studies (Clark, 1991). Prior to Southall et al. (2007), few formal criteria had been proposed for protecting hearing of multiple, mixed species in any heterogeneous taxa. There are still no comparable criteria for terrestrial wildlife. Southall et al. recognized that small terrestrial laboratory animals were likely poor models for large mammals with specialized ears adapted to a different medium. However, in the absence of direct information, extrapolations were used to support the development of the original criteria.

The Southall et al. (2007) noise exposure criteria were presented within an analytical framework that (1) categorized marine mammals into groups based on what was known about their hearing, (2) distinguished noise types with differing potential to affect hearing based on acoustical characteristics, and (3) utilized multiple exposure metrics to account for properties of sound that were expected to have the greatest influence on hearing. An important step in the analytical framework involved weighting functions to account for the frequency-dependent effects of noise for different marine mammal hearing groups. Such weightings for human hearing have a complex history, with multiple weighting curves developed for different applications. Weighting functions originally were developed for efficient telephony (see Houser et al., 2017), with later application to models of noise-induced human annoyance (e.g., Schomer, 1977). Weighting procedures were also intended to simplify operational criteria for preventing noise-induced hearing loss (von Gierke, 1965). Southall et al. (2007) provided auditory weighting functions to account for differential auditory sensitivity of different marine mammal hearing groups as a function of sound frequency. Given the extremely limited data available, the basis for deriving any auditory weightings for any group, but especially those with little or no direct hearing measurements, was debated extensively. Eventually, Southall et al. supported the use of deliberately broad weighting functions to discount exposure for noise at frequencies outside the presumed audible range, with explicit caveats and research recommendations to support the improvement of the criteria.

Regulatory approaches prior to Southall et al. (2007) generally failed to account for frequencies that animals heard relatively well or poorly. The weighting functions for a wide range of marine mammal species explicitly derived by Southall et al. were intended to be relatively coarse compared to the audiogram—admitting all frequencies that an animal could presumably hear but smoothing the transition to frequencies it could not hear. This approach, which used exponential functions, was based conceptually on a human weighting filter designed for high amplitude noise (human C-weighting) (Schomer, 1977; Harris, 1998). These "M-weighting" filters were developed for five marine mammal groups (low-, mid-, and high-frequency cetaceans, plus pinnipeds in water and pinnipeds in air) and allowed estimation of noise exposures that accounted for differential hearing sensitivity of each marine mammal hearing group to noise at different frequencies. Despite acknowledged limitations and the coarse nature of their design, the novel M-weighting filters became a *de facto* standard in some regulatory applications (e.g., Finneran & Jenkins, 2012; Bureau of Ocean Energy Management [BOEM], 2016).

Similar weightings have been proposed separately for laboratory animals (Bjork et al., 2000; Lauer et al., 2012), but none have been systematically applied or standardized for any other broad taxa of non-human animals. Various other approaches utilizing data on hearing sensitivity to predict frequency-specific sensitivity to noise exposure were explored by different taxa of free-ranging animals within the same time-frame, including Delaney et al. (1999) for strigiform owls, Verboom & Kastelein (2005) for harbor porpoises and harbor seals, Nedwell et al. (2007) for various aquatic species, and Terhune (2013) for harbor porpoises. There is some support for the use of auditory threshold functions for predicting behavioral responses to sound (i.e., animals cannot react if they cannot hear a sound); however, clear relationships between absolute auditory sensitivity and predisposition to hearing damage have yet to be demonstrated. Consequently, Southall et al. (2007) chose not to base weighting functions directly on auditory sensitivity, a conclusion that was revisited here.

The panel of subject-matter experts who contributed to Southall et al. (2007) was reconvened with some modifications[1] to consider all relevant available literature and update and expand the Southall et al. (2007) exposure criteria for TTS/PTS onset for all marine mammal species. The intent is to provide the best scientific interpretation and application of the available information within different marine mammal hearing groups while acknowledging data limitations for specific topics and for some hearing groups. As in Southall et al., the approach herein was to use available data to reasonably predict criteria for which effects are likely rather than necessarily proposing the most "protective" criteria. This is evident in the use of median values from available hearing and TTS-onset data and the use of median values from other hearing groups to estimate values for hearing groups for which no data exist, rather than using the lowest measured onset for any threshold or particular effect for any individual measured to represent the hearing group or other groups for which no such data exist. Policy and regulatory applications depend on a host of factors (e.g., population status, legal/regulatory considerations, and/or individual species issues for which differences may be justified). It is therefore important that for criteria to be most broadly useful in a variety of these contexts, they aim to quantify risk as a function of exposure at a population level rather than simply predicting the most severe possible consequence for any individual. A detailed discussion of this issue and potential implications is provided. It is acknowledged that additional data on intra- and interspecific variation in hearing and noise effect data are needed to more fully specify how risk varies as a function of exposure. Herein, acoustic criteria are defined for effects that are probable rather than possible. Subsequent criteria should use these data to more fully characterize risk probability as a function of exposure (e.g., in terms of percent likelihood of a certain effect) rather than as discrete levels above which effects are probable. With a probabilistic approach, managers could objectively evaluate the associated risk they were willing to accept on a case-by-case basis and in light of other factors. The need for additional supporting data and more explicit consideration of variation in hearing and TTS data within and between species in deriving and interpreting group-specific weighting and noise exposure functions is discussed.

These noise criteria are the latest in a series of previous and ongoing efforts to evaluate and predict the risk of various kinds of effects of noise on marine mammals. The initial such assessment was by Verboom & Kastelein (2005) for a few species of interest. Subsequent exposure criteria have been developed for single species (e.g., Tougaard et al., 2015), while others have focused on a broader number of species but primarily considered specific types of exposures (e.g., Finneran & Jenkins, 2012). The noise criteria here represent the next step in a sequential process of evolution of the criteria proposed by Southall et al. (2007), substantially modified with new analytical methods by Finneran (2016), and recently adopted as U.S. regulatory guidance by the NMFS (2016, 2018).

While the quantitative process described herein and the resulting exposure criteria here are based on, and in many respects are identical to, those derived by Finneran (2016) and adopted by the NMFS (2016, 2018), there are a number of significant distinctions. The exposure criteria here appear in a peer-reviewed publication and include all marine mammal species for all noise exposures, both under water and in air for amphibious species. NMFS (2016, 2018) provides regulatory guidance only for the subset of marine mammals under their jurisdiction and do not include criteria for aerial noise exposures, an important consideration in many locations for which some earlier assessments were made (Finneran & Jenkins, 2012). The exposure criteria here, while based on the Finneran (2016) quantitative method and consistent with the NMFS (2016, 2018) guidance where they overlap, are thus more broadly relevant, peer-reviewed, and less subject to potential changes in national regulatory policy. The later point was made evident in the re-evaluation and requisite reissuance of the NMFS (2016) guidance resulting from political pressure exerted in the form of a federal executive order (NMFS, 2018).

Further, the criteria here include a comprehensive review of all available data on direct measures of hearing, auditory anatomy, and emitted sound characteristics for all marine mammal species. Variation at many levels, by individual, age/sex class, health status, life history strategy, local area, population, species, and taxon (genus, family, etc.) is fully expected and should be directly incorporated when sufficient data are available. These data are used to evaluate and, in some cases, modify and expand the hearing group characterizations more subjectively derived by Finneran (2016) from the original Southall et al. (2007) groups. Six marine mammal hearing groups, two of which have different criteria depending upon the medium, are proposed here: three cetacean groups, phocid pinnipeds (true seals), other marine carnivores (comprising otariid pinnipeds, walruses, polar bears, and sea otters), and sirenians (manatees and dugongs) (as in Finneran, 2016). Two additional cetacean groups are identified for which some evidence exists to warrant additional division, with specific recommendations given for research for further evaluation. This is consistent with the approach taken by Southall et al. (2007) with regard to the proposed future segregation of phocid and otariid pinnipeds, which was later adopted. It should be noted that this results in some proposed differences in the terminology of hearing groups relative to those used in Finneran (2016) and NMFS (2016, 2018). These proposed differences in nomenclature may be confusing, but we believe they are justified (see the "Marine Mammal Hearing Groups and Estimated Group Audiograms" section and Appendices 1-6) and will support future criteria as new information emerges.

Southall et al. (2007) defined sound sources as "pulses" or "non-pulses" based on their characteristics at the source using a simple, measurement-based approach proposed by Harris (1998). As a simplifying measure, impulsive noise types (e.g., pile driving and seismic airguns) were distinguished based on their characteristics at the source without regard for well-known propagation effects that might change their appropriate characterization to non-impulsive at greater ranges. Here, we retain the same source categorization for impulsive and non-impulsive sources (as in Table 1, Southall et al., 2007) but note that the respective exposure criteria (impulsive or non-impulsive) should be applied based on signal features likely to be received by animals rather than by signal features at the sound source. Specific methods by which to estimate the transition from impulsive noise to non-impulsive noise are being developed in a parallel effort by some of the authors here and by other members of this panel.

The same dual exposure metrics used by Southall et al. (2007, Appendix A) are used here for impulsive noise criteria: (1) *frequency-weighted sound exposure level* (SEL), defined here as ten times the logarithm to the base ten of the ratio of the time integral of the square of the instantaneous frequency-weighted sound pressure to the reference value of 1 μPa^2-s or (20 μPa^2)-s for water and air, respectively, and (2) *unweighted peak sound pressure level* (hereafter peak SPL), defined as 20 times the logarithm to the base ten of the ratio of the maximum absolute value of the instantaneous unweighted sound pressure to the reference value of 1 μPa or 20 μPa for water and air, respectively. These two metrics are applied under the condition that exceeding either threshold by the specified level is sufficient to result in the predicted TTS or PTS onset. The different exposure metrics are required to account for different aspects of exposure level and duration: SEL is a measure of sound energy of exposure accumulated over time and over multiple exposures, whereas SPL is a measure of absolute maximum exposure. For impulsive exposures, both criteria are defined for all marine mammal groups. However, for non-impulsive exposures, only frequency-weighted SEL criteria are given here, replacing the dual exposure metric approach proposed by Southall et al. (2007). Given the typically much longer duration of most common non-impulsive noises (e.g., vessel noise and dredging) relative to any embedded transient components and given the very high peak SPL values required to induce TTS/PTS, there are virtually no scenarios for which the SEL criterion would not be met prior to an exposure exceeding what would be the associated dual-metric peak SPL criteria (which are thus not given). The assumption here is that SEL values will be calculated over the entire duration of a discrete noise exposure and/or will be cumulative over multiple repeated noise exposures that occur in sufficiently rapid succession. While a 24-h intermittency period has previously been proposed to "reset" the SEL accumulation (Southall et al., 2007) as a precautionary approach, limited subsequent data (see Finneran, 2015) suggest that in some instances a shorter interval would be more appropriate in terms of considering multiple exposures as discrete events rather than continuing to accumulate noise energy. This is an important area of needed research discussed later in greater detail.

Human occupational damage risk criteria for hearing loss, in addition to considering discrete noise exposures, are designed to provide sufficient protection for hearing over decades to working lifetimes, assuming that the majority of potentially damaging exposure is likely to be experienced in the workplace, with time for recovery in relative silence between shifts (Baughn, 1973; American Academy of Audiology, 2003; Daniell et al., 2003; Kerr et al., 2017). There is clearly a similar need for distinct and different marine mammal exposure criteria that consider potential long-term hearing loss produced by cumulative exposure over years, decades, or lifetimes. Despite this, the criteria presented herein remain limited to identifiable noise exposure events on much shorter time scales. Unfortunately, the available data for marine mammals are inadequate to predict long-term noise-induced hearing loss (NIHL) from cumulative exposure, and there are no measurements of cumulative received exposures available over the required time-scales for individuals and populations. Criteria for long-term noise exposure will require data on hearing effects of longer-term exposures and on the durations of quiet required to recover from these effects (e.g., Ward et al., 1976).

The derivation of hearing group-specific weighting functions and TTS/PTS onset involves five general processes, each with a number of basic steps, assumptions, and, in many cases, requisite extrapolations. These processes are as follows:

1. Identify marine mammal hearing groups using available data on hearing, auditory anatomy, and sound production.

2. Estimate hearing parameters for each species grouping and estimate group audiograms.

3. Derive group-specific auditory weighting and noise exposure functions using generic band-pass filter equations and group-specific hearing and TTS data.

4. Calculate group-specific TTS onset using either exposure functions (SEL) or extrapolation methods from TTS-onset measurements (SPL).

5. Calculate group-specific PTS onset (both SEL and SPL) using estimates of TTS growth rates.

Following a synthesis of recent scientific data on hearing and the effects of noise that are collectively relevant to this process (see next section), the first two processes are described in the "Marine Mammal Hearing Groups and Estimated Group Audiograms" section. The derivation of auditory weighting and exposure functions and the calculation of associated TTS- and PTS-onset levels are described in the "Marine Mammal Auditory Weighting and TTS Exposure Functions" section.

Finally, key research requirements to improve quantitative methods for evaluating the auditory effects of noise on marine mammals are identified and discussed in the "Research Recommendations" section.

Recent Progress in Understanding Marine Mammal Hearing and the Effects of Noise on Hearing

Substantial progress has been made in quantifying marine mammal hearing and the effects of noise on hearing for a range of taxa since the review provided by Southall et al. (2007). Recent reviews of TTS (Finneran, 2015) and auditory masking (Erbe et al., 2016) in marine mammals summarize the current state of knowledge in these fields. Herein, we consider recent scientific data, organized as it relates to specific sections of the proposed exposure criteria, including absolute hearing capabilities, auditory weighting functions, and the fatiguing effects of noise. (**Note:** Common names are used within the main text, and taxonomic references for all species are provided within corresponding appendices.)

New Research on Marine Mammal Absolute Hearing Capabilities

Numerous studies have been published in the past decade on absolute (unmasked) hearing capabilities in various marine mammals, both in water and in air (primarily for pinnipeds). These data are reviewed here, with particular emphasis on previously untested species and increased sample sizes within species.

There are still no direct measurements of underwater hearing available for any mysticete, and such measurements are unlikely to be obtained in the near future. Anatomical data and modeling can be used to estimate audible ranges and frequencies of best hearing but cannot be used to estimate hearing sensitivity or generate empirical audiograms. Anatomical advances relevant to evaluating baleen whale hearing include suggested hearing ranges for right, bowhead, and humpback whales based on histology and computerized tomography (CT) of inner ears (Ketten, 1994; Parks et al., 2007b; Mountain et al., 2008; Tubelli et al., 2012a); identification of potential fatty sound conduction pathways to the inner ear in minke whales (Yamato et al., 2012); estimated hearing ranges and best hearing frequencies from CT scanning and histology-based finite element modeling (FEM) for minke whales (Tubelli et al., 2012b); and estimated hearing profiles using FEM modeling from CT scans of fin whales (Cranford & Krysl, 2015).

Several recent studies provide direct information to describe underwater hearing in odontocete cetaceans. These include audiograms for the bottlenose dolphin (Popov et al., 2007), white-beaked dolphin (Nachtigall et al., 2008), Indo-Pacific humpback dolphin (Li et al., 2012), beluga whale (Finneran et al., 2009; Castellote et al., 2014; Popov et al., 2015), killer whale (Branstetter et al., 2017), short-finned pilot whale (Schlundt et al., 2011), long-finned pilot whale (Pacini et al., 2010), Gervais' beaked whale (Cook et al., 2006; Finneran et al., 2009), and Blainville's beaked whale (Pacini et al., 2011). New audiometric data are also available for two high-frequency specialists: (1) the harbor porpoise and (2) finless porpoise (Popov et al., 2006, 2011; Kastelein et al., 2010, 2012a, 2015a).

The phenomenon of auditory gain control has been discovered in several cetaceans. Auditory gain control during echolocation has been demonstrated for the false killer whale (Nachtigall & Supin, 2008), bottlenose dolphin (Mooney et al., 2011), and harbor porpoise (Linneschmidt et al., 2012). Changes in hearing thresholds following conditioning with an auditory cue warning of the impending arrival of loud sounds have also been measured in the false killer whale (Nachtigall & Supin, 2013), the bottlenose dolphin (Nachtigall & Supin, 2014, 2015), the beluga whale (Nachtigall et al., 2016a), and the harbor porpoise (Nachtigall et al., 2016b). These studies reveal an apparent level of plasticity in hearing sensitivity, which presumably provides a temporary reduction in susceptibility to noise exposure. Evidence of auditory gain control, while intriguing, remains challenging to integrate into noise exposure criteria. Whether the ability to adjust hearing sensitivity affords "protection" to odontocetes exposed to noise in contexts where it may be predictable is unknown. However, these results support the observation that four different echolocating species found in widely divergent environments have additional adaptive and protective mechanisms to tolerate noise exposure (see Nachtigall et al., 2018). This suggests that they may be able to learn to change their hearing sensation levels when warned that loud sounds are about to occur. This could render the exposure criteria presented herein somewhat conservative in such scenarios, although additional research is needed to further evaluate this.

Recent studies provide new hearing data for phocid pinnipeds, with complete underwater and in-air audiograms published for harbor seals (Kastelein et al., 2009; Reichmuth et al., 2013), spotted seals (Sills et al., 2014), and ringed seals (Sills et al., 2015). New hearing data are also available for otariid pinnipeds, with in-air measurements for Steller sea lions (Mulsow & Reichmuth, 2010) and underwater and in-air audiograms for California sea lions (Mulsow et al., 2011, 2012; Reichmuth & Southall, 2012; Reichmuth et al., 2013). Reichmuth et al. (2013) reviewed amphibious hearing abilities in phocid and otariid pinnipeds. Audiometric data for other marine mammal groups not included in the original criteria are also now available for some marine carnivores, including sea otters (Ghoul & Reichmuth, 2014) and polar bears (Nachtigall et al., 2007; Owen & Bowles, 2011), as well as sirenians, including the West Indian manatee (Gerstein et al., 1999; Mann et al., 2005; Gaspard et al., 2012) and Amazonian manatee (Klishin et al., 1990).

These studies augment earlier research considered by Southall et al. (2007). Increasing knowledge of marine mammal hearing abilities informs the designation of marine mammal hearing groups (see "Marine Mammal Hearing Groups" section). Further, some of the new hearing data contribute to the audiograms estimated for each hearing group (see "Marine Mammal Auditory Weighting and TTS Exposure Functions" section). All available marine mammal hearing data, as well as data on anatomy and sound production relevant for evaluating audible range, are discussed in the "Marine Mammal Hearing Groups" section, with a description of the evaluation methods and assumptions used in the detailed syntheses provided in the Appendices.

Recent Studies Relevant to Auditory Weighting Functions

Largely in response to the need to improve upon the marine mammal auditory weighting functions derived by Southall et al. (2007), a number of subsequent studies have evaluated frequency-dependent aspects of hearing, with the goal of informing derivation of weighting functions. Weighting functions for humans have been derived from idealized versions of equal loudness functions, which describe perception of relative sound amplitude across the frequency range of human hearing (Fletcher &

Munson, 1933; Yost, 2000; Houser et al., 2017). To obtain these functions, experimental subjects are asked to compare sounds of various frequencies and levels to a sound of known level at a reference frequency. The resulting family of curves defines human loudness perception. Direct measurements of equal loudness in marine mammals are limited to a single study of equal loudness in bottlenose dolphins (Finneran & Schlundt, 2011) that parallels the methods used to derive auditory weighting functions in humans.

Equal latency functions (describing the latency of response to a stimulus across a range of frequencies) correlate well with loudness in humans and have been proposed as a method for estimating equal loudness functions in laboratory animals. Within marine mammals, reaction times to suprathreshold tones have been measured in bottlenose dolphins, harbor porpoises, and pinnipeds (Reichmuth et al., 2013; Wensveen et al., 2014; Mulsow et al., 2015). Finally, studies of frequency-specific temporal integration also provide insight into the derivation of weighting functions given their relationship to equal latency, direct measurements of which are used to evaluate relative differences in perception relevant to weighting functions. Recent studies have quantified these parameters in harbor porpoises (Kastelein et al., 2010) and several pinniped species (Holt et al., 2012).

Recent Marine Mammal TTS Data

One of the most active areas of research on the effects of noise on marine mammal hearing has been TTS studies using non-impulsive noise as reviewed by Finneran (2015). Many of these studies address data needs articulated by Southall et al. (2007) regarding TTS-onset, growth, and frequency-specific differences in these parameters. Recent TTS studies have included six of the eight marine mammal groups to be identified herein, with studies both under water and in air for the amphibious marine carnivores. No studies have been conducted to date on any aspect of TTS in mysticetes or sirenians.

Extensive research on TTS from non-impulsive noise exposure has been conducted on several odontocete cetacean species since Southall et al. (2007), including the bottlenose dolphin (Mooney et al., 2009; Finneran et al., 2010; Finneran & Schlundt, 2010, 2013), beluga whale (Popov et al., 2014), harbor porpoise (Kastelein et al., 2011, 2012b, 2013a, 2013b, 2014a, 2014b, 2015b), and finless porpoise (Popov et al., 2011). Recent TTS studies in pinnipeds have also been conducted using non-impulsive noise (Kastak et al., 2007; Kastelein et al., 2012c, 2013a).

A few TTS studies have also been conducted in marine mammals using impulsive noise sources. These studies are more limited than those using non-impulsive sources, in part because of methodological challenges in generating these signals within laboratory settings in ways that approximate their characteristics as experienced by animals in the field. However, progress in this area addresses a major knowledge gap from Southall et al. (2007). New studies include those on the bottlenose dolphin (Finneran et al., 2015), harbor porpoise (Lucke et al., 2009; Kastelein, 2013; Kastelein et al., 2015a), and several pinniped species (Reichmuth et al., 2016) exposed to seismic pulses or impulsive pile-driving noise.

Recent Studies of Auditory Masking in Marine Mammals

As discussed above, the exposure criteria developed here focus on the residual effects of noise exposure (TTS/PTS) rather than simultaneous interference from noise, including auditory masking. Exposure criteria for identifying masking analogous to standards for preventing speech interference in humans (e.g., Kryter, 1994) are clearly relevant to broader anthropogenic noise issues for marine mammals. While issues related to masking are not considered in depth here, sufficient progress has been made that explicit masking criteria within specific contexts may soon be possible (see Erbe et al., 2016). Recent empirical studies have considered masking in a wide range of marine mammal species (Lemonds et al., 2011, 2012; Branstetter et al., 2013), including harbor porpoises (Kastelein & Wensveen, 2008), manatees (Gaspard et al., 2012), spotted and ringed seals (Sills et al., 2014, 2015), California sea lions (Cunningham et al., 2014), and sea otters (Ghoul & Reichmuth, 2014).

Marine Mammal Hearing Groups and Estimated Group Audiograms

Marine Mammal Hearing Groups

Numerous authors have recognized that differences in frequency-specific hearing sensitivity among different animals influence how they are affected by noise exposure. Southall et al. (2007) proposed relatively broad marine mammal hearing groups, each containing many species that still had some expected differences among them, based on what was known or inferred about these differences. Within these groupings, procedures were developed to derive applicable group-specific weighting functions and to more narrowly predict the effects of noise exposure. This was intended to account for biological differences in frequency sensitivity that had previously been ignored in regulatory applications.

Southall et al. (2007) defined five groups of marine mammals, based on phylogenetic relationships and a combination of auditory, physiological, and behavioral characteristics (where known). These groups included three subdivisions of the cetaceans (mysticete whales, dolphins, and porpoises) corresponding to typical frequency ranges of known or estimated hearing sensitivity and sound production parameters, as well as common auditory anatomical features: *low-frequency cetaceans* (baleen whales), *mid-frequency cetaceans* (including most odontocetes), and *high-frequency cetaceans* (including a subset of odontocetes specialized for high frequencies). Seals and sea lions (pinnipeds) comprised the other hearing group with their amphibious nature resulting in functional hearing groups for *pinnipeds in water* and *pinnipeds in air*.

These initial groupings accounted for gross frequency-specific differences in hearing, but it was clear from the outset that subsequent modifications were necessary and inevitable. For instance, Southall et al. (2007) suggested that additional hearing groups would likely be justified in future noise exposure criteria (e.g., separation of phocid and otariid pinnipeds) as additional information on both hearing capabilities and the effects of noise on hearing became available. Southall et al. also focused on species regulated by the NMFS, which excluded a number of species, including sirenians (manatees and dugongs), walrus, sea otters, and polar bears. Furthermore, the inability to account for what were expected to be numerous sources of inter- and intraspecific variation within hearing groups was identified as clearly important but lacking a sufficient empirical basis. The absence of data in many related areas to address these issues was acknowledged by Southall et al., along with a strategic research plan to improve future criteria.

A revised set of marine mammal hearing groups and associated frequency-weighting functions were proposed by Finneran (2016) for U.S. Navy regulatory compliance processes. This approach was subsequently used in a U.S. regulatory policy guidance document (NMFS, 2016, 2018) for evaluating the potential effects of underwater noise exposure for marine mammal species specifically under their jurisdiction. Similar marine mammal hearing groups are identified here, with several notable distinctions. While cetaceans retain their three-part grouping, phocid seals and all other marine carnivores are now considered separately in terms of both underwater and aerial hearing, as these species are amphibious (in-air criteria were not proposed by NMFS, 2016, 2018). Furthermore, a modified nomenclature for marine mammal hearing groups is proposed, accounting for further divisions identified within the mysticete and odontocete cetaceans (discussed below). While we argue that there is evidence to support further segregation of marine mammal groupings, at present, there are insufficient data to explicitly develop distinct exposure criteria because of the absence of TTS/PTS-onset data with which to do so. Southall et al. (2007) faced a similar problem with regard to the phocid and otariid pinnipeds, which were originally grouped together despite some evidence supporting their segregation. Herein, a similar approach is taken. The basis for further segregation is identified, and additional research needs to inform these assessments as further distinctions are presented.

To re-evaluate the segregation of marine mammal species into appropriate hearing groups, published literature describing audiometry, auditory anatomy, and sound production were reviewed and evaluated for all marine mammal species (Appendices 1-6). Audiometric data included measurements of hearing sensitivity across species-typical frequency ranges obtained using behavioral (psychophysical) methods and measurements of hearing sensitivity (primarily over mid- and high-frequency hearing ranges) obtained using neurophysiological methods. Auditory anatomy was considered with respect to basic ear types defined by sound conduction mechanisms and morphology of middle and inner ear structures, as well as by cochlear type where possible. Additionally, quantitative predictions of low- and/or high-frequency hearing limits derived from auditory models were evaluated.

Several characteristics of sound production were also considered for each marine mammal species. Frequency information regarding social sound emissions was summarized for all species where data were available. Further, for odontocete cetacean species that echolocate, frequency content of known or suspected echolocation clicks was described. In addition, the types of clicks produced while searching for prey (based on Fenton et al., 2014) were also considered in relation to hearing group distinctions. The logic, methods, and source data for species categorized into hearing groups are detailed within each appendix (each corresponding to the hearing groups described below, with aerial and underwater characteristics for the amphibious marine carnivores appearing in combined appendices). In addition to validating the species groupings presented here, these appendices enable identification of species for which few or no data are available, or for which available data are in conflict. In these cases, groupings are based on extrapolation to the most closely phylogenetically related species.

It is important to note that while many types of studies provide insight into possible hearing characteristics, only behavioral (psychophysical) audiometry provides direct measurements of hearing that include the entire auditory perceptual system. Further, unlike neurophysiological methods, behavioral audiometry can be effectively used to measure hearing at low frequencies (subject to availability of a suitably large enclosure) and, thus, can describe the complete shape of hearing sensitivity curves. These studies are inherently costly, limited to few individuals, and constrained to species that can reasonably be studied in long-term captivity. Such data are therefore available for only 15% of marine mammal species but have high value to the development of frequency-specific weighting functions. Consequently, behavioral audiometric data for marine mammals have been vetted to ensure that only data from healthy individuals with apparently normal hearing are used to develop weighting functions. Such data are exclusively applied in the derivation of estimated group audiograms (see "Estimated Group Audiograms for Marine Mammals" section). Neurophysiological measurements of auditory evoked potentials (AEPs), obtained from recording electrodes, are reported for all marine mammal studies that present frequency-specific response thresholds (typically obtained with narrow-band clicks or sinusoidally amplitude-modulated stimuli). These data are limited in the frequencies that can be tested and are not always similar to behavioral hearing thresholds that involve the complete hearing process through to perception. For marine mammal species tested thus far, AEPs do not adequately describe the lowest-frequency portion of their hearing. However, they do provide reliable estimates of high-frequency hearing limits and, thus, inform understanding of the hearing range, which varies by hearing group.

Anatomical data provide useful information about similarities and differences in auditory structures among marine mammal species. A complete review of marine mammal auditory anatomy is beyond the scope of this article. Herein, the defining features of the auditory pathway are considered, including the basic type of mammalian ear exhibited by each species (see Fleischer, 1978; expanded by Nummela, 2008) and descriptions of cochlear types (e.g., Ketten & Wartzok, 1990; Ketten, 1992; Manoussaki et al., 2008). These data provide a basis for rough groupings of species in the absence of any audiometric information. In addition, quantitative estimates of low- and high-frequency hearing limits derived from anatomical models have been included for which these data are available and are tied to the type of models used to generate the information. Additional details regarding anatomical modeling methods applied to different hearing groups are provided within each respective appendix. At present, auditory models applied to marine mammals include those based on cochlear spiral radii ratios (Manoussaki et al., 2008; Ketten & Mountain, 2014; Racicot et al., 2016), basilar membrane thickness-to-width ratios (e.g., Ketten, 2000; Parks et al., 2007b), basilar membrane frequency place maps (Ketten, 1994; Ketten & Mountain, 2014), finite element models of sound pressure passing through the head to the bony structures encasing the ear (Cranford & Krysl, 2015), and sound pressure transductions and transfers through the structures of the middle ear (Tubelli et al 2012a, 2012b). Additionally, measures of middle ear stiffness provide information that supports models of middle-ear transfer functions, providing relative information on frequencies associated with best sensitivities (e.g., Miller et al., 2006; Zosuls et al., 2012). All auditory models seek to describe how sound stimulates portions of the auditory pathway and how these structures transform acoustic energy into mechanical and thence neural stimuli. These models have inherent constraints and limitations—no one anatomical model provides complete audiometric data because the final percept that is "hearing" requires a series of coupled elements. Therefore, readers are strongly advised to consider the hearing limits predicted by various auditory models in the context of how many of the multiple, specific components are modeled and their role as well as the methodology employed. In many cases, models using similar approaches and common, defined anatomical elements with realistic stimuli that do not grossly exceed normal conditions will provide the most reliable insight into probable hearing and hearing differences across species.

Information concerning the sounds produced by different species has been used to make basic inferences about auditory sensitivity. This approach should be used with caution, in part because the hearing abilities of animals have likely not evolved exclusively to support communication (e.g., Fay & Popper, 2012), and peak hearing sensitivity generally does not necessarily correspond directly to predominant frequencies present in species-typical vocalizations (e.g., Ladich & Yan, 1998; Pytte et al., 2004; Arch & Narins, 2008; Velez et al., 2015). However, it is likely that most animals are able to hear social sounds produced by conspecifics in at least part of the frequency range occupied by the dominant energy in their sounds. Echolocating species tend to show enhanced hearing sensitivity in frequency regions associated with centroid or peak spectra of their echolocation clicks (e.g., Wartzok & Ketten, 1999; Ketten, 2000; Surlykke & Nachtigall, 2014). The Appendices include the frequency ranges of reported frequencies for sounds used for communication by marine mammals. The Appendices also separate information about the frequency content of echolocation clicks produced by odontocete species. Because these signals tend to be broadband, centroid or peak frequency data (rather than overall frequency range) are reported where possible. While it is acknowledged that these may be imperfect predictors, information about the frequency content of sound emissions can provide at least some indirect information regarding the range of hearing for a given species, and similarities in sound emissions in related species can be used to hypothesize similarities in hearing abilities.

A distinguishing acoustic feature of odontocete species is the type of click they emit when searching for prey. We have followed the convention established by Fenton et al. (2014) by describing these clicks as multiple pulse (MP), frequency-modulated (FM), broadband high frequency (BBHF), or narrow-band high frequency (NBHF). Among the odontocetes, the NBHF click type has been particularly useful in parsing a number of high-frequency specialized species from other odontocetes as it is only present within species in this group. Further, the presence of FM click types in a number of odontocete species provide one line of evidence for a potential future split beyond that presently proposed. Given these considerations and taking into account all available information regarding audiometry, anatomy, and sound production characteristics—with particular emphasis on frequency ranges of hearing—eight discrete hearing groups are identified, including (1) LF cetaceans, (2) HF cetaceans, (3) VHF cetaceans, (4) sirenians (SI), (5) phocid carnivores in water (PCW), (6) phocid carnivores in air (PCA), (7) other marine carnivores in water (OCW), and (8) other marine carnivores in air (OCA) (Table 1).

There are several new distinctions in group nomenclature compared to those in some earlier criteria used by Southall et al. (2007), Finneran (2016), and NMFS (2016, 2018). The use of *carnivores* as opposed to *pinnipeds* reflects the inclusion of several non-pinniped marine mammal taxa. The distinction between *HF* and *VHF cetacean* groups (as opposed to mid- and high-frequency) reflects the regions of best hearing sensitivities within these groups, often including frequencies approaching or exceeding 100 kHz; these frequencies would be more appropriately described within marine bioacoustics as high to very high. Further, as discussed in more detail below, a number of anatomical and sound production properties suggest a potential distinction of *very low-* (VLF) and *LF cetaceans* among mysticetes. Some evidence also suggests a potential segregation of *mid-frequency* (MF) and *HF cetaceans* in addition to the distinction of HF and VHF cetaceans. Subsequent noise exposure criteria may consider deriving explicit auditory weighting functions for these additional groups. If supported by future research, this would be analogous to our present use of multiple weighting functions among marine carnivores rather than the single weighting function used for all pinnipeds in Southall et al. (2007).

Low-Frequency (LF) Cetacean Hearing Group

The LF cetacean group contains all of the mysticetes (see Appendix 1 for more details on issues discussed below). The absence of direct hearing data for this taxon continues to warrant substantial caution in attempting to predict their hearing capabilities and any potential susceptibility of their hearing to noise exposure. Audible frequency ranges estimated for baleen whales from vocalization frequencies and anatomical modeling, limited anecdotal observations of spontaneous responses to tonal signals in free-ranging animals, as well as the phylogenetic distinctions from odontocete cetaceans support the general designation of the mysticetes as a discrete, LF-oriented hearing group. The pinna is absent (as for all cetaceans); the external auditory canal is thin and partially occluded; a distinct conical wax plug is present on the lateral side of the tubular, everted tympanic membrane; and the auditory pathway may involve specialized fats (Yamato et al., 2012). The mammalian middle ear for all LF cetacean species is the mysticete type (Nummela, 2008), which is characterized by tympanic and enlarged periotic bones that are fused anteriorly and posteriorly, as well as massive ossicles that are loosely articulated and a voluminous, hyper-inflated middle ear cavity (Ketten, 1992). For mysticete species that have been evaluated, the cochlea is distinct in that the basilar membrane is exceptionally broad at the apical end. This cochlea has been termed type M (mysticete), although more recent data argue for probable subdivisions within this group that need to be further explored (Ketten, 1992; Ketten et al., 2016).

Within this group, several lines of evidence suggest that some whales may be more sensitive to very low frequencies (see Ketten, 1992, 2000; Edds-Walton, 1997) and, therefore, may form a distinct category. The relatively larger mass of blue, fin, bowhead, and right whales compared to other baleen whales, and the VLF components of most of their vocalizations, combined with anatomical characteristics including relatively larger basilar membranes and larger cochlear radii ratios (Ketten et al., 2016), suggest that some of these species may be specialized for the use of very low frequencies. Thus, these species may be distinguished from other species such as minke and humpback whales, which more commonly use higher sound frequencies in species-typical vocal communication. However, as noted above, many mammalian species possess best hearing above the lower end of their vocalization frequency range. Recent anatomical modeling of auditory structures in some mysticete species is generally consistent with the expectation of hearing sensitivity exceeding vocal range (Tubelli et al., 2012a; Cranford & Krysl, 2015) as is anatomical modeling of cochlear radii ratios conducted by Ketten &

Table 1. Proposed marine mammal hearing groups, applicable auditory weighting functions, genera or species within each proposed group, and the associated appendix within which available data on hearing, auditory anatomy, and sound production are reviewed

Marine mammal hearing group	Auditory weighting function	Genera (or species) included	Group-specific appendix
Low-frequency cetaceans	LF	Balaenidae (*Balaena*, Eubalaenidae spp.); Balaenopteridae (*Balaenoptera physalus*, *B. musculus*)	1
		Balaenopteridae (*Balaenoptera acutorostrata*, *B. bonaerensis*, *B. borealis*, *B. edeni*, *B. omurai*; *Megaptera novaeangliae*); Neobalenidae (*Caperea*); Eschrichtiidae (*Eschrichtius*)	
High-frequency cetaceans	HF	Physeteridae (*Physeter*); Ziphiidae (*Berardius* spp., *Hyperoodon* spp., *Indopacetus*, *Mesoplodon* spp., *Tasmacetus*, *Ziphius*); Delphinidae (*Orcinus*)	2
		Delphinidae (*Delphinus*, *Feresa*, *Globicephala* spp., *Grampus*, *Lagenodelphis*, *Lagenorhynchus acutus*, *L. albirostris*, *L. obliquidens*, *L. obscurus*, *Lissodelphis* spp., *Orcaella* spp., *Peponocephala*, *Pseudorca*, *Sotalia* spp., *Sousa* spp., *Stenella* spp., *Steno*, *Tursiops* spp.); Montodontidae (*Delphinapterus*, *Monodon*); Plantanistidae (*Plantanista*)	
Very high-frequency cetaceans	VHF	Delphinidae (*Cephalorhynchus* spp.; *Lagenorhynchus cruciger*, *L. austrailis*); Phocoenidae (*Neophocaena* spp., *Phocoena* spp., *Phocoenoides*); Iniidae (*Inia*); Kogiidae (*Kogia*); Lipotidae (*Lipotes*); Pontoporiidae (*Pontoporia*)	3
Sirenians	SI	Trichechidae (*Trichechus* spp.); Dugongidae (*Dugong*)	4
Phocid carnivores in water	PCW	Phocidae (*Cystophora*, *Erignathus*, *Halichoerus*, *Histriophoca*, *Hydrurga*, *Leptonychotes*, *Lobodon*, *Mirounga* spp., *Monachus*, *Neomonachus*, *Ommatophoca*, *Pagophilus*, *Phoca* spp., *Pusa* spp.)	5
Phocid carnivores in air	PCA		
Other marine carnivores in water	OCW	Odobenidae (*Odobenus*); Otariidae (*Arctocephalus* spp., *Callorhinus*, *Eumetopias*, *Neophoca*, *Otaria*, *Phocarctos*, *Zalophus* spp.); Ursidae (*Ursus maritimus*); Mustelidae (*Enhydra*, *Lontra feline*)	6
Other marine carnivores in air	OCA		

Mountain (2014) and discussed further by Ketten et al. (2016). At present, there is insufficient direct information—notably, no direct measurements of hearing sensitivity or TTS for any species—to make an explicit distinction between VLF and LF cetaceans or to propose separate auditory weighting functions and TTS/PTS onset. It is unlikely that such direct hearing measurements will be obtained in the near future given the substantial logistical challenges of working with these species, which include the largest animals on Earth.

While neurophysiological, AEP methods are a possible alternative that has been considered, they will be challenging to use for several reasons, including the large body size of animals and the expected limitations at low frequencies. Thus, despite acknowledging differences among the mysticetes and possible differences in susceptibility to VLF sounds, these species are assigned a single common weighting function (LF cetaceans). However, subsequent research on comparative auditory anatomy integrating knowledge of other LF species (e.g., Ketten et al., 2016) and controlled measurements of behavioral responses to sound in free-ranging animals to evaluate certain aspects of hearing, such as frequency ranges of detection, should be promoted and could guide future noise exposure criteria regarding the potential VLF/LF divisions suggested for consideration here.

High-Frequency (HF) Cetacean Hearing Group

The HF cetacean group contains most delphinid species (e.g., bottlenose dolphin, common dolphin, and pilot whale), beaked whales, sperm whales, and killer whales (see Appendix 2). Hearing sensitivity has been directly measured for approximately one-third of the species within this group using either behavioral audiometry or neurophysiological, AEP measurements. Given best hearing sensitivity at frequencies of several tens of kHz or higher for many of the species in this hearing group, they are described as HF species here; it should be noted that this represents most of the same species identified as MF cetaceans by Southall et al. (2007), Finneran (2016), NMFS (2016, 2018), and Houser et al. (2017).

All odontocetes lack pinnae and a functional auditory meatus and, instead, use a unique auditory pathway of acoustic fats aligned with the lower jaw to direct sound to the ears (Wartzok & Ketten, 1999). Two middle ear types are present within the HF cetaceans (Fleischer, 1978; Nummela, 2008). The odontocete ear type is present in most species (and all delphinids) studied to date and is designed to acoustically isolate ear structures from the rest of the skull. The physeteroid ear type is present within Physeteridae and Ziphiidae families in the HF group, as well as Kogiidae within the VHF cetaceans (below); this ear type features a tightly fused tympanic and periotic bone and several distinct cochlear characteristics (see Wartzok & Ketten, 1999).

Predictions of hearing frequency ranges derived from anatomical modeling are available currently for relatively few species (notably the harbor porpoise and bottlenose dolphin). Sound production (including both social and echolocation signals) is complex, diverse, and generally well-described across most HF cetacean species (for a detailed review, see Appendix 2). Echolocation click type distinctions based on Fenton et al. (2014) provide additional insight into the distinction of HF cetaceans from other hearing groups and support a possible further segregation among them (see below). Three click types have been described among the HF cetaceans: (1) broadband high-frequency clicks (BBHF), (2) frequency-modulated (FM) upsweeps, and (3) multi-pulsed (MP) click types. Most HF cetacean species produce BBHF clicks while searching for prey. Sperm whales are unique in producing extremely loud, relatively low-frequency MP clicks with multiple pulses caused by reverberation of the signal within the head. All beaked whales studied produce an FM click while searching for prey, and some species have been shown to produce a more broadband click in the terminal phases of prey capture. No HF cetacean species produce narrow-band high-frequency (NBHF) clicks, which are exclusive to the VHF cetaceans (below). The distinction between the HF cetaceans described in Appendix 2 vs the LF cetaceans and the specialized VHF cetaceans is thus supported by combined scientific evidence, including phylogeny, direct measurements of frequency ranges of hearing, anatomical distinctions, frequency ranges of acoustic signals, and echolocation click type distinctions.

Within the HF cetaceans, a potential further segregation is proposed here for species that may be relatively more sensitive to lower frequencies than other odontocetes in this group, specifically sperm whales, killer whales, and beaked whales. Several lines of evidence support such a distinction. First, these species are generally larger than other odontocetes. While there is not a clearly linear relationship between body size and hearing sensitivity, a general trend of lower HF limits and better LF sensitivity with increasing body mass has been documented (e.g., see Heffner & Heffner, 2008). In terms of direct hearing measurements, limited AEP data for a stranded sperm whale (Ridgway et al., 2001) suggest best hearing sensitivity between 5 and 20 kHz. Limited AEP data for beaked whales (Cook et al., 2006; Finneran et al., 2009; Pacini et al., 2011) indicate relatively broad ranges of good sensitivity extending below at least 5 kHz. Earlier behavioral hearing data for killer whales (Szymanski et al., 1999) have recently been augmented by complete audiograms for six killer whales (Branstetter et al., 2017). These results do not necessarily suggest major differences in HF hearing cut-offs from other HF cetacean species but do indicate relatively good hearing at low frequencies compared with other species. Finally, as mentioned above, both the sperm whales and beaked whales have categorically distinct echolocation click signal types from all other HF cetaceans. While they also differ from one another, they are similar in having a lower center frequency of the predominant click energy than clicks of other HF cetaceans. However, these biosonar signal distinctions of sperm and beaked whales do not apply to killer whales, which are much more similar to the other HF cetaceans in this regard. Given these several lines of evidence, subsequent criteria should consider, based on additional research results, whether sperm, beaked, and killer whales should be considered as a separate (MF cetacean) hearing group. This issue is by no means resolved, however, and there are presently insufficient supporting data on hearing and (particularly) TTS/PTS-onset thresholds to establish discrete noise exposure criteria for these species from those derived for the HF cetaceans.

Very High-Frequency (VHF) Cetacean Hearing Group

The VHF cetacean group (see Appendix 3) comprises the true porpoises, most river dolphin species, pygmy/dwarf sperm whales, as well as a number of oceanic dolphins (Commerson's, Chilean, Heaviside's, Hector's, Hourglass, and Peale's dolphins). Direct measurements of hearing using behavioral and/or AEP methods are available for three species within this group, each indicating substantially higher upper-frequency hearing limits than HF cetaceans, with best sensitivity in some species exceeding 100 kHz. The

VHF cetaceans lack a functional auditory meatus but possess an auditory pathway of acoustic fats in the lower jaw. They have an odontocete middle ear type (Nummela, 2008) and temporal bones (the tympanoperiotic complex) that are acoustically isolated from the rest of the skull with dense ossicles, as well as cavernous tissue in the middle ear cavity (e.g., Ketten, 1994, 2000). The inner ear features hypertrophied cochlear duct structures, dense ganglion cell distributions, and several distinguishing cochlear parameters (see Appendix 3). It should be noted that these features are common to essentially all odontocetes and not specific to this group, but these features are particularly prominent within the VHF species.

The VHF cetaceans show some differences in sound production compared to the other hearing groups. Several parameters of search-phase echolocation signals distinguish the VHF cetaceans. Center frequencies exceed 100 kHz in almost all species and 150 kHz in several, representing the highest such values in marine mammals. The NBHF echolocation click type (as defined by Fenton et al., 2014) is exclusively present in all VHF cetacean species and does not occur within any other cetaceans; this includes the six delphinid species categorized as VHF cetaceans, including the *Cephalorhynchus* spp. and two species of the genus *Lagenorhynchus* (hourglass and Peale's dolphin). Thus, direct hearing measurements, anatomy-based predictions of hearing range (see Racicot et al., 2016), and multiple characteristics of biosonar signals are all generally consistent in distinguishing the VHF from the HF cetaceans (see Appendix 3 for more details).

Sirenian (SI) Hearing Group

The SI group includes the manatees and dugongs (see Appendix 4). These species differ from cetaceans and marine carnivores both phylogenetically and in their natural history. Some behavioral and electrophysiological hearing data are available for manatees, indicating some similarities to HF cetaceans and phocid pinnipeds. But based on their taxonomic differences, auditory anatomical distinctions, and apparent differences in aspects of sound production, they are considered here as a separate group. The pinnae are absent, the auditory meatus is thin and apparently occluded, the tympanic membrane is enlarged and bulges outward, and the ossicles are massive with unique features, including oil-filled bony structures (Ketten et al., 1993). They are characterized as having the sirenian ear type, with a U-shaped tympanic bone fused to a much larger periotic bone (Nummela, 2008), which, unlike most other mammals, does not surround the middle ear cavity. Earlier anatomical predictions of auditory range for West Indian manatees suggested they would be sensitive from the infrasound range to less than 20 kHz, with peak sensitivity around 8 kHz, but direct measurements indicate that hearing can extend from low frequencies to above 60 kHz (see Appendix 4). Only underwater auditory weighting and exposure functions and TTS/PTS-onset levels are derived given that these species, like cetaceans, are functionally obligate aquatic.

Phocid Carnivores in Air (PCA) and Water (PCW) Hearing Groups

This group contains all the true seals, including harbor, gray, and freshwater seals; elephant and monk seals; and both Antarctic and Arctic ice seals (see Appendix 5). Southall et al. (2007) noted the significant differences in hearing between the phocid and otariid pinnipeds, particularly the much higher, upper-frequency hearing limits of phocids measured in water, but concluded there were insufficient data on unmasked amphibious hearing and especially the effects of noise on hearing to consider separate groups, weighting functions, and TTS/PTS-onset levels. A number of subsequent audiometric studies have been published which confirm the extremely broad (7 to 8 octaves in some species) range of best hearing sensitivity among phocid seals (which for this family is the widest among any mammalian taxa), with upper-frequency cut-offs exceeding 60 kHz in almost all species (see Reichmuth et al., 2013; Finneran, 2016). These, along with a number of anatomical characteristics, unequivocally distinguish phocid seals from other pinnipeds and related marine carnivores. These true seal species lack outer pinnae and have cavernous tissue lining the auditory meatus and middle ear cavity (Møhl, 1968; Repenning, 1972; Wartzok & Ketten, 1999). They possess a phocid middle ear type (Nummela, 2008), with features including an enlarged tympanic membrane, ossicles, and middle ear cavity. Given their amphibious nature and fundamental differences in hearing, and the effects of noise between the two media, discrete aerial and underwater auditory weighting and exposure functions and TTS/PTS-onset thresholds are presented here.

Other Marine Carnivores in Air (OCA) and Water (OCW) Hearing Groups

This group contains all non-phocid marine carnivores, including the otariid seals (sea lions and fur seals), walruses, sea otters, and polar bears (see Appendix 6). Recent studies have been published on key species representing each of the main taxa in this group. The combined audiometric, anatomical, and sound production data indicate a clear segregation between the phocid seals and other marine carnivores which have less sensitive HF hearing. Nearly all species included in this group share a common *freely mobile* ear type, which features a loose connection between the ossicles and the skull (Fleischer, 1978; Nummela, 2008). The one exception is the walrus, which has an ear that is somewhat intermediate to a freely mobile ear and the ear type characteristic of phocids. The walrus has enlarged ossicles, a large tympanic membrane, and, like phocids, lacks pinnae, but the shape and form of the ossicles and other morphological features are distinctively otariid in form (Repenning, 1972). Subsequent research on walrus audiometry, including TTS measurements, and auditory anatomy would support further evaluation of their characterization within the marine carnivores either within phocid or non-phocid hearing groups or, potentially, as a distinct hearing group. Here, they are included with the other marine carnivores both in air and water.

Across these non-phocid marine carnivore species, there are relatively large differences in natural history and the proportion of time spent in and out of water. However, all are amphibious mammals and are known or likely to have amphibious differences in hearing and the effects of noise on underwater hearing. Consequently, separate aerial and underwater auditory weighting and exposure functions and TTS/PTS-onset thresholds are included for this marine mammal hearing group as well.

Estimated Group Audiograms for Marine Mammals

Substantial uncertainties and data gaps remain in understanding marine mammal hearing, but considerably more information exists for some species than was available to Southall et al. (2007). As a result, a more quantitative approach to characterizing group-specific hearing is now possible, the relative support for which depends on the amount and quality of the underlying direct measurements of hearing. The objective is to apply systematic methods and the best available scientific information in describing group-specific hearing for each of the marine mammal hearing groups described in the previous section. The approach is described below, followed by its application in estimating group audiograms. For the LF cetaceans for which no audiograms or direct measurements of hearing at any frequency for any species exist, we estimated hearing parameters relying upon extensive assumptions and extrapolation, including mathematical modeling using anatomical parameters, characteristics of sound production, and assumptions based on other species). This group (LF cetaceans) is thus described separately (last) within this section, with considerable associated caveats, given the extent to which it differs from the median-based method used to interpret direct hearing data in other groups.

The approach in estimating group audiograms to represent many species within each marine mammal group is to use median values among available data across individuals of different species. Clearly, there is substantial individual variability (both documented and expected) within and among species in the hearing groups identified herein. A comprehensive, quantitative description of this variability within and between all species would be desirable to more fully understand the validity of the hearing groups proposed and potential species-specific deviation from the median-based estimated group audiograms. However, the existing marine mammal hearing data are at present inadequate (with the exception of a very few species) to support such an analysis of variance. This is an acknowledged limitation of the quantitative approach taken and an area where subsequent criteria will benefit from additional data. Given these constraints, the use of a median-derived interpretation of the available data was deemed the most appropriate given the need to consider all species within a reasonable number of hearing groups rather than failing to consider some taxa at all.

Estimated group audiograms derived with median values from available direct measurements of hearing are used to establish several important metrics related to hearing—namely, auditory weighting and exposure functions for estimating the effects of noise on hearing (see the “Marine Mammal Auditory Weighting and TTS Exposure Functions” section). Estimated group audiograms are derived using both absolute and normalized (to the frequency of best sensitivity) thresholds from behavioral hearing studies, following the methodology of Finneran (2016). Such data are available for at least three individuals (and, in some cases, many more) within all but one marine mammal hearing group. Differences in hearing sensitivity have been measured between well-established behavioral audiometric methods (based on animal responses to experimental stimuli using the complete auditory and perceptual systems) and AEP measurements (based on electrophysiological responses within a portion of the auditory system). The AEP method is not capable of testing the full range of hearing as described, so AEP thresholds are not quantitatively applied in deriving estimated group audiograms. However, they were considered directly in hearing group designations for some species (along with other indirect methods of evaluating hearing capabilities as discussed above). Furthermore, some existing behavioral hearing data were considered but excluded from the estimated group audiograms. The excluded data were from individuals with obvious HF hearing loss or other evident aberrations from the normal species audiograms (e.g., obvious notches or thresholds known to be elevated for that species for a clear or likely reason such as auditory masking in the testing enclosure or frequency-specific hearing loss). For individuals tested in multiple studies, data at overlapping frequencies were averaged such that only one value for any individual was used at any frequency tested. However, multiple measurements from the same individual at different frequencies were treated as independent measurements. As a simplifying assumption deemed reasonable based on a general understanding of normal hearing in marine and other mammals, linear interpolation was used to generate a threshold estimate for every unique frequency tested for any individual in the marine mammal hearing group. This was done so that the results from all individuals contained threshold estimates at all frequencies, which could be considered.

Estimated group audiograms were determined based on the median threshold value at each test frequency among all individuals of any species within a hearing group for which behavioral hearing data were available. This approach incorporated all available data but minimized the influence of outlier values relative to the use of averages. The group audiograms were determined in two ways. First, the original (absolute) threshold values from every individual included among each group (in dB re 1 µPa [underwater thresholds] or dB re 20 µPa [aerial thresholds]) were used to determine group-wide median threshold values at each test frequency. These median thresholds were then used to derive estimated group audiograms (see below). Second, *normalized* thresholds were determined for each individual. This process involved subtracting thresholds at each frequency from the lowest threshold value obtained at any frequency. For example, if the lowest threshold measured within an individual for any frequency was 68 dB re 1 µPa at 10 kHz and a threshold of 88 dB re 1 µPa was measured at 1 kHz, the normalized threshold for 1 kHz would be 20 dB, whereas the normalized threshold for 10 kHz would be 0 dB.

Median threshold values were then fit by the following equation derived by Finneran (2016), which was modified from an equation used by Popov et al. (2007) to describe audiograms in dolphins. Finneran (2016) included additional frequency parameters to produce a shallower slope in the region of best sensitivity given the intended broader application across multiple species within groups and acknowledged data limitations for many species being represented:

Equation (1)

$$T(f) = T_0 + A\log_{10}\left(1 + \frac{F_1}{f}\right) + \left(\frac{f}{F_2}\right)^B$$

where $T(f)$ is the threshold at frequency f. Other variables are curve fitting parameters determined from the available group-specific behavioral hearing data:

T_0 fits the overall vertical position of the curve such that the lowest value occurs at the frequency at which the lowest threshold was measured.

F_1 is the inflection point of the LF rolloff.

A is a fitting parameter related to the slope of the LF rolloff.

F_2 is the inflection point and slope of the HF rolloff.

B is a fitting parameter related to the slope of the HF rolloff.

The resulting equation provides a standardized means of estimating a representative absolute and normalized audiogram function for all species within the group. It should be recognized that for all groups, these are estimated functions based on data from a few species and individuals. These curves represent the best fit to the limited existing data based on the assumptions and procedures described herein, but it should be clearly recognized that most species within each group have not been directly tested.

The resulting estimated group audiograms have features typical of mammalian hearing: linear-log threshold decrease with variable slope at low frequencies and a rapid increase in threshold at high frequencies that can be fit with an exponential function. Equation (1) was fit to the available median threshold data using nonlinear regression for each marine mammal group except LF cetaceans.

The original and normalized behavioral hearing threshold data used for most marine mammal hearing groups are discussed below, followed by the different approach taken in proposing a preliminary estimated group audiogram for LF cetaceans given the absence of direct hearing measurements. The resulting estimated group audiograms (using the absolute and normalized threshold data, respectively) based on the fitted curves are given for the odontocete (HF and VHF) cetaceans (Figures 1 & 2), sirenians (Figures 3 & 4), marine carnivores in water (Figures 5 & 6), and marine carnivores in air (Figures 7 & 8). The associated curve fitting parameters for all groups are given subsequently (Tables 2 & 3). Audiometric data that were available but not directly applied are specified, along with the reason for exclusion, within the respective group-specific appendix in which all audiometric and auditory anatomy data are presented. The curve fits based on a different estimation procedure of all fitting parameters for the LF cetaceans are presented separately (Figures 9 & 10).

Estimated Group Audiograms for Odontocete Cetaceans (HF & VHF)
For HF cetaceans, audiometric data were used for the following species and individuals tested: bottlenose dolphin (Johnson, 1967 [*n* = 1]; Ljungblad et al., 1982 [*n* = 1]; Lemonds, 1999 [*n* = 1]; Brill et al., 2001 [*n* = 1]; Schlundt et al., 2007 [*n* = 1]; Finneran et al., 2010 [*n* = 1]), beluga whale (White, 1978 [*n* = 1]; Awbrey et al., 1988 [*n* = 3]; Johnson et al., 1989 [*n* = 1]; Ridgway et al., 2001 [*n* = 2]; Finneran et al., 2005b [*n* = 1]), killer whale (Szymanski et al., 1999 [*n* = 2]), Risso's dolphin (Nachtigall et al., 1995 [*n* = 1]), striped dolphin (Kastelein et al., 2003 [*n* = 1]), tucuxi dolphin (Sauerland & Dehnhardt, 1998 [*n* = 1]), false killer whale (Thomas et al., 1988) [*n* = 1]), and Pacific white-sided dolphin (Tremel et al., 1998 [*n* = 1]). These combined data were applied to derive the HF cetacean estimated group audiograms for the original (absolute sensitivity) threshold data (Figure 1, left) and normalized values (Figure 2, left).

For VHF cetaceans, audiometric data were used for the following species and individuals tested: harbor porpoise (Kastelein et al., 2002a [*n* = 1]; Kastelein et al., 2010 [*n* = 1]; Kastelein et al., 2015 [*n* = 1]) and Amazon river dolphin (Jacobs & Hall, 1972 [*n* = 1]). These combined data were used to derive the VHF cetacean estimated group audiograms for the original threshold data (Figure 1, right) and normalized values (Figure 2, right).

Estimated Group Audiograms for Sirenians (SI)
Behavioral hearing data were used for the following species and individuals tested: West Indian manatee (Gerstein et al., 1999 [*n* = 2]; Mann et al., 2005 [*n* = 2]). The secondary decrease in thresholds at below 0.3 kHz evident in Gerstein et al. (1999) may have been the result of non-auditory (tactile) sensitivity to vibration; these values were consequently excluded from the determination of the estimated group audiogram. These combined data were applied to derive SI estimated group audiograms for the original threshold data (Figure 3) and normalized values (Figure 4).

Estimated Group Audiograms for Phocids and Other Marine Carnivores in Water (PCW & OCW)
For PCW, audiometric data were used for the following species and individuals tested: northern elephant seal (Kastak & Schusterman, 1999 [*n* = 1]), harbor seal (Terhune, 1988 [*n* = 1]; Kastelein et al., 2009 [*n* = 1]; Reichmuth et al., 2013 [*n* = 1]), spotted seal (Sills et al., 2014 [*n* = 2]), and ringed seal (Sills et al., 2015 [*n* = 1]). These combined data were applied to estimate the PCW group audiograms for the original threshold data (Figure 5, left) and normalized values (Figure 6, left).

For OCW, audiometric data were used for the following species and individuals tested: northern fur seal (Moore & Schusterman, 1987 [*n* = 2]; Babushina et al., 1991 [*n* = 1]), California sea lion (Mulsow et al., 2012 [*n* = 1]; Reichmuth & Southall, 2012 [*n* = 2]; Reichmuth et al., 2013 [*n* = 1]), Steller sea lion (Kastelein et al., 2005 [*n* = 2]), walrus (Kastelein et al., 2002b [*n* = 1]), and sea otter (Ghoul & Reichmuth, 2014 [*n* = 1]). These combined data were applied to derive OCW estimated group audiograms for the original threshold data (Figure 5, right) and normalized values (Figure 6, right).

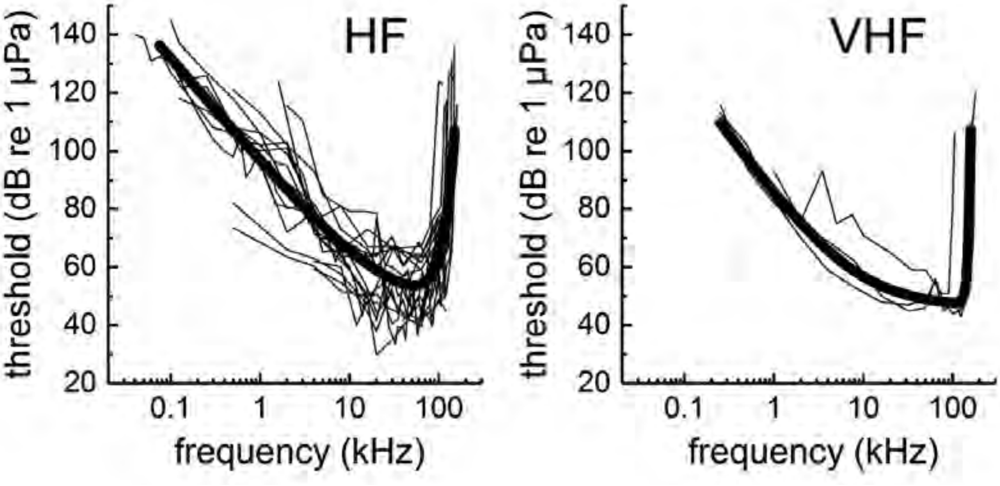

Figure 1. Estimated group audiograms based on original behavioral threshold data for high-frequency (HF) cetaceans (left) and very high-frequency (VHF) cetaceans (right)

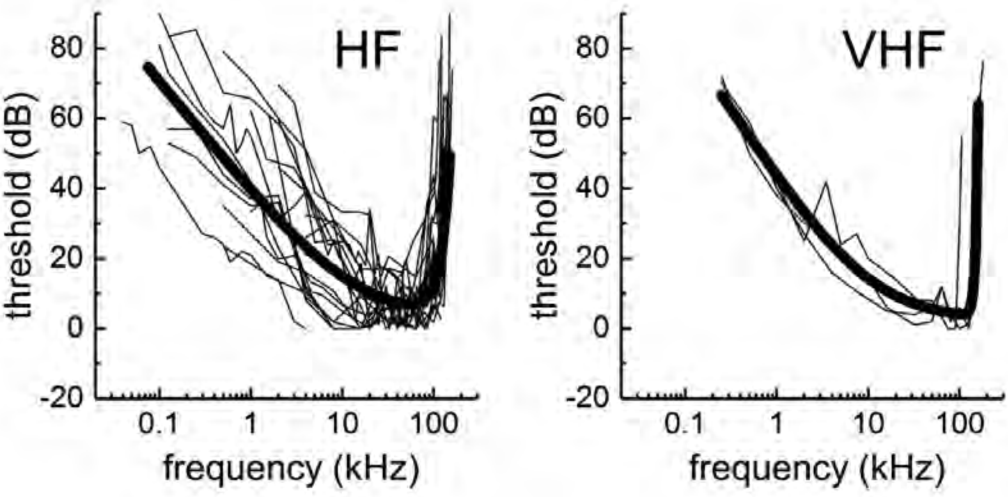

Figure 2. Normalized estimated group audiograms for HF cetaceans (left) and VHF cetaceans (right)

Estimated Group Audiograms for Phocids and Other Marine Carnivores in Air (PCA, OCA)

For PCA, audiometric data were used for the following species and individuals tested: harbor seal (Reichmuth et al., 2013 [*n* = 1]), spotted seal (Sills et al., 2014 [*n* = 2]), and ringed seal (Sills et al., 2015 [*n* = 1]). These combined data were applied to derive estimated group audiograms for the original PCA threshold data (Figure 7, left) and normalized values (Figure 8, left).

For OCA, audiometric data were used for the following species and individuals tested: northern fur seal (Moore & Schusterman, 1987 [*n* = 3]; Babushina et al., 1991 [*n* = 1]), California sea lion (Mulsow et al., 2011 [*n* = 1]; Reichmuth et al., 2013 [*n* = 1]), Steller sea lion (Mulsow & Reichmuth, 2010 [*n* = 1]), polar bear (Owen & Bowles, 2011 [*n* = 1]), and sea otter (Ghoul & Reichmuth, 2014 [*n* = 1]). These combined data were applied to derive OCA estimated group audiograms for the original (absolute) threshold data (Figure 7, right) and normalized values (Figure 8, right).

Estimated Audiogram Parameter Values for Marine Mammal Groups Based on Direct Measurements of Hearing

From the available data, median (50th percentile) threshold values were determined or estimated at each frequency and then fit by Equation (1) using fitting parameters specified. The resulting parameters and goodness of fit values ($\boldsymbol{R}^2$) to the group-specific estimated group audiograms are given for all absolute (Table 2) and normalized (Table 3) threshold data. While these parameters are related to different aspects of estimated hearing across species, including best absolute sensitivity and respective differences at frequencies

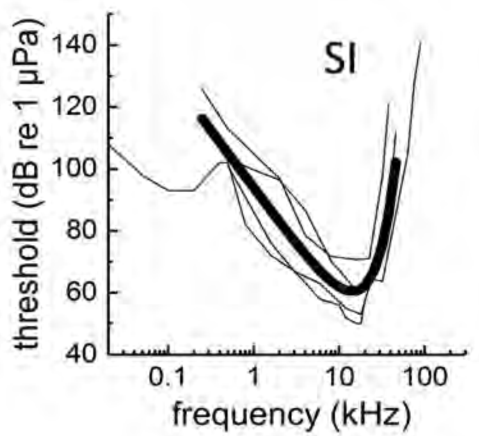

Figure 3. Estimated group audiogram based on original behavioral threshold data for sirenians (SI)

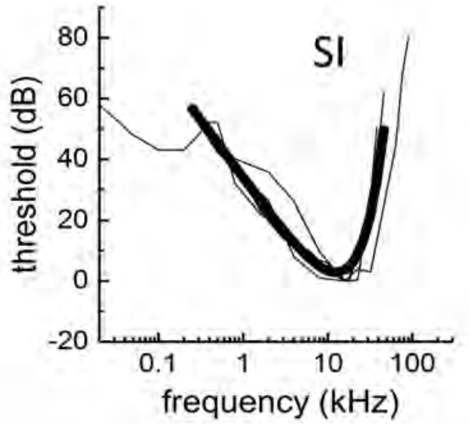

Figure 4. Normalized estimated group audiogram for SI

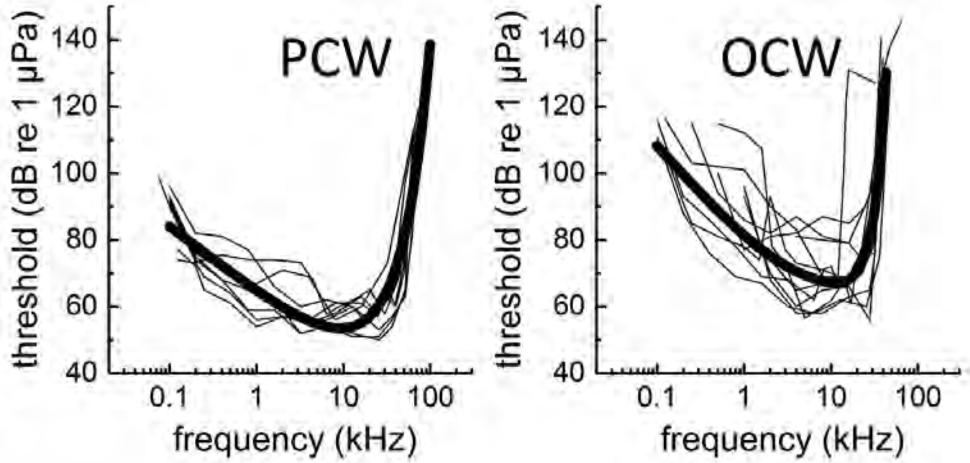

Figure 5. Estimated group audiograms based on original behavioral threshold data for marine carnivores in water (left: phocid carnivores in water [PCW]; right: other carnivores in water [OCW])

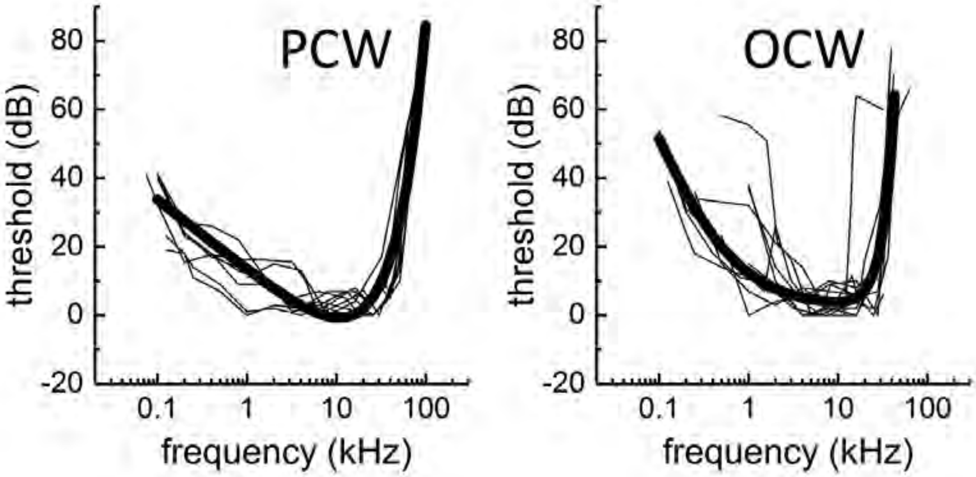

Figure 6. Normalized estimated group audiograms for marine carnivores in water (left: PCW; right: OCW)

below and above the region of best sensitivity, they should be recognized as simply equation fitting parameters and not interpreted as estimates of specific features of the estimated audiograms. The extent to which they differ from certain features is dependent on the overall shape of the resulting curves. For instance, T_0 fits the vertical position of the curve and is comparable to the estimated absolute threshold at best hearing sensitivity for some species groups (e.g., HF cetaceans) but is very different for other groups (e.g., PCA) based simply on the shape of the function and the fit required.

Preliminary Estimated Hearing Parameters for Mysticete Cetaceans (LF)

For LF cetaceans, no direct hearing data (behavioral or electrophysiological) were available at any frequency for any species. That is, there are no comprehensive, directly measured audiograms for any baleen whale from which we can estimate an LF cetacean group audiogram as was done for all other species groups. To avoid simply not providing criteria for these species and to provide some consistency in the overall approach with the other hearing groups, an alternative approach was used to estimate hearing parameters for the LF cetaceans. While determination of these curve fitting

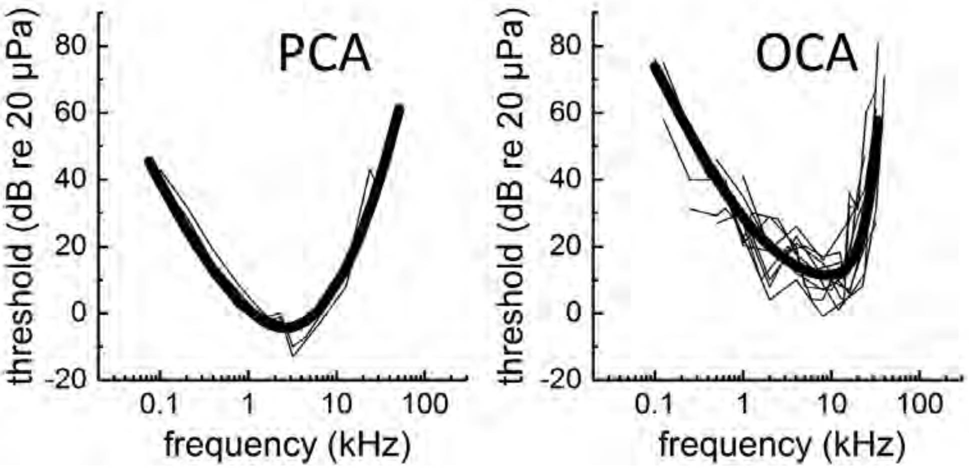

Figure 7. Estimated group audiograms based on original behavioral threshold data for marine carnivores in air (left: phocid carnivores in air [PCA]; right: other carnivores in air [OCA])

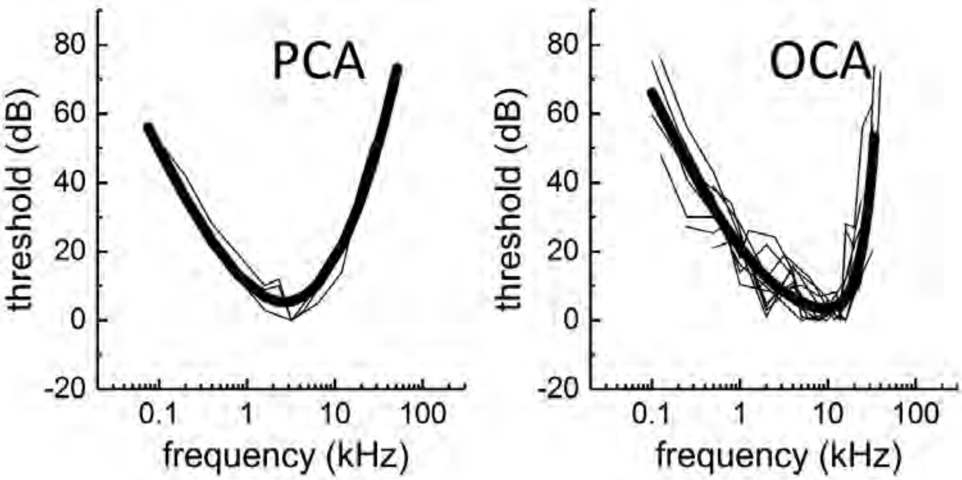

Figure 8. Normalized estimated group audiograms for marine carnivores in air (left: PCA; right: OCA)

parameters is based on limited data for all groups, this process is fundamentally different for the LF cetaceans in that every parameter was estimated without direct data from *in vivo* hearing studies to inform the estimate. Consequently, the underlying assumptions of this alternative methodology are discussed separately. The resulting estimated hearing parameters are given here and should be interpreted with full acknowledgment of the absence of direct data and the extensive requisite extrapolation.

A diverse range of studies were considered in estimating LF cetacean hearing parameters. These included basilar membrane dimensions (e.g., Ketten, 1994, 2014; Parks et al., 2007b; Ketten & Mountain, 2014), scaling relationships between inter-aural time differences and upper-frequency limits of hearing (see Ketten, 2000), an extrapolation of cat and human threshold data based on earlier frequency-place maps for the humpback whale (Houser et al., 2001), and finite element models of head-related and middle-ear transfer functions. Finite element models of middle ear functions (Tubelli et al., 2012a, 2012b) and skull vibrational bone force curve models (Cranford & Krysl, 2015) informed the determination of the LF slope of the functions (***A*** = 20 dB/decade). Estimates of the audible range of hearing and frequencies of best sensitivity were made based on an integration of results from Houser et al. (2001), Tubelli et al. (2012b), and Cranford & Krysl (2015), which suggest that peak sensitivity

Table 2. Estimated group audiogram parameter values determined by the best fit of Equation (1) for marine mammal groups based on directly measured behavioral hearing thresholds

Marine mammal hearing group	T_0 (dB)	F_1 (kHz)	F_2 (kHz)	A	B	R^2
HF	46.2	25.9	47.8	35.5	3.56	0.977
VHF	46.4	7.57	126	42.3	17.1	0.968
SI	-40.4	3,990	3.8	37.3	1.7	0.982
PCW	43.7	10.2	3.97	20.1	1.41	0.907
OCW	63.1	3.06	11.8	30.1	3.23	0.939
PCA	-110	5.56	1.02 × 10-6	69.1	0.289	0.973
OCA	6.24	1.54	8.24	55.6	2.76	0.978

Table 3. Normalized estimated group audiogram parameters values determined by the best fit of Equation (1) for marine mammal groups based on directly measured behavioral hearing thresholds

Marine mammal hearing group	T_0 (dB)	F_1 (kHz)	F_2 (kHz)	A	B	R^2
HF	3.61	12.7	64.4	31.8	4.5	0.960
VHF	2.48	9.68	126	40.1	17	0.969
SI	-109	5,590	2.62	38.1	1.53	0.963
PCW	-39.6	368	2.21	20.5	1.23	0.907
OCW	2.36	0.366	12.8	73.5	3.4	0.958
PCA	-71.3	4.8	6.33 × 10-5	63	0.364	0.975
OCA	-1.55	1.6	8.66	54.9	2.91	0.968

occurs between ~1 to 8 kHz for the species modeled, with best sensitivity range of hearing (defined as occurring within ~40 dB of peak sensitivity) ranging from ~30 Hz to ~30 kHz depending on species. The F_1 (LF inflection point) parameter was selected such that thresholds in the 1 to 8 kHz range were within 3 dB of the lowest threshold. Note that this implies considerably reduced sensitivity for some LF species at frequencies emphasized in their vocal repertoire (e.g., the narrowband 20-Hz tonal signals of fin whales; Watkins, 1981; Edds-Walton, 1997). However, it is important not to overlook that the fundamental frequency of a vocalization is not necessarily the key feature for communication or perception but, rather, as has been demonstrated in other species, components, such as the envelope and/or harmonics, may be of equal or greater significance.

The LF high-frequency hearing parameters were determined using hearing data from other marine mammals. Specifically, the median value of the B fitting parameter (related to the slope of HF component) for all other marine mammal groups measured in water (HF, VHF, SI, PCW, and OCW). Given this slope (B = 3.2), the F_2 parameter (HF inflection point) was determined as 9.4 kHz such that the estimated threshold at 30 kHz was within 40 dB of the lowest threshold.

Given the absence of any direct measurements of hearing sensitivity, the vertical position of the estimated audiogram was determined based on available behavioral audiometric measurements in other marine mammals. The T_0 fitting parameter was estimated as 53.2 dB based on the median of the lowest hearing thresholds for all other marine mammal groups in water (HF, VHF, SI, PCW, and OCW).

An estimated audiogram for the LF cetaceans was then derived (Figure 9) using these fitting parameter values in Equation (1). No goodness of fit (R^2) value was determined given the lack of direct hearing data with which to compare the curve, underscoring the necessary caveats regarding the estimated audiogram. As with other groups, an estimated normalized audiogram was then derived using identical values for F_1, F_2, A, and B and value of T_0 (0.8 dB) that resulted in the lowest point of the curve (frequency of best sensitivity) equaling 0 dB (Figure 10).

These estimated curves suggest better sensitivity and a broader audible frequency range than anatomically based indirect estimates of hearing for humpback (Houser et al., 2001) and fin (Cranford & Krysl, 2015) whales and are in closer agreement with earlier publications of inner ear frequency maps noted above. The hearing parameters estimated for LF cetaceans are generally consistent with broad predictions of LF sensitivity in mysticetes based on vocal behavior (Parks et al., 2007a) and the predictions of Clark & Ellison (2004) who estimated best hearing sensitivities of 60 to 70 dB re 1 µPa for baleen whales. This estimate was based upon the assumption that hearing sensitivity evolves to be 16 to 24 dB above typical ocean ambient noise spectrum levels given a critical ratio of 16 to 24 dB.

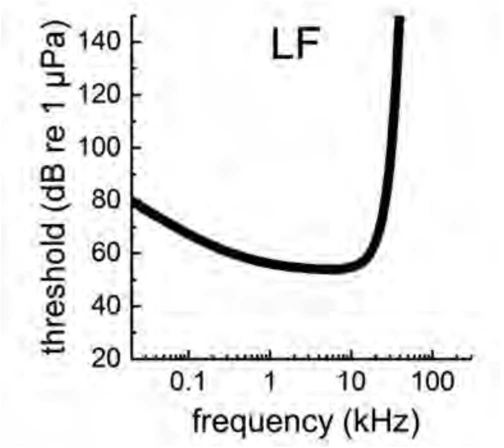

Figure 9. Estimated group audiogram for low-frequency (LF) cetaceans proposed with extensive assumptions, extrapolations, and caveats (see text for details)

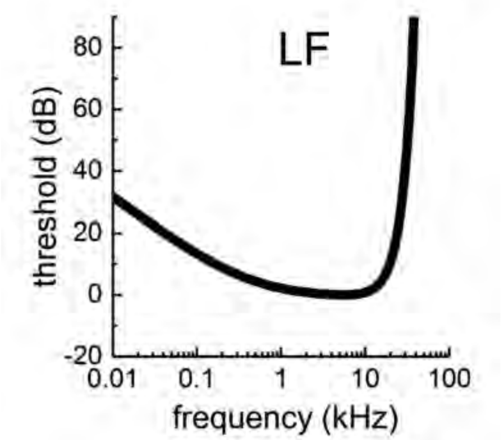

Figure 10. Normalized estimated group audiogram for LF cetaceans proposed with extensive assumptions, extrapolations, and caveats (see text for details)

Marine Mammal Auditory Weighting and TTS Exposure Functions

Weighting Functions and Exposure Functions
Marine mammal hearing groups were identified, and hearing parameters were estimated in the absence of complete data on many individuals of all species to provide what is believed to be a best estimate of hearing among the group as a function of frequency as described above.

At frequencies where an animal has sensitive hearing (lower thresholds), it is more likely to be more susceptible to auditory effects of noise exposure (i.e., lower TTS-onset thresholds) because the relative difference between noise and hearing threshold (often called *sensation level*) is greater for the same exposure level than for frequencies for which the animal has less sensitive hearing (higher thresholds). That is, while effects can occur for frequencies outside an animal's range of best hearing sensitivity, there is a general relationship between hearing sensitivity and susceptibility to noise exposure, allowing conclusions related to frequency-dependence of hearing capabilities to roughly inform assessments of susceptibility to potential auditory effects (see Yost, 2006). This approach has been validated for a range of terrestrial animals (Kerr et al., 2017) and supported by research on marine mammals in the last decade (see Finneran, 2015). The available hearing data used to derive estimated group audiograms were used in combination with other audiometric data (i.e., equal loudness, equal latency, and TTS measurements) to derive *auditory weighting functions* and corresponding *noise exposure functions*. These complementary functions provide different ways to visualize the frequency-specific effects of noise on different species with different hearing characteristics. *Auditory weighting functions* serve as frequency-specific filters that quantify how noise may affect an animal given its spectral content and how it relates to the spectral characteristics of an individual's potential susceptibility to noise. Weighting functions are used to de-emphasize noise at frequencies where susceptibility is lower. *Noise exposure functions* represent exposure levels for the onset of TTS or PTS as a function of noise frequency. Weighting functions and noise exposure functions have identical shapes but are inversely related, in a similar fashion as auditory sensitivity and hearing threshold. For both functions, identical values are determined for lower- and upper-frequency values at which either relative sensitivity or a threshold for a defined exposure begins to change. Similarly, slope parameters describing the rate of this change at both low and high frequencies are identical, although with inverse signs (negative for weighting functions; positive for exposure functions). However, the *anchor* values determining the vertical positions of each function are different. Whereas weighting functions are grounded at a nominal amplitude of 0 dB (at best hearing sensitivity) with negative weighting at relatively lower and higher frequencies, exposure functions have a minimum value at the lowest threshold for a known or estimated effect level (e.g., TTS) and show higher onset thresholds for different frequencies at values determined by the shape of the function. Methods used to determine these functions within different marine mammal groups are described herein.

Weighting functions have been primarily developed and evaluated systematically in humans, with limited efforts to develop them for non-human animals. Weighting functions are similar to "band-pass" filters—they include a central region corresponding to greatest susceptibility to noise along with lower- and higher-frequency regions where the relative susceptibility is lower (reflected as negative values on these curves). Weighting functions provide a group-specific means of calculating how a specific noise exposure would potentially affect the hearing of an animal given the extent to which the frequency spectra match frequency-specific hearing sensitivity. For noise exposures that occur at frequencies where animals are less susceptible, the effective exposure is reduced according to the weighting function (see Figure 1 in Houser et al., 2017). Effects of noise on an animal are determined by first weighting the noise exposure by filtering the noise using the weighting function. This is analogous to adding the weighting function amplitude (in dB) to the noise spectral amplitude (in dB) at each frequency, then integrating the weighted noise spectra across frequency to obtain the *weighted noise exposure level*, which describes exposure for the entire frequency range with a single metric. The weighted exposure level is then compared to the *weighted threshold* for TTS or PTS. The weighted threshold represents the exposure level required for the onset of TTS/PTS at frequencies where the weighting function has an amplitude of 0 dB (the peak of the weighting function). If the weighted exposure level is greater than or equal to the weighted threshold, TTS or PTS is assumed to occur. Predicting the effects of a noise exposure, therefore, requires both the weighting function and the weighted thresholds for TTS/PTS.

As described above, Southall et al. (2007) proposed frequency-specific auditory M-weighting functions for five marine mammal hearing groups utilizing the underlying format of C-weighting functions in humans, an idealized version of the human 100-phon equal-loudness curve. Due to the disproportional growth in loudness with increases in relative intensity (loudness recruitment) with increasing level (Yost, 2006), equal loudness functions tend to flatten at higher received levels. The M-weighting functions only estimated upper- and lower-frequency cut-off values defined very conservatively—just 6 dB down from estimated best sensitivity. This was deliberate given the extreme data limitations on hearing and the effects of noise on hearing for most marine mammal species at the time, and the resulting weighting functions were quite broad and flat across most of the audible range. Auditory weighting functions for each hearing group here are defined to better describe relative hearing sensitivity within the audible range using the more data-derived, systematic approach of Finneran (2016), based on the following equation for a generic band-pass filter:

Equation (2) $$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\}$$

where *W*(*f*) is the weighting function amplitude (in dB) at frequency *f* (in kHz). LF transition values ($\boldsymbol{f_1}$ in kHz) represent the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve. These have been described as *cut-offs* (Finneran, 2016), but it is important to note that they do not represent the lowest sound frequencies at which animals can hear. Some of the values are in fact unreasonable or illogical if interpreted in that manner. The specific amplitude of the weighting and exposure functions at $\boldsymbol{f_1}$ depends on the value of the LF slope of each curve, which are defined below. HF transition values ($\boldsymbol{f_2}$ in kHz) represent the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve. Again, the specific amplitude of either function at $\boldsymbol{f_2}$ depends on the upper-frequency slope of the curves. The LF exponent value (***a*** – dimensionless) defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low frequencies (the LF slope) is 20***a*** dB/decade. The HF exponent value (***b*** – dimensionless) defines the rate of decline of weighting function amplitude at high frequencies, becoming linear with the logarithm of frequency. The change in weighting function amplitude with frequency at high frequencies (the HF slope) is -20***b*** dB/decade. The constant ***C*** defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Noise exposure functions combine the frequency-dependent weighting function with the weighted threshold value to represent exposure levels for the onset of TTS or PTS as a function of noise frequency. Exposure functions provide a group-specific function that characterizes and visualizes how noise exposure would induce a defined effect at different sound frequencies. Exposures equal to the group-specific TTS exposure function curve at a specific frequency would be predicted to result in TTS onset (typically defined as 6 dB TTS), with exposures exceeding these values resulting in some greater magnitude of TTS depending on the value above the curve and TTS growth relationships (see the following section). The exposure function minimum value equals the weighted threshold for TTS (or PTS onset). This value occurs at the frequency where the weighting function has a peak; this is typically similar to, but not necessarily identical to, the frequency of best hearing sensitivity (lowest threshold). Onset TTS levels increase for frequencies below and above this lowest point in the exposure function.

Exposure functions are complementary to weighting functions and are, therefore, defined using a similar equation:

Equation (3) $$E(f) = K - 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\}$$

where $E(f)$ is the exposure function amplitude (in dB) at frequency f (in kHz). The parameters $\boldsymbol{f_1}$, $\boldsymbol{f_2}$, $\boldsymbol{a}$, and $\boldsymbol{b}$ are identical to those for the weighting function (Equation [2]). The parameter $\boldsymbol{K}$ determines the vertical position of the curve (as described in greater detail below). It is defined so that the minimum amplitude of the function equals the weighted TTS or PTS threshold estimated for each marine mammal hearing group.

In addition to the general similarities between Equations (2) and (3), several additional points are worth noting: (1) the second term in each equation is identical and defines the shape of each curve; (2) the change in sign before the second term (positive in Equation [2]; negative in Equation [3]) indicates that the functions are vertically inverted forms of each other; and (3) the parameters $\boldsymbol{K}$, $\boldsymbol{C}$, and the weighted threshold for TTS/PTS ($\boldsymbol{T_w}$) are not independent. Since $\boldsymbol{C}$ is defined such that the peak of Equation (2) is zero and $\boldsymbol{K}$ is defined such that the minimum of Equation (3) equals $\boldsymbol{T_w}$, Equations (2) and (3) can be manipulated to show that $\boldsymbol{T_w} = \boldsymbol{C} + \boldsymbol{K}$. Additional details regarding these parameters and the relationships between their use in weighting and exposure functions are provided in Figure 1 of Finneran (2016).

Derivation of Function Parameters

Group-specific parameters for the non-impulsive TTS exposure functions and auditory weighting functions were derived following Finneran (2016). This involves both the application of function parameters described above for the weighting and exposure functions as well as a method of using available TTS data within groups where available or extrapolated from other groups where unavailable.

First, the values of $\boldsymbol{a}$ and $\boldsymbol{b}$ were defined for each group. Next, an iterative process was used whereby $\boldsymbol{f_1}$ and $\boldsymbol{f_2}$ were varied to minimize the differences between the exposure function and available, non-impulsive TTS-onset data for the HF and VHF groups. While TTS studies have been conducted for at least one species of most of the marine mammal groups, these are the only groups within which sufficient TTS data has been obtained in at least (but in many cases) one individual at multiple frequencies (see Finneran, 2015). That is, direct measurements of TTS that were available at enough frequencies to evaluate frequency differences were used to inform the shape of the weighting and exposure functions by manipulating the $\boldsymbol{f_1}$ and $\boldsymbol{f_2}$ parameters. These limited available TTS data were used directly for most hearing groups (an alternate approach was used for LF cetaceans) to inform the shape of the weighting and exposure functions rather than, for instance, simply inverting the estimated group audiograms. The results of the iterative process allowed $\boldsymbol{f_1}$ and $\boldsymbol{f_2}$ to be estimated for the remaining groups, albeit with acknowledgment of the greater underlying uncertainty in these estimations given this extrapolation. With $\boldsymbol{f_1}$, $\boldsymbol{f_2}$, $\boldsymbol{a}$, and $\boldsymbol{b}$ defined for all groups, the parameter $\boldsymbol{K}$ for the TTS exposure function was defined to provide the best fit between the exposure functions and the available TTS-onset data (HF, VHF, PCW, OCW, PCA, and OCA) or estimated TTS onset (SI and LF). The weighted TTS threshold was then determined from the minimum of the exposure function. Finally, the parameter $\boldsymbol{C}$ was defined for each group by setting the maximum value of Equation (2) to zero. These steps are described in detail next.

The LF exponent ($\boldsymbol{a}$) was determined for each group using the smaller (shallower) slope of either the LF slope from the estimated group audiogram or the LF slope of equal latency contours, where available. Audiogram slopes were calculated (using this slope) across a frequency range of one decade, beginning with the lowest frequency present for each group, except for the LF cetaceans for which this value was defined in the assumptions for the estimated group audiogram. Additionally, LF slopes based on equal latency measurements, which are the basis for such functions in humans (see Houser et al., 2017), were determined. This was done for those species for which sufficient data were available, which included HF cetaceans (bottlenose dolphin; Mulsow et al., 2015), VHF cetaceans (harbor porpoise; Wensveen et al., 2014), PCA (harbor seal; Reichmuth, 2013), and OCA (California sea lion; Mulsow et al., 2015). The group-specific slopes at lower frequencies (s_0) were determined for other species groups using the LF slope from estimated group audiograms. The resulting s_0 values and the group-specific frequency of best hearing sensitivity (f_0) based on direct hearing measurements are shown for most marine mammal groups below (Table 4). For the LF cetaceans, given the lack of direct data, a different approach was taken to estimate these values. The f_0 parameter for LF cetaceans derived from the estimated audiogram is predicted to occur at 5.6 kHz based on an integrated interpretation of Houser et al. (2001) and Cranford & Krysl (2015) as described above. Given the lack of equal latency data, the s_0 value for LF cetaceans was estimated as 20 dB/decade based on the A fitting parameter used to derive the estimated group audiogram.

Because of the extreme lack of HF data (e.g., equal loudness or latency contours) with which to estimate this parameter, the HF exponent (b) for all hearing groups was defined as $b = 2$, based on prior weighting functions (Southall et al., 2007; Finneran, 2016), including the upper-frequency slope of human C-weighting functions. This is an area of specific needed research given the influence of this parameter on the overall shape of the function.

Group-specific values for frequencies f_1 and f_2 were defined as the frequencies at which the estimated group audiogram threshold values exceed the lowest threshold value (e.g., threshold at f_0; see Table 5) by a difference threshold (DT). The purpose of identifying this parameter was to establish a common relative relationship across all groups between the shape of the weighting function and the estimated group audiogram by using the limited available TTS data. The value of DT was determined in an iterative fashion by minimizing the mean-squared error between the exposure functions and available non-impulsive TTS data for the HF and VHF groups (the only groups with sufficient TTS-onset data at multiple frequencies). This value for DT was then extrapolated for use with all other hearing groups. If the value of DT were set to zero, the weighting function shape would be similar to the inverse shape of the estimated group audiogram. Increasing DT values progressively "compresses" the weighting function, making it broader compared to the audiogram near the frequency region of best sensitivity (see Finneran, 2016, for specific comparisons). This compression process has some of the same effects as loudness recruitment in equal loudness curves, which become flatter with increasing level (Yost, 2006). Compression accounts for available TTS data, which show smaller differences in TTS onset across frequencies than would be predicted by the shape of the inverse audiogram in the region near best sensitivity (Houser et al., 2017). Differences between the exposure functions calculated here using both auditory and TTS data, and simple predictions from an inverse audiogram

Table 4. Frequency of best hearing (f_0) and the magnitude of the low-frequency slope (s_0) derived from estimated group audiograms (from either original and normalized data) and/or equal latency contours. Where both estimates exist, the lowest respective slope values (in bold) were used to determine the low-frequency exponent value (a). The lack of direct hearing data for LF cetaceans forced an estimate of these parameters (see text).

	Original data estimated group audiogram		Normalized data estimated group audiogram		Equal latency curves
Marine mammal hearing group	f_0 (kHz)	s_0 (dB/decade)	f_0 (kHz)	s_0 (dB/decade)	s_0 (dB/decade)
HF	55	35	58	**31**	**31**
VHF	105	37	105	**36**	50
SI	16	36	12	37	--
PCW	8.6	19	13	20	--
OCW	12	27	10	39	--
PCA	2.3	41	2.3	42	**41**
OCA	10	45	10	45	**27**

Table 5. Marine mammal group-specific auditory weighting function and TTS exposure function parameters. Note that function parameter ***K*** for the LF and SI groups was estimated using TTS-onset data extrapolated from individuals in other marine mammal groups tested in water.

Marine mammal hearing group	f_1 (kHz)	f_2 (kHz)	a	B	K (dB)	R^2	C (dB)
LF	0.20	19	1	2	179	--	0.13
HF	8.8	110	1.6	2	177	0.825	1.20
VHF	12	140	1.8	2	152	0.864	1.36
SI	4.3	25	1.8	2	183	--	2.62
PCW	1.9	30	1	2	180	--	0.75
OCW	0.94	25	2	2	198	0.557	0.64
PCA	0.75	8.3	2	2	132	--	1.50
OCA	2.0	20	1.4	2	156	--	1.39

method are shown in the exposure function figures below. These comparisons illustrate both the differences in predicted sensitivity and the fact that experimental measurements of TTS onset at different frequencies are better predicted using the empirically based weighting functions than a simple inverse audiogram method.

The value of ***K*** was determined to minimize the mean squared error between the exposure function and measured or estimated TTS onset. A unique value of ***K*** was determined for each group. For hearing groups for which no TTS onset data exist (LF cetaceans and SI), TTS onset at the frequency of best hearing (f_0 from Table 4) was estimated based on the assumption that the differences between hearing threshold and TTS onset at f_0 would be similar across groups. Specifically, the median numeric difference between the non-impulsive TTS onset (in dB re 1 μPa^{2}s) for species groups tested in water (HF, VHF, PCW, and OCW) and their respective estimated group audiogram thresholds at f_0 (in dB re 1 μPa) was determined to be 126 dB. This value was added to the estimated threshold at f_0 for LF cetaceans (54 dB re 1 μPa) to produce an estimated TTS-onset value at f_0 of 180 dB re 1 μPa^{2}s. For sirenians (SI), using the f_0 hearing threshold of 61 dB re 1 μPa and the median numeric difference of 126 dB produced a TTS-onset estimate at f_0 of 187 dB re 1 μPa^{2}s. These extrapolated values were then used to determine ***K*** and derive associated exposure functions. The weighted TTS threshold was determined from the minimum of the exposure function. The parameter ***C*** was determined for each group by setting the maximum value of Equation (2) to zero.

Auditory weighting and exposure functions for all marine mammal hearing groups were determined using these parameters and Equations (2) and (3) for weighting and exposure functions, respectively. The weighting functions show relative differences in the predicted magnitude of noise effect relative to the predicted most sensitive frequency (e.g., where W(f) = 0 dB), and the exposure functions show the estimated TTS-onset levels for different noise exposure frequencies. For the LF, HF, and VHF cetacean hearing groups, auditory weighting functions (Figure 11) and auditory exposure functions (Figure 12) are shown below. Similarly, auditory weighting and exposure functions are given for the SI hearing group (Figures 13 & 14, respectively), PCW and OCW hearing groups (Figures 15 & 16), and PCA and OCA hearing groups (Figures 17 & 18).

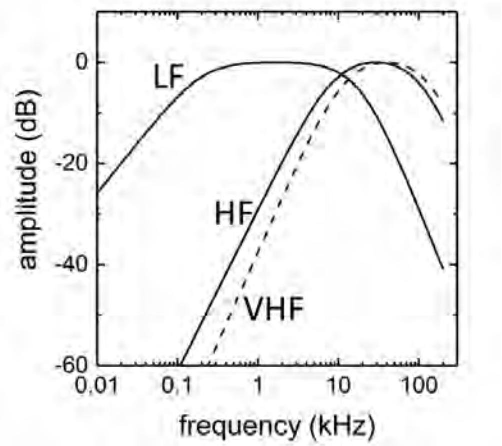

Figure 11. Derived auditory weighting functions for LF, HF, and VHF (dashed line) cetaceans generated with Equation (2) using parameters given in Table 5

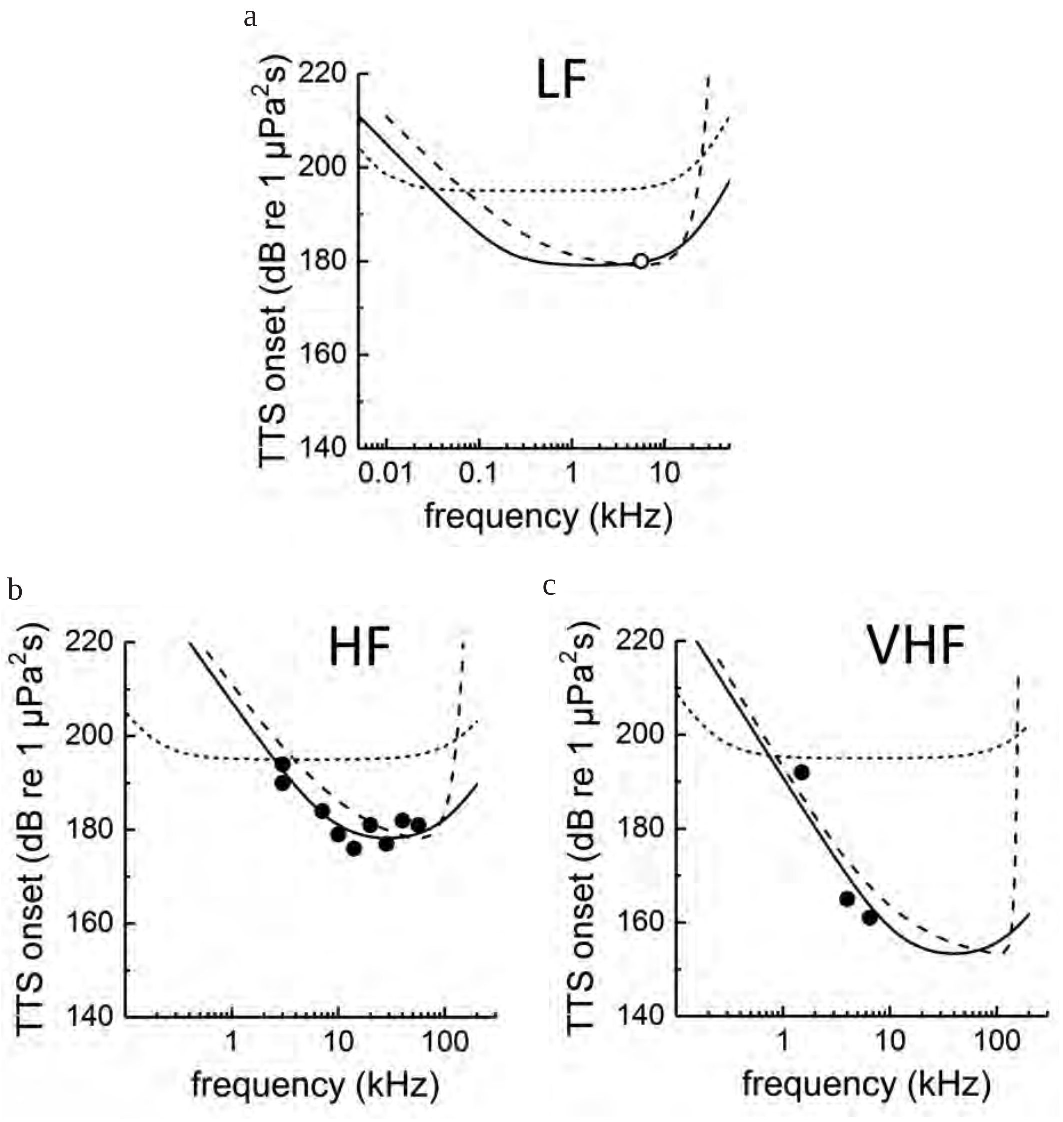

Figure 12. Exposure functions (solid lines) for LF (top), HF (bottom left), and VHF (bottom right) cetaceans generated with Equation (3) using parameters from Table 6. Open symbol for LF cetaceans indicates the estimated TTS onset at f_0 based on TTS data from other groups given that no direct empirical data exist for any LF species. Filled symbols indicate empirical onset TTS exposure data used to determine exposure functions for HF and VHF cetaceans. Normalized estimated group audiograms (dashed lines) are shown for comparison with a minimum value identical to that of the associated exposure functions. Estimated exposure functions derived from M-weighting filters each respective group with a minimum value set at the estimated TTS-onset value (dotted lines) are also shown for comparison (derived from Southall et al., 2007).

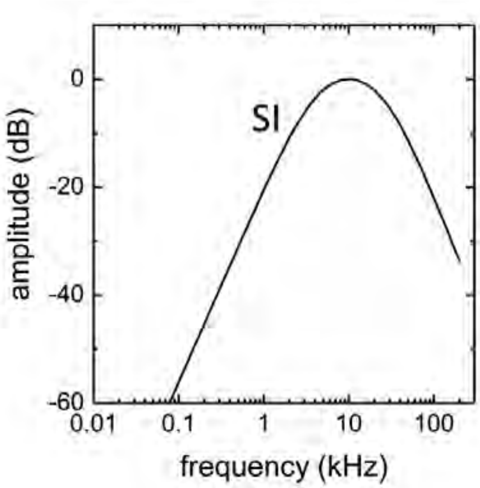

Figure 13. Derived auditory weighting function for SI generated with Equation (2) using parameters given in Table 5

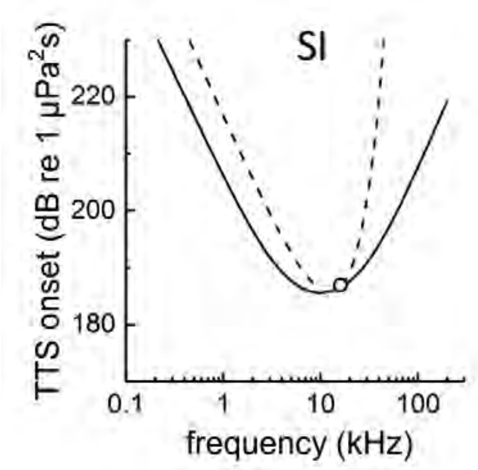

Figure 14. Exposure function (solid line) for sirenians generated with Equation (3) using parameters given in Table 6. The normalized SI estimated group audiogram (dashed line) is shown for comparison with a minimum value identical to that of the exposure function. The open symbol indicates the estimated TTS onset given that no TTS data of any kind exist for sirenians. The SI normalized estimated group audiogram (dashed line) is shown for comparison with a minimum value identical to that of the associated exposure functions.

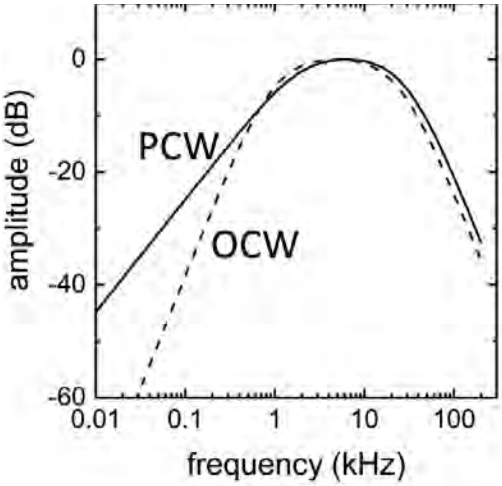

Figure 15. Derived auditory weighting functions for marine carnivores in water (PCW and OCW) generated with Equation (2) using parameters given in Table 5

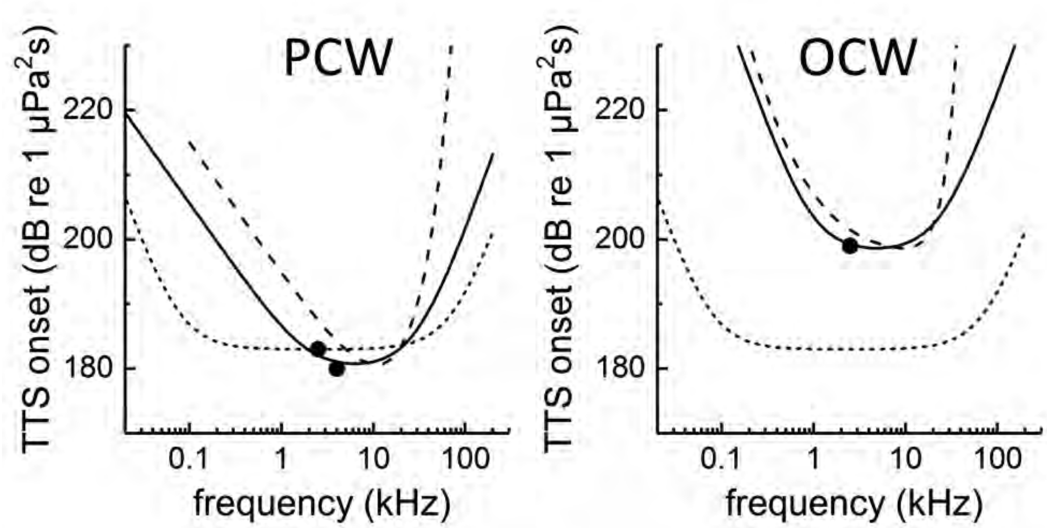

Figure 16. Exposure functions (solid lines) for marine carnivores in water (PCW and OCW) generated with Equation (3) using parameters given in Table 6. Filled symbols indicate empirical onset TTS exposure data used to determine the exposure function. Normalized estimated group audiograms for PCW and OCW (dashed lines) are shown for comparison with a minimum value identical to that of the associated exposure functions. Estimated exposure functions derived from M-weighting filters for pinnipeds in water with a minimum value set at the estimated TTS-onset value (dotted lines) are also shown for comparison on both plots; this was a single function for all pinnipeds in Southall et al. (2007).

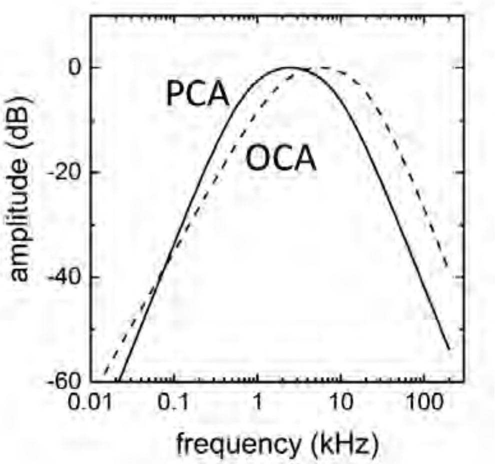

Figure 17. Derived auditory weighting functions for marine carnivores in air (PCA and OCA) generated with Equation (2) using parameters given in Table 5

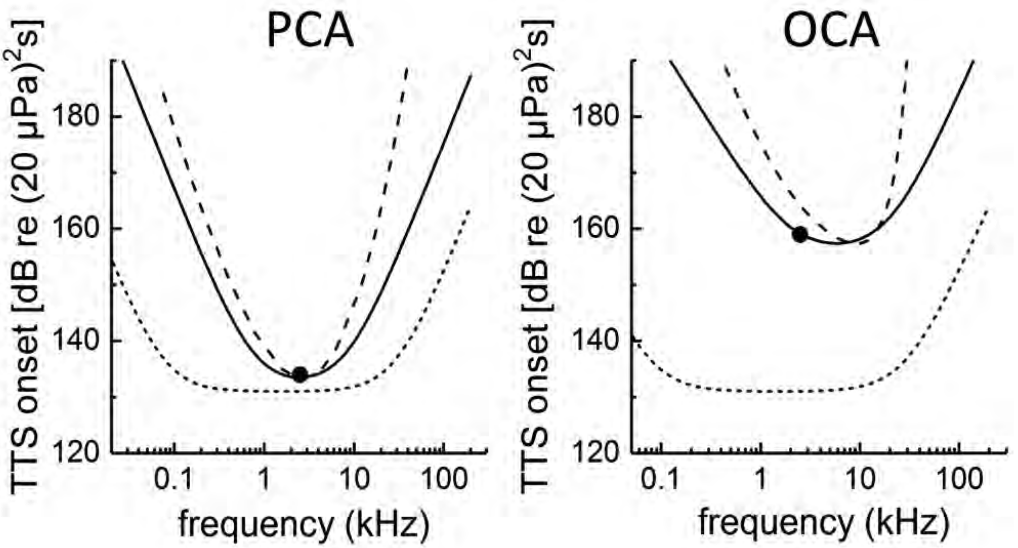

Figure 18. Exposure functions (solid lines) for marine carnivores in air (PCA and OCA) generated with Equation (3) using parameters given in Table 6. Filled symbols indicate empirical onset TTS exposure data used to determine the exposure function. Normalized estimated group audiograms for PCA and OCA (dashed lines) are shown for comparison with a minimum value identical to that of the associated exposure functions. Estimated exposure functions derived from M-weighting filters for pinnipeds in air with a minimum value set at the estimated TTS-onset value (dotted lines) are also shown for comparison on both plots; this was a single function for all pinnipeds in Southall et al. (2007).

Marine Mammal TTS- and PTS-Onset Thresholds

Finneran (2016) proposed systematic modeling procedures to improve on the general approach developed by Southall et al. (2007) to define onset thresholds. These procedures are applied here to generate modified noise exposure criteria for TTS and PTS onset. Frequency-weighted exposure levels for TTS onset were determined from exposure functions (above) in units of weighted SEL. Extrapolation procedures for estimating impulsive noise TTS onset were then applied using results of studies with non-impulsive noise (described in more detail in the "TTS and PTS Criteria for Impulsive Noise Exposure" section).

Dual metric criteria (frequency-weighted SEL and unweighted peak SPL) are proposed for impulsive signals for all marine mammal groups, with the effect (TTS or PTS) being assumed to occur if an exposure exceeds the criterion for either metric. For non-impulsive sounds, only weighted SEL metrics are presented (i.e., no peak SPL criterion). For multiple exposures of either type, SEL provides a means of integrating cumulative exposures. There are insufficient direct measures of TTS from different exposure intermittency patterns in marine mammals to define an explicit duration of intermittency between exposures following which they should be considered discrete exposures and, thus, no longer accumulated using a single SEL value. While Southall et al. (2007) suggested a 24-h period for this interval, some of the basis for that distinction was related to behavioral issues rather than explicitly hearing effects. Limited available data on exposure intermittency and recovery from a hearing perspective would suggest that a shorter than 24-h exposure intermittency would be appropriate to reset the cumulative SEL calculations for multiple exposures (see Finneran, 2015). It is unlikely that a simple and uniform relationship exists across all species and exposure scenarios and that case-specific evaluations will likely be required to evaluate an appropriate reset duration. We simply note that in many realistic exposure conditions, the 24-h rule for SEL "reset" may be inappropriately long and that further scientific investigation of these issues, especially for species with some existing TTS data, is clearly needed.

For both impulsive and non-impulsive sounds, TTS onset was defined as the exposure required to produce 6 dB of TTS from either direct measurements or extrapolation of available data (as in Southall et al., 2007). Modified extrapolation methods were used to estimate TTS growth and predict exposures for which 40 dB of TTS would occur. This is identical to the value Southall et al. (2007) used as an estimate of PTS onset, although here this is not presumed to represent the onset of physical injury as there are no available empirical data to test this assumption.

TTS and PTS Criteria for Non-Impulsive Noise Exposure

Weighted exposure thresholds for non-impulsive TTS onset are based on the minimum of the non-impulsive TTS exposure functions (Figures 12, 14, 16 & 18; Table 6). Note that the exposure function minimum is not necessarily equal to the TTS threshold at the frequency of best hearing sensitivity (f_0). As described above, for marine mammal groups for which direct TTS data were available, they were applied directly in the derivation of exposure functions. For marine mammal groups with no direct measurements (LF cetaceans and sirenians), marine mammal TTS data from other groups were applied, with the assumptions and caveats described.

To estimate PTS-onset criteria for non-impulsive noise in terms of SEL, an exposure level of 20 dB above the TTS-onset level (6 dB TTS) was used for each marine mammal group. This assumes the same growth rate (1.6 dB TTS/dB noise) from the point of TTS onset (6 dB TTS) to estimated PTS onset (40 dB TTS) used in Southall et al. (2007); this growth rate is now supported with limited empirical data on TTS growth for a few marine mammal species (reviewed in Finneran, 2015). The associated non-impulsive SEL TTS- and PTS-onset criteria for all marine mammal hearing groups are given in Table 6.

TTS and PTS Criteria for Impulsive Noise Exposure

The TTS and PTS exposure SEL functions for impulsive sources are assumed to be identical in shape to the group-specific non-impulsive functions, with the values for the constant K being the only parameter derived explicitly for impulsive sources. There is currently extremely limited data on impulsive noise TTS onset for marine mammals across a range of exposure frequency conditions with which to evaluate this (Finneran, 2015; Houser et al., 2017), although the existing data are not inconsistent with this assumption. For species groups for which impulsive TTS data are available (HF and VHF cetaceans), impulsive noise SEL TTS thresholds were determined by applying group-specific weighting functions to the exposure waveforms that produced TTS and then calculating the associated weighted SELs. For species groups for which no impulsive TTS-onset data exist, weighted SEL thresholds were estimated using the relationship between the median non-impulsive noise weighted TTS-onset threshold and the median impulsive weighted TTS threshold for the HF and VHF cetacean groups (as in Southall et al., 2007).

For the HF and VHF cetaceans, non-impulsive noise TTS-onset thresholds are 178 and 153 dB re 1 μPa^{2}s, respectively, while impulsive noise TTS-onset thresholds (derived using Equation [3]) are 170 and 140 dB re 1 μPa^{2}s, and the median difference is 11 dB. Thus, for each of the remaining groups for which impulsive noise TTS data are not available, the SEL-based impulsive noise TTS-onset threshold is estimated to occur 11 dB below the non-impulsive noise TTS-onset thresholds (from Table 6).

Table 6. TTS- and PTS-onset thresholds for marine mammals exposed to non-impulsive noise: SEL thresholds in dB re 1 μPa^{2}s under water and dB re (20 μPa)^{2}s in air (groups PCA and OCA only)

Marine mammal hearing group	TTS onset: SEL (weighted)	PTS onset: SEL (weighted)
LF	179	199
HF	178	198
VHF	153	173
SI	186	206
PCW	181	201
OCW	199	219
PCA	134	154
OCA	157	177

As in Southall et al. (2007), a dual metric approach is retained for impulsive stimuli, and the weighted SEL threshold is used in conjunction with an unweighted peak SPL threshold. Few TTS studies have been conducted in marine mammals using representative impulsive noise sources such as pile driving and airgun signals (see Finneran, 2015), in part given the extensive challenges in successfully generating impulsive stimuli in laboratory conditions that approximate exposure conditions for such sources with free-ranging animals. This limits the available information upon which to base peak SPL onset criteria; at present, impulsive TTS data are available for just the HF and VHF species. For these species groups, peak SPL thresholds for TTS were directly based on empirical data. For other species groups for which no TTS data exist, peak SPL thresholds were determined as the difference (in dB) between the impulsive noise peak SPL TTS onset (in dB re 1 μPa) and the hearing threshold at the frequency of best sensitivity (f_0) (in dB re 1 μPa; see Tables 3 & 4) for the HF and VHF cetaceans. For the HF cetacean group, the hearing threshold at f_0 is 54 dB re 1 μPa, and the peak SPL TTS-onset threshold is 224 dB re 1 μPa, a difference of 170 dB. For the VHF cetaceans, the hearing threshold at f_0 is 48 dB re 1 μPa, and the peak SPL-based TTS-onset threshold is 196 dB re 1 μPa, a difference of 148 dB.

The above calculations make clear the substantial deviation in relative exposure sensation level required to induce TTS for the VHF relative to HF groups and raises the issue of how to extrapolate the results to other species for which data do not exist. The VHF cetaceans are clearly more sensitive than other hearing groups in a number of ways discussed throughout this article—notably, lower hearing thresholds and lower TTS-onset thresholds for different noise types. Thus, applying the much smaller difference between hearing and TTS thresholds for VHF species to other hearing groups could be seen as unrepresentative, and a case could be made for applying the difference between these values for HF cetaceans exclusively. However, a precautionary argument could also be made in the absence of direct data to apply the lower dynamic range of VHF cetaceans to all other groups. The approach taken here, in keeping with the overall central tendency philosophy, was to use the median value of the two differences (as in Finneran, 2016). Given the greater overall sensitivity of the VHF cetaceans, their inclusion in this median value is somewhat conservative, but this avoids going to the extreme of applying data from a hearing group that appears fundamentally different from other marine mammals.

The median difference between hearing threshold and TTS onset for HF and VHF cetaceans based on empirical TTS data using impulsive signals is thus 159 dB. For other species groups in water (LF, SI, PCW, and OCW), 159 dB was added to the value of the hearing threshold at f_0 to estimate the impulsive noise peak SPL TTS-onset thresholds. For all marine carnivores in air, there are no published TTS data for impulsive noise exposures. Given the lack of data, a nominal 15 dB offset is used (as in Southall et al., 2007) between the SEL-based TTS threshold and the peak SPL-based threshold. As in Southall et al. (2007) and Finneran (2015), no frequency-weighting is applied to any of the proposed peak SPL criteria.

For impulsive exposure, dual metric PTS-onset thresholds were estimated using an identical approach in terms of TTS growth rates to that proposed by Southall et al. (2007). For SEL-based TTS thresholds, this approach prescribes adding 15 dB to the TTS-onset threshold to estimate PTS onset based on a 2.3 dB TTS/dB noise relationship using the results of studies in chinchillas (Henderson & Hamernik, 1986). For peak SPL criteria, 6 dB is added to TTS-onset threshold to estimate PTS onset based on a ~6 dB TTS/dB noise relationship using the results of the same study.

Using the methods and assumptions described above for each marine mammal group, the associated impulsive SEL and peak SPL TTS- and PTS-onset criteria were calculated, and the resulting exposure criteria are presented in Table 7. Two selected examples are given to illustrate this approach—one in which direct empirical data were available (VHF cetaceans) and one in which extrapolation methods were applied (PCW).

For the VHF cetaceans, the empirically based SEL TTS-onset criterion for impulsive noise is 140 dB re 1 μPa^2s, and the associated SEL PTS-onset criteria is 155 dB re 1 μPa^2s. The peak SPL TTS criterion is 196 dB re 1 μPa, and the associated peak SPL PTS-onset criteria is 202 dB re 1 μPa (i.e., $PTS_{pk} = TTS_{pk} + 6$ dB).

For the PCW group for which direct impulsive TTS data are unavailable, onset criteria were derived using the assumptions described above as follows. The SEL TTS-onset criterion for impulsive noise was estimated as 170 dB re 1 μPa^2s (181 dB re 1 μPa^2s for non-impulsive TTS onset -11 dB), and the associated SEL PTS-onset threshold was estimated as 185 dB re 1 μPa^2s. Peak SPL TTS onset was estimated as 212 dB re 1 μPa (53 dB at f_0 + 159 dB), and the associated peak SPL PTS-onset criteria threshold was estimated as 218 dB re 1 μPa.

Table 7. TTS- and PTS-onset thresholds for marine mammals exposed to impulsive noise: SEL thresholds in dB re 1 μPa²s under water and dB re (20 μPa)²s in air (groups PCA and OCA only); and peak SPL thresholds in dB re 1 μPa under water and dB re 20 μPa in air (groups PCA and OCA only).

Marine mammal hearing group	TTS onset: SEL (weighted)	TTS onset: Peak SPL (unweighted)	PTS onset: SEL (weighted)	PTS onset: Peak SPL (unweighted)
LF	168	213	183	219
HF	170	224	185	230
VHF	140	196	155	202
SI	175	220	190	226
PCW	170	212	185	218
OCW	188	226	203	232
PCA	123	138	138	144
OCA	146	161	161	167

Considerations of Variability and Uncertainty in Regulatory Applications of TTS and PTS Criteria

The exposure criteria proposed here for TTS and PTS onset for non-impulsive and impulsive noise exposures are derived using median values of available data in several areas. We believe that this provides a reasonable best estimate of these effects across many species within hearing groups in light of the limited data in many areas and requisite extrapolation measures. However, there are relevant considerations related to individual variability in susceptibility to noise exposure and context-dependent aspects of exposure scenarios that should be noted. The single threshold-level exposure criteria given here will, almost by definition, underestimate potential effects for some scenarios and overestimate effects for others, the extent of each potential outcome depending on the degree of individual variability as well as key contextual aspects of exposure.

Nowacek et al. (2007) highlighted concerns regarding the use of single threshold-level exposure criteria for predicting the effects of noise on populations of marine mammals given known and expected variability. Subsequent authors have attempted to model regulatory implications of step-function thresholds in terms of predicting impacts within populations for both auditory (Gedamke et al., 2011) and behavioral (National Academies of Sciences, Engineering, and Medicine, 2017) effects. For example, Gedamke et al. (2011) modeled the impact of variability and uncertainty on estimates of TTS in baleen whales exposed to seismic surveys and concluded that, given their underlying assumptions, a step-function threshold would substantially underestimate ranges for potential effects for the most sensitive one-third of the population. Their approach began with single threshold estimates like those provided here (Tables 6 & 7), albeit with more limited supporting data, and then developed probabilistic risk functions for specific applications in which variability was estimated for TTS onset, variation in received level as a function of sound propagation, and behavior of the animals such as avoidance of the sound source. Herein, we provide a simple assessment of the available TTS-onset data to illustrate some of these considerations as they relate to the application of step-function thresholds. The available data are admittedly limited, but this example is simply intended to illustrate the relative implications of variability that do exist based on the type of effect being evaluated and the overall physical ranges over which effects may occur depending upon species- or group-specific sensitivity.

Just as individual differences exist within and between species in terms of absolute hearing sensitivity relative to estimated group audiograms, variability also exists in terms of individual TTS and PTS onset relative to exposure function predictions. At present, it is difficult to quantify variability in TTS onset among marine mammals given how little data exist on TTS onset for multiple individual subjects from multiple species within each hearing group to sound exposures at the same frequency. The only such marine mammal data currently available are from two bottlenose dolphins tested at 3 kHz for which onset of TTS occurred at SEL of 190 and 194 dB re 1 μPa²s, respectively. In an effort to address

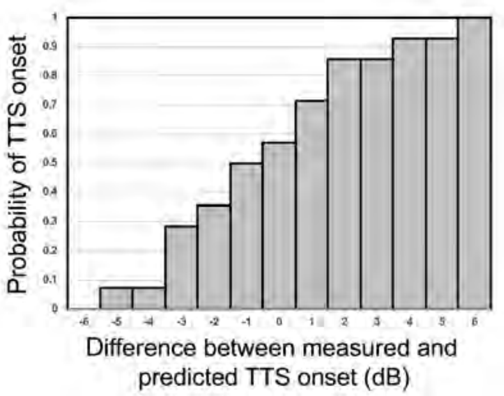

Figure 19. Cumulative distribution function (CDF) for the deviation of frequency-specific TTS-onset measurements from levels predicted by the group-specific TTS exposure function

this issue, Gedamke et al. (2011) estimated variability by taking the standard deviation (SD) of the limited available TTS-onset data they used (5.2 dB) across the range of individuals and frequencies tested by Schlundt et al. (2000) and Finneran et al. (2005a). However, as evident in the estimated audiograms relative to exposure functions here, TTS-onset levels vary as a function of frequency. This means that some of the variation in TTS onset estimated using data available at the time by Gedamke et al. (2011) included variation by frequency, which is explicitly considered within the exposure functions derived herein.

While limited, the available TTS-onset data for individuals at different frequencies relative to group-specific exposure functions does provide insight in terms of variability around predicted effects. The available marine mammal TTS data used here include nine frequency-specific TTS-onset measurements from two HF cetacean subjects (including the values for each subject at 3 kHz mentioned above), three from one VHF cetacean subject, and two values from two different PCW subjects measured under water. By calculating the deviation of measured TTS onset from the value predicted by the exposure function for their hearing group at each test frequency, the variation among these five marine mammal subjects for which frequency-specific TTS-onset data exist may be evaluated. The cumulative distribution function (CDF) in the residual lack of fit of the TTS-onset thresholds to the exposure functions across all subjects is shown in Figure 19. This distribution has a considerably lower SD (2.8 dB) than the 5.2 dB value estimated by Gedamke et al. (2011) as would be expected given efforts to account for variation by frequency.

If this CDF is taken as a generalized representation of variability in the onset of an effect among a population of animals in the wild, a simplistic illustrative example may be used to compare the respective area over which TTS might be predicted to occur using either the single number threshold or a probability distribution based on the CDF. This example assumes a generic sound source with a source level of 220 dB re 1 μPa at 1 m and duration of 1 s, operating at a frequency for which the hearing group is most sensitive and with 20 $\log_{10}$(range) propagation loss. Using the proposed TTS-onset thresholds of 178 dB re 1 $\mu Pa^2 s$ for HF cetaceans, the predicted range for TTS onset is 126 m, and the area affected is 0.05 km^2. Using the proposed TTS-onset threshold of 153 dB re 1 $\mu Pa^2 s$ for VHF cetaceans, the predicted range is 2,240 m, and the area affected is 15.7 km^2. Assuming that exposed animals are evenly distributed with one/km^2, which could be a reasonable assumption for some species but a poor one for others, this results in an estimated 0.05 HF cetaceans and 15.7 VHF cetaceans experiencing TTS.

Conversely, if the CDF is used to estimate variability, the total number of individuals potentially affected would be determined by sequentially estimating the areas within which individuals with differential sensitivity would be exposed. The CDF here has 14 values (residual differences of measured to predicted TTS onset), ranging from -5 dB to +6 dB. For the HF cetaceans, this corresponds to TTS-onset estimates ranging from 178 - 5 = 173 dB re 1 $\mu Pa^2 s$ to 178 + 6 = 184 dB re 1 $\mu Pa^2 s$. For VHF cetaceans, this corresponds to TTS-onset estimates ranging from 153 - 5 = 148 dB re 1 $\mu Pa^2 s$ to 153 + 6 = 159 dB re 1 $\mu Pa^2 s$. Each observation can be taken to represent the estimated TTS-onset threshold for 1/14th of the population or 0.071. In this simple example, the number of individuals that would experience TTS is estimated given the simple assumptions here for individuals with differential sensitivity based upon the variability in the CDF. The estimated number of the most sensitive individuals in the population equals the area corresponding to received levels (for the HF cetaceans) out to 173 dB re 1 $\mu Pa^2 s$ (estimated range: 224 m; area: 0.157 km^2) times 0.071, resulting in 0.011 individuals with the greatest sensitivity within that area. This process is repeated for each step in the CDF corresponding to increasingly nearer areas multiplied by a probability of 0.071. The resulting values for each area are then summed. The result of this process for this example yields total estimates of 0.06 HF cetaceans and 20 VHF cetaceans experiencing TTS, which are 20 and 27% higher relative to the single threshold estimates of 0.05 (HF) and 15.7 (VHF), respectively. Even though there is an equally small proportion of animals assumed to be in the relatively more sensitive subset of individuals for both HF and VHF, there is a larger difference between the methods for the VHF cetaceans because the larger ranges yield larger areas within which more sensitive animals might be exposed at levels predicted to result in TTS.

This example, using limited available data, is not intended to serve as the basis for empirical risk functions for TTS or PTS onset. Rather, they are given primarily to highlight some valid concerns relating to the use of step-function thresholds, the limited data available regarding variability in the onset of auditory effects used to derive exposure criteria, and the need to consider underlying variability in regulatory applications in some manner. The amount of variation shown in the CDF (Figure 19) is derived from measurements from a few individuals from a single species within each of three marine mammal hearing groups. Better estimates of variability in TTS onset within and among species of each hearing group are needed to evaluate whether this level of observed variability is broadly representative, particularly within groups for which no such data exist. Regulatory processes evaluating predicted effects and/or establishing safety mitigation zones should occur within a broader decision framework than simply calculating predicted effects from exposure criteria. Such a framework should integrate information regarding the source of interest, transmission loss in the location, movement patterns of animals with respect to the source (e.g., behavioral avoidance that may reduce higher-level exposures), and features of typical group structure (solitary vs highly social), and should provide at least some means of estimating the variation and uncertainty related to these key factors.

Research Recommendations

The past decade has seen substantial advances in published scientific data on marine mammal hearing and the effects of noise on hearing. Combined with existing data on these issues, these new results have provided a more robust basis for the revised noise exposure criteria presented herein for predicting the fatiguing effects of noise on marine mammal hearing. However, as has been the case in human noise standards for many decades, this will continue to be an iterative, self-correcting process as subsequent scientific results become available (see "Discussion" section).

While noting some of the extensive research recommendations regarding marine mammal hearing, auditory weighting functions, and the effects of noise made in several additional recent reviews (e.g., Finneran, 2015; Erbe et al., 2016; Houser et al., 2017), several key research areas are identified and specific topics for which additional studies are needed to improve and evolve marine mammal noise exposure criteria are highlighted. We also identify several important considerations regarding the derivation of noise exposure criteria and provide some concluding emergent observations based on the current state of this field.

Absolute Hearing Capabilities and Auditory Weighting Functions

While progress has been made in many areas, it is important to recognize that we lack any measurements of hearing in most marine mammal species (see Appendices). Some untested species fall within taxa for which numerous audiometric measurements have been made for related species, which permits some reasonable level of extrapolation within "functional" hearing groups (e.g., Reichmuth et al., 2013). Clearly, additional hearing data for any untested species will be useful to inform subsequent estimations of group-specific audiograms. However, given limited access to study many species in traditional research settings, a strategic approach could be to prioritize efforts for species within less well-represented taxa. Alternatively, testing could focus on species that may be more distantly related to other members of hearing groups (e.g., Antarctic ice seals, other otariids, bearded seals, walrus, and polar bears) for which hearing data are available. This approach should enable a more effective use and extrapolation of the data available to evaluate the marine mammal species groups proposed here given that direct measurements of hearing are unlikely for all species. Taxa for which affinities are unclear, such as within the white-sided dolphins (Appendices 2 & 3), should also be prioritized, particularly for studies relating anatomy to audiometric measurements. Additional data on equal loudness and equal latency are also needed, with a specific need for data at high frequencies given the complete lack of available information with which to inform the HF slope of auditory weighting and exposure functions for all groups.

The most notable example of needed data in terms of hearing sensitivity is within the baleen whales (LF cetaceans) for which there are no direct measurements of hearing for any species. Progress has been made in anatomical modelling methods to describe how certain aspects of auditory systems respond to sound and may influence how whales hear. However, the capacity of these approaches to predict hearing with any confidence and to reliably inform the derivation of exposure or weighting functions has not yet been validated within other well-studied species for which hearing is well-known. Studies demonstrating the predictive efficacy of these methods in other marine mammals in terms of their ability to accurately predict both frequency ranges of hearing and absolute hearing sensitivity are clearly needed. Similar comparative data from terrestrial mammal taxa that are sensitive to LF sound in air would also be very useful. The models described above treat LF sensitivity as comparable to HF sensitivity, but the available data suggest that animals are prone to lose HF hearing preferentially as a function of age (Clark, 1991). The limited data available on cetaceans are consistent with this finding (Ridgway & Carder, 1997), and this may be a particularly important consideration with regard to estimating HF hearing in baleen whales, which are generally quite long-lived.

As discussed, future approaches to studying the hearing of LF cetaceans will almost certainly rely on comparative anatomical modeling in other LF species given the challenges in obtaining direct hearing measurements. Direct measurements of hearing in LF cetaceans using electrophysiological methods could continue to be pursued (e.g., within stranding scenarios) as this is among the most likely methods for obtaining direct hearing data for mysticetes. However, it should be recognized that while such data may prove useful for some frequencies, they will likely not be useful for the lowest frequencies of most interest (< 5 kHz) given limitations of AEP methods. Further, they may prove feasible only in the youngest and smallest members of the group. Behavioral methods for free-ranging animals using orienting response methods (e.g., measuring behavioral changes in animals exposed to experimental sounds of different frequency content) could be applied in baleen whales (Frankel et al., 1995) as demonstrated in other marine mammals (see Ghoul & Reichmuth, 2014). While such approaches will be unlikely to measure absolute hearing at many frequencies because of masking noise in the environment and the movement of free-ranging animals, they could provide useful insights into some hearing capabilities for baleen whales, notably upper hearing limits. There has been some feasibility work using spontaneous responses of this type (Dahlheim & Ljungblad, 1990) but so far not under controlled or semi-controlled conditions (e.g., with an animal entrapped in a weir; Lien et al., 1990). Finally, the potential distinction among VLF and LF cetaceans considered above (see "Marine Mammal Hearing Groups & Estimated Group Audiograms" section) is noted as an area of additional evaluation. Characteristics of vocal behavior and auditory anatomy suggest a potential segregation of the baleen whales into two or even more groups. To explore this potential distinction, specific research attention using combinations of anatomical, electrophysiological, and behavioral methods should be applied to species for which at least some underlying data and proven capabilities to study free-ranging animals exist within each of the respective groups (e.g., VLF: blue whales; LF: minke whales). Given the endangered status and LF sensitivity of these species, acquiring additional data remains a priority, but, realistically, our ability to quantitatively describe hearing and the effects of noise on hearing in baleen whales is likely to remain limited for the foreseeable future.

Another area of research interest in terms of potential additional division of marine mammal hearing groups relates to hearing in sperm and beaked whales. As discussed above, their large body size, echolocation click characteristics, and relatively lower-frequency content of species-typical echolocation clicks suggest a possible distinction of these species, along with killer whales, from other odontocetes (HF and VHF cetaceans). Recently obtained behavioral hearing data for killer whales in a study with a relatively large sample size ($n = 8$) (Branstetter et al., 2017) were not included within the estimated group audiograms here (discussed further below), but they clearly expand our understanding of hearing in this species. The upper-frequency cut-off for killer whales in this study (114 kHz) occurs at comparable frequencies (within an octave) of the HF composite audiogram and most individual species audiograms. However, relatively better hearing for killer whales at low frequencies observed by Branstetter et al. (2017) relative to some other odontocetes, and especially the distinctions in some anatomical and echolocation signal parameters (see Appendix 2), are consistent with the species' potential separation from the HF cetaceans along with sperm and beaked whales.

The challenges of collecting behavioral audiometric measurements on sperm whales are similar to those for mysticetes, but research building on earlier efforts to use AEP methods on live-stranded animals (e.g., Ridgway et al., 2001) would provide unique opportunities as has more recently been accomplished with several beaked whales (Cook et al., 2006; Finneran et al., 2009; Pacini et al., 2010). However, the same caveats regarding AEP testing at low frequencies and the elevated estimates of absolute hearing sensitivity relative to behavioral hearing thresholds may limit data for the same reasons discussed above. Further anatomical and behavioral evaluations could also provide some insight into the potential segregation of these species as with MF cetaceans.

Finally, a better understanding of relationships between AEP and behavioral threshold data are needed across species. Both methods have provided great insight into the hearing of marine mammals, and each has strengths and limitations. Behavioral methods, with sufficient training and experimental and noise controls, have provided the most consistently reliable and robust measurements of hearing sensitivity across wide ranges of frequencies. However, they are time-consuming and expensive to conduct properly, usually involve small sample sizes, and are unlikely to be applicable for many species that are not maintained in captive settings. Conversely, AEP methods do not require trained subjects, have been conducted in field settings with stranded and/or anesthetized animals, and may be used to generate larger sample sizes on uncommon species. However, as discussed, these methods are limited in their ability to test hearing at relatively low frequencies. Furthermore, across most marine mammal species tested, AEP methods typically result in less consistent predictions of absolute sensitivity compared to behavioral studies; results generally suggest less sensitive hearing than behavioral methods, with increasing divergence at lower frequencies. Some frequencies at the low and high ends of the behaviorally determined hearing range do not elicit detectable AEPs. While AEP data were excluded in deriving estimated group audiograms and weighting and exposure functions, the value and importance of AEP methods are clearly recognized, particularly given the ability to test less common species (e.g., during attempts to rehabilitate them after a stranding).

Results from a number of AEP studies were an important part of the evaluation and species assignments within hearing groups herein (see Appendices). Such studies will likely provide the only means of obtaining additional data for many species to evaluate and refine the hearing groups distinguished here. Subsequent effort should be made to systematically evaluate the relationships between AEP and behavioral methods across frequencies in species for which hearing is relatively well-known, including within terrestrial mammals, to evaluate how AEP results could be integrated, perhaps with associated correction factors, into the estimation of group audiograms and, ultimately, weighting and exposure functions.

Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS)

Major strides have been made in understanding TTS onset and growth in marine mammals (Finneran, 2015), with many findings since Southall et al. (2007) that enable a much more informed derivation of criteria here. However, additional studies are still needed to address key questions.

The issue of better understanding relationships between AEP and behavioral hearing data is also relevant to quantifying TTS. AEP methods could be used to test TTS for some species and contexts for which traditional behavioral methods are impractical or impossible. AEP methods also provide additional information in terms of neural signal about auditory response at levels above hearing thresholds that can provide additional insight into the effects of noise. Furthermore, data suggest that some electrophysiological methods (including AEP) may be more sensitive indicators of auditory system dysfunction compared to behavioral threshold measures—for example, by providing information on potential changes in specific auditory structures that contribute to the AEP waveform.

For non-impulsive noise sources, additional studies are also needed, particularly for certain marine mammal taxa (e.g., marine carnivores and sirenians), to build on observations in some odontocetes of major differences in TTS as a function of exposure frequency spectra—that is, explicit evaluation of auditory exposure function predictions of TTS onset in several species from each marine mammal taxa would ideally be collected. This is especially important within the VHF cetaceans given that TTS-onset levels to date are so different than in other taxa, and studies are almost exclusively limited to measures from a single species, the harbor porpoise. Of additional interest are additional TTS measurements for relatively low-exposure frequencies (below several kHz). Across taxa, the LF hearing range appears to be less susceptible to PTS, but it is unclear whether low frequencies are less susceptible generally. It should be recognized that while postmortem analyses of hearing structures may provide some insight into potential auditory injury related to noise exposure, direct TTS studies will almost certainly not be possible in the near future for LF cetaceans. Not only is access a matter of chance in acquiring potential research subjects (e.g., live stranding), but technical developments are also still needed to collect useful AEPs (Ridgway et al., 2001). Recognizing this, subsequent TTS studies of the effects of LF noise within hearing groups that are also more sensitive at low frequencies and for which increasingly more data exist (e.g., phocid seals) should be evaluated in terms of their potential extrapolation to the LF cetaceans.

While more recent marine mammal results suggest that the TTS growth rates predicted by Southall et al. (2007) appear to be reasonable approximations, more studies in taxa other than odontocete cetaceans would ideally be collected. Additional studies are clearly needed regarding how noise exposure intermittency and recovery time in relatively quiet conditions influence TTS growth and recovery patterns within selected species, ideally in a manner that provides support for comparative assessment within and across hearing groups. Such studies should quantify exposure using a number of different metrics, including, but not limited to, SPL, duration, variable frequency, and SEL for each exposure and accumulated across exposures to evaluate dual criteria predictions, the assumptions underlying SEL as an integrative exposure metric, and the appropriate exposure intermittency for which cumulative SEL values should be reset.

Additional studies of impulsive noise TTS are needed for almost all species. Of particular importance are studies in which systematic variation of peak SPL, SEL, signal duration (especially shorter or longer than temporal integration time), and frequency content are performed to test the weighting function and validity of the dual criteria for peak SPL and SEL. Furthermore, studies with more realistic exposure to real-world impulsive noise sources are needed. This is clearly challenging in laboratory contexts, but recent studies have made some progress in using and characterizing exposure parameters for operational impulsive noise sources (e.g., Kastelein et al., 2013b; Finneran et al., 2015; Reichmuth et al., 2016). Subsequent studies should continue to try to replicate exposure waveforms from impulsive sources, including propagation effects for distances at which received levels may occur. Almost no data exist on TTS growth rates for impulsive noise in marine mammals, including for moderate levels of TTS (20 dB) and higher. This is a key research need as are issues related to multiple impulse noise exposure and patterns of intermittency and recovery as well. Further impulsive noise TTS data will support a more informed and taxon-specific estimation of differences between impulsive and non-impulsive noise and, thus, the most appropriate means of utilizing non-impulsive noise in extrapolating or interpreting more limited impulsive noise TTS data.

Finally, recent data indicate that some marine mammals have reduced hearing sensitivity when warned of an impending noise exposure, suggesting a potential for self-protection from noise exposures and raising important questions regarding the uncertainties in determining any absolute effects of external noise on hearing (Nachtigall & Supin, 2013, 2014, 2015; Nachtigall et al., 2016a, 2016b). The extent to which such mechanisms could reduce susceptibility to noise exposure is unknown but should be investigated. Of particular importance is testing whether this mechanism is a specialization associated with echolocation or is also present in non-echolocators. This would help inform the extent to which TTS data from echolocators can be appropriately extrapolated to non-echolocators and vice versa. Also unknown is the extent to which existing TTS data have been affected by potential self-mitigation (i.e., could experimental subjects predict impending noise exposures or adapt to ongoing noise to protect their hearing?) and the likelihood of wild marine mammals performing similar actions when exposed to man-made noise. As an example, there is considerable literature on humans showing that initial moderate exposures are protective against exposures to high amplitude noise (e.g., Campo et al., 1991; Niu et al., 2007).

Discussion

Advances in the scientific understanding of how marine mammal hearing is affected by noise have allowed refinement of methods originally proposed by Southall et al. (2007) to predict effects of noise. To do so, a comprehensive evaluation of all hearing, auditory anatomy, and sound production data available for every marine mammal species was reviewed and evaluated. Using these data and the systematic, quantitative methods developed by Finneran (2016), estimated audiograms were derived for seven of eight identified marine mammal hearing groups for which direct hearing data were available based on median values of behavioral audiograms from animals with normal hearing. A modified approach involving additional assumptions, extrapolations, and associated caveats was developed for the baleen whales (LF cetaceans). Ultimately, all marine mammal species were evaluated for the purposes of developing auditory weighting functions and proposing revised exposure criteria.

Available literature on direct and indirect measurements of hearing, auditory morphology, and aspects of sound communication was evaluated using specific criteria to inform categorization of different species into hearing groups (see Appendices). Using published scientific data (with several exceptions regarding LF cetaceans) available through the end of 2016, estimated group audiograms, auditory weighting functions, and TTS/PTS exposure functions were derived for each group, including both underwater and aerial criteria for all amphibious species.

One of the most important conclusions to emerge from the rapidly evolving science in this field is the critical importance of noise spectrum, in addition to SPL and duration, in determining potential effects on marine mammal hearing. While this was addressed to some degree in the derivation of M-weighting (Southall et al., 2007), the substantially more quantitative approach to weighting functions possible with considerably more available data derived by Finneran (2016) and applied here more appropriately emphasizes potential effects of exposure within frequency regions of relative better hearing sensitivity and greater susceptibility to noise exposure. Interestingly, the derivation of both estimated group audiograms and weighting and exposure functions that integrate aspects of TTS data provide support for slightly more flattened functions than a simple inverse audiogram approach as suggested in slightly different forms for marine mammals by Verboom & Kastelein (2005) and Nedwell et al. (2007) and for some terrestrial mammals (see Bjork et al., 2000; Lauer et al., 2012). These previous approaches have not incorporated aspects of hearing loss into the derivation of weighting functions. The approach herein derives best-fit functions that integrate both aspects of absolute hearing and auditory fatigue into functions that are somewhat flattened relative to auditory thresholds, at least at the low end of the range. This is generally consistent with the use of equal-loudness-based functions that have formed the basis for weighting functions in humans (Houser et al., 2017).

It should be recognized that the proposed criteria simply reflect another step forward in what will remain an iterative, self-correcting process expected to evolve for many decades. This has clearly been the case in the ongoing evolution of human noise exposure criteria of many kinds over the past half century (see Suter, 2009; Kerr et al., 2017). In fact, challenges in deriving broadly applicable quantitative noise exposure criteria for humans are much more straightforward than related efforts for marine mammals given that they consider a single species and have the benefit of many hundreds of direct studies on many thousands of subjects. Marine mammals include > 125 different species inhabiting every kind of marine habitat on the planet and are exceedingly diverse in their taxonomy, anatomy, and natural history. Furthermore, major gaps in scientific understanding of basic hearing abilities and direct measurements of key aspects of how noise affects hearing persist for most species, notably among the mysticete cetaceans. While strategic research approaches (see "Research Recommendations" section) will better inform subsequent evolutions in these criteria, many data gaps will remain for the foreseeable future. Given these profound challenges, the derivation of quantitative criteria and their application within regulatory applications come with associated and acknowledged cautions and caveats.

Since there continue to be no direct measurements of hearing or the effects of noise on hearing for any mysticete, one could debate a more prescriptive and narrower auditory weighting function than the M-weighting function proposed for LF cetaceans by Southall et al. (2007). However, readers should recognize that simply because the M-weighting function is much broader and flatter than the LF cetacean function derived herein, neither is necessarily more "protective" in all scenarios. The benefit of weighting is to quantify the stimulus as received by the auditory system; therefore, if the proposed function is not a good fit, it will not improve predictions. In addition, both the weighting functions and TTS/PTS exposure functions are required to evaluate the potential effect of noise exposure. While the LF group weighting function derived here is much narrower than M-weighting and effectively excludes less noise at frequencies outside the expected region of estimated best sensitivity, it conversely predicts greater potential auditory effects for noise within the region of best sensitivity by virtue of the lower associated TTS-onset threshold (see Tougaard et al., 2015). Furthermore, the weighting function and TTS-onset thresholds are derived in tandem and cannot simply be interchanged (e.g., retaining M-weighting and applying the current TTS-onset threshold, which is considerably lower than that used in Southall et al., 2007). The quantitative approach presented here represents a new option, using methods comparable to those used for other hearing groups that have direct supporting data. The M-weighting function remains an option that is less prescriptive in its assumptions and broader in terms of frequency but with caveats concerning onset thresholds and potentially much less predictive power. Progress made in indirect methods of evaluating hearing in mysticetes (e.g., modeling and sound production) allowed the proposed criteria to be developed with the best available data even though they were not directly applicable in deriving exposure criteria. Finding ways to improve predictions for LF cetaceans will remain a challenging issue for the foreseeable future. However, this reality cannot preclude efforts to use the best available information to make requisite decisions and assessments regarding potential noise impacts for these species.

The approach taken regarding categorization of species into hearing groups for the current criteria builds upon the Finneran (2016) expansion of the original Southall et al. (2007) groups, an approach that was adopted by NMFS (2016). However, here, both direct measurements of hearing and a more detailed evaluation of multiple types of indirect supporting information across all species were conducted to inform these categorizations and to propose several further modifications. This evaluation, which included assessments of middle ear and cochlear types as well as vocalization ranges and signal types, revealed a number of potential segregations within the existing groups and highlighted several species of interest that require additional investigation. The potential future subdivisions within the LF cetaceans (to include possible subsequent VLF and LF hearing groups) and within the HF cetaceans (to possibly include MF and HF hearing groups) are supported from various lines of evidence in anatomical features and sound production characteristics. However, at present, there are insufficient direct data on hearing and TTS onset to explicitly derive discrete estimated group audiograms. The broader LF and HF cetacean categories (with associated weighting and exposure functions) are thus retained here, but the likely need for additional VLF and MF is expressly identified for specific subsequent research and consideration.

The evaluation of hearing, anatomical, and sound production parameters also revealed several interesting species (and groups of species) in terms of hearing group categorization. For instance, the walrus has anatomical features intermediate between the phocid and other marine carnivores but is retained in the latter group based on available audiometric data (Appendix 2). There appears to be a clear distinction within the white-sided dolphins, based not only on the presence of VHF energy in echolocation signals in Peale's and hourglass dolphins (as in Finneran, 2016) but also (and perhaps more compelling) considering echolocation click type based on Fenton et al. (2014) relative to other odontocetes, including species within this genus (see Appendix 3). Finally, based on a similar assessment (Appendix 2), some of the river dolphins (family Platanistidae) are assigned here to the HF cetaceans as opposed to the categorical distinction of all river dolphins within the equivalent of the VHF cetacean group by Finneran (2016).

The approach taken here, which is consistent with almost all noise assessment and protective criteria for humans around the world (e.g., Kerr et al., 2017), was to use median values of available data in several areas (deriving estimated group audiograms and extrapolating TTS data among groups) as the best general predictive value of normal hearing and a reasonable best interpretation of the limited data on the effects of noise on hearing across species within the hearing groups proposed herein. However, it should be recognized that single, discrete threshold values for specified effects (TTS/PTS) do not capture all of the relevant information needed for some important regulatory considerations. For example, in establishing safety zones and estimating the total number of animals that might experience an effect within a population, failure to incorporate some estimates of variation and uncertainty can yield incorrect estimates. Substantial individual variability in hearing is known to exist both among different species in the same hearing groups relative to the predicted average value (see Figures 1, 3, 5 & 7) and between individuals in the same species (e.g., Houser & Finneran, 2006; Popov et al., 2007; Branstetter et al., 2017).

Although it may be reasonable to assume a symmetric distribution for TTS onset about a median value, the logarithmic nature of sound attenuation resulting from geometric spreading loss means that the actual area where animals are exposed to sound levels above thresholds will be smaller than the area where animals are exposed to levels below thresholds. Therefore, by ignoring individual variability, use of a single-value threshold (i.e., a step function) will underestimate the total number of affected animals in most scenarios, but increasingly so as the range to a particular effect increases. Thus, for effects such as TTS or (especially) PTS onset that require quite high levels for most hearing groups and, consequently, occur over smaller ranges, differences may be relatively small; whereas for more sensitive groups (e.g., VHF cetaceans in terms of hearing) or for behavioral effects that are more likely to occur at lower received levels and longer ranges, the differences between a step function and a probabilistic function may be much greater (see Box 2.2, National Academies of Sciences, Engineering, and Medicine, 2017). The extent to which step function thresholds may be problematic in terms of underestimating effects for some individuals depends on the exposure scenario in terms of sound sources, environmental parameters, and species-specific hearing and behaviors factors that affect the likelihood of TTS or PTS. To the extent possible given the available data, future exposure criteria should strive to generate exposure risk functions in addition to or instead of step function thresholds. Unfortunately, the requisite data are not presently available with which to derive probabilistic approaches that quantitatively characterize individual variance in hearing capabilities, TTS onset, and TTS growth to express exposure criteria within exposure-response probability functions. Fewer than half of all marine mammal species have direct hearing data of sufficient quality to represent normal hearing (almost all being from one or a few individuals), fewer than 10% of species have TTS measurements, and there are zero direct measurements of one of the primary effects evaluated here (PTS onset).

Simulations (e.g., Gedamke et al., 2011) can be used to assess the effects of uncertainty and individual variation on the risk of hearing loss as a function of distance from the sound source. Equally important for this kind of simulation is information specific to each application such as the source levels of sounds produced, transmission loss in the proposed site, life history and behavioral traits of the species in question, and conservation status of each population under review. However, this kind of simulation requires careful consideration of the underlying assumptions (e.g., behavioral avoidance) and judicious estimation of variation and uncertainty specific to the application and its site, with careful attention that decisions are appropriate for the specific regulatory setting.

Future scenarios could occur wherein the assumptions and extrapolations made here result in criteria being either overly or insufficiently protective in light of subsequent data. The latter occurred regarding the Southall et al. (2007) criteria for HF cetaceans (herein VHF cetaceans) for which additional data on harbor porpoises clearly supported the conclusion that much lower exposure criteria should be applied for this species (see Tougaard et al., 2015) and arguably for other species with similar hearing capabilities. Accordingly, revised (much lower) criteria were derived here for the VHF cetacean group using data reviewed in Tougaard et al. (2015) and using subsequent available data for species within this hearing group. Where direct information exists for a single species that is being evaluated within a regulatory context or where subsequent data suggest substantial deviation from the proposed criteria within hearing groups, decisionmakers should consider alternative interpretations of the proposed criteria.

The integrated nature of the quantitative methods applied herein should be recognized in any such alternative application. The approach used here is admittedly complex and, for many species, relies on inter-related extrapolations within and across marine mammal groups and, as in Southall et al. (2007), from terrestrial mammals. It may be tempting to recalculate and revise quantitative criteria with each new study that fills in key information gaps, especially given that this quantitative method allows such recalculation. However, in a practical sense, caution should be taken in doing so too frequently to avoid creating an ever-evolving set of criteria that are difficult or impossible for regulatory guidelines based upon them to follow.

An example of both the inter-related nature of the criteria and how new and important data may influence the quantitative results is the recent publication from a well-controlled, large sample size study of hearing in killer whales (Branstetter et al., 2017). These results substantially expand on the available data for a species of interest given considerations of their possible inclusion within an MF cetacean hearing group (see Appendix 2) and their potential contribution to the MF/HF estimated group audiogram. These results were unavailable when applicable data used for the current quantitative criteria were truncated, although they were known as this article was prepared. Just as Southall et al. (2007) acknowledged the existence of data on the initial impulse noise TTS studies on harbor porpoise (ultimately published by Lucke et al., 2009), the Branstetter et al. (2017) results are acknowledged here as important contributions to subsequent criteria (and recognized within the consideration of a potential MF cetacean hearing group) but not directly applied within the calculation of weighting and exposure functions. The perspective taken is that evolutions of the exposure criteria should occur at reasonably spaced intervals (a decade from Southall et al., 2007, was chosen) with a specified point for inclusion of data (end of 2016). However, given the awareness of the authors of these forthcoming data, an initial assessment of the implications of including the Branstetter et al. (2017) data was conducted. This revealed that their inclusion would not only result in slight changes in the shape and parameters of the HF cetacean estimated group audiogram and weighting function but, perhaps counter-intuitively, would also have small to moderate impacts on the exposure functions for other hearing groups (e.g., VHF cetaceans and marine carnivores) given the limited available data in some groups as well as the inter-related extrapolation methods applied across groups. This illustrates both the complex nature of the integrated assumptions and extrapolations inherent in the quantitative methods used herein as well as the potential pitfalls in incremental evolution in the criteria based on one or a few studies.

Finally, it is noted that the current criteria remain focused on the derivation of auditory weighting and exposure functions for the purpose of evaluating the potential fatiguing effects of discrete noise exposure (e.g., TTS/PTS). These approaches are not applicable in evaluating potential auditory effects of chronic noise exposure over periods of weeks, months, or years. As in human noise exposure criteria, this problem will require different methods and metrics other than the SPL or SEL metrics used here. Separate criteria are needed to evaluate behavioral responses and broader-scale auditory effects (e.g., auditory masking) and physiological effects (e.g., stress responses). These will necessarily involve different approaches but should consider integrating some aspects of the current criteria (e.g., weighting functions).

Note

[1] Members from the Southall et al. (2007) panel participating here included Brandon Southall, Ann Bowles, William Ellison, James Finneran, Roger Gentry, Charles Greene, Jr., Darlene Ketten, James Miller, Paul Nachtigall, and Peter Tyack. Colleen Reichmuth, Doug Nowacek, and Lars Bejder were added to the panel. Each of these individuals contributed to some degree to the current effort, with a majority contributing as co-authors to this article. Two companion efforts involving different subgroups of the panel worked in parallel on issues related to sound source characterization and the behavioral effects of noise exposure.

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Appendix 1. Low-Frequency Cetaceans

There are four cetacean families represented in the weighting function for low-frequency (LF) cetaceans: (1) Balaenidae (*Balaena* spp. and *Eubalaena* spp.), (2) Neobalenidae (*Caperea*), (3) Eschrichtiidae (*Eschrichtius*), and (4) Balaenopteridae (*Balaenoptera* spp. and *Megaptera*). Species data are consistent with the Society for Marine Mammalogy Committee on Taxonomy (2016). The baleen whales are considered with respect to available evidence from anatomical descriptions, predictions from anatomical models, and analyses of emitted sounds to validate the grouping of these 14 species to the assigned weighting function. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016. Considering the absence of data on audiometry for this group, the appendix also includes models and predictions of hearing based on anatomy from recent grey literature. Data are expressed as frequency ranges for each species where possible.

Audiometry data providing informative frequency data (from behavioral studies or neurophysiological studies) are not available for any mysticete species.

With respect to anatomy, the mammalian middle **ear type** for all species included in this group is the *mysticete type* (Nummela, 2008). This ear type has similarities to other cetaceans but with tympanic and periotic bones that are fused anteriorly and posteriorly to form a tympanoperiotic complex that is very large and heavy, and positioned close to the midline of the skull rather than laterally. Species in this group have disproportionately large periotic bones that are firmly coupled to the skull and very large corresponding middle ear cavities; within the middle ear cavity, the massive ossicles are loosely joined. In mysticetes, the pinna is absent; the auditory meatus is thin and partially occluded; and there is a conical, large wax plug, or "glove finger," on the lateral side of the tubular tympanic membrane. The auditory pathway may involve specialized fats associated with the ears (Yamato et al., 2012). The cochlea has notable features, including a basilar membrane that is extremely broad, especially at the apical (low-frequency) end; this cochlea has been termed Type M (mysticete) by Ketten (1994). Species for which cochlear morphometric data are available are noted in the appendix by the designation of the Type M cochlea. For summary reviews describing anatomy and species differences in mysticetes, see, for example, Ketten (1992, 2000) and Ketten et al. (2016).

Anatomy-based predictions of hearing range are reported for six species (predicted low-frequency hearing limit, predicted high-frequency hearing limit, or both). Note that anatomy-based models or measurements used to predict hearing limits are annotated by superscript by the method used: cochlear shape (radii ratios)[a]; inner ear frequency place maps[b]; basilar membrane thickness-to-width ratios[c]; and composite model estimates, including middle ear transform functions[d] or transform functions derived from finite element modeling either of head structures (combining pressure loading and skull vibration loading)[e] or middle ear structures.[f]

At least some **sound production data** are available for the 14 mysticete species that are presently recognized. Frequency ranges for sound production are cited as the broadest range of frequencies reported across all available cited studies for each species and are referenced to call types at the extremes of this range.

It is notable that the right whales (*Eubalaena glacialis*, *E. australis*, and *E. japonica*), bowhead whale (*Balaena mysticetus*), blue whale (*Balaenoptera musculus*), and fin whale (*Balaenoptera physalus*) are included in the LF cetacean weighting function; however, there is evidence to suggest that these species should be treated separately as very low-frequency (VLF) cetaceans that have better sensitivity to infrasonic sounds of even lower frequencies than other mysticetes. This distinction is based on several factors, including very large body size, exceptionally lower-frequency limits of sound production, high radii ratios based on cochlear morphology, and corresponding relatively long basilar membranes with small apical thickness-to-width ratios (Ketten et al., 2016).

Appendix 1, Table 1. Weighting functions: Low-frequency (LF) cetaceans

Taxon	Ear type	Auditory modeling	Sound production	References
Balaena mysticetus Bowhead whale	Mysticete middle ear, Type M cochlea	0.6[b] to 32[b] kHz	0.02 (moan) to 6 kHz (warble)	Audiometry: No data Anatomical modeling: Ketten, 1994[b]; Ketten et al., 2014[a] Acoustic: Ljungblad et al., 1980, 1982; Clark & Johnson, 1984; Cummings & Holliday, 1987; Würsig & Clark, 1993; Blackwell et al., 2007; Stafford et al., 2008; Delarue et al., 2009; Tervo et al., 2009, 2011, 2012
Eubalaena australis Southern right whale	Mysticete middle ear	--	0.02 (pulse) to 2.2 kHz (pulse, belch)	Audiometry: No data Anatomical modeling: No data Acoustic: Cummings et al., 1971, 1972, 1974; Payne & Payne, 1971; Saayman & Tayler, 1973; Clark, 1982; Parks et al., 2007a
Eubalaena glacialis North Atlantic right whale	Mysticete middle ear, Type M cochlea	0.016[a, b] to 25[b] kHz	0.02 to 22 kHz (gunshot)	Audiometry: No data Anatomical modeling: Ketten, 1994[b]; Parks et al., 2007b[c], Ketten et al., 2014[a] Acoustic: Matthews et al., 2001; McDonald & Moore, 2002; Vanderlaan et al., 2003; Parks & Tyack, 2005; Parks et al., 2007a; Trygonis et al., 2013
Eubalaena japonica North Pacific right whale	Mysticete middle ear	--	0.07 to 0.2 kHz (up calls)[1]	Audiometry: No data Anatomical modeling: No data Acoustic: McDonald & Moore, 2002; Mellinger et al., 2004; Munger et al., 2008, 2011
Balaenoptera acutorostrata Common minke whale	Mysticete middle ear, Type M cochlea	0.010[d, f] to 34[c] kHz	0.09 to 9 kHz (star wars, boing)	Audiometry: No data Anatomical modeling: Tubelli et al., 2012a[d], 2012b[f], Ketten et al., 2014[a, c] Acoustic: Beamish & Mitchell, 1973; Edds-Walton, 2000; Mellinger et al., 2000; Gedamke et al., 2001; Rankin & Barlow, 2005; Oswald et al., 2011; Risch et al., 2014a
Balaenoptera bonaerensis Antarctic minke whale	Mysticete middle ear	--	0.05 (downsweep, bio-duck) to 1 kHz (bio-duck)	Audiometry: No data Anatomical modeling: No data Acoustic: Schevill & Watkins, 1972; Risch et al., 2014b
Balaenoptera borealis Sei whale	Mysticete middle ear	--	0.02 (LF sweep) to 4 kHz (FM sweep)	Audiometry: No data Anatomical modeling: No data Acoustic: Knowlton et al., 1991; Rankin & Barlow, 2007; Baumgartner et al., 2008; Calderan et al., 2014; Romagosa et al., 2015
Balaenoptera edeni Bryde's whale	Mysticete middle ear	--	0.1 (LF tonal) to 0.9 kHz (pulsed moan)	Audiometry: No data Anatomical modeling: No data Acoustic: Edds et al., 1993; Oleson et al., 2003; Heimlich et al., 2005; Figueiredo, 2014; Rice et al., 2014; Širović et al., 2014; Viloria-Gómora et al., 2015

Balaenoptera omurai Omura's whale	Mysticete middle ear	--	0.01 to 0.05 kHz (AM call)	Audiometry: No data Anatomical modeling: No data Acoustic: Cerchio et al., 2015
Balaenoptera physalus Fin whale	Mysticete middle ear, Type M cochlea	0.02[e] to 20[e] kHz	0.01 (rumble, thud, 20-Hz signal) to 1 kHz (slam)	Audiometry: No data Anatomical modeling: Cranford & Krysl, 2015 Acoustic: Watkins et al., 1987; Edds, 1988; Thompson et al., 1992; McDonald et al., 1995a; Charif et al., 2002; Širović et al., 2007, 2013; Weirathmueller et al., 2013
Megaptera novaeangliae Humpback whale	Mysticete middle ear	0.018[a] to 15[b] kHz	0.02 (moan, grunt, creak, pulse train) to 24 kHz (mid-frequency tonal wail)	Audiometry: No data Anatomical modeling: Ketten, 1994[b]; Ketten et al., 2014[a] Acoustic: Hafner et al., 1979; Payne & Payne, 1985; Thompson et al., 1986; Simão & Moreira, 2005; Au et al., 2006; Dunlop et al., 2007; Stimpert et al., 2007, 2011; Zoidis et al., 2008
Caperea marginata Pygmy right whale	Mysticete middle ear	--	0.06 to 0.1 kHz (thump)	Audiometry: No data Anatomical modeling: No data Acoustic: Dawbin & Cato, 1992
Eschrichtius robustus Gray whale	Mysticete middle ear	--	0.01 (moan) to 20 kHz (clack)	Audiometry: No data Anatomical modeling: No data Acoustic: Cummings et al., 1968; Poulter, 1968; Fish et al., 1974; Norris et al., 1977; Crane & Lashkari, 1996; Stafford et al., 2007; Dahlheim & Castellote, 2016

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[1] See Beamish & Mitchell (1971) for suggestion of clicks extending to 31 kHz.

[2] Note that Crance et al. (2017) recently added gunshot calls to the species' repertoire. While not reporting frequency range, their figures show that these gunshots have energy exceeding 2 kHz and are consistent with data from the North Atlantic and southern right whale showing that at close range, these gunshots are broadband-pulsed calls with energy extending to substantially higher frequencies.

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Appendix 2. High-Frequency Cetaceans

Four odontocete families are represented in the high-frequency (HF) cetacean weighting function: Delphinidae (*Orcinus*, *Steno*, *Sousa* spp., *Sotalia* spp., *Tursiops* spp., *Stenella* spp., *Delphinus*, *Lagenodelphis*, *Lissodelphis* spp., *Grampus*, *Peponocephala*, *Feresa*, *Pseudorca*, *Globicephala* spp., *Orcaella* spp., *Lagenorhynchus acutus*, *L. obliquidens*, and *L. obscurus*), Physeteridae (*Physeter*), Montodontidae (*Delphinapterus* and *Monodon*), and Ziphiidae (*Berardius* spp., *Hyperoodon* spp., *Indopacetus*, *Mesoplodon* spp., *Tasmacetus*, and *Ziphius*). Note that the family Delphinidae is divided between the HF cetacean weighting function and the very low-frequency (VHF) cetacean weighting function, with species from the genus *Lagenorhynchus* additionally divided between these two weighting functions, with *L. acutus*, *L. albirostris*, *L. obliquidens*, and *L. obscurus* assigned to the HF cetacean group. Species listings are consistent with the Society for Marine Mammalogy Committee on Taxonomy (2016).

The HF cetaceans are considered with respect to available evidence from audiometric studies, anatomical descriptions, predictions from anatomical models, and analyses of emitted sounds to validate the grouping of these 57 odontocete species to the assigned HF cetacean weighting function. Data are expressed as frequency ranges for each species where possible. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016. In some cases, behavioral measurements of hearing and predictions of hearing based on anatomy from more recent sources or grey literature are included.

Audiometry data from behavioral (BEH) and neurophysiological (auditory evoked potential, [AEP]) studies are shown separately as the +60 dB frequency bandwidth from best measured sensitivity; sample sizes (number of different individuals [*n*]) are provided with the references. BEH hearing data are available for eight species. Note that due to their importance in the proposed weighting functions, only behavioral hearing studies meeting specific criteria are shown in the table; excluded studies are identified.[1] AEP measures are available for 12 of 57 species; note that all AEP studies reporting frequency-specific thresholds are included.

With respect to anatomy, two middle **ear types** are present within this grouping: (1) the *odontocete ear type* and (2) the *physeteroid ear type* (Nummela, 2008; see also Fleischer, 1978). Most odontocetes have an odontocete ear type which is uniquely designed to acoustically isolate the structures of the ear from the rest of the skull. The tympanic and periotic bones form a tympanoperiotic complex that is surrounded by air sinuses, and the middle ear cavity within is lined with distensible (cavernous) tissue to protect the ear from pressure during diving; the density of the tympanoperiotic complex and ossicles is very high relative to the skull, and the temporal bone is suspended by ligaments in a sinus filled with spongy mucosa to limit sound conduction from the skull (e.g., Ketten, 1994, 2000). Two families in the HF cetacean grouping, Physeteridae (*Physeter macrocephalus*) and Ziphiidae (*Berardius* spp., *Hyperoodon* spp., *Indopacetus*, *Mesoplodon* spp., *Tasmacetus*, and *Ziphius*), as well as Kogiidae (*Kogia* spp.) in the VHF cetacean grouping, have a physeteroid ear type. This ear type features tympanic and periotic bones that are tightly fused through a lateral synostosis. All odontocetes lack a pinna and functional auditory meatus and, instead, use a unique auditory pathway of acoustic fats aligned with the lower jaw to direct sound to the ears. Their inner ear features hypertrophied cochlear duct structures, extremely dense ganglion cell distribution, and unique basilar membrane dimensions (for summary, see Wartzok & Ketten, 1999). Odontocetes are differentiated into at least two types by the spiral parameters of the cochlea and characteristic thickness-to-width ratios along the length of the basilar membrane (Ketten & Wartzok, 1990). Type II cochleas have been described for at least five HF cetaceans (noted by species in this appendix); no HF cetaceans evaluated thus far have the morphology of a Type I cochlea seen in some VHF cetaceans (see Appendix 3). Type II cochleas have spiral geometry with logarithmically increasing interturn radii that resemble a "chambered nautilus" (Ketten & Wartzok, 1990).

Anatomy-based predictions of hearing range (predicted LF hearing limit, HF hearing limit, or both) are reported for only one species in the HF cetacean group, *Tursiops truncatus*. This species has been evaluated with multiple auditory models since the hearing abilities of this species is well documented. The anatomy-based models or measurements used to predict hearing limits in *T. truncatus* are annotated by superscript in the appendix by the method used: cochlear shape (radii ratios),[a] inner ear frequency place maps,[b] basilar membrane thickness-to-width width ratios,[c] or transform functions derived from finite element modeling of middle ear structures.[f] Auditory models of hearing in marine mammals are further informed by postmortem measures of stiffness of the middle ear (Miller et al., 2006) or basilar membrane (Zosuls et al., 2012) with known correlates to functional hearing in *T. truncatus*.

At least some **sound production data** are available for 42 of 57 species classified here as HF cetaceans. Frequency ranges for sound production are shown separately for social (SOC) and echoic (ECH) signals where applicable. The broadest range of frequencies reported across all referenced studies for each species are provided for SOC signals (i.e., total bandwidth). For ECH signals, the range of center (median) frequencies are provided where possible (denoted by $^+$); where these data are unavailable, the range of peak (dominant) frequencies are shown (denoted by ‡). ECH (click) signals are additionally classified by **click type** as suggested by Fenton et al. (2014). Among the HF cetaceans, three click types are evident: (1) *broadband high-frequency clicks* (BBHF), (2) *frequency-modulated* (FM) upsweeps, and (3) *multi-pulsed* (MP) signals (Fenton et al., 2014). Most HF cetacean species exhibit BBHF clicks while searching for prey, which are brief, high-intensity, broadband signals. Sperm whales (*Physeter macrocephalus*) are unique among all odontocetes in producing an extremely loud, relatively lower-frequency ECH signal with multiple pulses, caused by structured reverberation of the signal within the head. Beaked whales produce a steep FM click while searching for prey and a more broadband click in the terminal phases of prey capture. No odontocetes classified as HF cetaceans are reported to produce *narrow-band high-frequency* (NBHF) clicks, which are exclusive to the VHF cetacean grouping.

While the sperm whale, beaked whales (Family Ziphiidae: *Berardius* spp., *Hyperoodon* spp., *Indopacetus*, *Mesoplodon* spp., *Tasmacetus*, and *Ziphius*), and the killer whale (*Orcinus orca)* are included in the HF cetacean weighting function at this time, there is some suggestion that these species should be treated separately as "mid-frequency" cetaceans, with better sensitivity to sounds of lower frequencies than other HF cetaceans. These species are outliers to the rest of the HF group for several reasons. *Physeter* and the beaked whales have a physeteroid middle ear type in contrast to the odontocete type ear exhibited by other HF species. While all other HF cetaceans emit BBHF clicks, sperm and beaked whales produce lower-frequency, alternative ECH signals. In addition, killer whales produce relatively lower-frequency broadband clicks. Interestingly, hearing data for *Orcinus* and two beaked whales confirms an upper range of hearing extending above 90 kHz. More data will be required to better understand possible differences in how hearing is related to sound production between these species and other HF cetaceans.

Nearly all delphinids are HF cetaceans that emit BBHF clicks while searching for prey. The exception is the genus *Cephalorhynchus* and the species presently identified as *Lagenorhynchus australis* and *L. cruicger*. These species produce NBHF clicks and are classified as VHF cetaceans (see Appendix 3). The phylogenetic split among species of the genus *Lagenorhynchus* will likely be resolved by the pending reclassification of the two NBHF species (*L. australis* and *L. cruicger*) to a new or different genus (see Tougaard & Kyhn, 2010). *L. albirostris* is an interesting case with ambiguous classification at the high-frequency end of the HF cetacean grouping. The species produces BBHF clicks but with evidence of unusually HF spectral energy (Rasmussen & Miller, 2002),[3] and it has an extreme upper-frequency limit of hearing of 160 kHz (Nachtigall et al., 2008); however, *L. albirostris* remains classified as HF for the time being based on echolocation signal type and phylogenetic parsimony.

Most odontocetes that inhabit shallow-water, cluttered environments produce NBHF clicks and have presumed exceptional ultrasonic hearing; these include the porpoises and most of the river dolphins that are classified as VHF cetaceans. One exception is *Platanista gangetica*. This species has been shown to emit a broadband transient click with relatively low-frequency energy (Jensen et al., 2013). *Platanista* is the sole living species of the family Platanistidae. As this species has no close relatives, and no available data related to hearing, it has been classified with the HF cetaceans based only upon these features of sound production. Other inshore or nearshore species in the HF cetacean group include *Sotalia fluviatilis*, *S. guianensis*, and *Orcaella brevirostris*, which all emit BBHF clicks while searching for prey.

Appendix 2, Table 1. Weighting function: High-frequency (HF) cetaceans

Taxon	Audiometry	Ear type	Auditory modeling	Sound production	Click type	References
Physeter macrocephalus Sperm whale	--	Physeteroid middle ear, Type I cochlea	--	SOC: 0.4 (squeal) to 9 kHz (coda) ECH: 3 to 26 kHz$^+$	MP	Audiometry: No data Anatomical models: No data Acoustic: Backus & Schevill, 1966; Levenson, 1974; Watkins & Schevill, 1977, 1980; Watkins, 1980; Weilgart & Whitehead, 1988; Goold & Jones, 1995; Madsen et al., 2002a, 2002b; Møhl et al., 2003; Weir et al., 2007
Berardius arnuxii Arnoux' beaked whale	--	Physeteroid middle ear	--	SOC: 5 kHz (whistle)	--	Audiometry: No data Anatomical models: No data Acoustic: Rogers & Brown, 1999
Berardius bairdii Baird's beaked whale	--	Physeteroid middle ear	--	ECH: 12 to 46 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Dawson et al., 1998; Baumann-Pickering et al., 2013a, 2013b; Stimpert et al., 2014
Hyperoodon ampullatus Northern bottlenose whale	--	Physeteroid middle ear	--	SOC: 3 (whistle) to 16 kHz (whistle) ECH: 32 to 51 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Hooker, 2002; Wahlberg et al., 2011a; Moors-Murphy, 2015
Hyperoodon planifrons Southern bottlenose whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Indopacetus pacificus Tropical bottlenose whale	--	Physeteroid middle ear	--	ECH: 12 to 38 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Rankin et al., 2011; Baumann-Pickering et al., 2013b
Mesoplodon bidens Sowerby's beaked whale	--	Physeteroid middle ear	--	ECH: 32 to 51 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Cholewiak et al., 2013
Mesoplodon bowdoini Andrews' beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon carlbubbsi Hubb's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data

Mesoplodon densirostris Blainville's beaked whale	AEP: < 6 to 117 kHz	Physeteroid middle ear	-	SOC: 1 (whistle) to 12 kHz (whistle) ECH: 30 to 57 kHz$^+$	FM	Audiometry: AEP: Pacini et al., 2011— *n* = 1 Anatomical models: No data Acoustic: Johnson et al., 2004, 2006; Rankin & Barlow, 2007; McDonald et al., 2009; Ward et al., 2011; Baumann-Pickering et al., 2013a; Ward Shaffer et al., 2013
Mesoplodon europaeus Gervais' beaked whale	AEP: < 5 to > 90 kHz	Physeteroid middle ear	--	ECH: 37 to 55 kHz$^+$	FM	Audiometry: AEP: Cook et al., 2006; Finneran et al., 2009—*n* = 2 Anatomical models: No data Acoustic: Gillespie et al., 2009; Baumann-Pickering et al., 2013b
Mesoplodon ginkgodens Ginkgo-toothed beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon grayi Gray's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon hectori Hector's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon hotaula Deraniyagala's beaked whale	--	Physeteroid middle ear	--	ECH: 30 to 66 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Baumann-Pickering et al., 2013a, 2013b
Mesoplodon layardii Strap-toothed beaked whale Layard's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon mirus True's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon perrini Perrin's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon peruvianus Pygmy beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mesoplodon stejnegeri Stejneger's beaked whale	--	Physeteroid middle ear	--	ECH: 46 to 76 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Baumann-Pickering et al., 2013b
Mesoplodon traversii Spade-toothed whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data

Tasmacetus shepherdi Tasman beaked whale Shepherd's beaked whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Ziphius cavirostris Cuvier's beaked whale goose-beaked whale	--	Physeteroid middle ear	--	ECH: 28 to 47 kHz$^+$	FM	Audiometry: No data Anatomical models: No data Acoustic: Frantzis et al., 2002; Zimmer et al., 2005; Baumann-Pickering et al., 2013b
Orcinus orca Killer whale	BEH: 0.2 to 140 kHz AEP: < 1 to 90 kHz	Odontocete middle ear	--	SOC: 0.1 (click burst) to 75 kHz (ultrasonic whistles) ECH: 22 to 80 kHz$^+$	BBHF	Audiometry: BEH: Szymanski et al., 1999—*n* = 2; exclude Hall, 1972; AEP: Szymanski et al., 1999—*n* = 2; see also recent paper from Branstetter et al., 2017—*n* = 6, with individuals "A" and "B" excluded Anatomical models: No data Acoustic: Schevill & Watkins, 1966; Diercks et al., 1971; Steiner et al., 1979; Dahlheim & Awbrey, 1982; Ford & Fisher, 1983; Hoelzel & Osborne, 1986; Morton et al., 1986; Moore et al., 1988; Ford, 1989; Barrett-Lennard et al., 1996; Thomsen et al., 2001; Au et al., 2004; Van Opzeeland et al., 2005; Miller, 2006; Riesch et al., 2006, 2008; Simon & Ugarte, 2006; Simon et al., 2007; Samarra et al., 2010; Riesch & Deecke, 2011; Simonis et al., 2012
Delphinapterus leucas Beluga	BEH: 0.04 to 130 kHz AEP: < 4 to 150 kHz	Odontocete middle ear	--	SOC: 0.1 (whistle, pulsed calls) to 21 kHz (whistle, pulsed calls) ECH: 40 to 120 kHz$^+$	BBHF	Audiometry: BEH: White et al., 1978; Awbrey, 1988; Johnson et al., 1989; Ridgway et al., 2001; Finneran et al., 2005b— *n* = 8; exclude Finneran et al., 2005b (individual *Turner*); AEP: Popov & Supin, 1990; Klishin et al., 2000; Mooney et al., 2008; Popov et al., 2013; Castellote et al., 2014—*n* = 12 Anatomical models: No data Acoustic: Kamminga & Wiersma, 1981; Sjare & Smith, 1986; Au et al., 1987; Turl et al., 1991; Belikov & Bel'kovich, 2001, 2005, 2006, 2007; Karlsen et al., 2001; Rutenko & Vishnyakov, 2006; Lammers & Castellote, 2009; Chmelnitsky & Ferguson, 2012
Monodon monoceros Narwhal	--	Odontocete middle ear	--	SOC: 0.3 (whistle, pulsed calls) to 24 kHz (pulsed calls) ECH: 53 kHz$^+$ (mean)	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Watkins et al., 1971; Ford & Fisher, 1978; Møhl et al., 1990; Miller et al., 1995; Shapiro, 2006; Marcoux et al., 2012; Stafford et al., 2012; Rasmussen et al., 2015; Koblitz et al., 2016
Delphinus delphis Short- and long-beaked common dolphins	--	Odontocete middle ear	--	SOC: 0.3 (whistle) to 44 kHz (whistles) ECH: 25 to 35 kHz‡	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Busnel & Dziedzic, 1966; Fish & Turl, 1976; Moore & Ridgway, 1995; Oswald et al., 2003; Ansmann et al., 2007; Petrella et al., 2012; Azzolin et al., 2014
Feresa attenuata Pygmy killer whale	AEP: 5 to 106 kHz	Odontocete middle ear	--	ECH: 70 to 85 kHz$^+$	BBHF	Audiometry: AEP: Montie et al., 2011—*n* = 2 Anatomical models: No data Acoustic: Madsen et al., 2004

Globicephala macrorhynchus Short-finned pilot whale	AEP: < 10 to 105 kHz	Odontocete middle ear	--	SOC: 2 (whistle) to 40 kHz (whistle) ECH: 3 to 13 kHz^{+}	BBHF	Audiometry: AEP: Schlundt et al., 2011; Greenhow et al., 2014— *n* = 5 Anatomical models: No data Acoustic: Fish & Turl, 1976; Rendell et al., 1999; Oswald et al., 2003; Baron et al., 2008; Jensen et al., 2011
Globicephala melas Long-finned pilot whale	AEP: < 4 to 89 kHz	Odontocete middle ear	--	SOC: 0.1 (chirp, squeal) to 24 kHz (whistle)	--	Audiometry: AEP: Pacini et al., 2010— *n* = 1 Anatomical models: No data Acoustic: Steiner, 1981; Rendell et al., 1999; Nemiroff, 2009; Azzolin et al., 2014
Grampus griseus Risso's dolphin	BEH: 1.6 to 100 kHz^{2} AEP: < 4 to 142 kHz	Odontocete middle ear, Type II cochlea	--	SOC: 0.1 (grunt) to 29 kHz (whistle) ECH: 24 to 131 kHz^{+}	BBHF	Audiometry: BEH: Nachtigall et al., 1995—*n* = 1; AEP: Nachtigall et al., 2005—*n* = 1 Anatomical models: Wartzok & Ketten, 1999; Nummela, 2008 Acoustic: Au, 1993; Rendell et al., 1999; Corkeron et al., 2001; Philips et al., 2003; Madsen, 2004; Soldevilla et al., 2008; Smith et al., 2016
Lagenodelphis hosei Fraser's dolphin	--	Odontocete middle ear	--	SOC: 4.3 (whistle) to 24 kHz (whistle)	--	Audiometry: No data Anatomical models: No data Acoustic: Leatherwood et al., 1993; Watkins et al., 1994; Oswald et al., 2007
Lagenorhynchus acutus Atlantic white-sided dolphin	--	Odontocete middle ear	--	SOC: 0.1 (squawk) to 20 kHz (whistle) ECH: 44 to 86 kHz^{+}	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Ding et al., 1995; Herzing, 1996; Au & Herzing, 2003; Hamran, 2014
Lagenorhynchus albirostris White-beaked dolphin	AEP: < 16 to 160 kHz	Odontocete middle ear, Type II cochlea	--	SOC: 1 to 47 kHz (pulses) ECH: 82 to 98 kHz$^{+, 3}$	BBHF^{3}	Audiometry: AEP: Nachtigall et al., 2008—*n* = 2 Anatomical models: No data Acoustic: Watkins & Shevill, 1972; Mitson, 1990; Rendell et al., 1999; Rasmussen & Miller, 2002, 2004; Simard et al., 2008; Atem et al., 2009
Lagenorhynchus obliquidens Pacific white-sided dolphin	BEH: 0.3 to 139 kHz	Odontocete middle ear	--	SOC: 2 (whistle) to 20 kHz (whistle) ECH: 22 to 38 kHz‡	BBHF	Audiometry: BEH: Tremel et al., 1998—*n* = 1 Anatomical models: No data Acoustic: Caldwell & Caldwell, 1970b; Soldevilla et al., 2008
Lagenorhynchus obscurus Dusky dolphin	--	Odontocete middle ear	--	SOC: 1 (whistle) to 28 kHz (whistle) ECH: 90 to 100 kHz^{+}	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Ding et al., 1995; Matthews et al., 1999; Au & Würsig, 2004; Au et al., 2010; Vaughn-Hirshorn et al., 2012

Lissodelphis borealis Northern right whale dolphin	--	Odontocete middle ear	--	SOC: 1 (whistle) to 49 kHz (burst pulse) ECH: 23 to 41 kHz‡	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Leatherwood & Walker, 1979; Rankin et al., 2007
Lissodelphis peronii Southern right whale dolphin	--	Odontocete middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Orcaella brevirostris Irrawaddy dolphin	--	Odontocete middle ear	--	SOC: 1 (whistle) to 22 kHz (creak, buzz, squeak) ECH: 70 to 109 kHz^{+}	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Van Parijs et al., 2000; Jensen et al., 2013; Ingale & Lokhande, 2015
Orcaella heinsohni Australian snubfin dolphin	--	Odontocete middle ear	--	SOC: 6 (whistle) to 13 kHz (whistle)	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Berg Soto et al., 2014
Peponocephala electra Melon-headed whale	--	Odontocete middle ear	--	SOC: 1 (whistle) to 25 kHz (whistle) ECH: 21 to 38 kHz^{+}	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Baumann-Pickering et al., 2010, 2015a; Frankel & Yin, 2010; Kaplan et al., 2014
Pseudorca crassidens False killer whale	BEH: 2 to 111 kHz AEP: < 4 to > 45 kHz	Odontocete middle ear	--	SOC: 3 (whistle) to 9 kHz (whistle) ECH: 25 to 87 kHz^{+}	BBHF	Audiometry: BEH: Thomas et al., 1988—$n = 1$; exclude Yuen et al., 2005; AEP: Yuen et al., 2005—$n = 1$ Anatomical models: No data Acoustic: Mizue et al., 1969; Kamminga & van Velden, 1987; Thomas et al., 1988; Thomas & Turl, 1990; Brill et al., 1992; Au et al., 1995; Murray et al., 1998; Rendell et al., 1999; Oswald et al., 2003; Madsen, 2004; Kloepper et al., 2012; Madsen et al., 2013; Baumann-Pickering et al., 2015b
Sousa chinensis Indo-Pacific humpback dolphin	AEP: < 5.6 to 135 kHz	Odontocete middle ear	--	SOC: 0.5 (grunt) to 28 kHz (whistle) ECH: 57 to 134 kHz^{+}	BBHF	Audiometry: AEP: Li et al., 2012—$n = 1$ Anatomical models: No data Acoustic: Schultz & Corkeron, 1994; Van Parijs & Corkeron, 2001a, 2001b; Goold & Jefferson, 2004; Sims et al., 2012; Xu et al., 2012; Li et al., 2013; Wang et al., 2013; Berg Soto et al., 2014; Fang et al., 2015; Hoffman et al., 2015; Kimura et al., 2016
Sousa plumbea Indian Ocean humpback dolphin	--	Odontocete middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Sousa sahulensis Australian humpback dolphin	--	Odontocete middle ear	--	ECH: 86 to 125 kHz^{+}	BBHF	Audiometry: No data Anatomical models: No data Acoustic: de Freitas et al., 2015

Sousa teuszii Atlantic humpback dolphin	--	Odontocete middle ear	--	SOC: 1 (whistle) to 24 kHz (whistle)	--	Audiometry: No data Anatomical models: No data Acoustic: Weir, 2010
Sotalia fluviatilis Tucuxi	BEH: < 4 to > 135 kHz AEP: < 5 to 140 kHz	Odontocete middle ear	--	SOC: 0.2 (whistle) to 29 kHz (whistle) ECH: 60 to 148 kHz$^+$	BBHF	Audiometry: BEH: Sauerland & Dehnhardt, 1998—*n* = 1; AEP: Popov & Supin, 1990—*n* = 2 Anatomical models: No data Acoustic: Caldwell & Caldwell, 1970a; Norris et al., 1972; Nakasai & Takemura, 1975; Kamminga et al., 1993; Ding et al., 1995; Monteiro-Filho & Monteiro, 2001; Wang et al., 2001; Azevedo & Simão, 2002; Erber & Simão, 2004; Azevedo & Van Sluys, 2005; Pivari & Rosso, 2005; May-Collado & Wartzok, 2010; Yamamoto et al., 2015
Sotalia guianensis Guiana dolphin	--	Odontocete middle ear	--	SOC: 0.3 (gargle) to 40 kHz (whistle)	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Wiersma, 1982; Monteiro-Filho & Monteiro, 2001; Duarte de Figueiredo & Simão, 2009; May-Collado & Wartzok, 2009; May-Collado, 2010, 2013; Deconto & Monteiro-Filho, 2013, 2016; de Andrade et al., 2014, 2015; Lima & Le Pendu, 2014; Barrios-Garrido et al., 2016; Leão et al., 2016
Stenella attenuata Pantropical spotted dolphin	--	Odontocete middle ear, Type II cochlea	--	SOC: 3 (whistle) to 22 kHz (whistle) ECH: 83 kHz$^+$ (mean)	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Ding et al., 1995; Oswald et al., 2003; Schotten et al., 2004
Stenella clymene Clymene dolphin	--	Odontocete middle ear	--	--	--	Audiometry: No data Anatomy: No data Acoustic: No data
Stenella coeruleoalba Striped dolphin	BEH: 2 to 154 kHz	Odontocete middle ear	--	SOC: 1 (whistle) to 34 kHz (whistle)	--	Audiometry: BEH: Kastelein et al., 2003—*n* = 1 Anatomical models: No data Acoustic: Oswald et al., 2003; Azzolin et al., 2013; Papale et al., 2013
Stenella frontalis Atlantic spotted dolphin	--	Odontocete middle ear	--	SOC: 1 (whistle) to 32 kHz (whistle) ECH: 44 to 86 kHz$^+$	--	Audiometry: No data Anatomical models: No data Acoustic: Caldwell & Caldwell, 1971; Caldwell et al., 1973; Steiner, 1981; Ding et al., 1995; Lammers et al., 2003; Baron et al., 2008; Azevedo et al., 2010; Frankel et al., 2014; Jensen et al., 2015
Stenella longirostris Spinner dolphin	--	Odontocete middle ear	--	SOC: 0.8 (whistle) to 26 kHz (whistle) ECH: 33 to 81 kHz$^+$	--	Audiometry: No data Anatomical models: No data Acoustic: Watkins & Schevill, 1974; Steiner, 1981; Brownlee & Norris, 1994; Bazúa-Durán & Au, 2002, 2004; Lammers et al., 2003, 2004; Oswald et al., 2003; Schotten et al., 2004; Baumann-Pickering et al., 2010

Steno bredanensis Rough-toothed dolphin	AEP: < 10 to > 120 kHz	Odontocete middle ear	--	SOC: 3 (whistle) to 29 kHz (whistle) ECH: 16 to 29 kHz[+]	BBHF	Audiometry: AEP: Mann et al., 2010—*n* = 1 Anatomical models: No data Acoustic: Norris & Evans, 1967; Oswald et al., 2003; Seabra de Lima et al., 2012; Rankin et al., 2015
Tursiops aduncus Indo-Pacific bottlenose dolphin	--	Odontocete middle ear	--	SOC: 0.5 (whistle) to 28 kHz (whistle) ECH: 85 to 114 kHz[+]	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Morisaka et al., 2005; Hawkins & Gartside, 2009; Hawkins, 2010; Wahlberg et al., 2011a, 2011b; Gridley et al., 2012; de Freitas et al., 2015; Lubis et al., 2016; Ward et al., 2016; Wulandari et al., 2016
Tursiops truncatus Common bottlenose dolphin	BEH: 0.4 to 146 kHz AEP: < 5 to 169 kHz	Odontocete middle ear, Type II cochlea	0.15[a] to 163[b] kHz	SOC: 0.1 (thunk) to 165 kHz (creak) ECH: 23 to 102 kHz[+]	BBHF	Audiometry: BEH: Johnson, 1967; Ljungblad et al., 1982; Lemonds, 1999; Brill et al., 2001; Schlundt et al., 2008; Finneran et al., 2010—*n* = 6; exclude Finneran et al., 2005a, 2007; AEP: Popov & Supin, 1990; Houser & Finneran, 2006; Popov et al., 2007; Finneran et al., 2008, 2011; Houser et al., 2008; Mann et al., 2010—*n* > 39 Anatomical models: Ketten, 1994[b]; Tubelli et al., 2012[f]; Ketten et al., 2014[a, b]; Racicot et al., 2016[a] Acoustic: Lilly & Miller, 1961; Evans & Prescott, 1962; Lilly, 1963; Caldwell & Caldwell, 1968, 1979; Diercks et al., 1971; Evans, 1973; Au et al., 1974; Fish & Turl, 1976; Kamminga, 1979; Au & Penner, 1981; Steiner, 1981; Au et al., 1982; Wiersma, 1982; dos Santos et al., 1990; Au, 1993, 2004; Jacobs et al., 1993; Ding et al., 1995; McCowan & Reiss, 1995; Schultz et al., 1995; Connor & Smolker, 1996; Blomqvist & Amundin, 2004; Boisseau, 2005; Azevedo et al., 2007; van der Woude, 2009; Hawkins, 2010; Simard et al., 2011; Wahlberg et al., 2011b; Branstetter et al., 2012; Azzolin et al., 2014; Frankel et al., 2014; Buscaino et al., 2015; Gridley et al., 2015
Platanista gangetica South Asian river dolphin Indian river dolphin Ganges river dolphin	--	Odontocete middle ear	--	ECH: 54 to 72 kHz	BBT	Audiometry: No data Anatomical models: No data Acoustic: Herald et al., 1969; Andersen & Pilleri, 1970; Kamminga, 1979; Jensen et al., 2013

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[1] Due to the primary role of behavioral audiometric data in determining the shape of the weighting function, only psychophysical studies meeting certain criteria were used to determine group-specific audiograms (see "Estimated Group Audiograms for Marine Mammals" section); citations for individuals were excluded if data for the same individual were reported elsewhere, if hearing loss was suspected, if audiograms appeared aberrant (e.g., obvious notches or flattened shape), or if masking or other environmental or procedural factors likely influenced reported data. While these data were excluded from the group audiograms, the excluded citations may still provide useful information about the sounds that can be detected by a given species.

[2] Note that the BEH (Nachtigall et al., 1995) and AEP (Nachtigall et al., 2005) audiograms for *Grampus griseus* are incongruous. The difference in high-frequency hearing limit for a young stranded individual suggests that the behavioral audiogram for the trained adult subject was not representative. However, as Finneran (2016) and National Marine Fisheries Service (2016) do not exclude this behavioral audiogram, we note this anomaly but do not exclude these data from the composite audiogram in the "Estimated Group Audiograms for Marine Mammals" section.

[3] Note that for *Lagenorhynchus albirostris*, some BBHF echolocation signals contain a secondary peak in the spectrum, with energy above 200 kHz (Rasmussen & Miller, 2002).

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Appendix 3. Very High-Frequency Cetaceans

There are six odontocete families represented in the very high-frequency (VHF) weighting function: Phocoenidae (*Neophocaena* spp., *Phocoena* spp., and *Phocoenoides*), Iniidae (*Inia*), Kogiidae (*Kogia*), Lipotidae (*Lipotes*), Pontoporiidae (*Pontoporia*), and Delphinidae (*Cephalorhynchus* spp., *Lagenorhynchus australis*, and *L. cruciger*). Note that the family Delphinidae is divided between the high-frequency (HF) cetacean weighting function and the VHF cetacean weighting function, with species from the genus *Lagenorhynchus* additionally split between these two weighting functions. The species listings provided here are consistent with the Society for Marine Mammalogy Committee on Taxonomy (2016). With respect to the mixed phylogeny of delphinids between the HF and VHF weighting functions, it is notable that both *L. australis* and *L. cruciger* are now thought to belong to a phylogenetic group aligned with the *Cephalorhynchus* genus, which is also assigned to the VHF group. These two *Lagenorhynchus* species are likely to be reassigned to the *Cephalorhynchus* genus or a new genus (for review, see Tougaard & Kyhn, 2010), which would be consistent with the assignment of *L. australis* and *L. cruciger* to the VHF weighting function.

The VHF odontocetes are considered with respect to available evidence from audiometric studies, anatomical descriptions, predictions from anatomical models, and analyses of emitted sounds to validate the grouping of these 18 species to the assigned VHF cetacean weighting function. Data are expressed as frequency ranges for each species where possible. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016; this appendix also includes models and predictions of hearing based on anatomy from recent grey literature.

Audiometry data from behavioral (BEH) and neurophysiological (auditory evoked potential [AEP]) studies of hearing are shown separately as the +60 dB frequency bandwidth from best measured sensitivity; sample sizes (number of different individuals [*n*]) are provided with the references. BEH hearing data are available for two VHF odontocete species. Note that due to their importance in the proposed weighting functions, only BEH hearing studies meeting specific criteria are shown in the table; excluded studies are identified.[1] AEP measures are available for three species; note that all AEP studies reporting frequency-specific thresholds are included.

With respect to **anatomy**, the mammalian middle ear type for most species in this group is the *odontocete ear type* (Nummela, 2008), which is uniquely designed to acoustically isolate the structures of the ear from the rest of the skull. The tympanic and periotic bones form a tympanoperiotic complex that is surrounded by air sinuses, and the middle ear cavity within is lined with distensible (cavernous) tissue to protect the ear from pressure during diving; the density of the ossicles is very high relative to the skull, and the temporal bone is suspended by ligaments in a sinus filled with spongy mucosa to limit sound conduction from the skull (e.g., Ketten, 1994, 2000). One genus, *Kogia*, has a *physeteroid ear type* (Nummela, 2008; see also Fleischer, 1978) which features tympanic and periotic bones that are tightly fused through a lateral synostosis, and a bony plate (the tympanic plate) in place of a more compliant tympanic membrane. All odontocetes lack a pinna and functional auditory meatus, and, instead, use a unique auditory pathway of acoustic fats in the lower jaw to direct sound to the ears. Their inner ear features hypertrophied cochlear duct structures, extremely dense ganglion cell distribution, and unique basilar membrane dimensions (for summary, see Wartzok & Ketten, 1999). Odontocetes are differentiated into at least two types by the spiral parameters of the cochlea and characteristic thickness-to-width ratios along the length of the basilar membrane (Ketten & Wartzok, 1990). Type I cochleas have been described for at least two VHF cetaceans; no VHF cetaceans evaluated thus far have the morphology of a Type II cochlea. Type I cochleas, as seen in *Phocoena phocoena* and *Inia geoffrensis*, have spiral geometry with a relatively constant interturn radius curve like that of a "tightly coiled rope" (Ketten & Wartzok, 1990, p. 95).

Anatomy-based predictions of hearing range (predicted low-frequency hearing limit, high-frequency hearing limit, or both when available) are reported for seven species. Data for six of these species are reported by Racicot et al. (2016) and include estimates of the low-frequency hearing limit derived from cochlear shape (radii ratios)[a] based on the method of Manoussaki et al. (2008). The final species, *P. phocoena*, is best studied in terms of anatomy. Data are reported by Racicot et al. (2016), as are similar radii ratio data from Ketten et al. (2014). There are also independent low- and high-frequency limits for this species predicted by inner ear frequency place maps[b] (Ketten et al., 2014). Note that predictions of hearing limits from auditory modeling obtained from different models are not analogous; therefore, the hearing limits provided in the appendix are annotated by the method used.

At least some **sound production data** are available for 15 of 18 species classified as VHF cetaceans. Frequency ranges for sound production are shown separately for social (SOC) and echoic (ECH) signals where applicable. The broadest range of frequencies reported across all referenced studies for each species are provided for SOC signals (total bandwidth). For ECH signals, the range of center (median) frequencies are provided where possible (denoted by $^+$); where these data are unavailable, the range of peak (dominant) frequencies are shown (denoted by ‡). ECH (click) signals are additionally classified by **click type** as suggested by Fenton et al. (2014). Cetaceans categorized as VHF all produce narrow-band high-frequency (NBHF) clicks while searching for prey. This is a derived signal that has arisen independently in several phylogenetic groups (e.g., porpoises, some non-whistling dolphins, some river dolphins, and the genus *Kogia*). While best studied in harbor porpoises (*P. phocoena*), this NBHF click type is also present in six delphinids (*Cephalorhynchus* spp., *L. australis*, and *L. cruciger*), as well as in inshore or nearshore species (*I. geoffrensis*, *Pontoporia blainvillei*, and the [now likely extinct] *Lipotes vexillifer*). The NBHF click type is thought to be related to foraging in shallow or cluttered environments, although it is also observed in at least one open water species (*Kogia breviceps*; Madsen et al., 2005).

It is notable that *Platanista gangetica* was originally classified as VHF, along with other river dolphins. However, this species has been shown to emit a broadband transient click with relatively low-frequency energy (Jensen et al., 2013). *Platanista* is the sole living species of the family Platanistidae. As this species has no close relatives, and no audiometric or auditory anatomy data are available, it has been classified with the HF odontocetes rather than the VHF odontocetes based solely upon features of sound production.

Appendix 3, Table 1. Weighting function: Very high-frequency (VHF) cetaceans

Taxon	Audiometry	Ear type	Auditory modeling	Sound production	Click type	References
Lagenorhynchus australis Peale's dolphin	--	Odontocete middle ear	--	SOC: 0.3 to 5 kHz (buzz) ECH: 123 to 138 kHz[+]	NBHF	Audiometry: No data Anatomical models: No data Acoustic: Schevill & Watkins, 1970; Kyhn et al., 2010
Lagenorhynchus cruciger Hourglass dolphin	--	Odontocete middle ear	--	ECH: 124 to 132 kHz[+]	NBHF	Audiometry: No data Anatomical models: No data Acoustic: Kyhn et al., 2009; Tougaard & Kyhn, 2010
Cephalorhynchus commersonii Commerson's dolphin	--	Odontocete middle ear	0.3[a] to – kHz	SOC: 0.2 (cry) to 16 kHz (whistle) ECH: 120 to 171 kHz[+]	NBHF	Audiometry: No data Anatomical models: Racicot et al., 2016[a] Acoustic: Watkins & Schevill, 1980; Kamminga & Wiersma, 1981, 1982; Yeh et al., 1981; Evans et al., 1988; Dziedzic & de Buffrenil, 1989; Kyhn et al., 2010; Yoshida et al., 2014; Reyes Reyes et al., 2015, 2016
Cephalorhynchus eutropia Chilean dolphin	--	Odontocete middle ear	--	ECH: 126 kHz[+]	NBHF	Audiometry: No data Anatomical models: No data Acoustic: Götz et al., 2010
Cephalorhynchus heavisidii Heaviside's dolphin	--	Odontocete middle ear	--	SOC: 0.8 to 4.5 kHz (cries) ECH: 121 to 130 kHz[+]	NBHF[2]	Audiometry: No data Anatomical models: No data Acoustic: Watkins et al., 1977; Morisaka et al., 2011
Cephalorhynchus hectori Hector's dolphin	--	Odontocete middle ear	--	SOC: squeals and cries ECH: 125 to 132 kHz[+]	NBHF[3]	Audiometry: No data Anatomical models: No data Acoustic: Dawson & Thorpe, 1990; Thorpe & Dawson, 1991; Thorpe et al., 1991; Kyhn et al., 2009
Neophocaena asiaeorientalis Narrow-ridged finless porpoise Yangtze finless porpoise	--	Odontocete middle ear	--	ECH: 100 to 135 kHz[‡]	NBHF	Audiometry: No data Anatomical models: No data Acoustic: Li et al., 2005, 2007[4]
Neophocaena phocaenoides Indo-Pacific finless porpoise	AEP: < 8 to > 152 kHz	Odontocete middle ear	0.3[a] to – kHz	ECH: 142 kHz[+] (mean)	NBHF	Audiometry: AEP: Popov et al., 2005, 2011—*n* = 4 Anatomical models: Racicot et al., 2016[a] Acoustic: Pilleri et al., 1980; Kamminga et al., 1986; Akamatsu et al., 1998; Goold & Jefferson, 2002

Phocoena dioptrica Spectacled porpoise	--	Odontocete middle ear	0.2^{a} to – kHz	--	--	Audiometry: No data Anatomical models: Racicot et al., 2016^{a} Acoustic: No data
Phocoena phocoena Harbor porpoise	BEH: 0.3 to 160 kHz AEP: < 10 to 160 kHz	Odontocete middle ear, Type I cochlea	0.25^{a} to 220^{b} kHz	SOC: see endnote 5 ECH: 125 to 200 kHz^{+}	NBHF	Audiometry: BEH: Kastelein et al., 2002, as updated by Kastelein, 2010; Kastelein et al., 2010, 2015—n = 3; exclude Andersen, 1970; AEP: Popov et al., 1986; Popov & Supin, 1990; Ruser et al., 2016—n = 28 Anatomical models: Ketten, 1994^{a}; Ketten et al., 2014^{b}; Racicot et al., 2016^{a} Acoustic: Busnel & Dziedzic, 1966; Schevill et al., 1969; Dubrovskii et al., 1971; Møhl & Andersen, 1973; Kamminga & Wiersma, 1981; Wiersma, 1982; Verboom & Kastelein, 1995; Au et al., 1999; Kastelein et al., 1999; Teilmann et al., 2002; Villadsgaard et al., 2007; Hansen et al., 2008; Madsen et al., 2010; Clausen et al., 2011; Kyhn et al., 2013
Phocoena sinus Vaquita	--	Odontocete middle ear	0.2^{a} to – kHz	ECH: 128 to 139 kHz‡	NBHF	Audiometry: No data Anatomical models: Racicot et al., 2016^{a} Acoustic: Silber, 1991
Phocoena spinipinnis Burmeister's porpoise	--	Odontocete middle ear	0.4^{a} to – kHz	--	--	Audiometry: No data Anatomical models: Racicot et al., 2016 Acoustic: No data
Phocoenoides dalli Dall's porpoise	--	Odontocete middle ear	0.2^{a} to – kHz	ECH: 121 to 147 kHz^{+}	NBHF	Audiometry: No data Anatomical models: Racicot et al., 2016^{a} Acoustic: Bassett et al., 2009; Kyhn et al., 2013
Inia geoffrensis Amazon river dolphin Boto	BEH: < 1 to > 105 kHz AEP: < 8 to > 130 kHz	Odontocete middle ear, Type I cochlea	--	SOC: 0.06 (pulse) to 48 kHz (whistle) ECH: 55 to 138 kHz^{+}	NBHF	Audiometry: BEH: Jacobs & Hall, 1972—n = 1; AEP: Popov & Supin, 1990—n = 4 Anatomical models: No data Acoustic: Caldwell & Caldwell, 1970; Penner & Murchison, 1970; Diercks et al., 1971; Norris et al., 1972; Evans, 1973; Kamminga, 1979; Wiersma, 1982; Kamminga et al., 1993; Ding et al., 1995; Wang et al., 2001; Podos et al., 2002; May-Collado & Wartzok, 2007; Ladegaard et al., 2015; Yamamoto et al., 2015; Amorim et al., 2016
Lipotes vexillifer[6] Yangtze river dolphin Chinese river dolphin Baiji	--	Odontocete middle ear	--	SOC: 3 (whistle) to 19 kHz (whistle) ECH: 92 kHz^{+}	NBHF[7]	Audiometry: BEH: exclude Wang et al., 1992—n = 1 Anatomical models: No data Acoustic: Jing et al., 1981; Wang et al., 1989, 2006; Xiao & Jing, 1989; Akamatsu et al., 1998

Pontoporia blainvillei Franciscana	--	Odontocete middle ear	--	ECH: 139 kHz‡ (mean)	NBHF[8]	Audiometry: No data Anatomical models: No data Acoustic: Melcón et al., 2012; Tellechea & Norbis, 2014
Kogia breviceps Pygmy sperm whale	--	Physeteroid middle ear	--	SOC: 1.4 to 1.5kHz ECH: 125 to 130 kHz‡	NBHF	Audiometry: No data Anatomical models: No data Acoustic: Thomas et al., 1990; Marten, 2000; Ridgway & Carder, 2001; Madsen et al., 2005
Kogia sima Dwarf sperm whale	--	Physeteroid middle ear	--	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data

[1] Due to the primary role of behavioral audiometric data in determining the shape of the weighting function, only psychophysical studies meeting certain criteria were used to determine group-specific audiograms (see "Estimated Group Audiograms for Marine Mammals" section); citations for individuals were excluded if data for the same individual were reported elsewhere, if hearing loss was suspected, if audiograms appeared aberrant (e.g., obvious notches or flattened shape), or if masking or other environmental or procedural factors likely influenced reported data. While these data were excluded from the group audiograms, the excluded citations still provide useful information about the sounds that can be detected by a given species.

[2] Note that Watkins et al. (1977) also report lower-frequency buzz clicks (below 5 kHz) for *Cephalorhynchus heavisidii*; a recent report from Martin et al. (2018) confirms a broadband click type produced by this species with energy < 100 kHz in addition to NBHF clicks.

[3] Note that Götz et al. (2010) also report lower-frequency buzz clicks (with center frequency of 100 kHz) for *Cephalorhynchus eutropia.*

[4] Note that Li et al. (2005, 2007) use the species listing *Neophocaena phocaenoides asiaeorientalis.*

[5] Note that Verboom & Kastelein (1995) describe whistles for *Phocoena phocoena* with a frequency range of 0.04 to 0.6 kHz and clicks of 1,800 Hz; further, Busnel & Dziedzic (1966) also describe signals with a frequency range up to 8 kHz. However, the production of low-frequency clicks has been explained as insignificant components of high-frequency clicks or acoustic artifacts by Hansen et al. (2008), and there is no substantive updated evidence that harbor porpoises produce whistles.

[6] *Lipotes vexillifer* is included here as listed by the Society for Marine Mammalogy Committee on Taxonomy (2016); however, we note that this species is almost certainly now extinct.

[7] Note that Xiao & Jing (1989) report the centroid frequency of a high-frequency click at 92 kHz for *Lipotes vexillifer* but also report the centroid frequency of a lower-frequency pulse at 5.6 kHz.

[8] Note that Tellechea & Norbis (2014) describe lower-frequency click production for *Pontoporia blainvillei* by neonates.

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Appendix 4. Sirenians

There are two sirenian families represented in the sirenian (SI) weighting function: Trichechidae (*Trichechus* spp.) and Dugongidae (*Dugong*). Species listings are consistent with the Society for Marine Mammalogy Committee on Taxonomy (2016). Manatees and dugongs are considered with respect to available evidence from audiometric studies, anatomical descriptions, and analyses of emitted sounds to validate the grouping of these four species to the assigned weighting function for acoustic exposure: SI. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016. Data are expressed as frequency ranges for each species where possible.

Audiometry data from behavioral (BEH) and neurophysiological (auditory evoked potential [AEP]) studies are shown separately as the +60 dB bandwidth from best measured sensitivity in water; sample sizes (number of different individuals [*n*]) are provided with the references. BEH hearing data are available for one species, *Trichechus manatus*. Note that only BEH hearing studies meeting specific criteria are shown in the audiometry column of the table; excluded studies are identified.[1] AEP data providing frequency-specific thresholds are available for one species, *Trichechus inunguis*.

With respect to **anatomy**, the mammalian middle ear type for the four species included in this group is the *sirenian ear type*, which features a U-shaped tympanic bone that is fused to a much larger periotic bone (Nummela, 2008); in contrast to other mammals, this tympanoperiotic complex is attached to the inner wall of the cranium and does not entirely surround the middle ear cavity with bone (Ketten et al., 1992; Nummela, 2008). In sirenians, the pinnae are absent, the auditory meatus is thin and apparently occluded, the tympanic membrane is enlarged and bulges outward, and the ossicles are massive with unusual features (Ketten et al., 1992). Significantly, the zygomatic process contains spongy bone that is oil filled; this unique feature, which is directly associated with bony structures connected to the tympanoperiotic complex, may be involved in selectively ducting sound to the ear (Ketten et al., 1992). While formal anatomy-based predictions of hearing range are presently unavailable for any sirenian species, early predictions of auditory range for *T. manatus* (based on review of middle and inner ear structures) suggested the species would be sensitive to “infrasound,” or sounds less than 20 kHz, with peak sensitivity around 8 kHz. Audiometry data shows that the hearing range in sirenians extends from low frequencies to above 60 kHz, with the perception of sounds below 0.02 kHz likely mediated by vibrotactile rather than acoustic cues (Gerstein et al., 1999; Gaspard et al., 2013).

Sound production data are available for three of four sirenian species. Frequency ranges for underwater sound production are cited as the broadest range of frequencies reported across all available studies for each species and are referenced to call types at the extremes of this range.

Appendix 4, Table 1. Weighting function: Sirenians (SI)

Taxon	Audiometry	Ear type	Auditory modeling	Sound production	References
Trichechus inunguis Amazonian manatee	AEP: < 5 to 60 kHz	Sirenian type	--	0.7 to 17 kHz (vocalization/ harmonic vocalization)	Audiometry: AEP: Klishin et al., 1990; Popov & Supin, 1990—*n* = 1 Anatomical models: No data Acoustic: Evans & Herald, 1970; Sousa-Lima et al., 2002; Sousa-Lima, 2006; Landrau-Giovannetti et al., 2014[2]
Trichechus manatus West Indian manatee Antillean manatee	BEH: < 0.25 to 72 kHz	Sirenian type	"Infrasound" to < 20 kHz	0.4 to 22 kHz (tonal harmonic vocalization)	Audiometry: Gerstein et al., 1999; Gaspard et al., 2012—*n* = 4; excluded Mann et al., 2005 Anatomical models: Ketten et al., 1992 Acoustic: Schevill & Watkins, 1965; Nowacek et al., 2003; O'Shea & Poché, 2006; Sousa-Lima et al., 2008; Miksis-Olds & Tyack, 2009; Grossman et al., 2014; Landrau-Giovannetti et al., 2014[2]; Rivera Chavarria et al., 2015
Trichechus senegalensis West African manatee	--	Sirenian type	--	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Dugong dugon Dugong	--	Sirenian type	--	0.15 (squeak) to 18 kHz (trills, chirp-squeak)	Audiometry: No data Anatomical models: No data Acoustic: Nair & Lal Mohan, 1975; Marsh et al., 1978; Anderson & Barclay, 1995; Ichikawa et al., 2003; Hishimoto et al., 2005; Parsons et al., 2013

[1] Due to the primary role of behavioral audiometric data in determining the shape of the weighting function, only psychophysical studies meeting certain criteria were used to determine group-specific audiograms (see "Estimated Group Audiograms for Marine Mammals" section); citations for individuals were excluded if data for the same individual were reported elsewhere, if hearing loss was suspected, if audiograms appeared aberrant (e.g., obvious notches or flattened shape), or if masking or other environmental or procedural factors likely influenced reported data. While these data were excluded from the group audiograms, the excluded citations may still provide useful information about the sounds that can be detected by a given species.

[2] Vocalization emitted in air and recorded with a hydrophone coupled to the skin

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Appendix 5. Phocid Carnivores

There is a single Carnivore family represented in the weighting functions for phocid carnivores in water (PCW) and phocid carnivores in air (PCA): Phocidae (*Cystophora*, *Erignathus*, *Halichoerus*, *Histriophoca*, *Hydrurga*, *Leptonychotes*, *Lobodon*, *Mirounga* spp., *Monachus*, *Neomonachus*, *Ommatophoca*, *Pagophilus*, *Phoca* spp., and *Pusa* spp.). Species listings provided are consistent with those of the Society for Marine Mammalogy Committee on Taxonomy (2016). True seals are considered with respect to available evidence from audiometric studies, anatomical descriptions, and analyses of emitted sounds to validate the grouping of these 18 species to the assigned weighting functions. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016. Data are expressed as frequency ranges for each species where possible and are considered separately for water (Table 1) and air (Table 2), as these species are amphibious.

Audiometry data from behavioral (BEH) and neurophysiological (auditory evoked potential [AEP]) studies are shown separately here as the +60 dB frequency bandwidth from best measured sensitivity; sample sizes (number of different individuals [*n*]) are provided with the references. BEH data are available for four species in water and three species in air. Note that only BEH hearing studies meeting specific criteria are shown in the tables; excluded studies are identified.[1] AEP measures are available for one species in water and three species in air. Note that all AEP studies reporting frequency-specific thresholds are included.

With respect to **anatomy**, the mammalian middle ear type for all species included in this group is the *phocid ear type* (Nummela, 2008), which features an enlarged tympanic membrane, ossicles, and middle ear cavity. Species in this group lack an outer pinna and have cavernous tissue lining the auditory meatus and middle ear cavity as an apparent adaptation for pressure regulation during diving (Møhl, 1968b; Repenning, 1972; Wartzok & Ketten, 1999). Some species have a spiral cartilage and musculature along the lateral portion of the external auditory canal that may function to close the canal under water. Anatomy-based predictions of hearing range are presently unavailable for any phocid carnivore.

Underwater **sound production data** are available for 12 of 18 species; in-air sound production data are available for 12 of 18 species. Frequency ranges for sound production are provided as the broadest range of frequencies reported across all available studies for each species and in each medium, and they are referenced to call types at the extremes of this range.

Appendix 5, Table 1. Weighting function: Phocid carnivores in water (PCW)

Taxon	Audiometry	Ear type	Sound production	References
Cystophora cristata Hooded seal	--	Phocid type	0.1 (snort, click) to 16 kHz (click)	Audiometry: No data Anatomical models: No data Acoustic: Schevill et al., 1963; Terhune & Ronald, 1973; Ballard & Kovacs, 1995
Erignathus barbatus Bearded seal	--	Phocid type	0.08 (groan) to 22 kHz (moan)	Audiometry: No data Anatomical models: No data Acoustic: Poulter, 1968; Ray et al., 1969; Stirling et al., 1983; Cleator et al., 1989; Terhune, 1999; Van Parijs et al., 2001; Van Parijs & Clark, 2006; Risch et al., 2007; Charrier et al., 2013; MacIntyre et al., 2013; Jones et al., 2014
Halichoerus grypus Gray seal	AEP: < 1.4 to 100 kHz	Phocid type	< 0.1 (click, hiss) to 40 kHz (hiss)	Audiometry: AEP: Ridgway & Joyce, 1975—*n* = 2 Anatomical models: No data Acoustic: Schevill et al., 1963; Schusterman et al., 1970; Oliver, 1978; Asselin et al., 1993
Histriophoca fasciata Ribbon seal	--	Phocid type	0.01 (downsweep) to 12 kHz (downsweep)	Audiometry: No data Anatomical models: No data Acoustic: Watkins & Ray, 1977; Miksis-Olds & Parks, 2011; Denes et al., 2013; Jones et al., 2014; Mizuguchi et al., 2016a
Hydrurga leptonyx Leopard seal	--	Phocid type	0.04 (growl, thump pulse) to 164 kHz (FM buzz)	Audiometry: No data Anatomical models: No data Acoustic: Poulter, 1968; Stirling & Siniff, 1979a; Thomas et al., 1983; Rogers et al., 1995, 1996; Thomas & Golladay, 1995; Rogers & Cato, 2002; Kreiss et al., 2014; Rogers, 2014
Leptonychotes weddellii Weddell seal	--	Phocid type	0.1 (short duration calls) to 15 kHz (unspecified)	Audiometry: No data Anatomical models: No data Acoustic: Thomas & Kuechle, 1982; Thomas & Stirling, 1983; Green & Burton, 1988; Morrice et al., 1994; Pahl et al., 1997; Evans et al., 2004; Moors & Terhune, 2004, 2005; Terhune, 2004; Terhune & Dell'Apa, 2006; Terhune et al., 2008; Doiron et al., 2012
Lobodon carcinophaga Crabeater seal	--	Phocid type	0.25 (low moan) to 5 kHz (high moan)	Audiometry: No data Anatomical models: No data Acoustic: Stirling & Siniff, 1979b; McCreery & Thomas, 2009; Klinck et al., 2010
Mirounga angustirostris Northern elephant seal	BEH: < 0.075 to > 60 kHz	Phocid type	--	Audiometry: BEH: Kastak & Schusterman, 1999—*n* = 1; excluded Kastak & Schusterman, 1998 Anatomical models: No data Acoustic: No data

Mirounga leonina Southern elephant seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Monachus monachus Mediterranean monk seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Neomonachus schauinslandi Hawaiian monk seal	--	Phocid type	--	Audiometry: BEH: excluded Thomas et al., 1990—*n* = 1 Anatomical models: No data Acoustic: No data
Ommatophoca rossii Ross seal	--	Phocid type	0.6 (siren) to 4.5 kHz (siren)	Audiometry: No data Anatomical models: No data Acoustic: Watkins & Ray, 1985
Pagophilus groenlandicus Harp seal	--	Phocid type	0.1 (adult call) to 10 kHz (adult call)	Audiometry: BEH: excluded Terhune & Ronald, 1972—*n* = 1 Anatomical models: No data Acoustic: Schevill et al., 1963; Watkins & Schevill, 1979; Terhune & Ronald, 1986; Miller & Murray, 1995; Serrano, 2001; Serrano & Terhune, 2001; Moors & Terhune, 2003, 2005; Van Opzeeland & Van Parijs, 2004; Rossong & Terhune, 2009; Van Opzeeland et al., 2009
Phoca largha Spotted seal Largha seal	BEH: < 0.1 to 87 kHz	Phocid type	0.2 (knock, drum, growl, sweep) to 3.5 kHz (drum)	Audiometry: Sills et al., 2014; Cunningham & Reichmuth, 2016—*n* = 2 Anatomical models: No data Acoustic: Beier & Wartzok, 1979; Yang et al., 2017
Phoca vitulina Harbor seal	BEH: < 0.1 to 79 kHz	Phocid type	0.02 (roar) to 24 kHz (roar)	Audiometry: BEH: Terhune, 1988; Kastelein et al., 2009; Reichmuth et al., 2013; Cunningham & Reichmuth, 2016—*n* = 4; excluded Møhl, 1968a; Kastak & Schusterman, 1998; Southall et al., 2005 Anatomical models: No data Acoustic: Schevill et al., 1963; Schusterman et al., 1970; Perry & Renouf, 1988; Hanggi & Schusterman, 1994; Van Parijs et al., 1997, 1999, 2003; Van Parijs & Kovacs, 2002; Bjørgesaeter et al., 2004; Sauvé et al., 2015; Nikolich et al., 2016; Casey et al., 2017; Sabinsky et al., 2017
Pusa caspica Caspian seal	--	Phocid type	--	Audiometry: excluded Babushina, 1997—*n* = 1 Anatomical models: No data Acoustic: No data
Pusa hispida Ringed seal	BEH: < 0.1 to > 72.4 kHz	Phocid type	0.02 (woof, click) to 30 kHz (click)	Audiometry: Sills et al., 2015—*n* = 1; excluded Terhune & Ronald, 1975; Sills et al., 2015 (individual "Natchek") Anatomical models: No data Acoustic: Schevill et al., 1963; Stirling, 1973; Stirling et al., 1983; Hyvärinen, 1989; Kunnasranta, 1996; Rautio et al., 2009; Jones et al., 2014; Mizuguchi et al., 2016b
Pusa sibirica Baikal seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data

Appendix 5, Table 2. Weighting function: Phocid carnivores in air (PCA)

Taxon	Audiometry	Ear type	Sound production	References
Cystophora cristata Hooded seal	--	Phocid type	0.1 (pup calls, male calls) to 6 kHz (growl, roar)	Audiometry: No data Anatomical models: No data Acoustic: Terhune & Ronald, 1973; Ballard & Kovacs, 1995
Erignathus barbatus Bearded seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Halichoerus grypus Gray seal	AEP: < 0.2 to > 29.7 kHz	Phocid type	0.25 (pup call) to 6 kHz (pup call)	Audiometry: AEP: Ridgway & Joyce, 1975; Ruser et al., 2014—*n* = 8 Anatomical models: No data Acoustic: Caudron et al., 1998; McCulloch et al., 1999
Histriophoca fasciata Ribbon seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Hydrurga leptonyx Leopard seal	AEP: < 1 to > 4 kHz	Phocid type	--	Audiometry: AEP: Tripovich et al., 2011—*n* = 1 Anatomical models: No data Acoustic: No data
Leptonychotes weddellii Weddell seal	--	Phocid type	0.09 (grunt) to 10 kHz (call)	Audiometry: No data Anatomical models: No data Acoustic: Terhune et al., 1993, 1994; Oetelaar et al., 2003; Collins et al., 2005, 2006; Collins & Terhune, 2007
Lobodon carcinophaga Crabeater seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Mirounga angustirostris Northern elephant seal		AEP: < 4 to > 4 kHz	Phocid type	Audiometry: BEH: excluded Kastak & Schusterman, 1998, 1999; Reichmuth et al., 2013—*n* = 1; AEP: Houser et al., 2007—*n* = 1 Anatomical models: No data Acoustic: Bartholomew & Collias, 1962; Le Boeuf & Peterson, 1969; Le Boeuf et al., 1972; Sandegren, 1976; Shipley et al., 1986; Southall et al., 2003; Holt et al., 2010; Casey et al., 2015
Mirounga leonina Southern elephant seal	--	Phocid type	0.02 (drumming, call) to 4 kHz (gargling, explosive)	Audiometry: No data Anatomical models: No data Acoustic: Sanvito & Galimberti, 2000; Sanvito et al., 2008

Monachus monachus Mediterranean monk seal	--	Phocid type	0.26 (pup call) to 3 kHz (female call)	Audiometry: No data Anatomical models: No data Acoustic: Muñoz et al., 2011
Neomonachus schauinslandi Hawaiian monk seal	--	Phocid type	0.10 (pup call, huh-huh) to 4 kHz (sneeze/cough)	Audiometry: No data Anatomical models: No data Acoustic: Miller & Job, 1992; Job et al., 1995
Ommatophoca rossii Ross seal	--	Phocid type	0.1 (pulse) to 1 kHz (pulse)	Audiometry: No data Anatomical models: No data Acoustic: Watkins & Ray, 1985
Pagophilus groenlandicus Harp seal	--	Phocid type	0.1 (pup call) to 10 kHz (pup call)	Audiometry: BEH: excluded Terhune & Ronald, 1971 Anatomical models: No data Acoustic: Miller & Murray, 1995; Van Opzeeland & Van Parijs, 2004; Van Opzeeland et al., 2009
Phoca largha Spotted seal Largha seal	BEH: < 0.075 to > 51.2 kHz	Phocid type	0.1 (grunt) to 3.5 kHz (drum)	Audiometry: Sills et al., 2014—$n = 2$ Anatomical models: No data Acoustic: Beier & Wartzok, 1979; Zhang et al., 2016
Phoca vitulina Harbor seal	BEH: < 0.1 to > 32.5 kHz AEP: < 1.4 to > 30 kHz	Phocid type	0.1 (pup call) to 9 kHz (pup call)	Audiometry: BEH: Reichmuth et al., 2013—$n = 1$; excluded Møhl, 1968a; Terhune, 1989, 1991; Kastak & Schusterman, 1998; Wolski et al., 2003; AEP: Wolski et al., 2003; Lucke et al., 2016—$n < 25$ Anatomical models: No data Acoustic: Ralls et al., 1985; Renouf, 1985; Perry & Renouf, 1988; Van Parijs & Kovacs, 2002; Khan et al., 2006; Sauvé et al., 2015
Pusa caspica Caspian seal	--	Phocid type	--	Audiometry: excluded Babushina, 1997—$n = 1$ Anatomical models: No data Acoustic: No data
Pusa hispida Ringed seal	BEH: < 0.075 to 40 kHz	Phocid type	0.4 (howl) to 0.7 (howl)	Audiometry: Sills et al., 2015—$n = 1$; excluded Sills et al., 2015 (individual "Natchek) Anatomical models: No data Acoustic: Sipilä et al., 1996; Rautio et al., 2009
Pusa sibirica Baikal seal	--	Phocid type	--	Audiometry: No data Anatomical models: No data Acoustic: No data

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[1] Due to the primary role of behavioral audiometric data in determining the shape of the weighting function, only psychophysical studies meeting certain criteria were used to determine group-specific audiograms (see "Estimated Group Audiograms for Marine Mammals" section); citations for individuals were excluded if data for the same individual were reported elsewhere, if hearing loss was suspected, if audiograms appeared aberrant (e.g., obvious notches or flattened shape), or if masking or other environmental or procedural factors likely influenced reported data. While these data were excluded from the group audiograms, the excluded citations still provide useful information about the sounds that can be detected by a given species.

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Appendix 6. Other Marine Carnivores

There are four Carnivore families represented in the other marine carnivores in water (OCW) and other marine carnivores in air (OCA) weighting functions: Odobenidae (*Odobenus*), Otariidae (*Arctocephalus* spp., *Callorhinus*, *Eumetopias*, *Neophoca*, *Otaria*, *Phocarctos*, and *Zalophus* spp.), Ursidae (*Ursus*), and Mustelidae (*Enhydra* and *Lontra*). Species listings provided are consistent with those of the Society for Marine Mammalogy Committee on Taxonomy (2016). In this appendix, the sea lions, fur seals, walrus, marine otter, sea otter, and polar bear are considered with respect to available evidence from audiometric studies, anatomical descriptions, and analyses of emitted sounds to validate the grouping of these 18 species to the assigned weighting functions for acoustic exposure. Citations used to populate this appendix are generally from peer-reviewed papers published through 2016. Data are expressed as frequency ranges for each species where possible and are considered separately for water (Table 1) and air (Table 2) as these species are amphibious.

Audiometry data from behavioral (BEH) and neurophysiological (auditory evoked potential [AEP]) studies are shown separately here as the +60 dB frequency bandwidth from best measured sensitivity; sample sizes (number of different individuals [*n*]) are provided with the references. BEH data are available for five species in water and six species in air. Note that only BEH hearing studies meeting specific criteria are shown in the table; excluded studies are identified.[1] AEP measures are available for three species in air and unavailable for any species in water. Note that all AEP studies reporting frequency-specific thresholds are included.

With respect to anatomy, the mammalian middle **ear type** for the species included in this group is the *freely mobile ear type* (Fleischer, 1978; Nummela, 2008), which features a loose connection between the ossicles and the skull. Species in this group have essentially terrestrial, broad-bore external ear canals, relatively small tympanic membranes, and moderate to distinctive pinnae; inner ear structures appear similar to terrestrial high-frequency generalists (Repenning, 1972; Wartzok & Ketten, 1999). The single exception in terms of anatomy is the walrus, which has an ear that is somewhat intermediate to a freely mobile ear type and a *phocid middle ear type* characterized by an enlarged tympanic membrane, ossicles, and middle ear cavity, and which lacks an external pinna (Repenning, 1972; Nummela, 2008). For example, while the walrus has enlarged ossicles and a large tympanic membrane, and lacks a pinna (like phocid seals), the shape and form of the ossicles and other morphological features are distinctively otariid in form (Repenning, 1972). Anatomy-based predictions of hearing range are presently unavailable for any species classified as other marine carnivores.

Underwater **sound production data** are available for six of 18 species; in-air sound production data are available for 16 of 18 species. Frequency ranges for sound production are provided as the broadest range of frequencies reported across all available studies for each species and in each medium, and they are referenced to call types at the extremes of this range.

Appendix 6, Table 1. Weighting function: Other marine carnivores in water (OCW)

Taxon	Audiometry	Ear type	Sound production	References
Odobenus rosmarus Walrus	BEH: < 0.125 to > 15 kHz	Intermediate to freely mobile and phocid type	0.2 (rasp) to 20 kHz (knock)	Audiometry: BEH: Kastelein et al., 2002—$n = 1$ Anatomical models: No data Acoustic: Schevill et al., 1966; Ray, 1975; Stirling et al., 1983; Schusterman & Reichmuth, 2008
Arctocephalus australis South American fur seal Peruvian fur seal	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Arctocephalus forsteri New Zealand fur seal	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Arctocephalus galapagoensis Galapagos fur seal	--	Freely mobile	0.1 (growl) to 2 kHz (snap/knock)	Audiometry: No data Anatomical models: No data Acoustic: Merlen, 2000
Arctocephalus gazella Antarctic fur seal	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Arctocephalus philippii Juan Fernandez fur seal Guadalupe fur seal	--	Freely mobile	0.12 to 0.2 kHz (LF pulses)	Audiometry: No data Anatomical models: No data Acoustic: Norris & Watkins, 1971
Arctocephalus pusillus Cape fur seal Australian fur seal	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Arctocephalus tropicalis Subantarctic fur seal	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Callorhinus ursinus Northern fur seal	BEH: < 0.5 to 41.1 kHz	Freely mobile	0.1 (click) to 4.5 kHz (click)	Audiometry: BEH: Moore & Schusterman, 1987; Babushina et al., 1991—$n = 3$ Anatomical models: No data Acoustic: Poulter, 1968
Eumetopias jubatus Steller sea lion	BEH: < 0.5 to > 32 kHz	Freely mobile	0.5 to 2 kHz (belch)	Audiometry: BEH: Kastelein et al., 2005—$n = 2$ Anatomical models: No data Acoustic: Poulter, 1968; Schusterman et al., 1970
Neophoca cinerea Australian sea lion	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data

Otaria byronia *(Otaria flavescens)* South American sea lion	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Phocarctos hookeri Hooker's sea lion New Zealand sea lion	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Zalophus californianus California sea lion	BEH: < 0.1 to 55 kHz	Freely mobile	< 0.08 (sweep) to 8 kHz (bark, bang)	Audiometry: BEH: Mulsow et al., 2012; Reichmuth & Southall, 2012; Reichmuth et al., 2013; Cunningham & Reichmuth, 2016—*n* = 4; excluded Schusterman et al., 1972; Kastak & Schusterman, 1998, 2002 Anatomical models: No data Acoustic: Schevill et al., 1963; Schusterman & Feinstein, 1965; Brauer et al., 1966; Schusterman et al., 1967; Poulter, 1968; Schusterman & Balliet, 1969
Zalophus wollebaeki Galapagos sea lion	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Ursus maritimus Polar bear	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Enhydra lutris Sea otter	BEH: < 0.125 to 36 kHz	Freely mobile	--	Audiometry: BEH: Ghoul & Reichmuth, 2014—*n* = 1 Anatomical models: No data Acoustic: No data
Lontra feline Marine otter	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data

Appendix 6, Table 2. Weighting function: Other marine carnivores in air (OCA)

Taxon	Audiometry	Ear type	Sound production	References
Odobenus rosmarus Walrus	--	Intermediate to freely mobile and phocid type	0.01 (guttural sounds) to 17 kHz (burp)	Audiometry: BEH: excluded Kastelein et al., 1993, 1996 Anatomical models: No data Acoustic: Miller & Boness, 1983; Miller, 1985; Kastelein et al., 1995; Verboom & Kastelein, 1995; Schusterman, 2008; Schusterman & Reichmuth, 2008; Charrier et al., 2010, 2011
Arctocephalus australis South American fur seal Peruvian fur seal	--	Freely mobile	0.4 (pup call) to 7 kHz (male threat)	Audiometry: No data Anatomical models: No data Acoustic: Trillmich & Majluf, 1981; Phillips & Stirling, 2000
Arctocephalus forsteri New Zealand fur seal	--	Freely mobile	0.1 (female pup attraction call) to 8 kHz (male bark)	Audiometry: No data Anatomical models: No data Acoustic: Page et al., 2001, 2002a, 2002b
Arctocephalus galapagoensis Galapagos fur seal	--	Freely mobile	0.2 (pup call) to 6 kHz (pup call)	Audiometry: No data Anatomical models: No data Acoustic: Trillmich, 1981
Arctocephalus gazella Antarctic fur seal	--	Freely mobile	0.1 (male guttural threat) to 9 kHz (pup call)	Audiometry: No data Anatomical models: No data Acoustic: Stirling, 1971; Page et al., 2001, 2002a, 2002b; St Clair Hill et al., 2001
Arctocephalus philippii Juan Fernandez fur seal Guadalupe fur seal	--	Freely mobile	0.5 (roar) to 7 kHz (roar)	Audiometry: No data Anatomical models: No data Acoustic: Peterson et al., 1968
Arctocephalus pusillus Cape fur seal Australian fur seal	--	Freely mobile	0.08 (male guttural threat) to 5.5 kHz (female pup attraction call)	Audiometry: No data Anatomical models: No data Acoustic: Stirling, 1971; Tripovich et al., 2005, 2006, 2008a, 2008b, 2009
Arctocephalus tropicalis Subantarctic fur seal	--	Freely mobile	0.1 (male bark) to 8 kHz (pup call)	Audiometry: No data Anatomical models: No data Acoustic: Page et al., 2001, 2002a, 2002b; St Clair Hill et al., 2001; Charrier et al., 2002, 2003a, 2003b, 2003c; Mathevon et al., 2004
Callorhinus ursinus Northern fur seal	BEH: 0.1 to > 32 kHz	Freely mobile	0.1 (pup call) to 8 kHz (pup call)	Audiometry: BEH: Moore & Schusterman, 1987; Babushina et al., 1991—$n = 3$ Anatomical models: No data Acoustic: Poulter, 1968; Lisitsyna, 1973; Takemura et al., 1983; Insley, 1992, 2001

Eumetopias jubatus Steller sea lion	BEH: < 0.125 to 32 kHz AEP: < 1 to 30 kHz	Freely mobile	0.03 (female call) to 4 kHz (male wheedling call)	Audiometry: BEH: Mulsow & Reichmuth, 2010—$n = 1$; AEP: Mulsow & Reichmuth, 2010; Mulsow et al., 2011b—$n = 5$ Anatomical models: No data Acoustic: Poulter, 1968; Campbell et al., 2002; Park et al., 2006
Neophoca cinerea Australian sea lion	--	Freely mobile	0.2 (female call) to 10 kHz (male bark)	Audiometry: No data Anatomical models: No data Acoustic: Charrier & Harcourt, 2006; Gwilliam et al., 2008; Pitcher et al., 2009; Ahonen et al., 2014
Otaria byronia *(Otaria flavescens)* South American sea lion	--	Freely mobile	0.2 (male growl) to 6 kHz (pup call)	Audiometry: No data Anatomical models: No data Acoustic: Fernández-Juricic et al., 1999; Trimble & Charrier, 2011
Phocarctos hookeri Hooker's sea lion New Zealand sea lion	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data
Zalophus californianus California sea lion	BEH: 0.13 to 37 kHz AEP: < 2 to 30 kHz	Freely mobile	0.1 (male/female bark) to 16 kHz (male/female bark)	Audiometry: BEH: Moore & Schusterman, 1987; Mulsow et al., 2011a; Reichmuth et al., 2013—$n = 4$; excluded Schusterman, 1974; Moore & Schusterman, 1987; Kastak & Schusterman, 1998; see also recent paper from Reichmuth et al., 2017; AEP: Finneran et al., 2011; Mulsow et al., 2011a, 2011b, 2014—$n = 23$ Anatomical models: No data Acoustic: Schusterman & Feinstein, 1965; Brauer et al., 1966; Schusterman, 1978; Schusterman et al., 1992
Zalophus wollebaeki Galapagos sea lion	--	Freely mobile	0.3 (female call) to 4 kHz (female call)	Audiometry: No data Anatomical models: No data Acoustic: Trillmich, 1981
Ursus maritimus Polar bear	BEH: < 0.25 to 29 kHz AEP: < 1.4 to > 22.5 kHz	Freely mobile	0.28 to 0.85 kHz (humming)	Audiometry: BEH: Owen & Bowles, 2011—$n = 2$; AEP: Nachtigall et al., 2007—$n = 3$ Anatomical models: No data Acoustic: Derocher et al., 2010
Enhydra lutris Sea otter	BEH: 0.23 to 38.2 kHz	Freely mobile	0.3 (coo) to 60 kHz (scream)	Audiometry: BEH: Ghoul & Reichmuth, 2014—$n = 1$ Anatomical models: No data Acoustic: Sandegren et al., 1973; McShane et al., 1995; Ghoul & Reichmuth, 2012
Lontra feline Marine otter	--	Freely mobile	--	Audiometry: No data Anatomical models: No data Acoustic: No data

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[1] Due to the primary role of behavioral audiometric data in determining the shape of the weighting function, only psychophysical studies meeting certain criteria were used to determine group-specific audiograms (see "Estimated Group Audiograms for Marine Mammals" section); citations for individuals were excluded if data for the same individual were reported elsewhere, if hearing loss was suspected, if audiograms appeared aberrant (e.g., obvious notches or flattened shape), or if masking or other environmental or procedural factors likely influenced reported data. While these data were excluded from the group audiograms, the excluded citations still provide useful information about the sounds that can be detected by a given species.

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COASTAL ZONE MANAGEMENT ACT CONSISTENCY DETERMINATION FOR Phantom Space Corporation Daytona-E and Laguna-E Launch Operations at Space Launch Complex 5, Vandenberg Space Force Base, California

November 2022

Prepared for

Space Launch Delta 30, Installation Management Flight
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ACRONYMS AND ABBREVIATIONS

BMPs	Best Management Practices
CARB	California Air Resources Board
C.F.R.	Code of Federal Regulations
CCMP	California Coastal Management Plan
CD	Consistency Determination
CNEL	A-weighted Community Noise Equivalent Level
CRLF	California red-legged Frog
CY	cubic yard(s)
CZMA	Coastal Zone Management Act
DAPTF	Declining Amphibian Populations Task Force
dB	decibel(s)
dBA	A-weighted decibel(s)
E	East
EA	Environmental Assessment
EPMs	Environmental Protection Measures
ESA	Endangered Species Act
FAA	Federal Aviation Administration
ft	foot or feet
ft^2	square feet
GN2	gaseous nitrogen
GSE	ground support equipment
HIF	Horizontal Integration Facility
HP	horsepower
ISO	Organization for Standardization
kg	kilogram(s)
km	kilometer(s)
LAA	May affect, likely to adversely affect
Lmax	maximum sound level
lbf	pound force
LEO	low-earth orbit
LOA	Letter of Authorization
LOX	liquid oxygen
LP	Launch Pad
m	meter(s)
mi	mile(s)
MMPA	Marine Mammal Protection Act
MSRS	ManTech SRS Technologies, Inc.
NA	Not Applicable
NCI	Northern Channel Islands
NE	No Effect
NL	Not Listed under the ESA
NLAA	May affect, not likely to adversely affect
NMFS	National Marine Fisheries Service

NOTAM	Notices to Airmen
NOTMARs	Local Notices to Mariners
NRHP	National Register of Historic Places
OWTS	Onsite Wastewater Treatment Systems Manual
Phantom	Phantom Space Corporation
PSCA	Pacific Spaceport Complex
psf	pounds per square foot
RP-1	Rocket Propellant 1
RWQCB	California Regional Water Quality Control Board
SBCAPCD	Santa Barbara County Air Pollution Control District
scf	standard-cubic-foot
SEL	sound exposure level
SLC	Space Launch Complex
SLD 30	Space Launch Delta 30
TEA-TEB	triethylaluminum-triethylboron
TEV	Transporter Erector Vehicle
U.S.	United States
U.S.C.	United States Code
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
VSFB	Vandenberg Space Force Base
VTF	Vertical Test Facility
W	West

1 INTRODUCTION

Space Launch Delta 30 (SLD 30) of the Department of the Air Force (DAF), United States (U.S.) Space Force (hereinafter, Space Force) submits this Consistency Determination (CD) for the California Coastal Commission’s review. The proposed action would implement Phantom Space Corporations (Phantom) Daytona-E and Laguna-E launch program and associated construction of a new launch facility at Space Launch Complex (SLC)-5 on Vandenberg Space Force Base (VSFB; Figure 1-1).

1.1 AUTHORITY

This CD is being submitted by the Space Force in compliance with Section 930 et seq. of the National Oceanic and Atmospheric Administration Federal Consistency Regulations (15 C.F.R. Part 930). The Space Force prepared this CD per Section 307(c)(1)(A) of the CZMA, as amended, 15 C.F.R. Part 930, and the enforceable policies of the CCA (California Public Resources Code, Division 20).

1.2 DETERMINATION

The project launch site (SLC-5) is located within the boundary of VSFB and owned by the Department of Defense. Although the CZMA federal lands definition excludes federal lands from the coastal zone, actions within them must be reviewed for consistency with the CCMP to the maximum extent practicable.

Phantom activities for construction and operation of SLC-5 have been developed to minimize and/or mitigate potential effects to coastal uses and/or resources to comply with the enforceable policies of the CCA, to the maximum extent practicable. Based on the review of the Proposed Action’s compliance with the CZMA, the Space Force has determined that the Proposed Action is consistent to the maximum extent practicable with the CCMP, pursuant to the requirements of the CZMA.

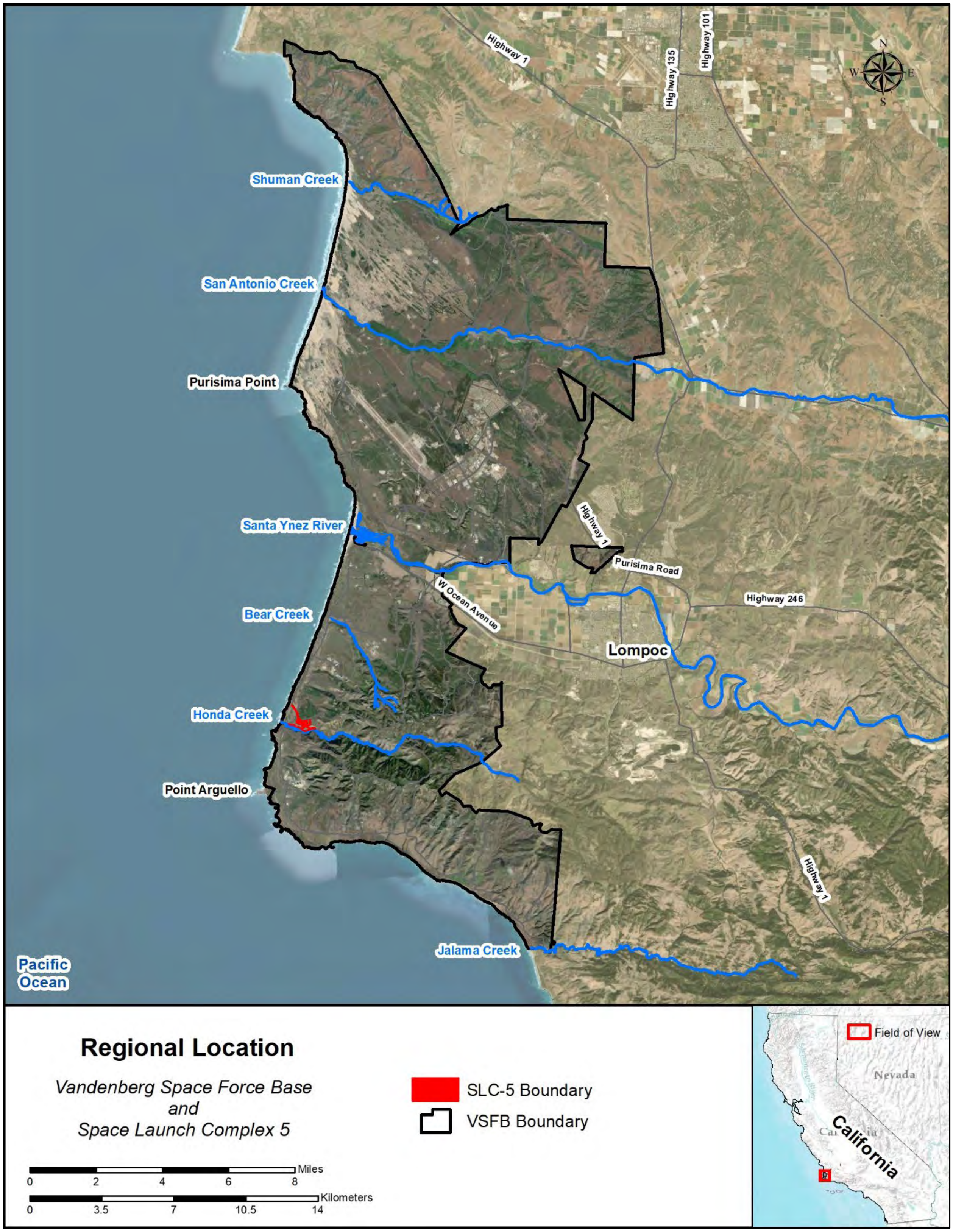

Figure 1-1: Regional location of Proposed Action Area

2 DESCRIPTION OF PROPOSED ACTION

2.1 PROPOSED ACTION

The Proposed Action is to re-construct a launch facility at the same SLC-5 location used by NASA between 1962 and 1994 to launch Scout space launch vehicles. At the completion of the Scout program in 1994, all facilities at SLC-5 were deactivated and then demolished between 2009 and 2012. The new SLC-5 launch facilities will operate Phantom Space Corporation's (Phantom) Daytona-E and Laguna-E launch program (Figure 1-1). Phantom would construct two launch pads and a Horizontal Integration Facility (HIF) at the site and install utilities and firebreaks. To meet fire safety standards, fire access roads around SLC-5 would require improvements and repairs. Phantom proposes to perform up to a combined total of 48 launches of the Daytona-E and the Laguna-E from SLC-5 annually. In addition, Phantom would conduct up to 48 vertical tests (static fire) annually. The following subsections detail the various components of the Proposed Action.

2.1.1 CONCEPT OF OPERATIONS

Phantom would perform primary vehicle and payload assembly offsite at the existing Phantom Factory in Tucson, Arizona, where first and second stages would be produced on assembly lines leveraging engines from Ursa Major in Denver, Colorado, other commercial supply chain vendors, and in-house fabrication of major components. Once assembled, the rockets would be shipped via commercial truck transport to VSFB. Payloads would be shipped from several locations, including Phantom's factories in Tucson, Florida, Colorado, and California. Final integration would be performed at SLC-5 with marriage of first and second stages and customer payload integration utilizing a HIF. Because the HIF would be constructed in Phase I-b (see Section 2.1.3, below), Phantom would initially install a temporary building for staging and payload integration. The flight-ready vehicle would then be mounted on a Transporter Erector Vehicle (TEV) and transported to one of two launch pads (SLC-5 East [E] and SLC-5 West [W]; Figure 2-2), erected, and mounted to a launch stool (Figure 2-1). Both Daytona-E and Laguna-E utilize liquid oxygen (LOX) and rocket propellant-1 (RP-1) or Jet-A, which would be loaded prior to launch. Both vehicles are described in greater detail in the following section. Phantom will coordinate each launch using a local operations center, to be housed at an existing VSFB facility, and an offsite Mission Operations Control center in Tucson, Arizona. Tracking equipment and instrumentation would be located at SLC-5 to support launches.

Figure 2-1: Launch Stool (conceptual design)

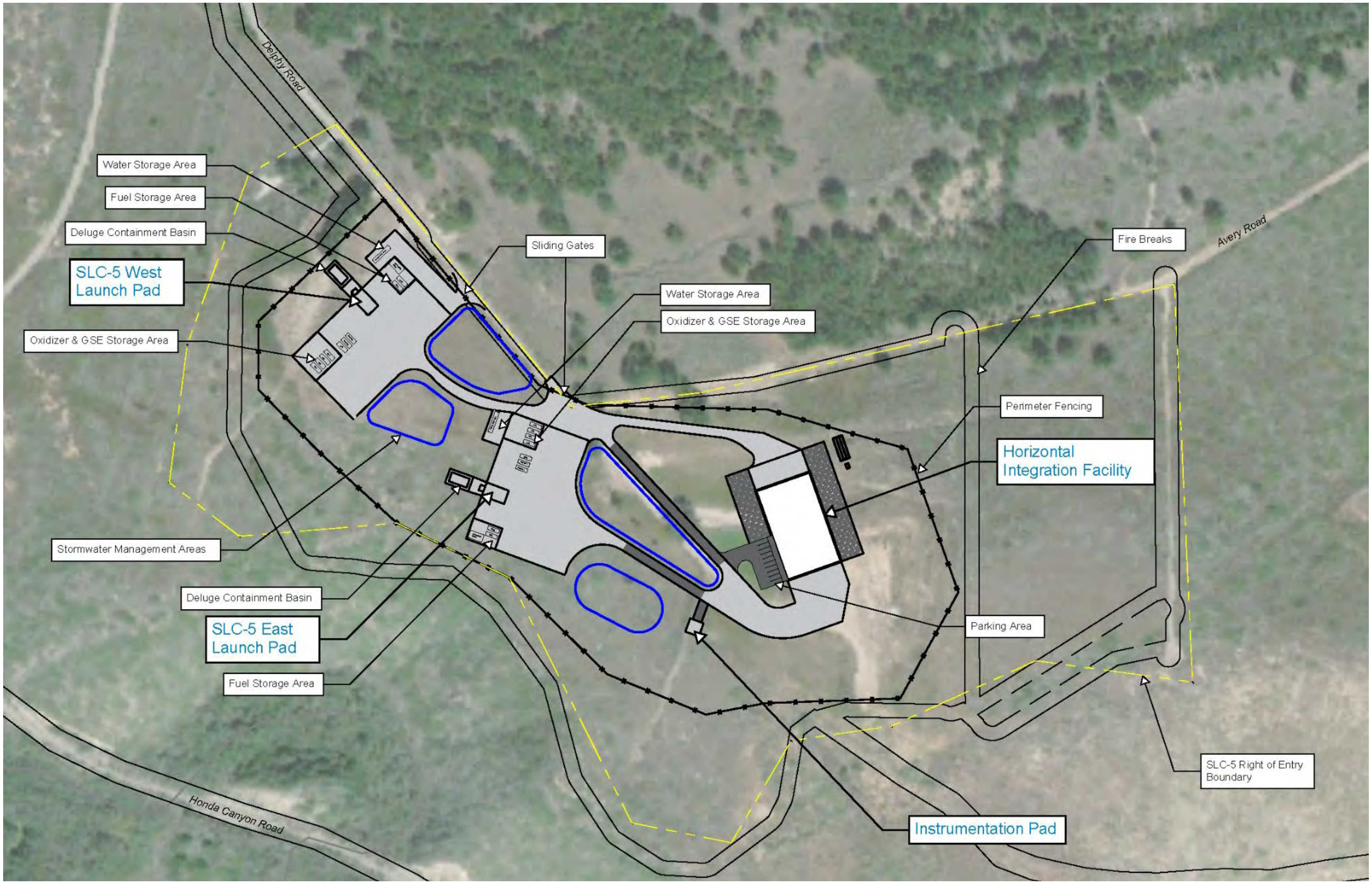

Figure 2-2: Conceptual Site Plan

A stationary 533 horsepower (HP) generator would be kept on site during launch operations for emergency backup power. This generator would be used as an emergency back-up power source only. It would be run once every two weeks for 30 minutes to test its integrity. In addition, Phantom may rely on a second 533 HP generator as primary power for SLC-5 for the first three years of operations if the installation of electrical utilities connecting to existing VSFB circuits is delayed (see Section 2.1.5).

Initially, mobile 24,000 standard-cubic-foot (scf) tube bank trailers would supply gaseous helium (one tube trailer per pad) and gaseous nitrogen (GN2) (two tube trailers per pad) to on-site ground support equipment (GSE) during launch operations. However, once approaching full launch cadence at SLC-5, Phantom would install a connection line to VSFB's high-pressure GN2 line through the utility corridor following Delphy Road, but still maintain at least one mobile tube bank trailer for GN2 onsite. A kerosene (RP-1 or Jet-A) fuel storage area would be designated for placement of International Organization for Standardization (ISO) portable tanks. At each SLC-5W and SLC-5E, up to two 20-ft 5,500-gallon ISO tanks would be connected to a fuel transfer manifold. The fuel transfer manifold would include a 275-gallon-per-minute pump, isolation valves, and 4-inch line from the storage area to the pad. There would be up to approximately 20,100 gallons of kerosene (RP-1 or Jet-A) stored in portable ISO tanks at SLC-5. Fuel transfer manifolds would provide basic filtration and a means to de-tank the launch vehicle. LOX storage would be provided by up to six 20-ft portable ISO tanks at each pad, or a total of approximately 26,000 gallons of LOX per pad.

In ignitor fill module would support the ignition systems for the Daytona-E and Laguna-E launch vehicles and Phantom first and second stage engines. This module would either supply gaseous oxygen and hydrogen or triethylaluminum-triethylboron (TEA-TEB) for ignition. After launch, onsite staff would return to the pad to inspect and safeguard the site and reconfigure GSE for storage. Initial activities would include purging lines and storing cart-based GSE systems. Any hazardous waste (e.g., waste kerosene) collected would be disposed of properly per federal, local, and base regulations.

Full SLC-5 cadence will require approximately 25-30 permanent onsite staff to support operations and 10 temporary staff during launches.

2.1.2 LAUNCH VEHICLE DESCRIPTIONS

Daytona-E is an expendable 54.4-foot (ft) two-stage, ground-launched vehicle (Figure 2-3). Both stages use LOX and kerosene-based RP-1 or Jet-A. The first stage utilizes seven Hadley engines (Figure 2-4; later to be converted to a single Ripley engine), the second stage uses a single vacuum optimized Hadly engine. The Hadley engines developed by Ursa Major are pump-fed ultra-high efficiency 3D printed rocket engines. Laguna-E is also a two-stage, expendable rocket, at 78.7 ft (Figure 2-3). The first stage is powered by 3 Ripley engines (Figure 2-4) that utilize LOX and RP-1 or Jet-A propellants. The Ripley engines are also developed by Ursa Major and pump-fed ultra-high efficiency 3D printed rocket engines. The second stage of the Laguna-E uses a single vacuum optimized Hadley engine. Both vehicle's primary structure is high-strength, reliable aluminum alloys.

The Daytona-E uses approximately 1,800 gallons of LOX and 1,000 gallons of RP-1 or Jet-A. Laguna-E utilizes approximately 4,000 gallons of kerosene-based propellant (RP-1 or Jet-A) and approximately 6,500 gallons of LOX. The mobile operations center would command loading and unloading of propellants. In order to reduce risk, the amount of time the vehicle is loaded with propellants and gases would be minimized by rapidly loading them onto the vehicle immediately prior to launch through high-capacity hard lines and flex hoses. Tank pressurization on both vehicles would be achieved with helium. Daytona-E and Laguna-E both utilize hydrogen or TEA-TEB ignition systems.

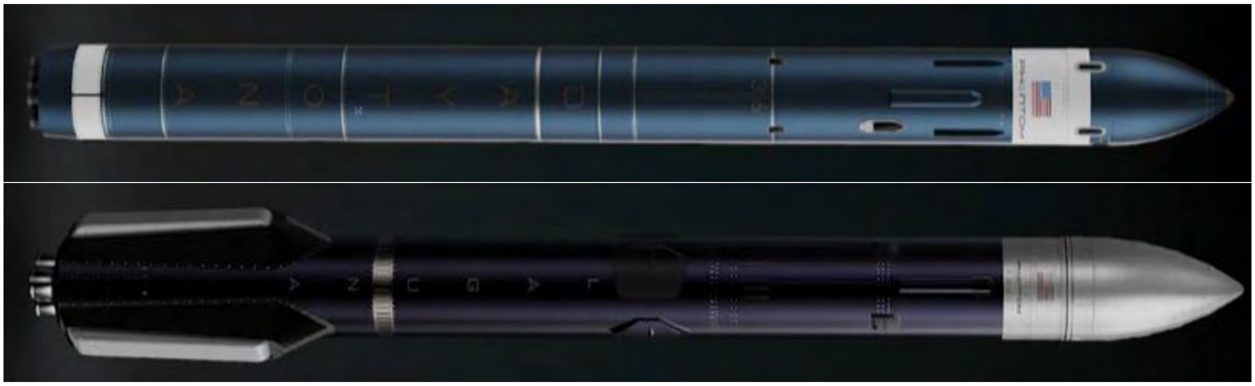

Figure 2-3: Daytona-E (top) and Laguna-E (bottom) Launch Vehicles (note: images not shown to scale)

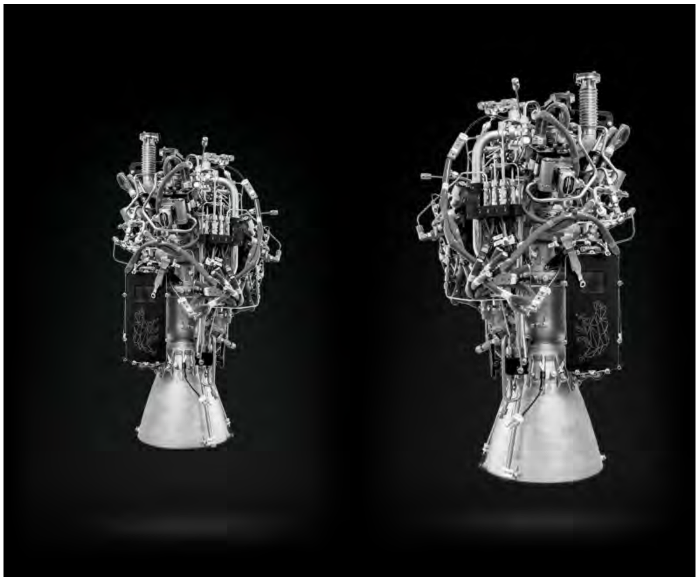

Figure 2-4: Ursa Major 3-D Printed Hadley Engine (left) and Ripley Engine (right)

Table 2-1: Launch Vehicle Specifications

Specification	Daytona-E	Laguna-E
Height	54.4 ft	78.7 ft
Target Mass to LEO	450 kg	1,200 kg
1st Stage Engines	7 Hadley	3 Ripley
2nd Stage Engines	1 Hadley	1 Hadley
Propellant	LOX/RP-1 or Jet-A	LOX/RP-1 or Jet-A
Total Propellant	27,000 pounds	110,000 pounds
Engine Ignition	Hydrogen/TEA-TEB	Hydrogen/TEA-TEB
Tank Pressurization	Helium	Helium
2nd Stage Attitude Control	Hydrogen Peroxide	Hydrogen Peroxide

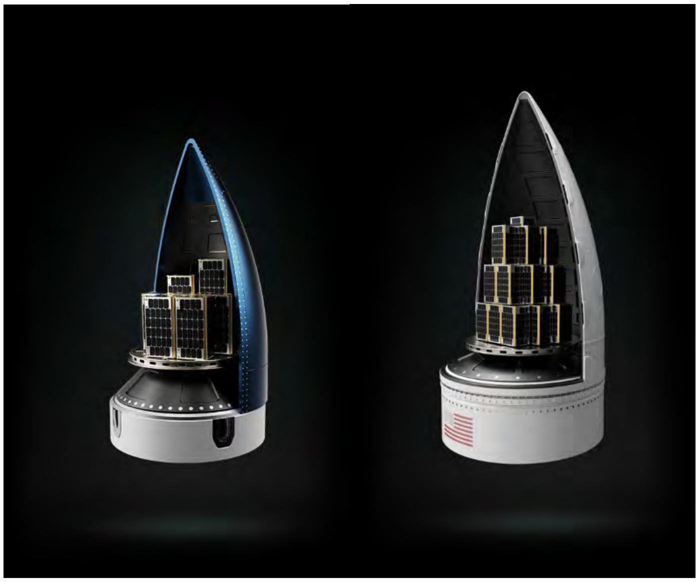

Figure 2-5: Daytona-E Fairing (left) and Laguna-E Fairing (right)

The fairings of both vehicles are designed to protect satellites and spacecraft on their way to orbit, minimizing shock and vibration, and support a wide variety of payloads. The Daytona-E fairing, at approximately 9.2 ft by 4.1 ft, can deliver 450 kilograms (kg) to low-earth orbit (LEO; Figure 2-5; Table 2-1); whereas the 11.5 ft by 6.5 ft Laguna-E fairing can deliver payloads of up to 1,200 kg into LEO (Figure 2-5; Table 2-1.

Stage separation in both vehicles is performed by pneumatic pushers. Phantom plans to use an autonomous flight termination system for the Daytona-E and Laguna-E, but may initially utilize manual flight termination systems. Both systems would utilize thrust termination. Onboard power is provided by a series of lithium-ion battery cells.

2.1.3 SLC-5 CONSTRUCTION AND INFRASTRUCTURE IMPROVEMENTS

The SLC-5 launch site was used by National Aeronautics and Space Administration between 1962 and 1994 to launch Scout space launch vehicles. At the completion of the Scout program in 1994, all facilities at SLC-5 were deactivated and then demolished between 2009 and 2012. The proposed new SLC-5 construction is located entirely within the previosuly disturbed area. Required infrastructure improvements are discussed below.

2.1.4 LAUNCH PAD AND HIF CONSTRUCTION

Prior infrastructure supporting the Scout launch program at SLC-5 was demolished and removed; however, some additional demolition may be required if any remaining structures or materials are encountered during construction. The Proposed Action would include the construction of two new concrete launch pads – SLC-5E and SLC-5W (Figure 2-2) in three separate phases. Phase I-a would include construction of SLC-5W, site security, roadways, and primary site utility connections (Figure 2-6). During Phase I-b, Phantom would construct the HIF and instrumentation pad. Phase II would incorporate the construction of SLC-5E, supporting roadways, and utility connections. As discussed above, installation of electrical utilities connecting SLC-5 to existing VSFB may be shifted from Phase I-a to Phase I-b or Phase II, in which case, Phantom would rely on a 533 HP diesel powered generator as primary power up to the first

3 years (8 launches) of operations. Each pad would serve dual use as launch pads and Vertical Test Facilities (VTF) and each be approximately 1,500 square feet (ft^2) in area. An approximately 12-ft by 12-ft launch stool would be installed at each pad.

Construction during Phases I and II would require an estimated total of 40,000 cubic yards (CY) of excavation and cut/fill to bring the site to the desired grade and install the structures and supporting infrastructure. An approximately 12.5-ft-deep flame deflector would be constructed under each launch stool that curves from vertical to horizontal to redirect at least 150,000 pound-force (lbf) thrust and ability to contain up to 8,000 -gallons of water deluge. The deflector would have a reinforced concrete mat foundation sized for the engine thrust. The deflector itself would be reinforced concrete and have a short reinforced concrete tunnel that will project the exhaust away from Honda Canyon and the launch vehicle and exit into the water deluge catch basin. The deflector and tunnel will use a refractory concrete top layer to protect the reinforced concrete below. In total, an estimated 10,000 CY of concrete would be required for Phase I and II construction of SLC-5E and SLC-5W. The 7,500-ft^2 HIF would provide a site for payload and stage integration and house up to four 55-gallon drums of RP-1 or Jet-A for engine flow tests. The site would also contain an instrumentation pad located to the southwest of the HIF (Figure 2-2).

Site lighting would be required for the right of entry, roadways, parking areas, building exterior, and launch pads. The lighting would be pole-mounted, bug-friendly, T24 compliant light-emitting diode flood lights. Approximately 36 light poles would be installed around the perimeter and interior of SLC-5. The light poles would have a maximum height of 40 ft and be placed in holes dug down to approximately 20 ft below the surface. The lights would be designed with the minimum lumens needed to meet operational and security requirements and would be shielded to minimize stray light from entering Honda Canyon. A preliminary lighting plan and photometric model are shown in Figure 2-7. These fixtures would be supplied from a lighting panel in the HIF and provided with full astronomical clock and photocell control.

To comply with requirements of Federal Aviation Administration (FAA) Launch Site Operator License approval, the entire SLC-5 complex would be bound by perimeter fencing generally comprised of 7-ft-tall chain link fence with 1-ft outriggers and 3-strand barbed wire.

2.1.5 UTILITIES

New electrical power, fiber communication lines, and water would be extended from existing sources to SLC-5. These utilities would be installed within the footprint of Delphy Road and within a 100-ft-wide utility corridor immediately south of the road (Figure 2-8). Electrical and fiber communication lines would either be buried or installed on poles within this utility corridor or the road to establish new service connections at the launch complex.

The HIF would also require permanent sanitary sewer service which would be comprised of an on-site septic system with a septic tank and leach field (Figure 2-2). The septic system would be designed in accordance with the regulations set forth in the California Regional Water Quality Control Board (RWQCB) Onsite Wastewater Treatment Systems Manual (OWTS).

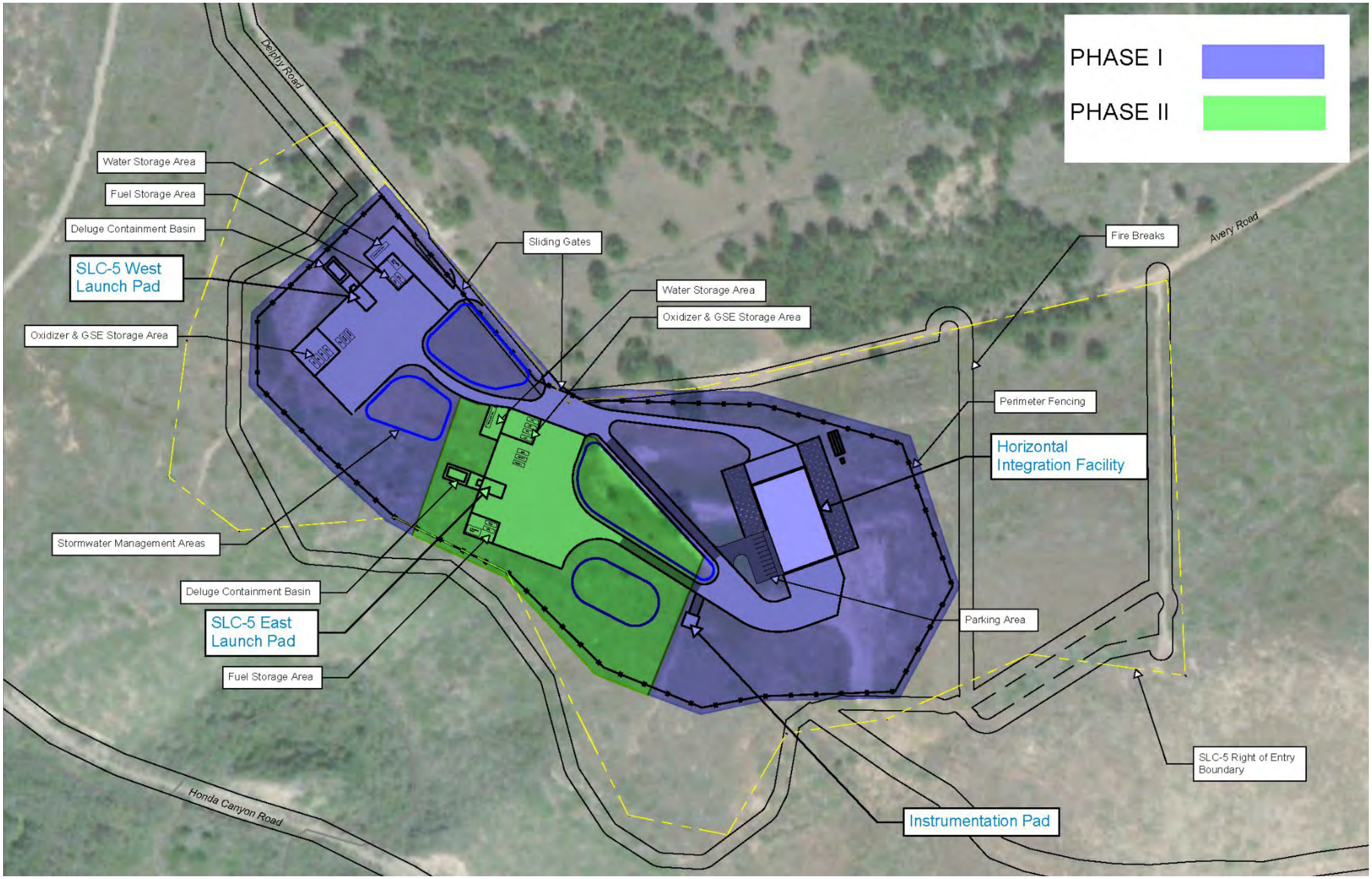

Figure 2-6: Construction Phases

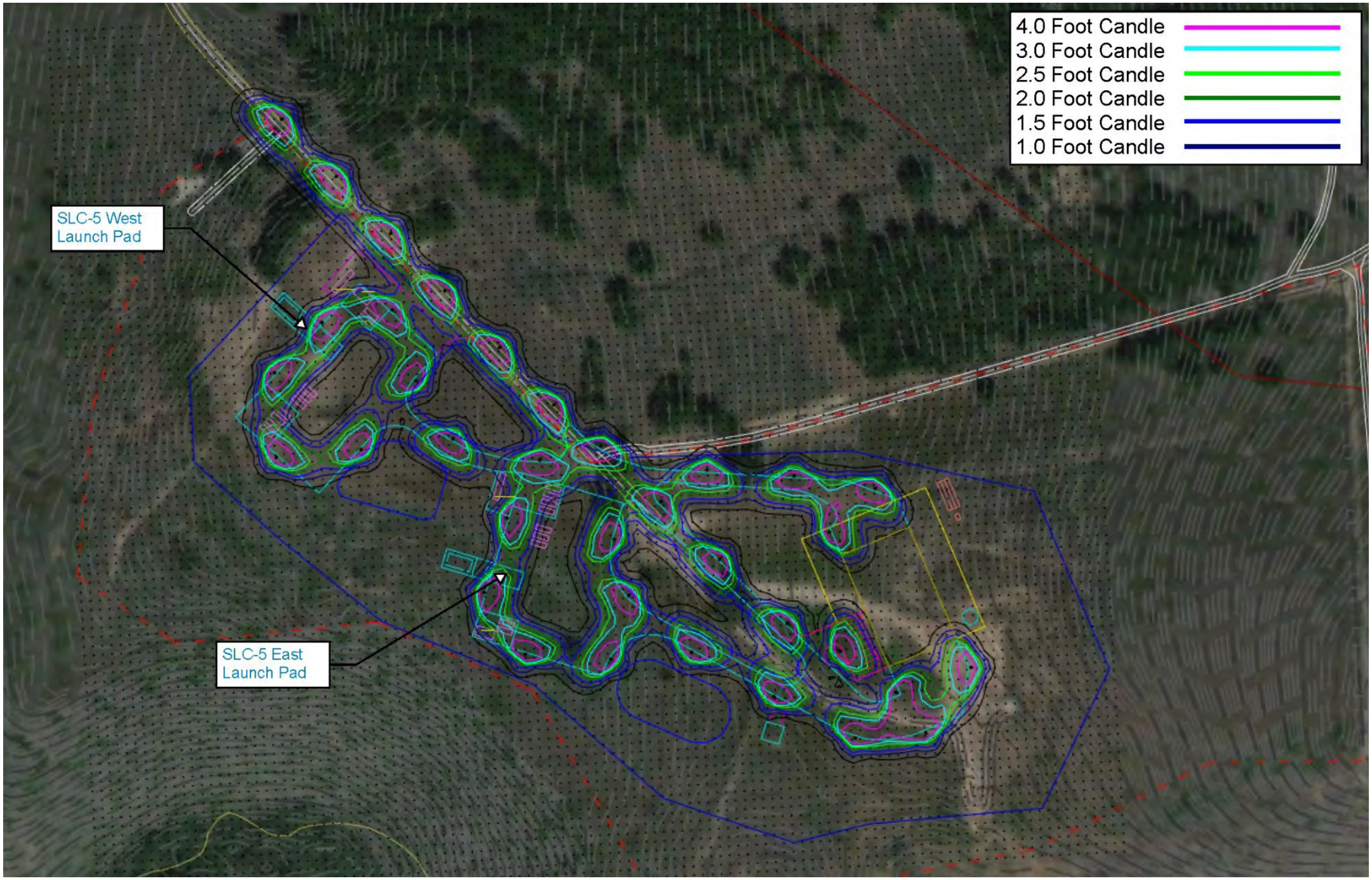

Figure 2-7: Preliminary Lighting Plan

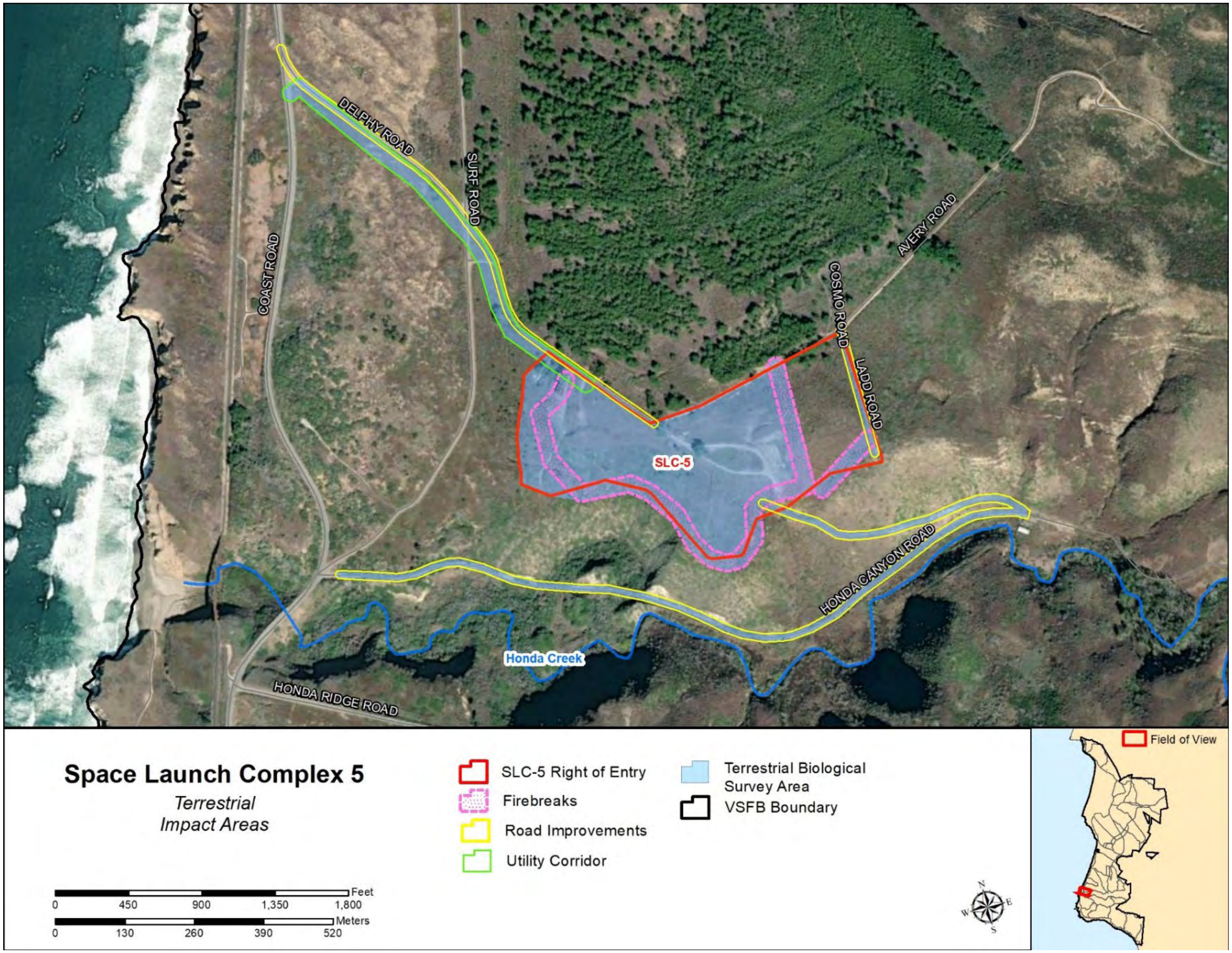

Figure 2-8: SLC-5 Construction and Ground Disturbance Areas

2.1.6 LAUNCH PROGRAM OPERATIONS

Phantom proposes to perform up to a combined total of 48 launches of the Daytona-E and the Laguna-E from SLC-5 annually. In addition, Phantom would conduct up to 48 static fire engine tests annually.

Prior to launch Phantom would deposit an estimated 6,500 to 8,000 gallons of deluge water into a flame bucket under the launch stool to reduce vibration. Phantom would design the pads at SLC-5E and SLC-5W so that there would be no water discharge into surrounding drainages. Immediately downstream of the flame deflector outlet, a concrete deluge containment basin would be provided that will collect deluge runoff. The deluge wastewater would be disposed of or discharged to grade per federal and state regulations and the RWQCB General Waiver for Specific Types of Discharges (or stand-alone state discharge permit). After each launch or storm event, Phantom would inspect the contents of the basin for any contamination per the waiver/permit. If the water is clean enough to go to grade, Phantom would discharge the water from the retention basin to an infiltration area or spray field.

Launch trajectories will be unique to the vehicle configuration, mission, and environmental conditions but within a range of potential launch azimuths from 168° and 220°. ManTech SRS Technologies, Inc. (MSRS) performed sonic boom modeling using PCBoom 4.99 for an array of potential trajectories and meteorological conditions (MSRS 2022). For both vehicles, a sonic boom (overpressure of high energy impulsive sound) up to 1.5 pounds per square foot (psf) would be generated during ascent while the first-stage booster is supersonic. The overpressure would be primarily directed at the Pacific Ocean south of Point Conception and south of the Northern Channel Islands (NCI).

MSRS used the Launch Vehicle Acoustic Simulation Model (RUMBLE), a fully featured time-simulation model, to predict the location and magnitude of engine noise during launch and static fire engine tests (MSRS 2022). The FAA's Office of Environment and Energy approved using RUMBLE for this project on 1 April 2022. Engine noise produced during the launch would impact the area between the Santa Ynez River and Sudden Ranch, (Figures 2-11 and 2-12). Static fire engine tests would be conducted within several days prior to each launch. During static fire, when the vehicle is in a vertical position on the pad, engine noise would be focused along the coastline between SLC-4 and SLC-6 (Figures 2-13 and 2-14). Approved models do not depict sonic booms intersecting any portion of the mainland or the NCI.

The A-weighted Community Noise Equivalent Level (CNEL) contours from 65 to 75 A-weighted decibels (dBA) are presented in Figures 2-15 and 2-16 (MSRS 2022). CNEL is a cumulative metric that accounts for all noise events in a 24-hour period. To account for increased sensitivity to noise at night, CNEL applies an additional 10 decibel (dB) adjustment to events during the acoustical nighttime period, defined as 10:00 PM to 7:00 AM, and a 4.8 dB adjustment to events during the acoustical evening period (7:00 PM to 10:00 PM) to account for decreased community noise during this period. For the Daytona and Laguna launch vehicles, the CNEL 65 dBA for launch and static fire events extend less than 1.2 miles (mi) (1.9 kilometers [km]) and 1.8 mi (2.9 km), respectively from SLC-5 and are contained entirely within VSFB (Figures 2-15 and 2-16).

Post-launch activities would include depressurizing and emptying ground support systems of any commodities, departure of mobile fuel trailers, and any other portable equipment. If an additional launch is planned the propellants would be purged and Phantom would perform a series of inspections and checkouts to begin preparations for the next launch. After a successful launch of the Daytona-E or Laguna-E, the first and second stages would separate during the phase in flight called Main Engine Cut Off. After separation, the first stage would fall to Earth into the Pacific Ocean approximately 230 to 660 nautical miles downrange and approximately 175 nautical miles west, at the closest, from the Baja Peninsula coastline. Figure 2-17 shows the range of potential splashdown sites in the broad ocean area. Phantom expects the first stage to break apart upon hitting the ocean and sink to the ocean floor at locations near the initial splashdown. The remaining stage would deliver the payload into orbit.

All launch operations would comply with the necessary notification requirements, including issuance of Notices to Airmen (NOTAMs) and Local Notices to Mariners (NOTMARs), consistent with current procedures. A NOTAM provides notice of unanticipated or temporary changes to components of, or hazards in, the National Airspace System (FAA Order JO 7930.2S, Notices to Airmen). A NOTMAR provides notice of temporary changes in conditions or hazards in navigable waterways. Western Range operations, which would include the proposed launches from SLC-5, currently follow the procedures stated in a Letter of Agreement (dated 15 June 2021) between VSFB and FAA. The Letter of Agreement establishes responsibilities and describes procedures for the SLD 30, Western Range Operations, within airspace common to the Oakland Air Route Traffic Control Center, Los Angeles Air Route Traffic Control Center, Santa Barbara Terminal Radar Approach Control Facility, Fleet Area Control and Surveillance Facility, Air Traffic Control System Command Center, Pacific Military Altitude Reservation Function, and Central Altitude Reservation Function areas of jurisdiction. The Letter of Agreement also defines responsibilities and procedures applicable to operations, which require the use of Restricted Areas, Warning Areas, Air Traffic Controlled Assigned Airspace, and/or altitude reservations within Western Range airspace.

The Proposed Action does not include altering the dimensions (shape and altitude) of the airspace. However, temporary closures of existing airspace issued by the FAA's Air Traffic Organization are Federal actions connected to the Proposed Action and thus analyzed in the Environmental Assessment (EA). Advance notice of these closures via NOTAMs would assist pilots in scheduling around any temporary disruption of flight activities in the area of operation. Launches would be of short duration and scheduled in advance to minimize interruption to airspace.

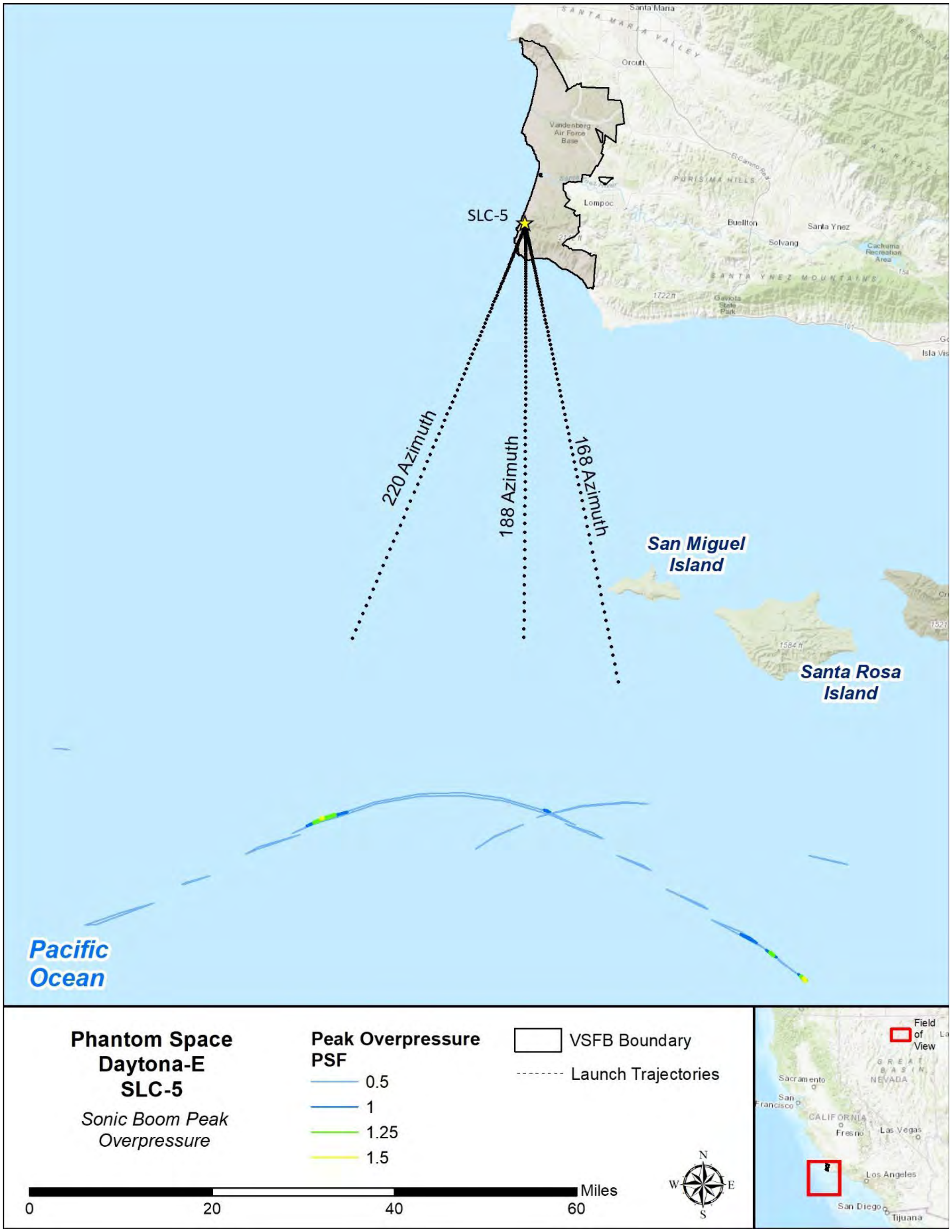

Figure 2-9: Predicted Sonic Boom Footprint for Daytona-E

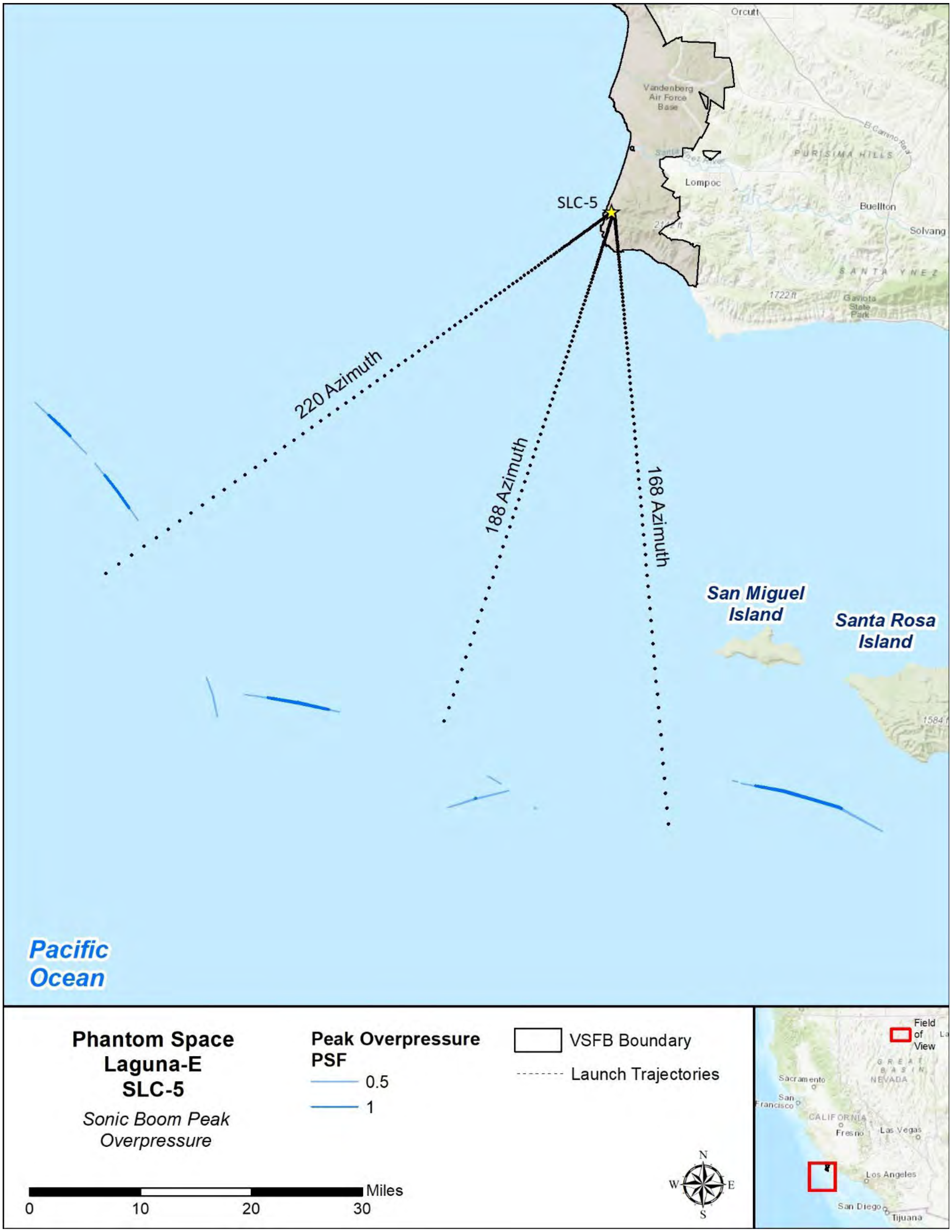

Figure 2-10: Predicted Sonic Boom Footprint for Laguna-E

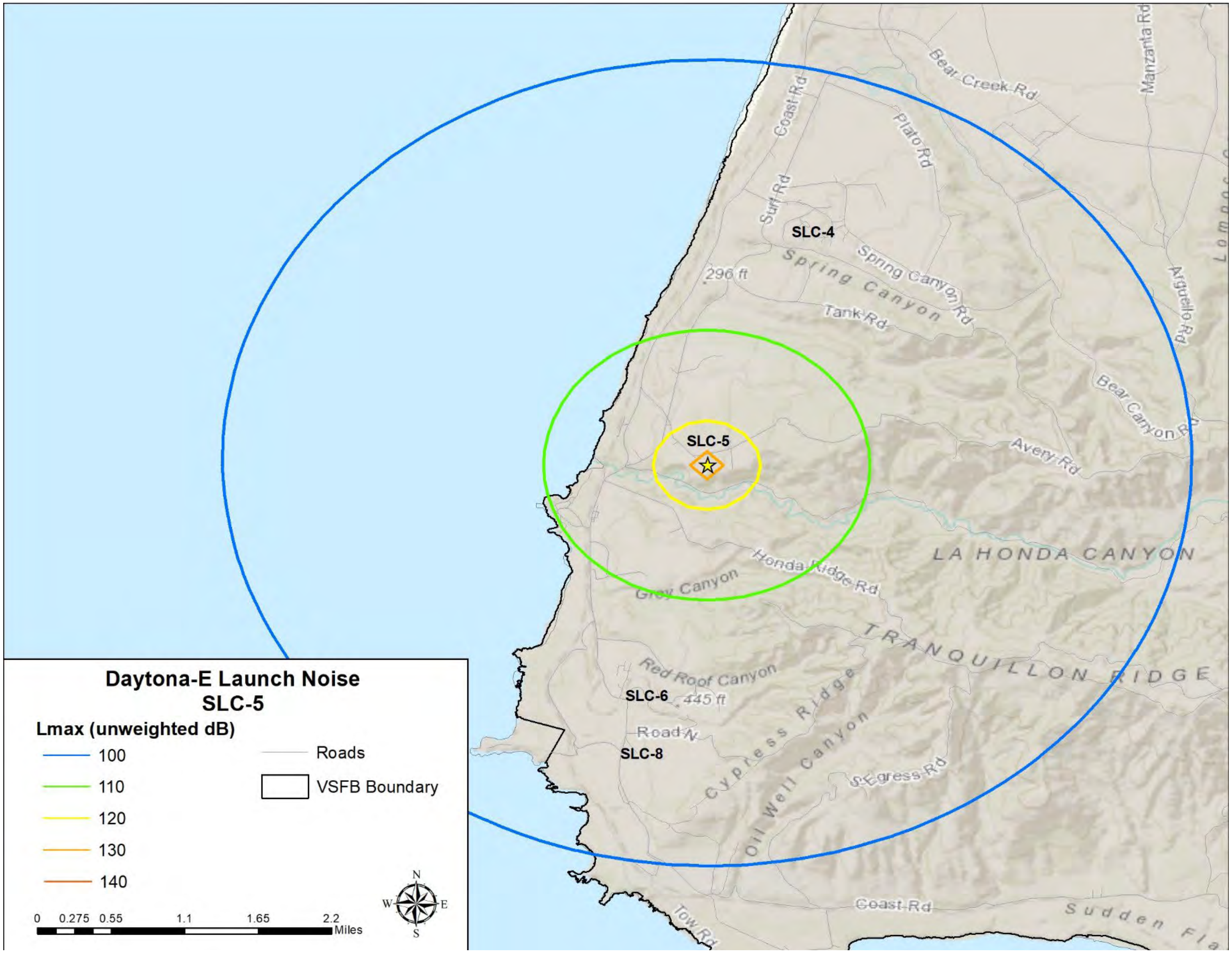

Figure 2-11: Maximum Engine Noise Distribution During Daytona-E Launch

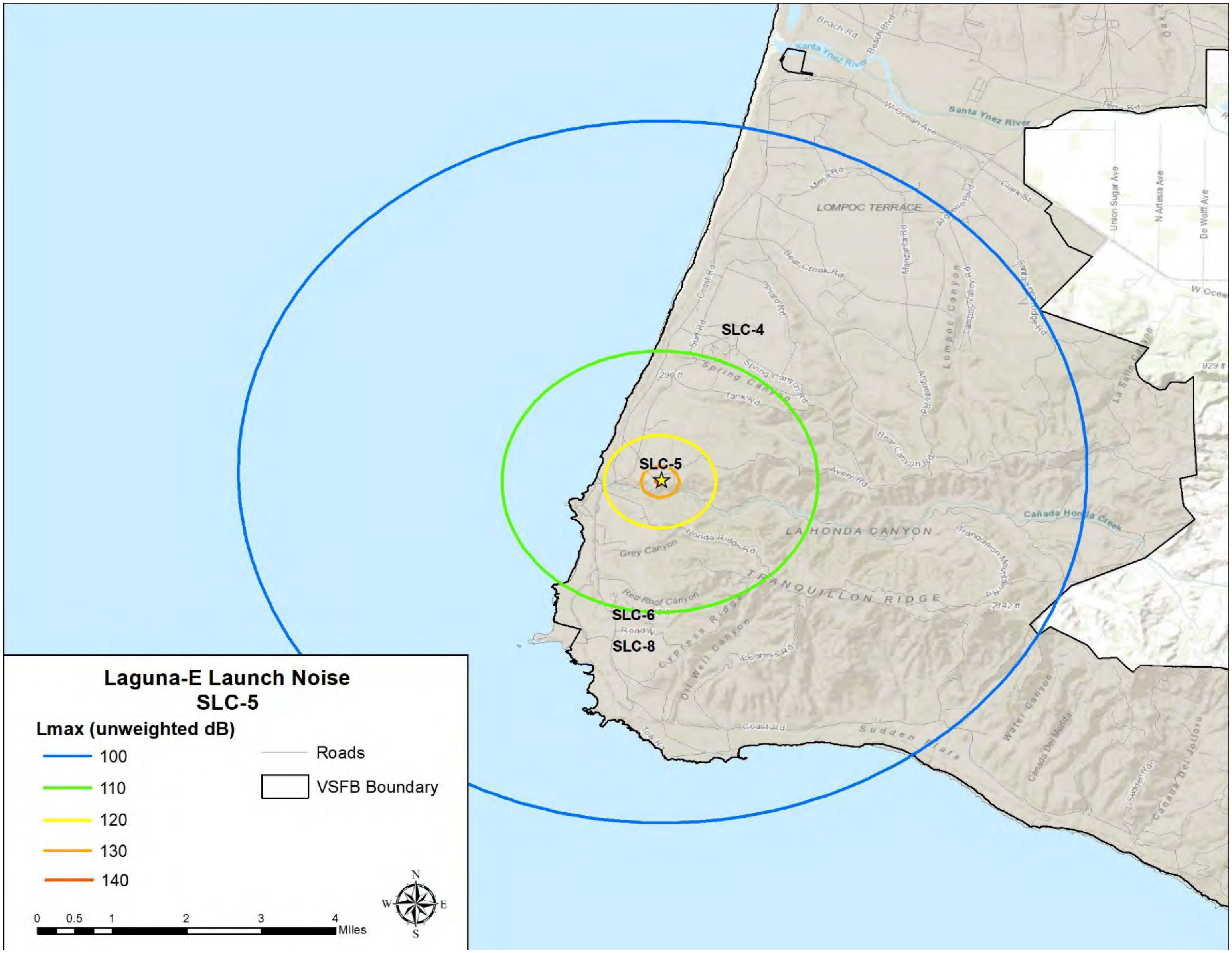

Figure 2-12: Maximum Engine Noise Distribution During Laguna-E Launch

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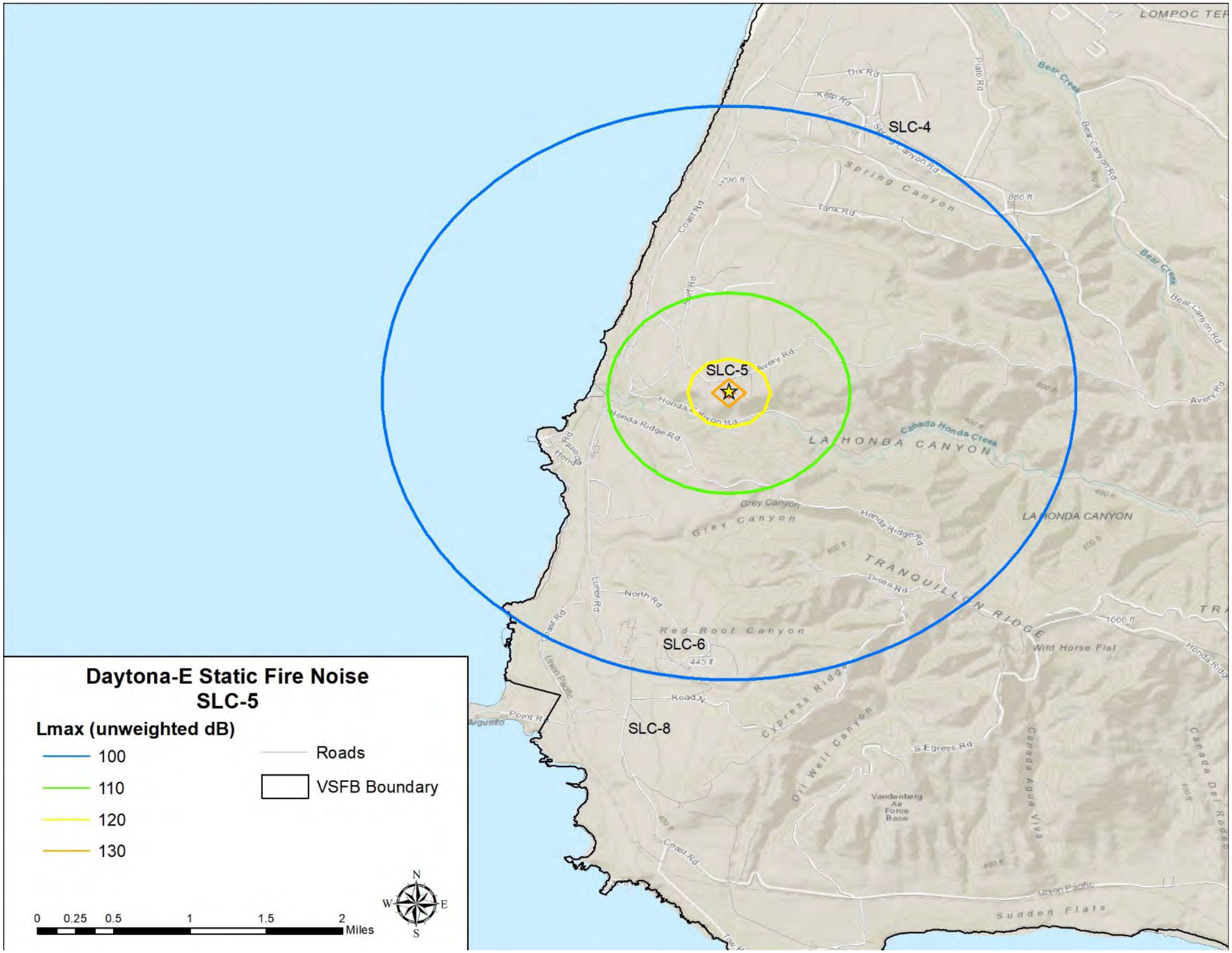

2

Figure 2-13: Maximum Engine Noise Distribution During Daytona-E Static Fire

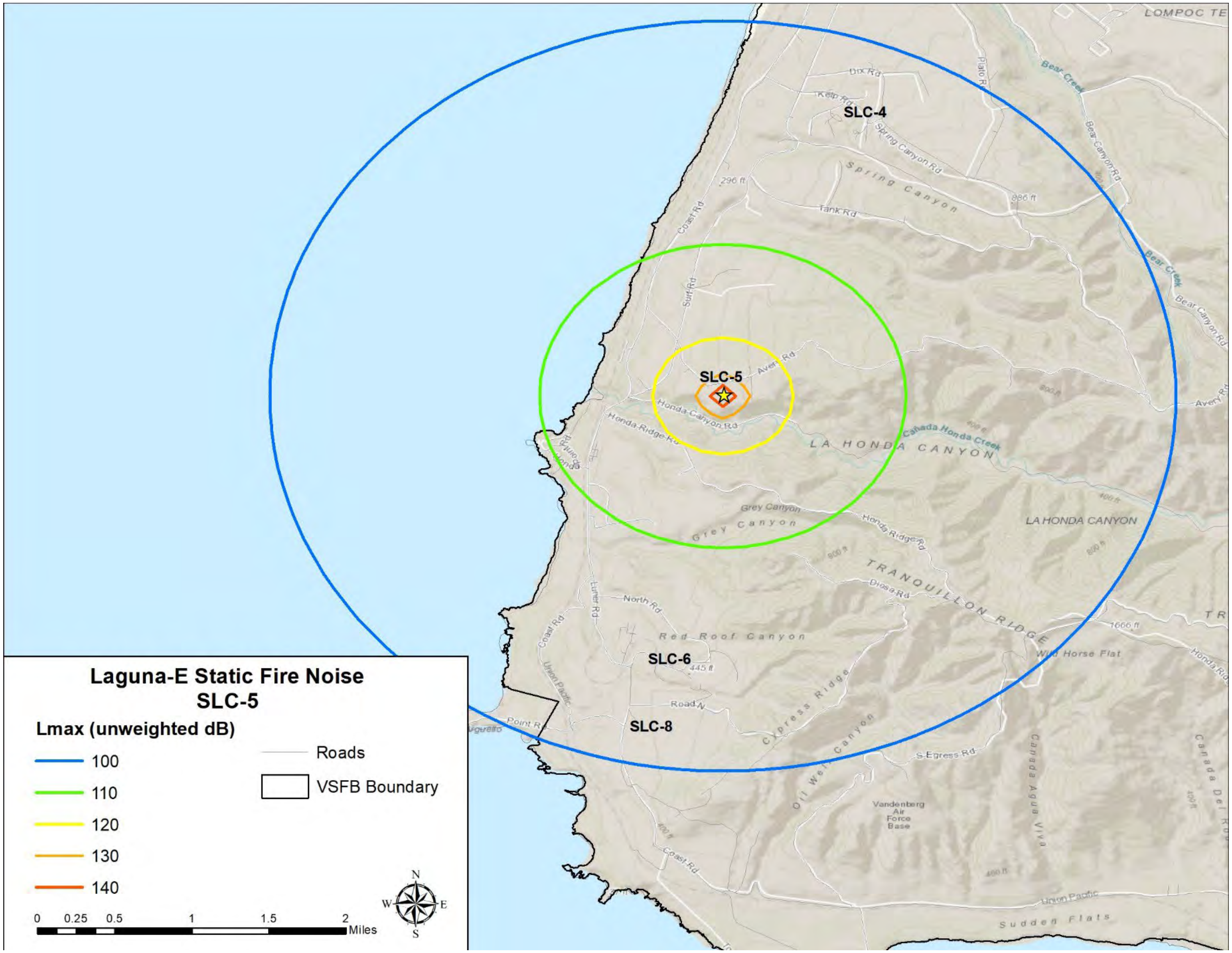

Figure 2-14: Maximum Engine Noise Distribution During Laguna-E Static Fire

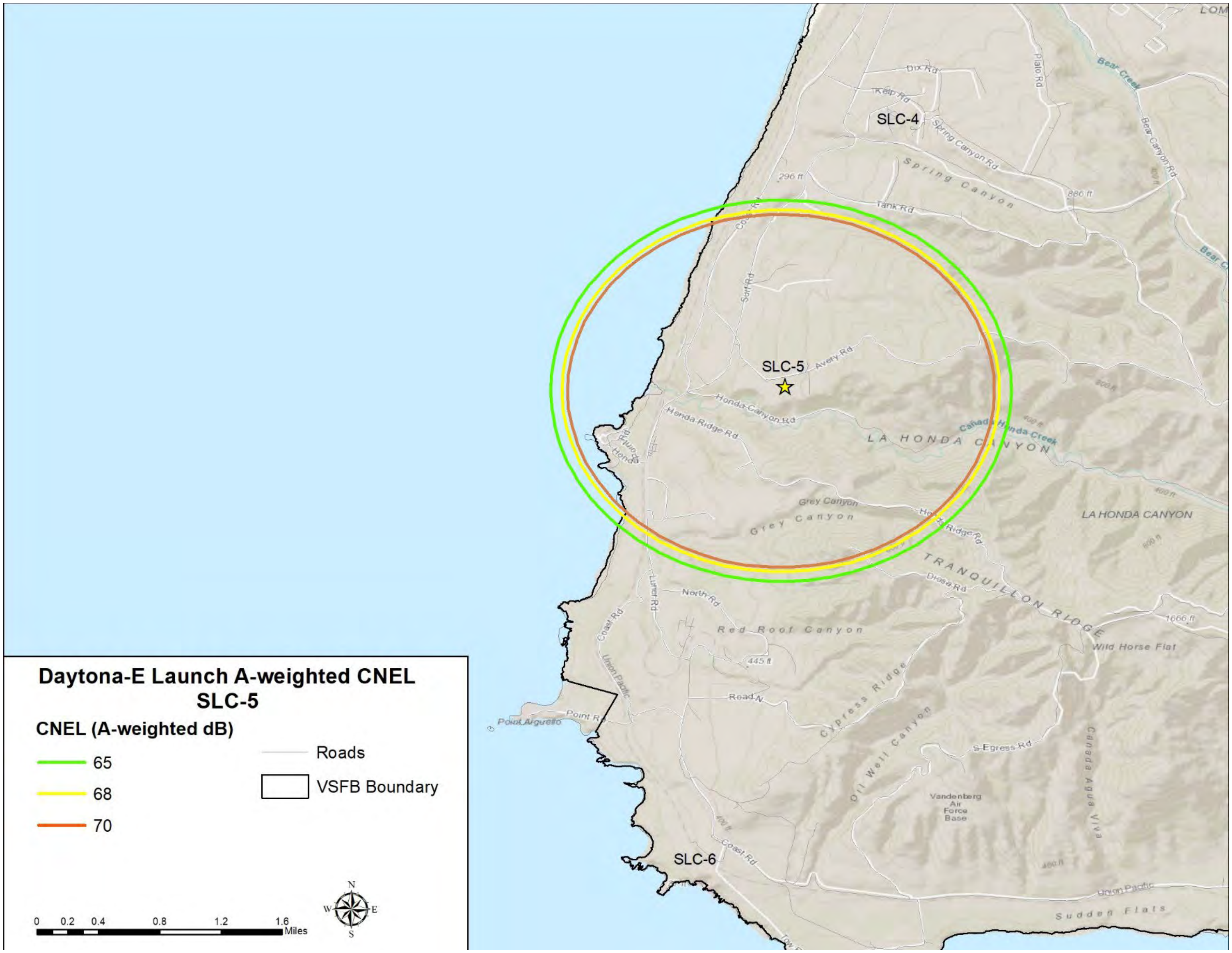

Figure 2-15: A-weighted Community Noise Equivalent Level during Daytona-E Launch

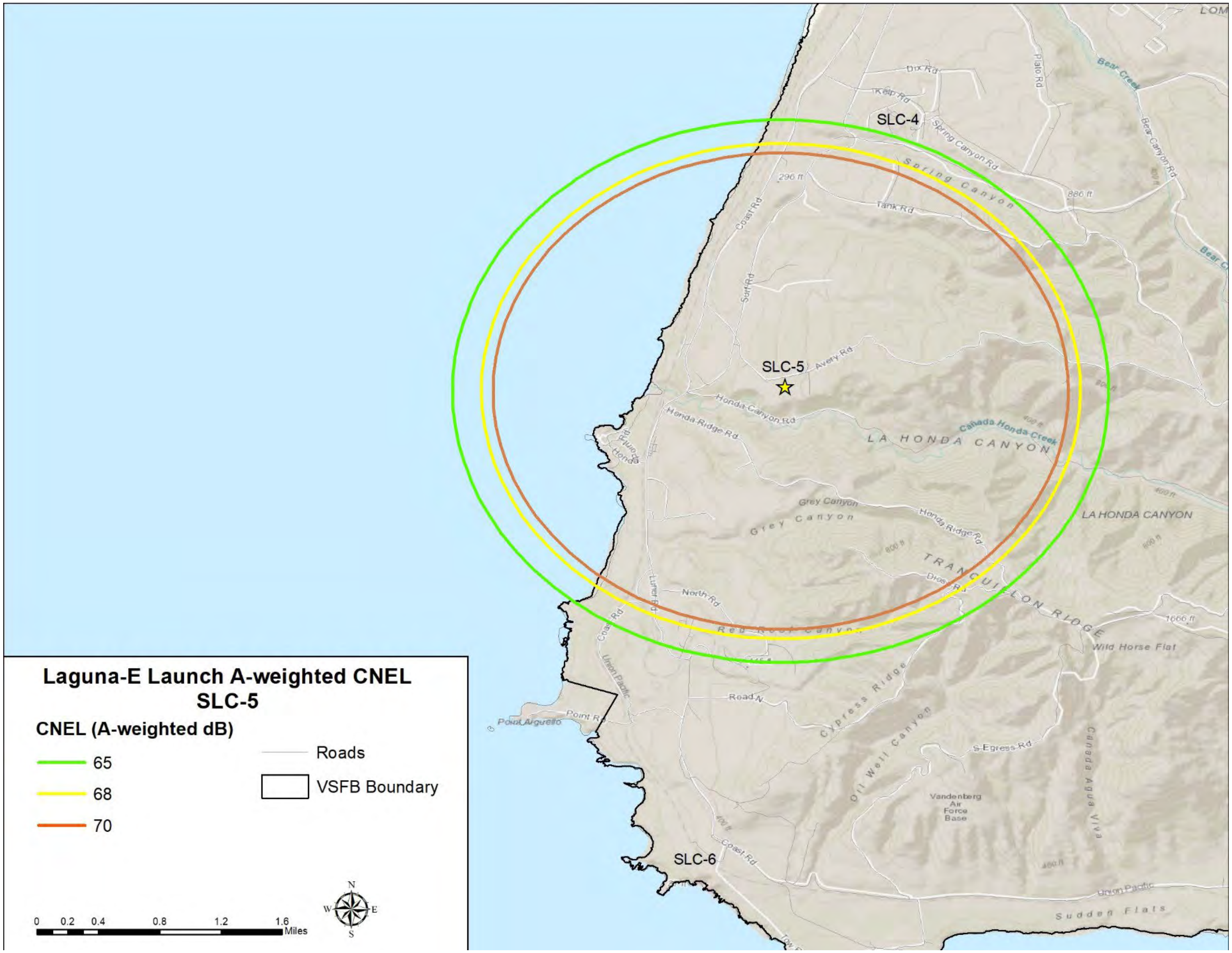

Figure 2-16: A-weighted Community Noise Equivalent Level during Laguna-E Launch

Figure 2-17: Daytona-E and Laguna-E First Stage Spashdown Zone in Broad Ocean Area

2.2 ALTERNATIVES ANALYSIS

As discussed in Section 2.1 (Selection Criteria) of the EA, SLD 30 identified a range of reasonable alternatives on VSFB and other sites by evaluating the ability of each alternative to meet the purpose and need of the Proposed Action and their ability to meet selection criteria. The criteria for site selection alternatives were:

1) Direct orbital access to high-inclination, polar, and sun-synchronous orbits.
2) Existing and approved commercial or federal spaceport and proven launch pad to meet an initial launch target date for Daytona-E in calendar year 2023.
3) Ability to support a regular cadence of launch preparation and operations, including:
    a. Ability to accommodate multiple launch pads for near-simultaneous operations.
    b. Ability to configure site to optimize for Phantom’s projected launch systems.
4) Provides minimal disruption to Phantom operations, including:
    a. Phantom staff having unimpeded access and use of the site.
    b. Ability to pre-position ground support equipment between launch operations.

In accordance with CEQ Regulations, reasonable alternatives were considered for Phantom’s launch program, but dismissed from detailed analysis as they did not meet the requirements of the program. Phantom assessed several sites at VSFB and the Pacific Spaceport Complex (PSCA) at Kodiak Island in Alaska. Both locations are existing spaceports providing access to high-inclination, polar, and sun-synchronous orbits. At VSFB, Phantom evaluated SLC-8, SLC-5, Boat Dock, Sudden Flats, and Boathouse Flats. In addition, Phantom considered Launch Pad (LP)-1, LP-2, LP-3C, and LP-3E at PSCA. The Boat Dock, Sudden Flats, and Boathouse Flats at VSFB and LP-3E at PSCA have not previously or currently had active launch operations, causing uncertainty in their potential to support efficient launch operations. The time necessary to resolve the uncertainty through research and studies fails to meet the timeline requirements under Criterion 2, above, and were therefore eliminated from further consideration.

VSFB’s SLC-8 and PSCA’s LP-1, LP-2, and LP-3C are currently approved for launch operation. However, they are shared multi-user launch sites for commercial and government launch operators. As such, Phantom would only be able to use these pads on a temporary basis. Doing so would present considerable disruption and logistical challenges to Phantom operations and would not support a regular launch cadence under Criteria 3 and 4 above. Therefore, these alternatives were also eliminated from further consideration, and only the Proposed Action and No Action Alternative have been carried forward for further evaluation

2.3 CONSISTENCY ANALYSIS/ANALYSIS OF EFFECTS

The effects test is a procedure where the project proponent determines whether the proposed activities comply with the federal consistency requirements of Section 307 of the CZMA (16 U.S.C. Section 1456) and its implementing regulations (15 C.F.R. Part 930). As defined in Section 304 of the CZMA, the term “coastal zone” does not include “lands the use of which is by law subject solely to the discretion of or which is held in trust by the Federal Government.” However, per DAF implementing regulations (AFMAN 32-7003, Section 3.26.2), the DAF is required to undertake federal actions in a manner consistent to the maximum extent practicable with the enforceable policies of California’s approved coastal zone management programs through the federal consistency process under the CZMA.

The Space Force analyzed the effects of the Proposed Action by looking at reasonably foreseeable direct and indirect effects on any coastal use or resource, and by reviewing relevant management program enforceable policies (15 C.F.R. Part 930.33[a][1]) and the Coastal Resources Planning and Management

Policies. Sections of the CCA relevant to this Proposed Action, as determined by the Space Force, include the following: Article 2 – Public Access (Section 30210 and 30211); Article 3 – Recreation (Section 30220); Article 4 – Marine Environment (Section 30230, 30231, 30232, 30234, and 30234.5); and Article 5 – Land Resources (Section 30244). Sections and Articles of the CCA not addressed below are not relevant to the Proposed Action.

Prior to evaluating whether the Proposed Action complies with the State of California's enforceable policies, the federal agency must first examine whether the Proposed Action would have a reasonably foreseeable effect on coastal zone uses or resources. Thus, the elements of the Proposed Action must first be examined to determine whether they have reasonably foreseeable effects before determining whether those effects are consistent with the State of California's enforceable policies. Coastal zone resources include both resources permanently located in the coastal zone (e.g., benthic organisms) and mobile resources (e.g., marine mammals and sea turtles) that typically move into and out of the coastal zone as part of a natural cycle.

The effects test evaluates the relative location of the Proposed Action to the coastal zone and the potential effects of stressors on coastal zone resources. The Space Force conducted the effects test and determined there are reasonably foreseeable effects to coastal uses and resources. The effects test for the Proposed Action is based on the locations of the proposed activities relative to the coastal zone and the potential effects of stressors on coastal zone resources.

The Proposed Action at VSFB could have the potential to affect coastal resources from acoustics (launch engine noise).

3 ENFORCEABLE POLICIES OF THE CALIFORNIA COASTAL MANAGEMENT PROGRAM

The Space Force reviewed the CCMP to identify enforceable policies relevant to the Proposed Action according to Division 20 of the California Public Resources Code, approved as part of the coastal program, and enforceable on the Space Force's Proposed Action. Section 3.1 (Enforceable Policies of the California Coastal Management Program That Are Not Applicable to the Proposed Action) identifies the CCMP policies that are not applicable to the Proposed Action. Section 3.2 (Enforceable Policies of the California Coastal Management Program That Are Applicable to the Proposed Action) provides an analysis of the CCMP policies that are applicable to the Proposed Action.

3.1 ENFORCEABLE POLICIES OF THE CALIFORNIA COASTAL MANAGEMENT PROGRAM THAT ARE NOT APPLICABLE TO THE PROPOSED ACTION

The CCMP policies not applicable to the Proposed Action are provided in Table 3-1 below.

Table 3-1: Enforceable Policies of the CCMP That Are Not Applicable to the Proposed Action

Article	Section	State Enforceable Policy	Explanation of Non-Applicability
Article 2: Public Access	30212	New development projects	The Proposed Action does not include any new development that would block or impede public access.
	30212.5	Public facilities; distribution	The Proposed Action does not include any public facilities.
	30213	Lower cost visitor and recreational facilities; encouragement and provision; overnight room rentals	The Proposed Action does not include any visitor or recreational facilities.
	30214	Implementation of public access policies; legislative intent	This section explains the legislative intent applicable to the foregoing public access policies, and does not constitute a separate public access policy.
Article 3: Recreation	30221	Oceanfront land; protection for recreational use and development	The Proposed Action does not include any development of oceanfront land that would reduce available areas for public use.
	30222	Private lands; priority of development purposes	The Proposed Action does not include any development of private lands within the Action Area.
	30222.5	Oceanfront lands; aquaculture facilities; priority	The Proposed Action does not affect coastal zone lands suitable for aquaculture.
	30223	Upland areas	The Proposed Action does not affect the availability of upland areas necessary to support coastal recreational uses.

Table 3-1: Enforceable Policies of the CCMP That Are Not Applicable to the Proposed Action (continued)

Article	Section	State Enforceable Policy	Explanation of Non-Applicability
Article 3: Recreation	30224	Recreational boating use; encouragement; facilities	The Proposed Action does not include the development of any recreational boating facilities.
Article 4: Marine Environment	30233	Diking, filling, or dredging; continued movement of sediment and nutrients	The Proposed Action does not include any diking, filling, or dredging activities.
	30235	Construction altering natural shoreline	The Proposed Action does not include construction that would alter the natural shoreline processes.
	30236	Water supply and flood control	The Proposed Action does not alter any rivers or streams.
	30237	Repealed	
Article 5: Land Resources	30241	Prime agricultural land; maintenance in agricultural production	The Proposed Action does not include any prime agricultural lands.
	30241.5	Agricultural lands; determination of viability of uses; economic feasibility evaluation	The Proposed Action does not include any agricultural lands.
	30242	Lands suitable for agricultural use; conversion	The Proposed Action does not include any agricultural lands.
	30243	Productivity of soils and timberlands; conversion	The Proposed Action does not include any timberlands.
Article 6: Development	30252	Maintenance and enhancement of public areas	The Proposed Action does not include any new development that would require maintenance or enhanced public access to the coast.
	30254	Public works facilities	The Proposed Action does not include any new or expanded public works facilities.
	30254.5	Terms or conditions on sewage treatment plant development; prohibition	The Proposed Action does not include the development of a sewage treatment plant.
	30255	Priority of coastal-dependent developments	The Proposed Action does not include any development within the coastal zone.

Table 3-1: Enforceable Policies of the CCMP That Are Not Applicable to the Proposed Action (continued)

Article	Section	State Enforceable Policy	Explanation of Non-Applicability
Article 7: Industrial Development	30260	Location or expansion	The Proposed Action does not include the development of coastal-dependent industrial facilities.
	30261	Tanker facilities; use and design	The Proposed Action does not include the use of existing or new tanker facilities.
	30262	Oil and gas development	The Proposed Action does not include any oil and gas development.
	30263	Refineries or petrochemical facilities	The Proposed Action does not include new or expanded refineries or petrochemical facilities.
	30264	Thermal electric generating plants	The Proposed Action does not include new or expanded thermal electric generating plants.
	30265	Legislative findings and declarations; offshore oil transport	This section explains the legislative findings applicable to offshore oil transportation, and does not constitute a separate public access policy.
	30265.5	Governor or designee; co-ordination of activities concerning offshore oil transport and refining; duties	The Proposed Action does not include activities concerning offshore oil transport and refining.

3.2 ENFORCEABLE POLICIES OF THE CALIFORNIA COASTAL MANAGEMENT PROGRAM THAT ARE APPLICABLE TO THE PROPOSED ACTION

The CCMP enforceable policies that apply to the Proposed Action are policies where one or more of the Proposed Action components could affect a coastal zone resource or use identified by the policy. The CCMP enforceable policies that apply to the Proposed Action are provided in Table 3-2.

Table 3-2: Enforceable Policies of the CCMP That Are Applicable to the Proposed Action

Article	Section	State Enforceable Policy
Article 2: Public Access	30210	Access; recreational opportunities; posting
	30211	Development not to interfere with access
Article 3: Recreation	30220	Protection of certain water-oriented activities
Article 4: Marine Environment	30230	Marine resources; maintenance
	30231	Biological productivity; water quality
	30232	Oil and hazardous substance spills
	30234	Commercial fishing and recreation boating facilities
	30234.5	Economic, commercial, and recreational importance of fishing
Article 5: Land Resources	30240(b)	Environmentally sensitive habitat areas; adjacent developments
	30244	Archaeological or paleontological resources
Article 6: Development	30250(a)	Developmnet location; existing developed areas
	30251	Scenic and visual qualities
	30253	Minimization of adverse impacts

3.2.1 ARTICLE 2: PUBLIC ACCESS

Policies

CCA Section 30210 – "Access; recreational opportunities; posting" states:

> *In carrying out the requirement of Section 4 of Article X of the California Constitution, maximum access, which shall be conspicuously posted, and recreational opportunities shall be provided for all the people consistent with public safety needs and the need to protect public rights, rights of private property owners, and natural resource areas from overuse.*

CCA Section 30211 – "Development not to interfere with access" states:

> *Development shall not interfere with the public's right of access to the sea where acquired through use or legislative authorization, including, but not limited to, the use of dry sand and rocky coastal beaches to the first line of terrestrial vegetation.*

Consistency Review

The Space Force controls access to VSFB and on-Base recreation areas. Public access to VSFB and nearby SLC-5 is not permitted. Personnel and approved contractors may participate in outdoor activities on VSFB, such as camping, picnicking, sunbathing, hiking, bird watching, nature photography, fishing, and hunting. The closest public access beaches include Jalama Beach County Park, Surf Beach, and County of Santa Barbara Ocean Beach Park. Proposed launches at SLC-5 would not require a need for closures at any of these beach or park areas except for Jalama Beach County Park. The Proposed Action would result in temporary and brief (non-permanent) closures of Jalama Beach County Park. The DAF has agreed to not exceed 12 beach closures per year (including Jalama Beach County Park) for all launch activities from VSFB.

The DAF provides notice to Santa Barbara County of a launch-related closure at least 72 hours prior to the event and the closures do not to exceed 48 hours. Phantom's proposed launches will comply with these procedures and will not exceed or increase the current allowable annual beach closures. These closures would be infrequent (no more than 12 times per year for all launch activities from VSFB) and would not substantially diminish the protected activities, features, or attributes Jalama Beach County Park.

Recreational and commercial boating and fishing occurs offshore of VSFB; however, impacts on offshore activities are unlikely other than temporary avoidance areas established during launch activities. Temporary avoidance areas for security and safety would not limit public access to adjacent areas. Areas would only be closed for the duration of the launch activity. The U.S. Coast Guard (USCG) would issue a NOTMAR that defines a public ship avoidance area for launch events. The avoidance area would be lifted as soon as the USCG determines it is safe to do so. Any impacts to recreation resources would be infrequent and temporary and would not result in a significant impact on recreation resources. Therefore, the Proposed Action would be consistent to the maximum extent practical with Section 30210 and 30211 of the CCA.

3.2.2 ARTICLE 3: RECREATION

Policies

CCA Section 30220 – "Protection of certain water-oriented activities" states:

> *Coastal areas suited for water-oriented recreational activities that cannot readily be provided at inland water areas shall be protected for such uses.*

Consistency Review

As described under Section 3.2.1.2 (Consistency Review), the Proposed Action would result in temporary closures of offshore areas of VSFB. Temporary closures of these areas for security and safety do not limit public access to or use of adjacent areas. Areas would be closed for the duration of the activity (no more than two hours) and reopened at the completion of the activity.

Due to the temporary and short-term duration of the activities (48 launches from SLC-5 annually), broadcasting of NOTMARs, and the expansive offshore area that would still be available to the public, accessibility impacts associated with water-oriented recreational activities would remain negligible. Therefore, the Proposed Action would be consistent to the maximum extent practical with Section 30220 of the CCA.

3.2.3 ARTICLE 4: MARINE ENVIRONMENT (MARINE RESOURCES)

Policies

CCA Section 30230 – "Marine resources; maintenance" states:

> *Marine resources shall be maintained, enhanced, and where feasible, restored. Special protection shall be given to areas and species of special biological or economic significance. Uses of the marine environment shall be carried out in a manner that will sustain the biological productivity of coastal waters and that will maintain healthy populations of all species of marine organisms adequate for long-term commercial, recreational, scientific, and educational purposes.*

Consistency Review

As shown in Table 3-3, there are five species that occur along in the marine environment off the VSFB coastline. One is federally listed as threatened under the Endangered Species Act (ESA) and four species are protected as defined under the Marine Mammal Protection Act (MMPA). The Space Force determined these species may be potentially affected by the Proposed Action from physical impacts during construction and noise impacts during construction and operation.

Table 3-3: Determination of Potential Impacts to Marine Mammals

Species	Status	ESA Effects Determination	MMPA Determination
Southern sea otter (*Enhydra lutris nereis*)	FT	NLAA	NE
Steller sea l–on - Eastern U.S. Stock (*Eumetopias jubatus*)	MMPA	NA	Level B
Northern elephant seal – California Breeding Stock (*Mirounga angustirostris*)	MMPA	NA	Level B
Pacific harbor seal – California Stock (*Phoca vitulina richardii*)	MMPA	NA	Level B
California sea lion – U.S. Stock (*Zalophus californianus*)	MMPA	NA	Level B

Notes: FE = Federally Endangered Species; FT = Federally Threatened Species; MMPA = Marine Mammal Protection Act, NA = not applicable; NE = no effect; NLAA = May affect, not likely to adversely affect; ESA = Endangered Species Act, MMPA = Marine Mammal Protection Act

In addition, there are up to 5 sea turtle species, 7 mysticetes (baleen whales), and 22 odontocetes (toothed cetaceans) that may be found within the region of influence. Sea turtles and cetaceans spend their entire lives in the water and spend most of their time (>90% for most species) entirely submerged below the surface. Additionally, when at the surface, sea turtle and cetacean bodies are almost entirely below the water's surface, with only the blowhole or head exposed for breathing. This minimizes exposure to in-air noise, both natural and anthropogenic, essentially 100% of the time because their ears are nearly always below the water's surface. As a result, in-air noise caused by sonic boom and engine noise would not affect sea turtle or cetacean species. Therefore, they were not considered further in the EA and are not considered further in this CD.

Southern Sea Otter (*Enhydra lutris nereis*)

Direct Impacts. No ground disturbing activities or vegetation management activities would occur within southern sea otter habitat; therefore, these actions will have no effect on the southern sea otter. The potential effects of noise and visual disturbance are discussed below.

Noise and Visual Impacts. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to southern sea otters. If otters are present directly offshore of SLC-5 during a Laguna-E launch, they would experience noise levels of less than 120 dB Lmax (refer to Figure 3.4-1 of the EA). During static fire noise directly off the coast of SLC-5 would be less than 115 dB Lmax. However, otters are only occasionally observed along the coast between Purisima Point and Point Arguello, likely transiting through the area. Beginning at the Boat Dock and continuing to the south along Sudden Flats, the inshore habitat supports expansive kelp beds and a relatively high density of otters (refer to Figure 3.4-1 of the EA). Noise levels during a Laguna-E launch would reach between 100 and 110 dB Lmax in these areas (refer to Figure 3.4-1 of the EA).

Exceptionally little sound is transmitted between the air-water interface; thus, in-air sound would not have a significant effect on submerged animals (Godin 2008). In addition, according to Ghoul & Reichmuth (2014), "Under water, hearing sensitivity [of sea otters] was significantly reduced when compared to sea lions and other pinniped species, demonstrating that sea otter hearing is primarily adapted to receive airborne sounds." This study suggested that sea otters are less efficient than other marine carnivores at extracting noise from ambient noise (Ghoul & Reichmuth 2014). Therefore, the potential impact of underwater noise caused by in-air sound would be insignificant and discountable.

Extensive launch monitoring has been conducted for sea otters on both north and south VSFB, with pre- and post-launch counts and observations conducted at rafting sites immediately south of Purisima Point for numerous Delta II launches from SLC-2 and one Taurus launch from Launch Facility-576E and at the rafting sites near Sudden Flats for two Delta IV launches from SLC-6. No abnormal behavior, mortality, or injury of effects on the population has ever been documented for sea otter because of launch-related disturbance (SRS Technologies, Inc. 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g; MSRS 2007a, 2007b, 2007c, 2008a, 2008b). More recently, for the SpaceX Falcon 9 SAOCOM launch and landing on 7 October 2018, sea otters were monitored during pre- and post-launch surveys on south VSFB (MSRS 2018b). The sonic boom received at the otter monitoring location was estimated at 0.71 psf and the maximum landing engine noise at this location was estimated at 99.5 dB Lmax. Count totals of both pups and adults were similar before and after the launch and there was no discernable impact on otters on south VSFB.

A prior study suggests that sea otters may be able to acclimate to sound exposures more than those anticipated due to the Proposed Action. Davis et al. (1988) conducted a study of northern sea otter's (*Enhydra lutris kenyoni*) reactions to various underwater and in-air acoustic stimuli. The purpose of the study was to identify a means to move sea otters away from a location in the event of an oil spill. Anthropogenic sound sources used in this behavioral response study included truck air horns and an acoustic harassment device (10 to 20 kHz at 190 dB) designed to keep dolphins and pinnipeds from being caught in fishing nets. The authors found that the sea otters often remained undisturbed and quickly became tolerant of the various sounds. When a fleeing response occurred because of the harassing sound, sea otters generally moved only a short distance (328 to 656 ft [100 to 200 m]) before resuming normal activity (Davis et al. 1988).

Curland (1997), studying the southern sea otter, also found that they may acclimate to disturbance. The author compared otter behavior in areas with and without human-related disturbance (e.g., kayaks, boats, divers, planes, sonic booms, and military testing at Fort Ord) near Monterey, California. Otters spent more time traveling in areas with disturbance compared to those without disturbance; however, there was no significant differences in the amount of time spent resting, foraging, grooming, and interacting, suggesting that the otters were becoming acclimated to regular disturbances from a variety of sources (Curland 1997). Extensive launch monitoring of sea otters on VSFB has shown that launch noise is not a primary driver of sea otter behavior or use of the habitat along Sudden Flats and has not had any apparent long-term consequences for populations, potentially indicating that this population has acclimated to launch activities. Therefore, any impacts because of noise or visual disturbance are expected to be limited to minor behavioral disruption and, therefore, insignificant. As such, VSFB has determined that the Proposed Action would have an insignificant impact on otters and therefore, may affect, but is not likely to adversely affect, the southern sea otter off the coast of VSFB.

Conclusion. Observations at VSFB have shown no abnormal behavior, mortality, or injury of otters during launch activities and noise studies have shown southern sea otters adapt to sound exposure. As a result, the Proposed Action would have an insignificant effect on southern sea otter. Therefore, VSFB has determined that the Proposed Action may affect, but is not likely to adversely affect, the southern sea otter and, therefore, would not be significant.

Marine Mammals Protected under the MMPA

Direct Impacts. No ground disturbing activities or vegetation management activities would occur within the habitat of the marine mammals listed in Table 3-3; therefore, these actions will have no effect on marine mammals.

Noise Impacts. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to marine mammals. During a Laguna-E launch, engine noise levels would be less than 110 dB Lmax at the nearest pinniped haulout at North Rocky Point (refer to Figure 3.4-2 of the EA). Daytona-E launches would reach approximately 102 dB Lmax at the same location and static fire tests of either vehicle would be less than 100 dB Lmax. These levels are less than those generated by the Delta II launch vehicle, which was measured at approximately 125 dBA at South Spur in 1996 (ENSR Consulting and Engineering 1996).

Sonic boom modeling of the planned trajectories predicts that both Daytona-E and Laguna-E would not produce a sonic boom that would impact the mainland or the NCI. Modeling also predicted that neither vehicle would produce a sonic boom over 1.5 psf (Figure 2-9 and Figure 2-10). Noise and visual disturbance can cause variable levels of disturbance to pinnipeds that may be hauled out within the areas of exposure, depending on the species exposed and the rocket engine sound levels. VSFB has monitored pinnipeds on VSFB during launches to characterize the effects of noise and visual disturbance on pinnipeds during numerous launches over the past two decades and determined there are generally no substantial behavioral disruptions or anything more than temporary affects to the number of pinnipeds hauled out on VSFB. Generally, only a portion of the animals present tend to react to sonic booms. Reactions between species are also different. For example, harbor seals and California sea lions tend to be more sensitive to disturbance than northern elephant seals. Normal behavior and numbers of hauled out pinnipeds typically return to normal within 24 hours or less after a launch event. No observations of injury or mortality to pinnipeds during monitoring were attributable to past launches. As a result, we expect the Proposed Action's potential impacts on MMPA protected pinnipeds to be limited to brief behavioral reactions.

Under the MMPA, the National Marine Fisheries Service (NMFS) issued a Final Rule for taking marine mammals incidental to VSFB launches (NMFS 2019a), and a Letter of Authorization (LOA; NMFS 2019b). The LOA allows launch programs to unintentionally take small numbers of marine mammals during launches. The SLD 30 is required to comply with the LOA listed conditions and address NMFS concerns regarding marine mammals at VSFB. Under the LOA, monitoring of marine mammals at VSFB is required during launches, including the proposed Daytona-E and Laguna-E launch program at SLC-5, under the following:

- Between 1 January and 30 June, pinniped monitoring at south Base haulout locations would commence at least 72 hours prior to a launch event and continue until at least 48 hours after each event.

Given the authorizations and Environmental Protection Measures (EPMs) in place (as described in Appendix A, Section A.3, Marine Biological Resources), including the required monitoring, the Proposed Action would not result in significant impacts on MMPA protected pinnipeds.

Consistency Review Conclusion

The Space Force and USFWS have initiated formal consultation for impacts resulting from the Proposed Action that may affect, but are not likely to adversely affect the southern sea otter. The Space Force will comply with the existing LOA issued by NMFS for Level B Harassment (behavioral disruption) of marine mammals and will implement necessary monitoring and mitigation activities to protect marine mammal species.

The Space Force has determined that the Proposed Action would not result in population-level impacts on any marine resources and biological productivity of coastal waters would be maintained for long-term commercial, recreational, scientific, and educational purposes. Therefore, the Proposed Action would be consistent to the maximum extent practicable with Section 30230 of the CCA.

3.2.4 ARTICLE 4: MARINE ENVIRONMENT (WATER QUALITY)

Policies

CCA Section 30231 – “Biological productivity; water quality” states:

> *The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored through, among other means, minimizing adverse effects of waste water discharges and entrainment, controlling runoff, preventing depletion of ground water supplies and substantial interference with surface water flow, encouraging waste water reclamation, maintaining natural vegetation buffer areas that protect riparian habitats, and minimizing alteration of natural streams.*

CCA Section 30232 – “Oil and hazardous substance spills” states:

> *Protection against the spillage of crude oil, gas, petroleum products, or hazardous substances shall be provided in relation to any development or transportation of such materials. Effective containment and cleanup facilities and procedures shall be provided for accidental spills that do occur.*

Consistency Review

Effects of the Proposed Action on marine biological resources are addressed in Section 3.2.3 (Article 4: Marine Environment [Biological Productivity]) with regard to CCA Sections 30230 and 30231 and terrestrial biological resources are addressed in Section 3.2.6 (Article 5: Land Resources) with regard to CCA Section 30240(b). The analysis determined that the Proposed Action would not affect biological productivity in the coastal zone, and the Proposed Action is consistent with Sections 30230, 30231, and 30240(b) to the maximum extent practicable.

The Proposed Action would result in potential impacts on surface and groundwater quality associated with construction and launch activities. This section will evaluate potential effects on water quality for consistency with the CCA Section 30230.

Surface Water

Constructing the SLC-5 launch site, installing utilities, establishing firebreaks, and making improvements to access roads would disturb soils, remove vegetation, increase impermeable surfaces, and increase the potential for hazardous materials to be spilled or released. The EPMs, as described in Appendix A, Sections A.4 (Water Resources) and A.8 (Hazardous Materials and Waste Management) and compliance with all existing federal and state regulations, would avoid and minimize impacts on surface waters from construction and operation at SLC-5. In addition, road improvements would follow standard recommended practices to avoid and minimize erosion potential (e.g., Bloser et al. 2012), dirt access roads would be inspected after rainstorms for indications of erosion, and repairs made promptly. Therefore, construction of SLC-5 and associated infrastructure would not have a significant effect on surface water.

The proposed launch activities at SLC-5 would create exhaust clouds; however, there are no solid fuels proposed, the design of the deflector would direct exhaust away from Honda Canyon, and emissions are not expected to have any effect on surface waters. Phantom would enroll in RWQCB's General Waiver for Specific Types of Discharges (or other state discharge permit) prior to discharging any water out of the deluge water retention basin. Any deluge water that remains after launches or stormwater that accumulates within the basin would be tested for contamination. If contamination is encountered, the contents would be pumped out and disposed of per the waiver/permit and state and Federal regulations. If the water is clean enough to go to grade, it would be discharged from the retention basin to an infiltration area or spray field. The Proposed Action is also exempt from the need for coverage under the NPDES Construction General Permit, due to there being no potential for discharge to Waters of the U.S. Therefore, impacts to surface water from launch operations at SLC-5 under the Proposed Action would not be significant.

Ground Water

Construction of the SLC-5 launch site and associated utilities would not require substantial excavation activities or require the use of footings that would interact with groundwater. At maximum cadence of 48 launches and static fires per year, the annual usage for deluge would range between 100,800 to 480,000 gallons (0.31 to 1.47 ac-ft). In addition, a maximum of 72,000 gallons (0.22 ac-ft) per year would be required to support the personnel and operational activities at SLC-5. Therefore, at maximum cadence, the Proposed Action will use up to 552,000 gallons (1.69 ac-ft) of water per year. To meet this need, the Space Force would install an extension to the VSFB water supply line. The current water source for VSFB is the San Antonio Creek Basin via four (4) water wells. There is an existing connection between State water and the VSFB water supply system; however, due to ongoing drought conditions and significant reductions in State water allocations, VSFB will remain on well water from the San Antonio Creek Basin for the foreseeable future. Annual VSFB water use over the past three years (2019 through 2021) has averaged 910,500,000 gallons (2,794 ac-ft) per year. The operations at SLC 5 would use up to 1.69 ac-ft per year, representing approximately 0.06% of the total annual water usage on VSFB. The Proposed Action's water usage would therefore be negligible and not contribute in any measurable way to the collective effects of water extraction requirements for all VSFB operations.

Deluge water remaining after launches and stormwater that is collected in the deluge basin would be managed per the RWQCB's General Waiver for Specific Types of Discharges enrollment conditions (or other state discharge permit). Any deluge water that remains after launches or stormwater that accumulates within the basin would be tested for contamination. If contamination is encountered, the contents would be pumped out and disposed of per the waiver/permit and state and Federal regulations.

If the water is clean enough to go to grade, it would be discharged from the retention basin to an infiltration area or spray field. During operation of SLC-5, accidental discharge of pollutants could occur; however, proper handling of hazardous materials and wastes management would reduce or eliminate potential contaminated runoff that could infiltrate groundwater. In addition, implementing EPMs to protect water resources (Appendix A, Section A.4, Water Resources) would further help protect groundwater resources. Therefore, the Proposed Action would not have significant impacts on groundwater.

Conclusion

The Proposed Action avoids substantially interfering with surface water flow and would not substantially alter the quality of coastal waters, streams, wetlands, or estuaries. Therefore, the Proposed Action is consistent to the maximum extent practicable with Sections 30231 and 30232 of the CCA.

3.2.5 ARTICLE 4: MARINE ENVIRONMENT (COMMERCIAL AND RECREATIONAL FISHING)

Policies

CCA Section 30234 – "Commercial fishing and recreational boating facilities" states:

> *Facilities serving the commercial fishing and recreational boating industries shall be protected and, where feasible, upgraded. Existing commercial fishing and recreational boating harbor space shall not be reduced unless the demand for those facilities no longer exists or adequate substitute space has been provided. Proposed recreational boating facilities shall, where feasible, be designed and located in such a fashion as not to interfere with the needs of the commercial fishing industry.*

CCA Section 30234.5 – "Economic, commercial and recreational importance of fishing" states:

> *The economic, commercial, and recreational importance of fishing activities shall be recognized and protected.*

Consistency Review

Southern California's west coast is a leading recreational fishing area. Weather and sea conditions allow for year-round fishing activity. Commercial passenger fishing vessels frequently offer single-day sport fishing excursions from Morro Bay and Port San Luis. Proposed launch activities would result in temporary restrictions of the waters off the coast of VSFB (48 launches annually). However, these are partial area closures, so boats can move to another area to fish without leaving the area entirely. Closures would typically be limited to specific areas and of short duration (no more than two hours), and areas would reopen when launch activities are complete. Therefore, impacts on recreational fishing would be less than significant. The Proposed Action is consistent to the maximum extent practicable with Sections 30234 and 30234.5 of the CCA.

3.2.6 ARTICLE 5: LAND RESOURCES

Policies

CCA Section 30240 (b) – "Environmentally sensitive habitat areas, adjacent developments" states:

> *Environmentally sensitive habitat areas shall be protected against any significant disruption of habitat values, and only uses dependent on those resources shall be allowed within those areas.*

CCA Section 30244 – "Archaeological or paleontological resources" states:

> *Where development would adversely impact archaeological or paleontological resources as identified by the State Historic Preservation Officer, reasonable mitigation measures shall be required.*

Consistency Review

Environmentally Sensitive Habitat Areas

As shown in Table 3-4, there are five species that occur within the vicinity of SLC-5 that are federally listed as threatened or endangered under the Endangered Species Act (ESA). The Space Force determined these species may be potentially affected by the Proposed Action from physical impacts during construction and noise impacts during construction and operation of the launch facility. The Space Force has initiated formal consultation with the USFWS for these species and the Biological Assessment has been included in this request for your awareness.

Table 3-4: Determination of Potential Impacts to Federally Listed Threatened & Endangered Species

Species	Status	ESA Effects Determination
FISHES		
Tidewater goby (*Eucyclogobius newberryi*)	FE	NLAA
AMPHIBIANS		
California red-legged frog (*Rana draytonii*)	FT	LAA
BIRDS		
California condor (*Gymnogyps californianus*)	FE	NLAA
Marbled murrelet (*Brachyramphus marmoratus*)	FT	NLAA
Western snowy plover (*Charadrius nivosus nivosus*)	FT	LAA

Notes: FE = Federally Endangered Species; FT = Federally Threatened Species; MMPA = Marine Mammal Protection Act, NA = not applicable; NE = no effect; NLAA = May affect, not likely to adversely affect; ESA = Endangered Species Act, MMPA = Marine Mammal Protection Act

Tidewater goby (TWG; *Eucyclogobius newberryi*)

Direct Impacts. The SLC-5 launch pads would be designed to direct any ejected steam or water and flame produced during launch away from Honda Canyon. As a result, there would be no potential impacts to Honda Creek, where suitable, but currently unoccupied TWG habitat is located. Therefore, the Proposed Action would not have any direct physical impacts on TWG.

Noise Impacts. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to TWG. During each of the 48 launch events that would occur on an annual basis, engine noise produced by the Laguna-E would reach 130 dB maximum sound level (Lmax) at potential TWG habitat in Honda Creek. Static fire events would similarly reach up to 130 dB Lmax at this location.

Exceptionally little sound is transmitted between the air-water interface (Godin 2008). Therefore, in-air sound during launches and static fire events is not expected to cause more than a temporary behavioral disruption to fish, if present, in Honda Creek. Since TWG have not been detected during regular survey efforts dating back to 2008 (MSRS 2009, 2016, 2018a), they are unlikely to be present during the proposed launch and static fire activities; however, TWG could potentially recolonize Honda Creek in the future.

Conclusion. Because of the low likelihood of TWG presence in Honda Creek and the minimal transfer of in-air noise into underwater noise, the anticipated level of disturbance from the Proposed Action would be discountable. Therefore, VSFB has determined that the Proposed Action may affect but is not likely to adversely affect the TWG and, therefore, would not be significant.

California red-legged frog (CRLF; *Rana draytonii*)

Direct Impacts. Direct impacts on post-metamorphic CRLF, including injury and mortality, may inadvertently occur during removal of vegetation, site grading and contouring, construction, firebreak and fire access road establishment, and site maintenance from the operation of heavy equipment, machinery, and vehicles. CRLF that may disperse through the Action Area could become entrapped in any holes or trenches left open overnight. However, open holes and trenches would be covered overnight and the risk of impacts on CRLF will be reduced because biologists will monitor construction activities and search for animals trapped in open holes and trenches. Any CRLF detected within the construction area would be captured and relocated to nearby suitable habitat. In addition, when any demolition, contouring, or construction is occurring at SLC-5, the active construction areas would be surrounded by exclusion fence. A United States Fish and Wildlife Service (USFWS) approved biologist would be present to monitor vegetation-clearing activities and move any CRLF encountered to the nearest suitable habitat out of harm’s way. Regardless, post-metamorphic frogs may be injured or killed during construction and vegetation clearing activities. The risk of introducing or spreading chytrid fungus would be reduced by requiring implementation of the Declining Amphibian Populations Task Force (DAPTF) Fieldwork Code of Practice (DAPTF 2019).

During launches, ejected steam, deluge water, and flame may injure or kill CRLF that are in the vicinity of the launch pad or exhaust ducts at time of launch. However, the launch pads would be designed to direct any ejected steam or water and flame away from Honda Canyon, therefore avoiding any potential impacts to Honda Canyon, where CRLF are known to breed and the most likely area for them to occur year-round. Additionally, the exhaust ducts would be maintained free of water between launches and deluge water would only be added for 20-seconds. Any ejected water would be captured in a retention basin. Retained water would be tested for hydrocarbon contamination in the days following each launch. If the resulting values are compliant with the Vandenberg Hazardous Waste Management Plan (Department of the Air

Force 2019), the water will be discharged to grade. Otherwise, water will be pumped and properly disposed of as wastewater. Any water retention basins would be designed to exclude access by CRLF. If such exclusion is not possible, and water is present in retention basin overnight, the basin would be checked daily for CRLF prior to pumping. Finally, due to vegetation management around the proposed launch pads, the likelihood of CRLF being present near the pads during launch events would be very low.

Noise Impacts. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to CRLF. During each of the 48 launch events that would occur on an annual basis, engine noise from Laguna-E vehicles would reach 130 dB Lmax in areas known to be occupied by CRLF in Honda Creek. Static fire events would similarly reach up to 130 dB Lmax in Honda Canyon. Engine noise would reach as high as 144 dB Lmax in upland CRLF dispersal habitat on SLC-5 during these events (refer to Figure 3.3-3 of the EA). However, vegetation management in the immediate vicinity of launch vehicle launch sites would make CRLF presence above ground in these areas unlikely during typical dry conditions.

All life stages of CRLF can detect noise and vibrations (Lewis & Narins 1985) and are assumed to be able to perceive the engine noise produced by launch vehicles. There are no studies on the effects of noise on CRLF, and few studies on the effects of noise disturbance on anurans in general. Those studies that have been conducted have often focused on the effects of sustained vehicle noise associated with roads near breeding ponds, which have been shown to have negative effects on individual frog's behavior and physiology and may have consequences for populations (see Parris et al. 2009 and Tennessen et al. 2014). However, impacts from engine noise would be of short duration and, therefore expected to have different effects on frogs than sustained noise.

Engine noise would likely trigger a startle response in CRLF, causing them to flee to water or attempt to hide in place. It is likely that any reaction would be dependent on the sensitivity of the individual, the behavior in which it is engaged when it experiences the noise, and the sound level (e.g., higher stimuli would be more likely to trigger a response). Regardless, the reaction is expected to be the same – the frog's behavior would be disrupted, and it may flee to cover in a similar reaction to that of a frog reacting to a predator. As a result, there could be a temporary disruption of CRLF behaviors including foraging, calling, and mating (during the breeding season). However, frogs tend to return to normal behavior quickly after being disturbed. Rodrıguez-Prieto and Fernandez-Juricic (2005) examined the responses in the Iberian frog (*Rana iberica*) to repeated human disturbance and found that the resumption of normal behavior after three repeated human approaches occurred after less than four minutes. Sun and Narins (2005) examined the effects of airplane and motorcycle noise on anuran calling in a mixed-species assemblage, including the sapgreen stream frog (*Rana nigrovittata*). Sun and Narins found that frogs reduced calling rate during the stimulus but the sapgreen stream frog increased calling rate immediately after cessation of the stimuli, likely in response to the subsequent lull in ambient sound levels. Similarly, qualified biologists working on VSFB and elsewhere in CRLF occupied habitat have routinely observed a similar response in this species after disrupting individuals while conducting frog surveys (A. Abela, M. Ball, and J. LaBonte, pers. obs.). CRLF would, therefore, be expected to resume normal activities quickly once the disturbance has ended and any behavioral response would be short term.

Although no studies have been conducted on hearing damage in CRLF, Simmons et al. (2014) found that consistent morphological damage of hair cells in the hearing structures of American bullfrogs (Lithobates catesbeianus), which are within the same Family as the CRLF (Ranidae), were observed with sound exposure levels (SEL) greater than 150 dB Lmax SEL. Even after such hearing damage, bullfrogs showed full functional recovery within 3 to 4 days, thus the hearing damage was temporary (Simmons et al. 2014).

CRLF in terrestrial environments may be exposed to engine noise levels of 144 dB Lmax and, therefore, even temporary hearing damage would be unlikely for CRLF that may be present. Additionally, due to vegetation management around the proposed launch vehicle sites, the likelihood of CRLF being present in terrestrial environments exposed to these noise levels would be very low and few individuals would be impacted.

The USSF will implement a monitoring program to track CRLF habitat occupancy, breeding behaviors, and tadpole densities in Lower Honda Creek (the area to receive the highest noise levels) as the frequency of launch and static fire under the Proposed Action gradually increases. As full tempo under the Proposed Action and the launch programs listed above will not reach maturity until 2028 to 2030, the USSF will be able to assess incremental changes in the acoustic environment at Lower Honda Creek using passive bioacoustic recorders and analyze these data to assess any associated impacts on the CRLF population. If CRLF occupancy, calling frequency, or tadpole densities decline from baseline by 15% or more, the 15% decline from baseline is maintained for two consecutive years, and the decline is attributed to an increase in Phantom's launch and static fire operations, VSFB would mitigate for these impacts by creating new CRLF breeding habitat at the San Antonio Creek Oxbow Restoration Area, an established wetland mitigation site that is located outside of areas currently impacted by launch noise on VSFB. Historically occupied by riparian vegetation, restoration efforts would focus on enhancing this abandoned tract of agricultural land to improve San Antonio Creek and provide breeding habitat for CRLF and thus offset any population level impacts at Honda Creek within an area that is not impacted by launch noise.

Artificial Lighting Impacts. The effects of artificial lighting on anurans are inconsistent and appear to vary by species and life stage (reviewed in Dutta 2018 and Froglife 2019). Frogs illuminated with acute artificial light originating from flashlights have been shown to reduce calling frequency (Baker & Richardson 2006; Hall 2016). Reduced calling has the potential to negatively impact breeding and, therefore, affect population dynamics (Baker & Richardson 2006).

The reaction to acute artificial light exposure may be different than that to diffused artificial ambient light, such as facility lighting. In studies on wood frogs (*Lithobates sylvaticus*), experimental exposure to artificial light at night was found to make them more vulnerable to other stressors such as parasites and pollution (May et al. 2019). In a study designed to mimic artificial light generated by street and outdoor lighting on common toads (*Bufo bufo*) during their breeding period, the total time spent in activity by male toads decreased by more than half due to decreases in activity during the night period. There were also changes in energy metabolism. Coupled, these changes have the potential to impact reproduction and overall fitness in species exposed to artificial light at night (Touzot et al. 2019).

If facility lighting associated with the Proposed Action results in an increased presence of artificial light in the Honda Creek riparian corridor CRLF are likely to be adversely impacted. However, except when necessary for safety or performance of launch operations, artificial lighting at the SLC-5 facility would be minimized during the hours of darkness. In addition, modeling of the preliminary lighting plan shows that lighting levels of 1-foot candle would not extend beyond the SLC-5 facility (refer to Figure 4.3-1 of the EA).

Habitat Impacts. The Proposed Action would not have any impacts to CRLF aquatic habitat. The Proposed Action may, however, result in a degradation in the quality of CRLF aquatic habitat in Honda Creek through exposure to artificial light at night. As noted above, artificial lighting at SLC-5 would be minimized during the hours of darkness, except when necessary for safety or performance of launch operations, and, to the maximum extent practicable, lights would be placed and designed to minimize illumination of Honda Canyon. Construction of SLC-5 and the associated firebreaks, fire access road maintenance, and utility corridor would result in impacts to approximately 37.8 ac (15.3 ha) of suitable CRLF upland dispersal habitat (Note: total excludes existing paved roads).

Conclusion. VSFB has determined that noise, artificial lighting, and potential physical impacts may affect, and are likely to adversely affect CRLF. To comply with the USSF's sections 7(a)(1) and 7(a)(2) obligations under the ESA, as well as the prospective USFWS Mitigation Policy, post-project restoration activities will be implemented. Restoration activities would align with the objectives of the CRLF Conservation Strategy (USFWS in prep) with the goal of achieving no net loss to the species. Therefore, effects on CRLF will not be significant.

Marbled Murrelet (MAMU; *Brachyramphus marmoratus*)

Direct Impacts. No ground disturbing activities or vegetation management activities would occur within or near MAMU habitat.

Noise and Visual Impacts. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to MAMU. This species has occasionally been observed between the late summer through winter foraging off the coast of south VSFB (eBird 2021). Although unlikely, if MAMU were present immediately off the coast during a Laguna-E launch event, they would experience engine noise of less than 120 dB Lmax (refer to Figure 3.3-4 of the EA). During static fire events, noise directly off the coast of SLC-5 would be less than 115 dB Lmax. Noise levels during Daytona-E launches and static fire events would be less than those produced by the Laguna-E. Additionally, the majority of MAMU are found in a band approximately 984 to 6,561 ft (300 to 2,000 meters [m]) from shore (Strachan et al. 1995) where noise levels would decrease to as low as 110 dB Lmax. MAMU do not nest on VSFB so exposure to noise impacts would be limited to foraging adults.

Very little data are available regarding MAMU's response to noise and visual disturbances; however, Bellefleur et al. (2009) examined the response of MAMU to boat traffic. MAMU response was found to depend on the age of the birds, the distance and speed of the boats encountered, and the season. MAMU either showed no reaction, flew, or dove in response. Late in the season (July through August), some MAMU were found to fly completely out of feeding areas when approached by boats traveling in excess of 17.9 mi per hour (28.8 km per hour). The dominant response of MAMU to approach by boats was, however, for birds to dive and resurface a short distance away. Therefore, we expect MAMU to dive and resurface as a startle response, but then return to normal behavior soon after each launch or static fire event has been completed.

Conclusion. Based on our analysis, MAMU are unlikely to be present during a launch or static fire event and if present may have a temporary behavioral reaction in response to noise. Thus, the Proposed Action would have a discountable effect on MAMU. Therefore, VSFB has determined that the Proposed Action may affect, but is not likely to adversely affect MAMU and, therefore, would not be significant.

Western Snowy Plover (SNPL; *Charadrius nivosus*)

Direct Impacts. No ground disturbing activities or vegetation management activities would occur within or near SNPL habitat; therefore, these actions would have no effect on SNPL. The potential effects of noise are discussed below.

Noise and Visual Disturbance. To evaluate the worst-case scenario, noise from the louder of the two proposed vehicles, the Laguna-E, was analyzed for potential impacts to SNPL. The nearest nesting areas would be exposed to levels between 100 and 110 dB Lmax during Laguna-E launches (refer to Figure 3.3-5 of the EA) and less than 100 dB Lmax during static fire events. SNPL monitoring for impacts from launch-related engine noise and visual disturbance has been conducted during numerous launches on VSFB. Direct observations of wintering birds were made during a Titan IV and Falcon 9 launch from SLC-4E (SRS Technologies, Inc. 2006b; Robinette and Ball 2013). The Titan IV launches resulted in sound levels of 130 dBA Lmax. SNPL did not exhibit any adverse reactions to these launches (SRS Technologies, Inc. 2006b; Robinette and Ball 2013) with the exception of one observation. During the launch of a Titan II from SLC-4W in 1998, monitoring of SNPL found the nest located closest to the launch facility had one of three eggs broken after the launch (Applegate and Schultz 1998). The cause of the damaged egg was not determined.

More recently on 12 June 2019, SNPL response was documented during a SpaceX Falcon 9 launch and first stage recovery at SLC-4. The return flight of the first stage to VSFB produced a 3.36 psf sonic boom and landing engine noise of 138 dB Lmax and 130 dB SEL, as measured on South Surf Beach. SNPL response to the noise impacts was documented via pre- and post-launch monitoring and video recording during the launch event. Incubating SNPL captured on video were observed to startle and either jump or hunker down in response to the sonic boom. One SNPL egg showed signs of potential damage. This egg was part of a three-egg clutch in which the other two eggs successfully hatched. It is not uncommon for one or more eggs from a successful nest to not hatch. Failure of the egg to hatch could not be conclusively tied to the launch event (Robinette and Rice 2019).

VSFB would augment the existing SNPL monitoring program on Base, which records habitat use, nesting efforts, nest fates, fledgling survival, and population size through each breeding season, with geospatial analysis of SNPL nesting and the noise environment. Sound level meters would be deployed immediately inland of South Surf Beach and a control site to characterize the noise environment during the breeding season within the Daytona-E and Laguna-E noise 100 dB L_{max} footprint. Geospatial analysis would be performed annually as Phantom's launch tempo gradually increases over six years to full cadence to assess whether patterns of nesting activity, nest fates, or fledgling success are negatively impacted by noise from the Proposed Action or other launch programs on VSFB. If geospatial analysis shows that a statistically significant decline in breeding effort or nest success over two consecutive years is attributable to the Proposed Action, VSFB would offset this impact by increasing predator removal efforts on Base to include the non-breeding season, particularly focusing on raven removal at and adjacent to VSFB beaches.

Conclusion. VSFB has determined that the Proposed Action may affect, and is likely to adversely affect, the SNPL on VSFB. VSFB would perform geospatial analysis to monitor the impacts of noise from the Proposed Action and other launch programs on Base to assess any potential adverse impacts on the species at VSFB as the launch frequency under the Proposed Action gradually increases and reaches full tempo. If adverse effects are found, VSFB would mitigate those effects by increasing predator management efforts on VSFB to comply with the USSF's sections 7(a)(1) and 7(a)(2) obligations under the ESA. Mitigation activities would align with the SNPL Recovery Plan (USFWS 2007), and 5-year review (USFWS 2019) with the goal of achieving no net loss to the species. Therefore, effects on SNPL will not be significant.

California Condor (*Gymnogyps californianus*)

Direct Impacts. The Proposed Action is outside the normal range of the species and the species is not known to breed within the Action Area; therefore, physical impacts to habitat associated with the Proposed Action would have no effect on California condor.

Noise and Visual Disturbance. It is difficult to analyze the effect human disturbance could have on California condors. Generally, California condors are less tolerant of human disturbances near nesting sites than at roosting sites. The species is described as being "keenly aware of intruders" and may be alarmed by loud noises from distances greater than 1.6 mi (2.6 km). In addition, the greater the disturbance in either noise level or frequency, the less likely the condor would be to nest nearby. As such, USFWS typically requires isolating roosting and nesting sites from human intrusion (USFWS 1996). Noise from a launch coupled with visual disturbance could cause a startle response and disrupt behavior if a condor is within the Proposed Action. Although launch noise and visual disturbance may cause a startle response and disrupt behavior, the likelihood of a condor being present during these activities is extremely low and, therefore, the effect of the Proposed Action would be discountable.

Conclusion. The overall likelihood of a California condor occurring within the Proposed Action Area during a launch or static fire event is extremely unlikely, hence, discountable. Therefore, VSFB has determined that Proposed Action may affect, but is not likely to adversely affect, the California condor and therefore, not be significant. The Space Force will coordinate with the USFWS and Ventana Wildlife Society to monitor for condor presence prior to launches.

Vegetation Communities

The proposed project will re-establish the SLC-5 launch site that was operated from by the National Aeronautics and Space Administration between 1962 and 1994 to launch Scout space launch vehicles. The site was fully demolished by 2012. The proposed new SLC-5 construction is located entirely within the previosuly disturbed area.

Construction Impacts. Figure 3-1 shows the vegetation (a mix of upland types) within the vicinity of the Proposed Action where construction would occur. During construction of SLC-5 and the associated infrastructure, Phantom would remove vegetation by discing, mowing, masticating, grading, and/or hand removal prior to construction activities in areas permanently or temporarily impacted by the Proposed Action. Table 3-4 provides estimates of permanent and temporary impacts to native and non-native vegetation occurring within the Proposed Action Area. A total of 25.8 ac (10.4 ha) of predominantly vegetated habitat (native and non-native) would be disced or mowed during the Proposed Action.

The Space Force would preserve existing native vegetation to the extent feasible while meeting construction and fire safety requirements. Additionally, native vegetation would be allowed to re-establish in areas where temporary impacts occur because Phantom would apply an appropriate native hydroseed mix in coordination with the SLD 30/CEI botanist. There is also an abundance of native vegetation on VSFB outside of the Proposed Action Area. For instance, VSFB has an estimated 16,884 ac (6,832 ha) of central coastal scrub, 2,675 ac (1,082 ha) of central coastal scrub / iceplant 2,101 ac (850 ha) of Venturan coastal sage scrub, and 1,247 (505 ha) of Venturan coastal sage scrub / herb (Wildscape Restoration 2009). The Space Force considers the small fraction of native vegetation loss from implementing the Proposed Action to be insignificant; therefore, the Proposed Action would not have a significant impact on vegetation resources.

If practicable, vegetation clearing will occur outside of bird nesting season (15 February through 15 August). If vegetation clearing occurs during nesting season, a qualified biologist would survey the area for nesting birds and delineate buffers around any found nests that are of sufficient size to prevent disturbance prior to vegetation clearing activities. Additional EPMs, as described in Appendix A, Section A.2 (Terrestrial Biological Resources), would be implemented to further avoid and minimize impacts on wildlife resources. As a result, potential impacts on wildlife species as a result of vegetation management would be less than significant.

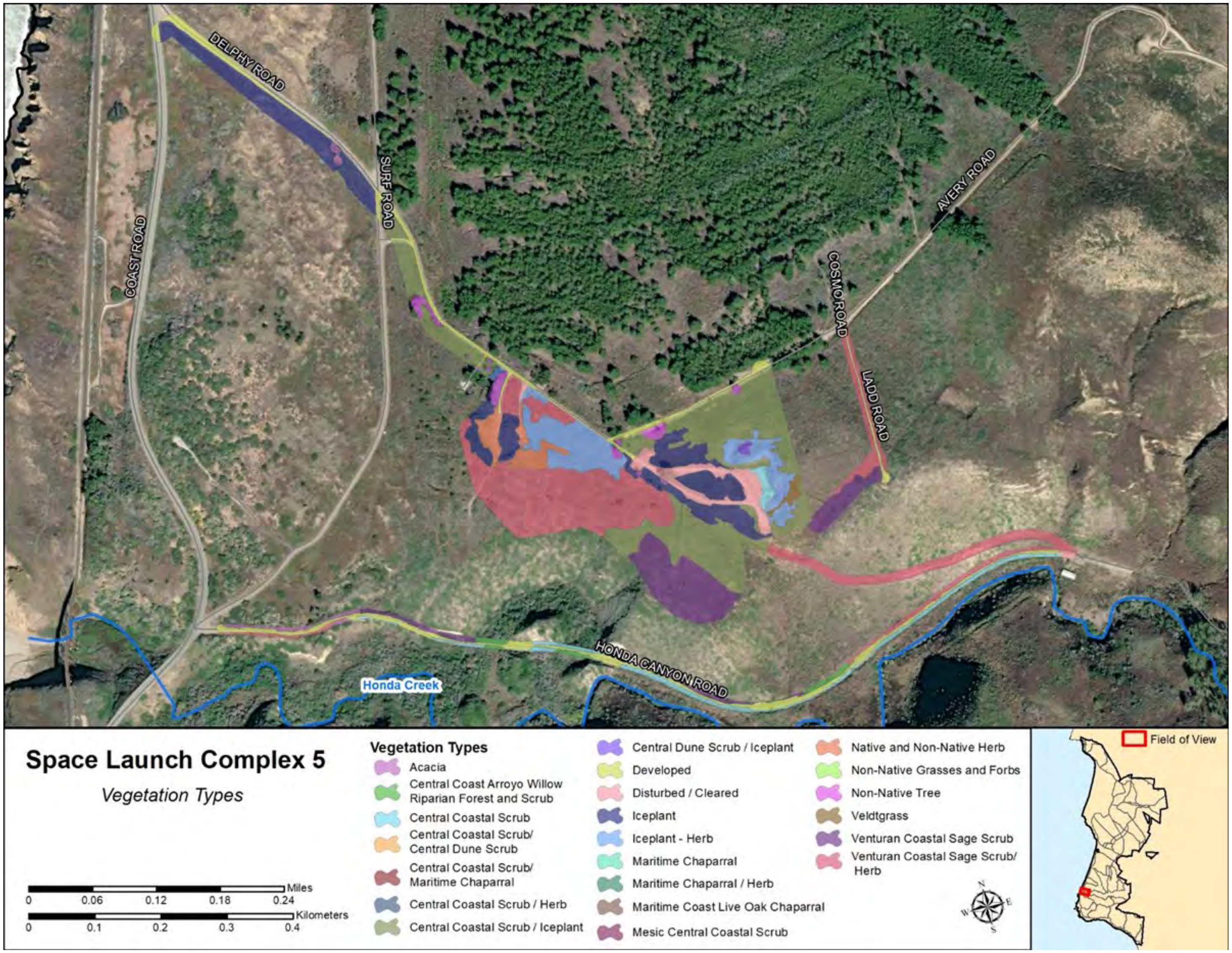

Figure 3-1: Vegetation Types within the vicinity of the Proposed Action

Table 3-5: Impacts on Vegetation Types

Vegetation Types	Not Impacted	Temporary Impacts	Permanent Impacts
Native			
Central Coast Arroyo Willow Riparian Forest and Scrub	0.22	0.12	
Central Coastal Scrub	0.17	1.09	0.27
Central Coastal Scrub / Iceplant	4.23	1.71	3.56
Central Dune Scrub / Iceplant			0.07
Native and Non-Native Herb			1.10
Venturan Coastal Sage Scrub	0.61		3.68
Venturan Coastal Sage Scrub / Herb	1.39		9.15
Total	**6.62**	**2.93**	**17.83**
Non-Native			
Acacia	0.25	0.08	0.03
Iceplant		2.61	3.73
Iceplant - Herb			3.51
Non-Native Tree		0.20	0.47
Veldtgrass			0.20
Total	**0.25**	**2.89**	**7.94**
Other			
Developed			4.10
Disturbed / Cleared			1.57
Total	**0.00**	**0.00**	**5.68**

Noise Impacts. Construction of the SLC-5 facility, associated utilities, road improvements, and vegetation clearing would generate noise and disturbance that could result in temporary impacts on wildlife species. Temporary disturbances due to noise and human presence related to these activities could disrupt foraging and roosting activities or cause wildlife species to avoid the work areas. We expect wildlife species to experience some level of noise disturbance during the day; however, construction activities would be temporary and only create noise above ambient levels over a relatively small area. Individuals would experience temporary behavioral disruption and likely move to adjacent suitable habitat until the noise disturbance ceases. A qualified biological monitor would oversee activities to ensure implementing EPMs designed to minimize and avoid impacts on native wildlife species (as described in Appendix A, Section A.2, Terrestrial Biological Resources). As a result, potential impacts on wildlife species resulting from noise associated with construction and vegetation management would be less than significant.

Temporary disturbances to terrestrial wildlife species within the Action Area would also occur during the launch and static fire events from noise caused by the firing and flight of the vehicles. Wildlife responses to noise can be behavioral or physiological – ranging from mild, such as an increase in heart rate, to more damaging effects on metabolism and hormone balance. Because responses to noise are species specific, exact predictions of the effects on each species are unreliable without data pertaining to those species or similar species.

During launches and static firings, noise levels up to 140 dB Lmax would be produced at SLC-5. Although exact predictions cannot be made, these noises are expected to elicit a startle response in terrestrial wildlife species with developed hearing abilities. Potentially, wildlife hearing thresholds could shift either permanently or temporarily in wildlife if they are active on the surface close to SLC-5 during launch and static fire events. Exceptionally little sound is transmitted between the air-water interface; thus, in-air sound would not have a significant effect on submerged animals (Godin 2008). Likewise, wildlife present below the ground surface would be insulated from noise impacts. Because the affected area is relatively small and the launch and static fire events are temporary, we expect behavioral disruptions and potential hearing threshold shifts would not have population-level impacts and therefore would not have a significant effect on wildlife resources.

Consistency Review Conclusion

The Space Force and USFWS have initiated formal consultation for impacts resulting from the Proposed Action that may affect, but are not likely to adversely affect the TWG, California condor, MAMU, and SNPL, and that may affect and are likely to adversely affect the CRLF.

The Space Force has determined that the Proposed Action would not result in population-level impacts on any biological resource and that native vegetation communities would be preserved to the maximum extent practicable. Further, restoration of temporarily disturbed sites would occur and all EPM’s would be followed (Appendix A). Therefore, the Proposed Action would be consistent to the maximum extent practicable with Section 30240 (b) of the CCA.

Archaeological or Paleontological Resources

Proposed launch sites and launch activities may occur in areas where archaeological or paleontological resources exist; however, protective measures would be implemented to ensure no adverse effects would occur. Four archaeological sites are present within the Action Area. Of the four archaeological sites, two sites (CA-SBA-538 and CA-SBA-2230) were determined to be ineligible for the National Register of Historic Places (NRHP), one is an NRHP-eligible site (CA-SBA-670), and one site (CA-SBA-2934) was considered not an historic property and potential ineligible for the NRHP because the site has appeared to be destroyed during construction of SLC-5. As part of development of the EA, three shovel test pits were conducted at the locations of three previously recorded isolated artifacts and one newly discovered isolated artifact. However, subsurface testing confirmed that all of the isolated artifacts were truly isolated and not surface manifestations of archaeological sites.

Of the four archaeological sites, only one is in an area that would require improvements to existing roads for improved fire safety and access. NRHP-eligible site CA-SBA-670 is bisected by Honda Canyon Road, which provides access to the launch site. However, the portion of Honda Canyon Road within CA SBA-670 would not require improvements, and the proposed activities within the site would be limited to removal of vegetation from the existing paved road segment. Based on this information and discussions with VSFB cultural resources personnel, no testing was required at this site. However, based on prior excavation results along the south side of Honda Canyon Road just east of the intersection of Coast, Surf, and Honda Canyon Roads, intact buried deposits associated with CA-SBA-670 could exist along Honda Canyon Road. The Proposed Action is a federal undertaking subject to compliance with Section 106 of the National Historic Preservation Act (NHPA) of 1966 as amended (16 U.S.C. § 470 et seq.). The DAF has completed Section 106 consultation with California State Historic Preservation Office (SHPO) concurrence under 36 C.F.R. Part 800. Exclusionary fencing is required where vegetation clearance is proposed within the boundaries of CA-SBA-670 to prevent accidental incursion into these deposits. With implementation of this protective measure, activities associated with the Proposed Action would have no adverse effect archaeological Resources.

Conclusion

Proposed launch site and activities may occur where archaeological or paleontological resources exist. However, protective measures currently in place would be implemented to ensure no adverse effects would occur. Therefore, the Proposed Action is consistent to the maximum extent practicable with Section 30244 of the CCA.

3.2.7 ARTICLE 6: DEVELOPMENT

Policies

CCA Section 30250 (a) – "Development location; existing developed areas" states:

> *(a) New residential, commercial, or industrial development, except as otherwise provided in this division, shall be located within, contiguous with, or in close proximity to, existing developed areas able to accommodate it or, where such areas are not able to accommodate it, in other areas with adequate public services and where it will not have significant adverse effects, either individually or cumulatively, on coastal resources. In addition, land divisions, other than leases for agricultural uses, outside existing developed areas shall be permitted only where 50 percent of the usable parcels in the area have been developed and the created parcels would be no smaller than the average size of surrounding parcels.*

CCA Section 30251 – "Scenic and visual qualities" states:

> *The scenic and visual qualities of coastal areas shall be considered and protected as a resource of public importance. Permitted development shall be sited and designed to protect views to and along the ocean and scenic coastal areas, to minimize the alteration of natural land forms, to be visually compatible with the character of surrounding areas, and, where feasible, to restore and enhance visual quality in visually degraded areas. New development in highly scenic areas such as those designated in the California Coastline Preservation and Recreation Plan prepared by the Department of Parks and Recreation and by local government shall be subordinate to the character of its setting.*

CCA Section 30253 – "New development" states:

> *New development shall do all of the following: (a) Minimize risks to life and property in areas of high geologic, flood, and fire hazard. (b) Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs. (c) Be consistent with requirements imposed by an air pollution control district or the State Air Resources Board as to each particular development. (d) Minimize energy consumption and vehicle miles traveled. (e) Where appropriate, protect special communities and neighborhoods that, because of their unique characteristics, are popular visitor destination points for recreational uses.*

Consistency Review

The SLC-5 launch site was used by National Aeronautics and Space Administration between 1962 and 1994 to launch Scout space launch vehicles. At the completion of the Scout program in 1994, all facilities at SLC-5 were deactivated and then demolished between 2009 and 2012. The proposed new SLC-5 construction is located entirely within the previosuly disturbed area and in close proximity to existing infrastructure to support operations. Adjacent land is used for similar operations. Therefore, the Proposed Action is consistent to the maximum extent practicable with Section 30250(a) of the CCA.

Scenic and visual qualities of coastal areas as a resource of public importance in developing the proposed launch site were considered. The former launch site (SLC-5) would be used for the proposed launch program. Proposed activities would be similar to launch activities that have been historically performed at this site and nearby launch sites on VSFB. Proposed construction at the launch site would not be in a highly scenic area for the public and viewsheds would not be substantially degraded because the project would still be consistent with launch operations and the operational character of the area. The proposed activities would not result in impacts on visual resources. Therefore, the Proposed Action is consistent to the maximum extent practicable with Section 30251 of the CCA.

The proposed launch site will not occur within the floodplain and will implement all appropriate Best Management Practices (BMP's) in stormwater management plans to prevent erosion. This project will not cause any changes to the Space Force hazardous operations or range safety procedures, nor cause exceedance of air quality standards or health-based standards for non-criteria pollutants. Therefore, the Proposed Action is consistent to the maximum extent practicable with Section 30253 of the CCA.

4 STATEMENT OF CONSISTENCY

The Space Force has reviewed the CCMP and has determined that the policies identified in Section 3.1 (Enforceable Policies of the California Coastal Management Program That Are Not Applicable to the Proposed Action) of this CD do not apply to the Proposed Action. In addition, the Space Force has determined that all or parts of the policies reviewed in Section 3.2 (Enforceable Policies of the California Coastal Management Program That Are Applicable to the Proposed Action) of this CD are applicable for purposes of assessing whether the project would be consistent to the maximum extent practicable with the CCMP. These policies include Sections 30210, 30211, 30220, 30230, 30231, 30232, 30234, 30234.5, 30240(b), 30244, 30250(a), 30251, and 30253.

An effects test was conducted by the Space Force to analyze how and to what degree the Proposed Action would affect California coastal zone uses and resources, as defined in the applicable, enforceable policies. The results of the effects test demonstrate that some components of the Proposed Action could have short-term, temporary effects to California coastal zone uses and resources. While some biological species may be affected, the Proposed Action would not have population-level effects. The Space Force would implement standard operating procedures and EPMs for the Proposed Action (Appendix A), which would reduce the potential impacts of its proposed activities on coastal zone uses and resources. The Space Force is conducting formal consultation with the USFWS and has completed informal consultation with NMFS for potential impacts on species listed under the ESA. NMFS has issued an LOA to the Space Force for potential Level B Harassment of marine mammals due to rocket, missile, or aircraft activities from VSFB. In addition, the Space Force completed consultation with the SHPO regarding effects of their actions on cultural properties listed in or eligible for inclusion in the NRHP. Therefore, the Proposed Action is consistent to the maximum extent practicable with the enforceable policies of the CCMP.

The Space Force requests the CCC concur that implementing SLC-5 construction and launch operations at this pre-existing launch site on VSFB would be consistent with CCA enforceable policies, to the maximum extent practicable.

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APPENDIX A – ENVIRONMENTAL PROTECTION MEASURES

Implementing the environmental protection measures (EPMs), outlined in Tables A.1-1 through A.9-1, would avoid or minimize potential adverse effects to various environmental resources during executing of the Preferred Alternative. Qualified Phantom personnel or contractor staff would oversee fulfilling EPMs.

A.1 Air Quality

The Santa Barbara County Air Pollution Control District (SBCAPCD) and California Air Resources Board (CARB) requires the dust control measures described in Table A.1-1 to decrease fugitive dust emissions from ground disturbing activities, as applicable to the Proposed Action.

Table A.1-1: Dust Control Measures

Air Quality – Dust Control Measures	
Measure	**Description/Purpose**
Water—preferably reclaimed—shall be applied at least twice daily to dirt roads, graded areas, and dirt stockpiles created during construction and demolition activities.	Prevents excessive dust at the staging areas. Watering frequency would be increased whenever wind speed exceeds 15 miles per hour.
After completing construction/demolition activities, disturbed soil shall be treated by watering, revegetating, or spreading soil binders.	Prevents wind erosion of the soil.
All fine material transported off-site shall be either sufficiently watered or securely covered	Prevents excessive dust.
All haul trucks, if needed and if driving off of paved surfaces, would be required to exit the site.	Must exit via an access point where a gravel pad or grizzly has been installed.
Stockpiles of soil or other fine loose material shall be stabilized by watering or another appropriate method.	Prevents wind-blown fugitive dust.
On-site vehicle speeds shall be limited.	Speed limit of 15 miles per hour.
Ground disturbance shall be limited.	Limited to the smallest practical area and to the least amount of time.
Designated personnel shall monitor project activities.	Meant to ensure that excessive dust is not generated at demolition sites.
The Proposed Action shall comply with storm water management plans, including Best Management Practices (BMPs).	To reduce dust emissions.
Any portable equipment powered by an internal combustion engine with a rated horsepower of 50 brake horsepower or greater used for this project shall be registered in the California State-wide Portable	Comply with State and local regulations.

Air Quality – Dust Control Measures	
Measure	**Description/Purpose**
Equipment Registration Program or have a valid SBCAPCD Permit to Operate.	
Earth moving shall comply with SBCAPCD Rule 345, Control of Fugitive Dust from Construction and Demolition Activities.	Under Rule 345, construction, demolition, or earthmoving activities are prohibited from causing discharge of visible dust outside the property line and must utilize standard BMPs to minimize dust from truck hauling, track-out/carry-out from active construction sites, and demolition activities.
Off-road construction equipment shall comply with all Federal, State, and local regulations.	Comply with Federal, State, and local regulations.

The following control measures listed in Table A.1-2 may be implemented to decrease diesel emissions, as applicable.

Table A.1-2: Control Measures to Decrease Diesel Emissions

Diesel Emissions Control Measures
✓ When feasible, the contractor may use equipment powered with Federally mandated “clean” diesel engines.
✓ The size of the engine in equipment and number of pieces of equipment operating simultaneously for the project should be minimized.
✓ Engines should be maintained in tune per manufacturer or operator’s specification.
✓ U.S. Environmental Protection Agency or CARB-certified diesel catalytic converters, diesel oxidation catalysts, and diesel particulate filters may be installed on all diesel equipment.
✓ When practicable, diesel equipment should be replaced with electrical equipment.
✓ The construction period should be lengthened during smog season (May through October), to minimize the number of vehicles and equipment operating at the same time.
✓ Alternatively, fueled construction equipment, such as compressed natural gas, liquefied natural gas, or electric, should be used if feasible.

A.2 Terrestrial Biological Resources

The EPMs listed below would be implemented to avoid, minimize, or characterize the effects of the Proposed Action on terrestrial biological resources. These EPMs require various levels of biological competency from personnel completing specific tasks, as defined in Table A.2-1.

Table A.2-1: Biological monitoring qualifications

Biologist Level	Necessary Qualifications
Permitted Biologist	Biologist with a valid and current USFWS section 10(a)(1)(A) Recovery Permit or specifically named as an approved biologist in a project-specific Biological Opinion. The Space Force will coordinate with the USFWS prior to assigning permitted biologists to this project
USFWS Approved Biologist	Biologist with the expertise to identify ESA listed species and species with similar appearance. The Space Force will review and approve the resumes from each individual, and then submit them to the USFWS for review and approval no less than 15 days prior to the start of the Proposed Action. Each resume will list their experience and qualifications to conduct specific actions that could potentially affect listed species and their habitats. A USFWS approved biologist could train other biologists and personnel during surveys and project work; in some cases, a USFWS approved biologist could also provide on-site supervision of other biologists.
Qualified Biologist	Biologist trained to accurately identify specific federally listed species and their habitats by either a Permitted or USFWS Approved biologist. This person could perform basic project monitoring but would need to have oversight from a permitted or USFWS approved biologist. Oversight will require a permitted or USFWS approved biologist to be available for phone/email consultation during the surveys and to have the ability to visit during monitoring/survey activities if needed.

A.2.1 General Measures

The measures described in Table A.2-2 would be implemented to minimize the potential impacts on terrestrial biological resources.

Table A.2-2: General Measures

Terrestrial Biological General Measures
✓ Disturbances shall be kept to the minimum extent necessary to accomplish project objectives.
✓ All excess materials excavated shall be removed and transported to a designated waste or fill site.
✓ All erosion control materials used would be from weed-free sources and, if left in place following project completion, constructed from 100% biodegradable erosion control materials (e.g., erosion blankets, wattles).
✓ All human-generated trash at the project site shall be disposed of in proper containers and removed from the work site and disposed of properly at the end of each workday. Large dumpsters can be maintained at staging areas for this purpose. All construction debris and trash shall be removed from the work areas upon completion of the project.

Terrestrial Biological General Measures
✓ Equipment vehicles (dozers, mowers, etc.) shall be cleaned of weed seeds prior to use in the construction area to prevent the introduction of weeds and be inspected by a qualified biological monitor to verify weed free status prior to use. Prior to site transport, any skid plates shall be removed and cleaned. Equipment should be cleaned of weed seeds daily especially wheels, undercarriages, and bumpers. Prior to leaving the construction area, vehicles with caked-on soil or mud shall be cleaned with hand tools such as bristle brushes and brooms at a designated exit area; vehicles may subsequently be washed at an approved wash area. Vehicles with dry dusted soil (not caked-on soil or mud), prior to leaving a site at a designated exit area, shall be thoroughly brushed; vehicles may alternatively be air blasted on site.
✓ Fueling of equipment will be conducted in a pre-designated location within the staging area and spill containment materials will be placed around the equipment before refueling.
✓ A qualified biological monitor shall inspect any equipment left overnight prior to the start of work. Equipment would be checked for presence of special status species in the vicinity and for fluid leaks.
✓ No holes or trenches will be left open overnight. Plywood sheets or steel plates may be used to cover holes or trenches or an escape ramp for wildlife would be installed if left open overnight. The biological monitor will inspect these locations before the resumption of work.
✓ If it is not practical to stage or operate project vehicles or equipment on paved or existing roadways and trails, vehicles and equipment will be staged and operated on non-native vegetation to the maximum extent practicable.
✓ Vegetation clearing would occur during daylight hours during periods where there is no rainfall.
✓ The contractor will provide a seeding and planting plan to 30 CES/CEIEA botanist for approval. Coordinate plantings/seed mix that may be similar to surrounding native vegetation with CEIEA. Native seeds may be collected on site where vegetation is removed. Soil must be properly prepared to provide seed germination. Amendments may be necessary. Control weeds for one-year post-construction to achieve at least the same amount or more of pre-construction native plant cover. After one year, provide report with plant list and cover, then coordinate site inspection with CEIEA for approval. Approval is dependent upon amount of native plant cover achieved.

A.2.2 Special Status Species

The Space Force and qualified Phantom personnel or contractor staff would ensure that all non-discretionary measures included in the USFWS Biological Opinion issued for the Proposed Action, listed in Table A.2-3 would be implemented during site preparation, construction, and operation of Phantom's launch program at SLC-5.

Table A.2-3: Special Status Species Measures

General Measures
✓ A Permitted or USFWS Approved biologist(s) shall be responsible for delineating areas where special status species are located or concentrated, relocating special status species during construction activities, and inspecting equipment and equipment staging areas for cleanliness and gas and oil leaks.
✓ A Permitted or USFWS Approved biologist(s) shall brief all project personnel prior to participating in construction activities. At a minimum, the training would include a description of the listed species and sensitive biological resources occurring in the area, the general and specific measures,

and restrictions necessary to protect these resources during project implementation, the provisions of the ESA and the necessity of adhering to the provisions of the ESA, and the penalties associated with violations of the ESA.

- ✓ If vegetation clearing occurs during the nesting period for non-raptor species (15 February through 15 August) a qualified biologist would survey the area for nesting birds and delineate buffers around any nests that are found that are of sufficient size to prevent disturbance in order to reduce risk of nest abandonment.

California Red-legged Frog Measures

- ✓ Permitted or USFWS Approved biologist(s) shall be present and monitor activities during construction at appropriate times when CRLF are likely to be encountered and required to be relocated.
- ✓ Pre-Project Surveys: A USFWS Approved Biologist will conduct pre-project surveys for CRLF. Additional surveys may be conducted on an as needed basis, determined by the biologists. Biologists will follow these measures:
  - From 15 November to 31 March, a USFWS approved or qualified biologists(s) (as needed) will conduct a pre-construction survey of Action Area within suitable aquatic, adjacent upland, or dispersal habitat (690 ft [210 m] from aquatic habitat or other distance as determined by a USFWS approved biologist following adaptive habitat assessment procedures) immediately before the onset of all work activities.
  - From 1 April to 14 November, a USFWS approved or qualified biologists(s) (as needed)will conduct a pre-project survey of the Action Area within suitable aquatic or upland habitat (140 ft [43 m] from aquatic habitat or other distance as determined by a USFWS approved biologist following adaptive habitat assessment procedures) to identify potential artificial water or shelter resources that may contain sheltering CRLF.
  - A USFWS approved or qualified biologists(s) (as needed) will repeat surveys following any precipitation event greater than 0.2 inches (0.5 centimeters) during a 24-hour period.
  - A USFWS approved or qualified biologists(s) (as needed) will monitor any initial ground disturbance or vegetation removal within suitable aquatic, adjacent upland, or dispersal habitat identified following the adaptive habitat assessment procedures. However, after the initial ground disturbance/vegetation removal is complete, no further monitoring would be required within these bare-dirt areas.
- ✓ During construction of the launch site, the following measures will be implemented:
  - The launch construction site will be encircled with minimum 3-ft-high (1-m-high) silt fencing, anchored with metal T-posts, and buried along the bottom edge to inhibit terrestrial wildlife, including CRLF, from entering the site. A qualified biologist will inspect the fence daily and direct maintenance to ensure its efficacy.
  - All work will occur during daylight hours during periods when there is no rainfall.
  - Any open holes or trenches will be covered with plywood or metal sheets if left overnight to minimize the risk of entrapment of CRLF.
  - Precipitation Events: Construction activities will not occur until 24 hours after an actual precipitation event greater than 0.2-inch (0.5-centimeter) accumulating within a 24-hour period.
  - No overnight staging of equipment or supplies would occur within 0.10 mi (0.16 km) of CRLF aquatic habitat in undeveloped areas, unless a designated staging area is identified, cleared for CRLF by a qualified biologist, and measures are implemented that

would preclude CRLF from accessing the supplies or equipment (e.g., drift fence barrier installed).

  - A qualified biologist will survey the site, including any open holes or trenches, each day prior to initiation of work.

✓ CRLF Relocation: A USFWS approved biologist would conduct any CRLF relocation. If CRLF are found within the Action Area during pre-project surveys, daily monitoring where required, or at any other time, all construction activity within the vicinity of the CRLF occurrence (if any) will cease and the following measures will occur:

  - If the project site is large and if the USFWS approved biologist is satisfied that work in a different area of the project can continue with no threat to CRLF, then that work can continue after workers have received a briefing on the area to avoid.
  - Construction activities within the vicinity of the CRLF occurrence will not begin or resume until a USFWS approved biologist relocates the CRLF or contacts the USFWS for alternate guidance.
  - Using the Declining Amphibians Task Force Fieldwork Code of Practice (DAPTF 2019), the USFWS approved biologist will relocate all life stages of CRLF the shortest distance possible to a location that is (1) within the same drainage, (2) contains suitable aquatic/upland habitat, and (3) is outside of the project impact area

✓ Any water retention basins would be designed to exclude access by CRLF. If such exclusion is not possible, and water is present in retention basin overnight, the basin will be checked daily for CRLF by a qualified biologist prior to pumping. The pump will be screened with 1/8-inch mesh

✓ Artificial Lighting:

  - Except when necessary for safety or performance of launch operations, or maintenance, artificial lighting at SLC-5 will be minimized during the hours of darkness.
  - The lighting plan would be designed such that lights are directed away from Honda Canyon and would be shielded to reduce scatter into undeveloped areas. Lighting plan design will minimize illumination of Honda Canyon such that that lighting levels of 1-foot candle would not extend beyond the SLC-5 facility.

✓ CRLF Baseline and Launch Monitoring:

  - The Space Force will conduct quarterly night surveys for CRLF and spring tadpole surveys of lower Honda Creek within the Maximum Sound Level (L_{max}) 120 unweighted decibels (dB) Laguna-E noise contour and a control site beginning the first calendar year of Phantom launch operations. The control site will be located at San Antonio Creek, west of Highway 1, an area that is outside of launch noise impacts on VSFB. The approach allows the Space Force to establish a baseline and assess if there are any changes in CRLF habitat occupancy, breeding behavior (calling), and breeding success (egg mass and tadpole densities) on lower Honda Creek and the control site as Phantom's launch and static fire tempo gradually increases over six years to reach full cadence. The following would be recorded and measured during the surveys:
    - CRLF detection density (number of frogs per survey hour), following the same survey methods conducted previously at these sites and throughout VSFB.
    - CRLF locations and breeding evidence (e.g., calling, egg masses).
    - Environmental data during surveys (temperature, wind speed, humidity, and dewpoint) to determine if environmental factors are affecting CRLF detection or calling rates.

        - Annual habitat assessments to measure flow rates, stream morphology, depths, and sediment to determine if any changes in CRLF metrics are associated with other environmental factors, such as drought.
        - Locations and densities of co-occurring anurans, including bullfrogs (*Lithobates catesbeianus*) and Baja California tree frogs (*Pseudacris hypochondriaca*).
    - Bioacoustic monitoring would be conducted annually during CRLF breeding season (typically November through April, depending on rainfall) to characterize the baseline noise environment and determine if there are changes in calling behaviors as launch and static fire tempo gradually increase over six years. Passive noise recorders and environmental data loggers (temperature, relative humidity, dew point) would be placed at two suitable breeding locations on lower Honda Creek within the 120 dB L_{max} Laguna-E noise contour and at two suitable breeding locations at the control site. The bioacoustic monitoring would also allow any impacts of launch and static fire events during the breeding season on calling behavior to be characterized and analyzed to assess whether CRLF calling frequency is affected by Phantom's gradual increase in launch and static fire tempo.
    - The Space Force will report on monitoring results within an annual report.
    - If CRLF occupancy, calling frequency, or tadpole densities decline from baseline by 15 percent (%) or more, the 15% decline from baseline is maintained for two consecutive years, and the decline is attributed to an increase in Phantom's launch and static fire operations, VSFB would mitigate for the loss of suitable habitat, as discussed below.
    - The Space Force would discontinue monitoring after concurrence from the USFWS if no adverse effects to CRLF occupancy, calling frequency, or tadpole densities are demonstrated after three years of monitoring once Phantom has achieved full or near full tempo.

- ✓ CRLF Mitigation
    - The Space Force would create new CRLF breeding habitat at a 2:1 ratio (habitat enhanced: habitat affected) for adverse effects to occupied CRLF habitat, as determined above, at the San Antonio Creek Oxbow Restoration Area, an established wetland mitigation site that is located outside of areas impacted by launch noise on VSFB. Historically occupied by riparian vegetation, restoration efforts would focus on enhancing this abandoned tract of agricultural land to improve San Antonio Creek and provide breeding habitat for CRLF.
    - Restoration, which has already been conducted at this site for other projects, would be conducted in the "expansion area" adjacent to existing restoration, will involve digging a channel that reaches ground water and using the spoils to create a berm that will be planted with willows. This method is already being used at the site and has proven successful at creating deep water aquatic habitat, suitable for CRLF breeding, and riparian woodland that simulate naturally occurring high-flow channels.
    - Actions taken within this area would include site preparation via herbicide application, plowing, container plant installation, seeding, willow pole planting (via water jet, hand-held power auger, or manually driving a steel rod into the ground), and watering via water truck. The mitigation actions for CRLF are included under an existing USFWS BO (2016-F-0103; USFWS 2018) and all applicable avoidance, minimization, and monitoring measures required under BO 2016-F-0103 would be implemented.
- ✓ The Space Force will track and report on restoration efforts and success within an annual report.

Western Snowy Plover Measures

- SNPL Monitoring
  - The Space Force would augment the current SNPL monitoring program on VSFB by performing acoustic monitoring and geospatial analysis of nesting activity on South Surf Beach and a control site (Minuteman Beach) to assess potential adverse effects from Daytona-E and Laguna-E launch and static fire activities.
    - The current Base-wide SNPL monitoring program estimates breeding effort, nest fates, and fledging success while recording patterns of habitat use through the season. This program would be augmented for the Proposed Action by placing sound level meters (SLMs) immediately inland of South Surf Beach within the Daytona-E and Laguna-E noise footprint and the control site to characterize the noise environment.
    - Acoustic monitoring would begin during the first calendar year of Phantom launch operations and continue annually during the breeding season as Phantom's program gradually increases over six years to full cadence. Geospatial analysis would be performed annually assess whether patterns of nesting activity, nest fates, or fledgling success are negatively impacted by noise from the Proposed Action as Phantom's launch and static fire tempo increases to full cadence.
    - The Space Force will report on monitoring results within an annual report
  - If geospatial analysis shows that a statistically significant decline (defined as a decline greater than the baseline annual variation in these variables over the past 10 years at South Surf Beach) in breeding effort or nest success that continues over two consecutive years within the areas impacted by noise from the Daytona-E and Laguna-E and that is attributable to the Proposed Action, as opposed to increased predation, coastal flooding, or other factors, the Space Force would mitigate for this impact (see below).
  - The Space Force will discontinue monitoring after concurrence from USFWS if no adverse effects attributable to the Proposed Action are documented after three years of monitoring once Phantom has reach full or near full tempo.
- SNPL Mitigation
  - The Space Force would increase predator removal efforts to include the non-breeding season, particularly focusing on raven removal at and adjacent to VSFB beaches.
  - Given that VSFB has already or will soon (under current planning) restore all available SNPL nesting habitat on Base, the biggest factor reducing nesting success is nest predation with significant impacts from ravens. The raven population, which is historically absent to rare in the region, has increased substantially over the past two decades to the species now being common due to human-related factors that have allowed their numbers to increase and range to expand. As documented, the raven population continues to increase each year. Offseason depredation will help reduce the population on Base prior to the breeding season which should increase nest success.
  - Predator control actions would include trapping, shooting, and tracking SNPL predators from VSFB beaches and surrounding areas on Base. The mitigation actions for SNPL are permitted under an existing USFWS BO (8-8-12-F-11R; USFWS 2015a) and all applicable

avoidance, minimization, and monitoring measures required under BO 8-8-12-F-11R would be implemented. VSFB also maintains a USFWS depredation permit. ✓ The Space Force will report on predator removal efforts and success within an annual report.
California Condor Measures
✓ Prior to any launch, the Space Force will determine if any condors are present by coordinating with Ventana Wildlife Society and USFWS personnel prior to launch. (Note: VSFB computers are unable to review the Service's "Daily Snapshot – California Condor Population" Google Earth imagery). The Space Force will contact the USFWS if condors appear to be near or within the area affected by a launch from SLC-5. If nearby, qualified biologists will monitor condor movements in the vicinity of VSFB and analyze data before, during, and after launch events to determine whether there was an effect on condor movement patterns.
✓ The Space Force will coordinate with current USFWS personnel, including Molly Astell, Wildlife Biologist, USFWS California Condor Recovery Program, at molly_astell@fws.gov or (805) 451-0379, Joseph Brandt, Wildlife Biologist, USFWS, at joseph_brandt@fws.gov, 805-677-3324, or 805-644-1766 extension 53324, or Steve Kirkland, California Condor Field Coordinator, USFWS California Condor Recovery Program, at steve_kirkland@fws.gov or 805-644-5185, extension 294. Ventana Wildlife Society contact information: Joe Burnett, joeburnett@ventanaws.org or 831-800-7424.

A.3 Marine Biological Resources

The Space Force and qualified Phantom personnel or contractor staff would ensure that all applicable minimization, monitoring, and avoidance measures in VSFB's LOA, listed in Table A.3-1, would be implemented during operation of Phantom's launch program at SLC-5.

Table A.3-1 Minimization, Monitoring, and Avoidance Measures

Minimization, Monitoring, and Avoidance Measures
✓ Sonic boom modeling would be completed prior to each launch to verify and estimate the overpressure levels and footprint.
✓ Between 1 January and 30 June, pinniped monitoring at south Base haulout locations would commence at least 72 hours prior to a launch event and continue until at least 48 hours after each event. Monitoring data collected would include multiple surveys each day that record the species, number of animals hauled out, general behavior, presence of pups, age class, and gender. Environmental conditions such as tide, wind speed, air temperature, and swell would also be recorded.

A.4 Water Resources

The following measures, as described in Table A.4-1, would be implemented to minimize impacts on water resources and stormwater:

Table A.4-1: Water Resources and Stormwater Measures

Water Resources and Stormwater Measures
✓ The site will be secured from potential erosion resulting from rain and wind events. Existing vegetation will be preserved to the extent feasible.

- ✓ Phantom would install hydroseed and erosion control measures on areas where temporary disturbances occur and any areas that may be prone to erosion. Phantom would use erosion control devices made from biodegradable materials and/or mulched native vegetation produced while clearing vegetation at the site. The hydroseed mix would be comprised of native plant species, developed in coordination with the 30 CES/CEI botanist.
- ✓ All equipment will be properly maintained and free of leaks during operation, and all necessary repairs carried out with proper spill containment.
- ✓ Fueling equipment will only occur in pre-designated areas with spill containment materials placed around the equipment before refueling. Stationary equipment will be outfitted with drip pans and hydrocarbon absorbent pads.
- ✓ Adequate spill response supplies will be maintained at the site during construction and operation for immediate response and clean up of any fuel spills.
- ✓ Hazardous materials will be stored in proper containers, placed in proper containment facilities covered prior to rain events.
- ✓ Vehicles and equipment will only be washed within staging areas. Performing high-pressure washing of undercarriages and wheel wells shall be prohibited at the project site.
- ✓ Trash disposal containers will be covered at all times. Any trash that escapes from containers will be picked up at the end of each day.
- ✓ Portable toilets must be properly secured to prevent tipping in windy conditions.
- ✓ Phantom would enroll in RWQCB’s General Waiver for Specific Types of Discharges (or other state discharge permit) prior to discharging any water out of the deluge water retention basin. Any deluge water that remains after launches or stormwater that accumulates within the basin will be tested for contamination. If contamination is encountered, the contents would be pumped out and disposed of per the waiver/permit and state and Federal regulations.
- ✓ Phantom would enroll in RWQCB’s General Waiver for Specific Types of Discharges prior to discharging any water out of the flame bucket or deluge water retention basin.
- ✓ Improvements to dirt roads would follow standard recommended practices to avoid and minimize erosion potential (e.g., Bloser et al. 2012) and would be inspected after rainstorms for indications of erosion, and repairs made promptly.
- ✓ Vegetation removal on the steep slopes on the east side of the site would be avoided to the extent practicable, unless necessary for fire safety.
- ✓ Concrete curing compound, concrete waste, and washout water will be properly managed to prevent pollution. Concrete washout water will be contained for evaporation.
- ✓ Phantom would design any septic system in accordance with the regulations set forth in the RWQCB OWTS Manual.

A.5 Cultural Resources

Phantom personnel or contractor staff will ensure the following measures, described in Table A.5-1, would be implemented to minimize impacts on sensitive archaeological resources:

Table A.5-1: Cultural Resources Measures

Cultural Resources Measures
✓ If previously undocumented cultural resources are discovered during maintenance activities, work would stop, and the procedures established in 36 C.F.R. 800.13 and the VSFB Integrated Cultural Resources Management Plan shall be followed.
✓ Exclusionary fencing required where vegetation clearance is proposed within the boundaries of CA-SBA-670.

A.6 Transportation

Phantom personnel or contractor staff will ensure the following measures, described in Table A.6-1, would be implemented to minimize the potential for adverse impacts on transportation resources:

Table A.6-1: Transportation Measures

Transportation Measures
✓ Employees may be encouraged to carpool and eat lunch on site.
✓ Truck trips should be scheduled during non-peak traffic hours to the greatest extent practicable.
✓ Phantom would coordinate with California Department of Transportation and the California Highway Patrol when necessary for the transportation of materials to the project site and for accessing the site through State Route 246.
✓ Warning signs, cones, and flaggers would be provided when necessary to warn roadway users of truck crossings on SR 246, and to control traffic flow if necessary.
✓ Construction equipment would not be parked along the shoulder of primary roadways during non-construction periods.

A.7 Human Health and Safety

Phantom personnel or contractor staff will ensure the following measures, described in Table A.7-1, would be implemented to minimize the potential for adverse impacts on human health and safety:

Table A.7-1: Human Health and Safety Measures

Human Health and Safety Measures
✓ Comply with Occupational Safety and Health Administration, Air Force Occupational Safety and Health, California Division of Occupational Safety and Health regulations, and other recognized standards and applicable Department of the Air Force regulations or instructions.
✓ Restrict general access to the proposed construction site through use of signs and fencing if feasible.
✓ Provide for the health and safety of workers and all subcontractors who may be exposed to operations or services. Submit a health and safety plan to VSFB and appoint a formally trained individual to act as safety officer. The appointed individual would be the point of contact on all problems involving job site safety.
✓ Coordinate with the Air Force Civil Engineer Center Environmental Operations Division Mitigation, Monitoring, and Reporting Program manager and contact with the weapons safety specialist for information on VSFB policies on unexploded ordnance safety for construction work at VSFB.
✓ Site-wide anomaly avoidance would be implemented since it is possible UXOs may be encountered outside of MMRP boundaries.
✓ Comply with all provisions and procedures prescribed for the control and safety of personnel and visitors to the job site.

A.8 Hazardous Materials and Waste Management

Phantom personnel or contractor staff will ensure the following measures, described in Table A.8-1, would be implemented to minimize impacts on hazardous materials and waste management:

Table A.8-1: Hazardous Materials and Waste Management Measures

Hazardous Materials and Waste Management Measures
✓ Proper disposal of hazardous waste would be accomplished through identification, characterization, sampling (if necessary), and analysis of wastes generated.
✓ All hazardous materials would be properly identified and used in accordance with manufacturer's specifications to avoid accidental exposure to or release of hazardous materials required to operate and maintain construction equipment.
✓ Hazardous materials would be procured through or approved by the Vandenberg Hazardous Materials Pharmacy (HazMart). Monthly usage of hazardous materials would be reported to the HazMart to meet legal reporting requirements.
✓ All equipment would be properly maintained and free of leaks during construction and maintenance activities. All necessary equipment maintenance and repairs would be performed in pre-designated controlled, paved areas to minimize risks from accidental spillage or release. Prior to construction, a Spill Prevention Plan would be submitted to SLD 30 Environmental Compliance Section for approval.
✓ Phantom would ensure employees and contractor staff are trained in proper prevention and cleanup procedures.
✓ Any activity requiring the connection to and the drawing of bulk water from the drinking water distribution system to support construction and repair projects shall require the approval and coordination of the Vandenberg Cross Connection Control and Backflow Prevention Program Manager.
✓ Phantom would store liquids, petroleum products, and hazardous materials in approved containers and drums and would ensure that any open containers are covered prior to rain events.
✓ Phantom would place chemicals, drums, or bagged materials on a pallet and, when necessary, secondary containment.

A.9 Solid Waste Management

Solid waste would be minimized by strict compliance with VSFB’s Integrated Solid Waste Management Plan. Phantom personnel or contractor staff will ensure the following measures, described in Table A.9-1, would be implemented to further minimize the potential for adverse impacts associated with solid waste:

Table A.9-1: Solid Waste Management Measures

Solid Waste Management Measure
✓ All materials that are disposed of off base would be reported to the SLD 30/CEI Solid Waste Manager.

California Red-Legged Frog
(Rana draytonii)

5-Year Review:
Summary and Evaluation


Rick Kuyper, US Fish and Wildlife Service

U.S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
Sacramento, California

December 2022

5-YEAR REVIEW

California red-legged frog (Rana draytonii)

I. GENERAL INFORMATION

PURPOSE OF 5-YEAR REVIEWS

The U.S. Fish and Wildlife Service (Service) is required by section 4(c)(2) of the Endangered Species Act (Act) to conduct a status review of each listed species at least once every five years. The purpose of a 5-year review is to evaluate whether or not the species' status has changed since it was listed (or since the most recent 5-year review). Based on the 5-year review, we recommend whether the species should be removed from the list of endangered and threatened species, be changed in status from endangered to threatened, or be changed in status from threatened to endangered. Our original listing of a species as endangered or threatened is based on the existence of threats attributable to one or more of the five threat factors described in section 4(a)(1) of the Act, and we must consider these same five factors in any subsequent consideration of reclassification or delisting of a species. In the 5-year review, we consider the best available scientific and commercial data on the species and focus on new information available since the species was listed or last reviewed. If we recommend a change in listing status based on the results of the 5-year review, we must propose to do so through a separate rule-making process defined in the Act that includes public review and comment.

SPECIES OVERVIEW

The California red-legged frog is the largest native frog in the western United States and typically exhibits red coloration on the abdomen and hind legs as an adult (Wright and Wright 1949, p. 417). The California red-legged frog predominately inhabits permanent fresh water sources such as streams, lakes, marshes, natural and manmade ponds, and drainages in valley bottoms and foothills (Jennings and Hayes 1994, pp. 64–65). The California red-legged frog also uses uplands near aquatic habitat for foraging, shelter, and dispersal to neighboring aquatic habitat up to 2.8 km away (Bulger *et al.* 2003, p. 90). The species currently is widespread in the nine-county San Francisco Bay area and is abundant along the Pacific Coast north of Ventura County. Isolated populations exist in the Sierra Nevada range and in Los Angeles, Mariposa, Ventura, and San Diego Counties. The northernmost range of the species is in Mendocino County and the southernmost range of the species is Baja California, Mexico (Peralta-García *et al.* 2016; p. 170).

METHODOLOGY USED TO COMPLETE THIS REVIEW

This review was prepared by the Sacramento Fish and Wildlife Office, following the Region 8 guidance issued in March 2008. We used information from the Service's 2002 Recovery Plan for the species (Service 2002), survey information from experts who have been monitoring various localities of this species, the California Department of Fish and Wildlife's California Natural Diversity Database (CNDDB), and peer-reviewed publications as our primary sources of information used to update the species' status and threats. We also received information from the Center for Natural Lands Management, the US Forest Service, and Vandenberg Air Force Base in response to our Federal Notice initiating this 5-year review (Service 2018). This 5-year review contains updated information on the species' biology and threats, and an assessment of that information compared to that known at time of listing. We focus on current threats to the species that are attributable to the Act's five listing factors. This review synthesizes all information to evaluate the listing status of the species and provide an indication of its progress towards recovery. Finally, based on this synthesis and the threats identified in the five-factor analysis, we recommend a prioritized list of conservation actions to be completed or initiated within the next 5 years.

CONTACT INFORMATION

Lead Regional Office: Bjorn Erickson, Regional Recovery Coordinator, California-Great Basin Region 10. peter_erickson@fws.gov

Lead Field Office: Amber Aguilera, Listing and Classification Division Supervisor, Sacramento Fish and Wildlife Office. amber_aguilera@fws.gov

Cooperating Field Office(s):

Cat Darst, Assistant Field Supervisor, Ventura Fish and Wildlife Office. cat_darst@fws.gov

Bradd Bridges, Listing and Recovery Division Supervisor, Carlsbad Fish and Wildlife Office. bradd_bridges@fws.gov

Vicky Ryan, Deputy Field Supervisor, Arcata Fish and Wildlife Office. vicky_ryan@fws.gov

Steve Detwiler, Listing and Recovery Division Supervisor, Bay Delta Fish and Wildlife Office. steven_dewiler@fws.gov

FEDERAL REGISTER (FR) NOTICE CITATION ANNOUNCING INITIATION OF THIS REVIEW

A notice announcing initiation of the 5-year review of this taxon and the opening of a 60-day period to receive information from the public was published in the Federal Register on June 18, 2018 (Service 2018). In response to this information request, we received information from the Center for Natural Lands Management, Vandenberg Air Force Base, and the US Forest Service.

LISTING HISTORY

Original Listing
FR Notice: 61 FR 25813 (Service 1996)
Date of Final Listing Rule: May 23, 1996
Entity Listed: *Rana aurora draytonii*, a subspecies
Classification: Threatened

ASSOCIATED RULEMAKINGS

Critical Habitat
FR Notice: 66 FR 14626 (Service 2001)
Date Designated: 3/13/2001

Revised Critical Habitat
FR Notice: 71 FR 19244 (Service 2006)
Date Revised: 4/13/2006

FR Notice: 75 FR 12816 (Service 2010)
Date Revised: 3/17/2010

4(d) Rule
FR Notice: 71 FR 19244 (Service 2006)
Date Finalized: 4/13/2006

REVIEW HISTORY

There are no previous 5-year reviews for the California red-legged frog.

SPECIES' RECOVERY PRIORITY NUMBER AT START OF 5-YEAR REVIEW

The recovery priority number for the California red-legged frog is 5C according to the Service's 2020 Recovery Data Call for the Sacramento Field Office, based on a 1-18 ranking system where 1 is the highest-ranked recovery priority and 18 is the lowest (Service 1983a; Service 1983b). This number indicates that the taxon is a species that faces a high degree of threat and has a low potential for recovery. The "C" indicates conflict with construction or other development projects or other forms of economic activity.

RECOVERY PLAN OR OUTLINE

Name of Plan or Outline: Recovery Plan for the California Red-legged Frog (*Rana aurora draytonii)*
Date Issued: May 28, 2002

II. REVIEW ANALYSIS

APPLICATION OF THE 1996 DISTINCT POPULATION SEGMENT (DPS) POLICY

The Endangered Species Act defines "species" as including any subspecies of fish or wildlife or plants, and any distinct population segment (DPS) of any species of vertebrate wildlife. This definition of species under the Act limits listing as distinct population segments to species of vertebrate fish or wildlife. The 1996 Policy Regarding the Recognition of Distinct Vertebrate Population Segments under the Endangered Species act (Service and NOAA 1996) clarifies the interpretation of the phrase "distinct population segment" for the purposes of listing, delisting, and reclassifying species under the Act.

No new information has come to light regarding the application of the DPS policy to the California red-legged frog.

INFORMATION ON THE SPECIES AND ITS STATUS

Species Biology and Life History

As discussed above, the California red-legged frog is the largest native frog in the western United States ranging from 1.5 to 5.1 inches in length (Stebbins 2003, p. 224). The abdomen and hind legs of adult California red-legged frogs are largely red and this coloration can extend throughout the body. The dorsum of adult California red-legged frogs contains prominent dorsolateral folds and adult coloration is typically brown, gray, olive, or reddish with small black flecks and larger irregular dark blotches with indistinct outlines (dorsal spots). The California red-legged frog is sexually dimorphic and females are larger than the males (Jennings *et al.* 1992, p. 3). Larvae (tadpoles) range from 0.8 to 8 cm in length and tadpole coloration is dark brown and yellow with darker spots (Storer 1925, p. 241). California red-legged frogs may live up to 10 years (Jennings *et al.* 1992, p. 3).

Breeding

California red-legged frogs are "irruptive" breeders where their breeding capacity is highly dependent on local environmental conditions, specifically the availability of cool water for egg deposition and larval maturation (Jennings and Hayes 1994, p. 62). California red-legged frogs breed from November to May and breeding activity typically begins earlier at southern coastal than northern coastal localities (Storer 1925, p. 2; Alvarez *et al.* 2013, pp. 547–548). Breeding may start as late as March or April in Sierra Nevada localities such as Hughes Pond, due to low temperatures at these sites in January and February (Tatarian and Tatarian 2008, p. 16). Breeding in Southern California localities may start as late as April, as exemplified in Matilija Canyon following the 2017 Thomas Fire (Patrick Lieske, US Forest Service, in litt. 2021). High water flows in the winter and spring also can delay breeding in streams and rivers (East Bay Regional Park District 2017, p. 29). During the breeding season, most non-dispersing frogs remain near the breeding site and do not move far into surrounding terrestrial habitat to forage (Wildlife Research Associates 2008, p. 11; Bulger *et al.* 2003, pp. 87–88).

California red-legged frogs typically breed at sites with a mix of open surface water and vegetated cover (Hayes and Jennings 1988, p. 151; Scott and Rathbun, 2006, pp. 14–15) but can breed at sites with dense shrubby riparian or emergent vegetation such as cattails (*Typha* spp.), tules (*Schoenoplectus acutus*) or overhanging willows (*Salix* spp.; Storer 1925, p. 239). Female California red-legged frogs lay only one egg mass in a breeding year and each egg mass contains between 300–4,000 eggs (Storer 1925, p. 240). Frogs typically deposit egg masses in relatively shallow water (less than 38 cm) on emergent vegetation within 1 meter of shore (Storer 1925, p. 239). However, the species can deposit eggs on a wide variety of substrates including boulders and cobbled substrate and submerged tips of overhanging branches (Alvarez *et al.* 2013, pp. 544–545). Additionally, frogs can deposit eggs up to 12 m from shore in water up to 3.2 m deep (Wilcox *et al.* 2017, p. 68) and successfully breed in ponds with water temperatures up to 30^{o} C (Rathbun 2012, p. 9). Ponds or streams completely choked with emergent vegetation such as cattails or giant reed (*Arundo* sp.) are generally considered unsuitable for breeding because the dense vegetation can impede adult California red-legged frog movement (Giessow *et al.* 2011, p. 159).

Egg masses hatch after 6–14 days (Storer 1926, p. 241), depending on water temperature. Reis (1999, p. 46) found the greatest number of tadpoles occurred in study plots with water depths less than 0.75 m. Larval developmental and growth rate are variable and likely temperature dependent (Fellers 2005, pp. 552–554). In some areas, larvae may overwinter and then develop into metamorphs the following spring, a phenomenon observed in Santa Clara, Marin, Contra Costa, and San Luis Obispo Counties (Fellers *et al.* 2001, entire).

The metamorph life stage is defined as the time an individual loses its tail and becomes a small froglet, which typically occurs four to five months after hatching but can occur as early as three months (Storer 1925, p. 241; Wright and Wright 1949, p. 422). California red-legged frogs metamorphose at a size of 1.6–2.0 cm snout-urostyle length and a weight of 0.3–0.9 g (Fellers 2005, p. 552). In general, metamorphosis occurs between May and September (Storer 1925, p. 241; Wright and Wright 1949, p. 422). Immediately after metamorphosis, froglets shelter near the natal pond. However, these froglets soon disperse in the fall to nearby moist uplands or aquatic habitat to avoid predation by larger, older frogs.

The juvenile life stage of California red-legged frogs spans from the time a frog starts metamorphosis until the frog reaches adulthood and is able to breed. On average, this life stage is from about five months of age to two years in California red-legged frogs. California red-legged frog males begin breeding around two years of age and females begin breeding around three years (Jennings and Hayes 1985, p. 96).

Terrestrial feeding and sheltering

Adult and juvenile frogs frequently use terrestrial areas with cover features near water sources (i.e., upland habitat; Bulger *et al.* 2003, p. 87; Tatarian 2008, pp. 164–166) to feed and shelter. Typically, these cover features include dense riparian vegetation, wood or rock debris, small mammal burrows, or artificial features such as discarded wooden boards or tires. Terrestrial forays for feeding and sheltering occur most often in the late summer and early fall (Bulger *et al.* 2003, p. 87; Tatarian 2008, pp. 165–166). Bishop *et al.* (2014, p. 139) found that that upland habitat supports the majority of the prey base for adult and juvenile California red-legged frogs. Bulger *et al.* (2003, p. 87) observed that sheltering terrestrial California red-legged frogs were hidden from view 96 percent of the time. The frogs were hidden from view mainly by live plants (79 percent), followed by woody debris/rootballs, small recesses in vertical banks, and forest floor litter. We more fully discuss characteristics of upland habitat in the Habitat or Ecosystem section below.

Long Distance Dispersal

While most adult and juvenile California red-legged frogs remain at breeding sites with permanent water, a minority (10–30 percent) migrate or disperse to neighboring water features when breeding is finished and/or when breeding pools dry (Bulger *et al.* 2003, p. 92; Christopher 2004a, p. iii; Fellers and Kleeman 2007, p. 279; Tatarian 2008, p. 165). These long-distance dispersal events between watersheds provide gene flow between populations in nearby watersheds and therefore are essential for maintaining metapopulation connectivity at a regional scale (Bulger *et al.* 2003, p. 93; Fellers and Kleeman 2007, p. 285; Tatarian 2008, pp. 165–166; Keung 2015, p. 45; Richmond *et al.* 2013, p. 818; Richmond *et al.* 2014, p. 136). Long-distance dispersal events typically are associated with rainfall (Bulger *et al.* 2003, p. 89; Tatarian 2008, pp. 159, 165), though California red-legged frogs may disperse in the absence of rainfall (Christopher 2004a, p. 50). Studies have observed both male-biased (Christopher 2004a, p. 21) and female-biased (Fellers and Kleeman 2007, p. 283) dispersal rates.

Dispersing California-red legged frogs typically travel less than 800 m between watersheds; however, a few individuals have been documented to move overland up to 3,200 m in wet coastal environments (Fellers and Kleeman 2007, p. 280; Bulger *et al.* 2003, p. 90). California red-legged frogs typically travel along riparian corridors (Fellers and Kleeman 2007, p. 280; Tatarian 2008, pp. 164–165) but are capable of dispersing through inhospitable habitats such as heavily grazed pastures or oak-grassland savannas (Bulger *et al.* 2003, pp. 91–92). Dispersal distances vary by local environmental conditions with much longer dispersal distances observed in cool, moist forested habitat in the northern coastal portion of the species range than in warmer, more arid habitat in the southern coastal portion of the species range. For example, Bulger *et al.* (2003, p. 92) observed that California red-legged frogs dispersed up to 500 m per day in the wet, cool habitat of the Santa Cruz Mountains whereas Christopher (2004a, p. 37) observed that California red-legged frogs moved up to 22 m per day in the warmer, more arid habitat of Santa Barbara County. Climate conditions in the Sierra Nevada region differ substantially from coastal areas and therefore long-distance dispersal behaviors of Sierra Nevada California red-legged frogs may also differ substantially and to date there have been few studies of dispersal by the species in this region. Notably, the National Park Service has conducted mark-recapture studies of California red-legged frogs in Yosemite National Park and found that at least one individual moved approximately 800 m overland between the Merced River and Ahwahnee Pond (Grasso, National Park Service, pers. comm. 2020.)

Diet

The diet of the California red-legged frog is highly variable and changes with age class. The diet of larvae is not well studied; however, their diet is likely similar to that of other ranid tadpoles, feeding on algae, diatoms, and detritus by grazing on the surface of rocks and vegetation (Kupferberg 1997, p. 431). For adult and juvenile frogs, Hayes and Tennant (1985, entire) analyzed the diets of California red-legged frogs from Cañada de la Gaviota in Santa Barbara County during the winter of 1981 and found invertebrates (comprising 42 taxa) to be the most common prey item consumed; however, they speculated that this was opportunistic and varied based on prey availability. They found that larger frogs consumed larger prey, including Pacific chorus frogs (*Pseudacris regilla*), three-spined stickleback (*Gasterosteus aculeatus),* and, to a limited extent, California mice (*Peromyscus californicus*), which were abundant at the study site (Hayes and Tennant 1985, p. 602; Fellers 2005, p. 554). Although larger vertebrate prey was consumed less frequently, it represented over half of the prey mass eaten by larger frogs suggesting that such prey may play an energetically important role in their diets (Hayes and Tennant 1985, p. 602). Bishop *et al.* (2014, p. 139) analyzed stomach contents of 98 frogs, and found that wet and dry season stomach content samples flushed from captured frogs had 90 percent terrestrial prey, and museum specimens contained 82 percent terrestrial prey. Spiders, aphids, froghoppers, and butterfly/moth larvae were the terrestrial invertebrate families consumed most. These data suggest that riparian and upland habitats adjacent to aquatic habitats support much of the prey base for California red-legged frogs.

Juvenile and adult frogs appear to vary in their feeding activity periods; juveniles feed for longer periods throughout the day and night, while adults feed nocturnally (Hayes and Tennant 1985, p. 604). Hayes and Tennant (1985, p. 605) noted that juveniles were significantly less successful at capturing prey, although all life history stages exhibited poor prey discrimination, feeding on several inanimate objects that moved through their field of view.

Spatial Distribution

The species historically occurred from sea level to approximately 1,600 m (Service 2002 p. 7) across 46 counties in California (Service 2002, p. 3). The species' historical coastal range extended along the Pacific Coast from its northern extent in central Mendocino County and western Tehama County through the California Coast Ranges to its southern extent in northern Baja California, Mexico (Jennings and Hayes, p. 63; Figure 1). The species' historical inland range included the western foothills of the Sierra Nevada and Cascade Ranges from Shasta County south to Madera County (Jennings and Hayes 1994, p. 63; Fellers 2005, p. 552). By the time of its listing in 1996, the distribution of the species had declined to only 243 streams or drainages within 22 counties, and we estimated that the species had lost 70 percent of its historical range (Jennings *et al.* 1992, p. 9; Service 1996, p. 25815) (Figure 1). Prior to listing, occurrence data for the species was limited to only 122 occurrences recorded in the California Natural Diversity Database (Service 1996, p. 25817).

Following listing in 1996, California red-legged observations recorded in the CNDDB increased to 633 at the time of the Service's 2002 Recovery Plan for the species (CNDDB 2022). Corresponding with this increase in number of records, in 2002 the species was known to occur in 256 streams or drainages within 28 counties (Service 2002, p. 1). As of January 2022, there are 1,667 occurrences across 34 counties, all below 1,430 m in elevation (CNDDB 2022). This increase in California red-legged frog observations recorded in CNDDB following its listing can likely be attributed to increased survey effort for the species during pre-project surveys in its suitable habitats rather than an increase in species distribution or abundance. With few exceptions, most novel occurrences are within a few miles of previously known localities and did not substantially increase the distribution of the species. A few notable exceptions are a new observation near Rincon Creek in Santa Barbara County (Sam Sweet, pers. comm. 2018); new translocated populations located within the Santa Monica Mountains Recreation Area in Los Angeles County, within Yosemite National Park in Mariposa County, on the Santa Rosa Plateau in Riverside County, and on private land in San Diego County; and identification of ten new localities in the Sierra Nevada mountain range (Barry and Fellers 2013, p. 481). The source of the translocated population in San Diego County was a newly observed locality near Whitewater in Riverside County (Backlin *et al.* 2017, p. 2). The Service and its partners translocated all California red-legged frogs from the Whitewater locality to the San Diego County translocation site following a wildfire and the Service no longer considers the Whitewater locality occupied.

Currently, the California red-legged frog is widespread in the San Francisco Bay nine-county area and abundant along the coast north of Ventura County (CNDDB 2022). Isolated populations persist in several Sierra Nevada localities, in Ventura County, in Los Angeles County, as well as two recently translocated populations in Riverside and San Diego (Barry and Fellers 2013, pp. 456–457; CNDDB 2022). Halstead *et al.* (2018, p. 15) used environmental DNA methods to investigate the putative northern extent of the species range in southern Mendocino County and concluded that the species likely does not inhabit the sampled areas in southern Mendocino County. The southern extent of the species' current range remains in Baja California outside of the United States (Peralta-García *et al.* 2016, p. 170). However, the populations within the Service's purview are geographically and reproductively isolated from Baja California populations and aside from their use as donor populations for translocation in Southern California, we do not discuss these Baja California populations further in this review.

In 2020, the Service developed a species range map for the California red-legged frog based on watershed occupancy by the species (Figure 1). To reflect only the contemporary distribution of the California red-legged frog, the Service used only observations that occurred following the listing of the species in 1996. The Service combined data from 1,463 post-1996 records across 31 counties in the CNDDB as of December 2019 and 3,168 post-1996 records from survey reports and other correspondence in Service files for a total dataset of 4,631 observations located across 40 counties. The Service's intent for the species range map was to identify areas where California red-legged frogs possibly could possibly occur rather than only areas where the species is known to occur. Therefore, the Service considered the entire HUC10 watershed where a post-1996 record occurred as potentially occupied by the species because of the cryptic nature of the species and its capability to migrate long distances. Based on known differences in the natural histories of Southern California and Sierra Nevada populations of California red-legged frog, the Service reduced this approach to considering only the record's HUC12 watershed as occupied for watersheds located south of Ventura County and in the Sierra Nevada range. Additionally, for HUC12 watersheds in the Sierra Nevada range the Service imposed an upper altitudinal limit of 1,550 m for potential occupancy. The Service further refined this watershed-based range map through multiple rounds of expert review. The Service's final range map for the species (Figure 1) includes a total of 18,571,388 acres across 40 counties. We used the Bureau of Land Management's California land status layer (https://navigator.blm.gov/api/share/1fca0357df7c87ae) to calculate the proportionate ownership of land within these 18,571,388 acres and found that 22.6 percent of the species range is on federal lands, 2.9 percent of the species range is on State or local government lands, and the remaining 74.5 percent of the species range is on private lands. Notably, inhospitable areas such as heavily developed urban areas are included in this watershed-based range map and therefore not all 18,571,388 acres identified in the range map contain suitable habitat for the species.

Figure 1. Current and historical range of the California red-legged frog. We do not include populations in Baja California, Mexico in this figure.

Habitat or Ecosystem

California red-legged frogs predominately inhabit permanent fresh water sources with salinities less than 7.0 parts per thousand (ppt; Jennings and Hayes 1990, pp. 17) such as streams, lakes, marshes, natural and manmade ponds, and drainages in valley bottoms and foothills (Jennings and Hayes 1994, pp. 64–65) though the species is capable of temporarily using habitat with salinities up to 36 ppt (California Department of Fish and Wildlife 2011, pp. 3–70). Typically, aquatic habitat contains either riparian or emergent vegetation though California red-legged frogs also are known to inhabit ephemeral creeks, drainages, and ponds with minimal riparian and emergent vegetation. California red-legged frogs use these types of aquatic features for breeding and non-breeding activities. California red-legged frogs can occur in a wide range of water quality conditions, but Bobzien and DiDonato (2007, p. 61) found that that they appear to prefer less turbid water relative to other co-occurring amphibian species. We describe below the varying habitats used by the California red-legged frog as categorized into Physical or Biological Features (PBFs) by the Service's 2010 final critical habitat rule for the species (Service 2010, pp. 12835-12836):

PBF 1: Aquatic breeding habitat

Aquatic breeding habitat is generally found in still or slow-moving water and can have a wide range of edge and emergent cover amounts. In streams and creeks, frogs have been documented in low, moderate, high, and extreme gradients ranging from 0.4 percent to 21.0 percent slopes; however, the most stable populations and the highest breeding densities occur in low and moderate stream gradient types (less than 4 percent) with minimal scouring flows (Bobzien and DiDonato 2007, pp. 32 and 58–59).

Depending on conditions, breeding sites typically retain water for a minimum of 20 weeks to allow for tadpole development and metamorphosis. Breeding sites typically also contain shelter such as vegetation, rocks, or other cover and water more than 0.7 m deep (Hayes and Jennings 1988, p. 147), though egg masses themselves are typically deposited on surfaces less than 38 cm deep (Storer 1925, p. 239). While California red-legged frogs typically use partially shaded pools and creeks with emergent vegetation as breeding habitat the species can deposit eggs in a large variety of habitats. For example, the California Department of Transportation (Caltrans) identified adults, tadpoles, and egg masses within a storm drainage system of a major cloverleaf intersection at Millbrae Avenue and State Route 101 in a heavily developed area of San Mateo County (Caltrans 2007, p. 17).

Barry and Fellers (2013, p. 476) found 12 historical and three recent occurrences in the Sierra Nevada were located in permanent or ephemeral creeks, often in close proximity to the headwaters, and concluded that pools along streams, rather than natural ponds which are nearly absent in the Sierra Nevada, comprised the principal historical natural aquatic habitat for the species throughout much of its range in the Sierra Nevada. However, as noted by Barry and Fellers (2013, p. 476), at the present time California red-legged frogs in the Sierra Nevada are known to only use manmade and natural ponds as aquatic habitat.

PBF 2: Aquatic non-breeding habitat

Non-breeding habitat is found in similar aquatic features as breeding habitat but these features may not hold water long enough for the species to successfully complete its aquatic life cycle. While generally found in freshwater habitats, adult California red-legged frogs can survive in saline water for short periods. For example, URS Corporation observed dispersing adults and sub-adults in salinities of up to 36 ppt (California Department of Fish and Wildlife 2011, pp. 3–70).

Non-breeding aquatic features provide habitat for foraging, shelter, movement, and other essential behaviors. In addition to the aquatic features used for breeding, aquatic non-breeding habitat may include plunge pools within intermittent creeks, seeps, quiet water refugia during high water flows, and springs of sufficient flow to withstand the summer dry period. California red-legged frogs also readily use disturbed areas such as channelized creeks and drainage ditches as aquatic habitat.

PBF 3: Upland habitat

Upland habitat consists of terrestrial areas adjacent to breeding and non-breeding aquatic habitats. Juvenile and adult California red-legged frogs use upland habitat for foraging, shelter, and movement. Several studies have observed California red-legged frogs spending a significant amount of time in terrestrial habitats and consuming large amounts of terrestrial prey as adults (Bulger *et al.* 2003, pp. 87–88; Wildlife Research Associates 2008, p. 11; Halstead and Kleeman 2017, p. 134).

Suitable upland habitat for the California red-legged frog includes nearly any terrestrial area within 100 m of aquatic habitat that contains cover features such as dense riparian vegetation, wood or rock debris, burrows, or anthropogenic cover including discarded tires and wooden boards. The extent of upland habitat used by California red-legged frogs for feeding and sheltering varies substantially by habitat condition. In the wet, cool habitat of the Santa Cruz Mountains, Bulger *et al.* (2003, p. 87) observed 90 percent of terrestrial non-dispersing frogs within 60 m of water and 10 percent were found up to 130 m from water. The frogs in this study remained in the uplands for 20 to 30 days on average with a maximum duration of 63 days. Contrastingly, in the arid, warmer habitat of Vandenberg Air Force Base in Santa Barbara County, Christopher (2004a, p. 30) observed 65 percent of terrestrial non-dispersing frogs within 5 m of water and one individual 43 m from water. The frogs in this study typically remained in the uplands for 7 to 21 days with a maximum duration of 23 days. In the Sierra Nevada region Wildlife Research Associates (2008, p. 11) observed no upland movements further than 20 m from the study pond for a maximum duration of 7 days.

PBF 4: Dispersal habitat

Dispersal habitat consists of terrestrial areas up to 3.2 km away from breeding and non-breeding aquatic habitat used by adult and juvenile California red-legged frogs to move along and between watersheds during long-distance dispersal events. Only 10–30 percent of adult and juvenile California red-legged frogs perform long-distance dispersal each year. As described by Bulger *et al.* (2003, p. 85), California red-legged frogs may “move overland in approximately straight lines to target sites without apparent regard to vegetation type or topography" and therefore California red-legged frogs may use almost any terrestrial area within dispersal distance as dispersal habitat. Notably, California red-legged frogs likely would not use areas delimited by significant passage barriers such as major roadways or walls as dispersal habitat.

Similar to upland habitat, the extent of dispersal habitat away from aquatic habitat is dependent on local conditions. Bulger *et al.* (2003, p. 90) observed that California red-legged frogs may disperse up to 2.8 km straight-line distance (3.2 km total distance traveled) away from their natal stream in the wet, cool environment of the Santa Cruz Mountains and spend up to 2 months dispersing between streams. Contrastingly, Christopher (2004a, p. 35) observed that California red-legged frogs dispersed a maximum of 209.3 m between ponds during the breeding season in the warm, arid environment of Vandenberg Air Force Base and frogs only spent up to 3 days dispersing between ponds. In the Sierra Nevada region Wildlife Research Associates (2008, pp.11–12) observed that California red-legged frogs dispersed a maximum of 208 m between the study pond and a neighboring seep area and stayed in the seep area for 62 days. The National Park Service observed a maximum dispersal distance of approximately 800 m overland (Grasso, pers. comm. 2020) during mark-recapture studies in Yosemite National Park.

Status of Habitat

To assess the status of the California red-legged frog's habitat across its range, we analyzed the current species range map produced by the Service in 2020 as described above in the Spatial Distribution section. Briefly summarized, the Service used post-1996 California red-legged frog observations to identify 142 HUC10 and HUC12 watersheds as the current geographic range of the species. These 142 watersheds ranged in size from 25 km^2 to 1075 km^2 and comprised a total of 18,571,388 acres. For comparison, we digitized the historical range map presented in the Service's 1996 listing rule for the species (Figure 1) and estimate that the historical geographic range of the species totaled approximately 43,206,623 acres. Based on a rough graphical comparison between the current species range map and the historical range map, we estimate the species has lost approximately 57 percent of its historical range rather than the previously estimated 70 percent (Service 1996, p. 25815). Primarily, the species has lost large portions of its historical range in the Central Valley and coastal areas south of Santa Barbara County.

In general, we expect range-wide habitat quality for the California red-legged frog to be degraded relative to the historical habitat quality of the species range as well as habitat quality at the time of the species' listing. We expect habitat quality has degraded near developed areas from encroachment by development, reduced water availability because of water withdrawals, and the presence of invasive plant and animal species. Additionally, we expect that habitat within the species range in general has become warmer and drier during the past century because of regional climate change resulting from post-industrialization anthropogenic carbon inputs. A warmer and drier climate reduces the water available to the California red-legged frog for life cycle activities. We discuss these threats to the species' habitat quality more fully in the Threats Assessment section below.

Connectivity

Historically, California red-legged frogs had a single contiguous species range which likely created a metapopulation dynamic where geographically separate populations maintained connectivity with one another through long-distance dispersal and subsequent gene flow. Such metapopulation dynamics foster population redundancy and resiliency by providing immigrants to extirpated or otherwise reduced populations and mitigating genetic drift between populations. As discussed above, the California red-legged frog has lost approximately 57 percent of its historical range, primarily in coastal areas south of Santa Barbara County and in the Central Valley. Populations in coastal areas south of Santa Barbara County currently are separated from one another by tens of kilometers and likely do not exchange migrants (Richmond *et al.* 2013, p. 818). Populations in the Sierra Nevada region are also currently geographically separate from one another and likely do not exchange migrants (Richmond *et al.* 2014, p. 134). Furthermore, these Sierra Nevada populations are genetically isolated from the rest of the species range by the formerly occupied Central Valley (Richmond *et al.* 2014, p. 134). Contrastingly, the California red-legged frog has retained much of its historical range in coastal areas north of Santa Barbara County and populations within this area have retained genetic connectivity with one another (Richmond *et al.* 2014, p. 134).

We expect that the status of connectivity within the species overall has decreased significantly relative to its historical status. At a regional scale, populations in the Sierra Nevada region have lost connectivity with the rest of the range of the species. Additionally, populations within the Sierra Nevada and coastal areas south of Santa Barbara County lack connectivity with other populations within these regions. Moreover, we expect that connectivity throughout the range of the species has decreased significantly as well, particularly with the placement of anthropogenic passage barriers such as major roadways or constructed walls between populations. Additionally, the observed and predicted overall trend of warmer and drier winters within the range of the California red-legged frog as a result of climate change may reduce the distance traveled by dispersing California red-legged frogs, which would further reduce connectivity within regions.

Abundance

Status of California red-legged frog abundance

To date, there has not been a range-wide survey of California red-legged frog abundance. It is difficult to reliably census California red-legged frogs in the field because of the cryptic habits of adults and juveniles and difficulties distinguishing larvae of the species from larvae of other ranid species. Currently, the most reliable census method for California red-legged frog is to perform repeated egg mass surveys during the breeding season (Wilcox *et al.* 2017, p. 70). Because female ranid frogs deposit only one egg mass a year (Wilcox *et al.* 2017, p. 66), the overall count of egg masses is a close approximation of the number of breeding adult female frogs using the survey area. While several egg mass survey efforts are ongoing, to date the only effort that has summarized abundance trends over time is the U.S. Geological Survey’s study of 5 breeding areas in Southern California. Below, we present abundance over time from the U.S Geological Survey’s study (Gallegos *et al.* 2022, Table 3).

Site	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Aliso Canyon	–	0	3	1	1	0	2	3	5	0	0	0	0	0
San Francisquito Canyon	0	2	5	9	10	29	49	93	127	27	34	10	13	72
East Las Virgenes Canyon	–	8	28	35	13	22	19	31	37	76	61	86	55	59
Las Virgenes Canyon	–	–	–	–	–	3	0	0	0	2	0	0	0	0
Whitewater Canyon	–	–	–	–	–	–	–	–	–	0	2	1	0	0

Table 1. Egg mass survey results over time for five breeding locations in Southern California. Reproduced from Table 3 of Gallegos et al. *(2022). A "-" entry indicates no survey was performed.*

The data presented by Gallegos *et al.* (2022, Table 3) indicate differing trends in abundance as reflected in egg mass counts across the five Southern California survey sites. From 2009 to 2021 the San Francisquito Canyon and East Las Virgenes Canyon populations each consistently produced egg masses. However, annual increases or declines in egg mass counts were not consistent between these populations despite their relative proximity to each other (ca. 45 kilometers). For example, between 2018 and 2019 the San Francisquito Canyon population abundance decreased from 34 to 10 egg masses while the East Las Virgenes Canyon population abundance increased from 61 to 86 egg masses. The Aliso Canyon, Las Virgenes Canyon, and Whitewater Canyon populations were not able to consistently sustain breeding activity. From these egg mass survey data, we cannot infer a consistent regional trend in abundance over time for these Southern California populations.

In general, we expect that current overall abundance of the California red-legged frog has decreased from its historical abundance and its abundance at listing in 1996. The species has lost approximately 57 percent of its geographic range and areas of the species' remaining habitat likely are degraded relative to their historical habitat quality. Nevertheless, local populations occasionally produce large numbers of California red-legged frogs, particularly in response to wet rainy seasons. For example, Padre Associates, Inc. detected hundreds of California red-legged frogs sheltering in an oil containment basin in Santa Barbara County (Padre Associates, Inc., 2017, p. 6). Similarly, VJS Biological Consulting (2013, p. 2) identified dozens of California red-legged frogs living in a small section of submerged concrete riprap along Tajiguas Creek in Santa Barbara County.

Genetic abundance estimates

Richmond *et al.* (2014, Table 1) estimated the effective population size (N_e) of California red-legged frog populations across the range of the species using genetic microsatellite data. Richmond *et al.* calculated median N_e values between 7 and 40 for sampled populations throughout its range. We discuss the entirety of Richmond *et al.* (2013) and Richmond *et al.* (2014) in the genetics section below.

Survival

California red-legged frogs experience high mortality rates at each life stage until adulthood. Jennings *et al.* (1992, p. 3) estimated that around 1 percent of eggs reach metamorphosis and 0.1 percent of eggs reach adulthood (Scott and Rathbun 2006, p. 13). In coastal lagoons, the most significant mortality factor for eggs is water salinity with a survivable limit of 50 ppt salinity (Jennings *et al.* 1990, p. 17). In other environments, such as freshwater streams and ponds, predation of eggs is likely the most significant mortality factor particularly if voracious invasive predators such as bullfrogs (*Lithobates catesbeianus*) and crayfish are in the area. Additional sources of mortality for eggs and larvae are burial by siltation or desiccation from aquatic habitat drying out.

Longitudinal studies of California red-legged frog survival are infrequent. Scott and Rathbun (2006, p. 13) reported 9.9 percent survivorship from metamorphosis through the first juvenile year and subsequent annual adult survivorship of 25 percent to 39 percent on the Central Coast. Fellers *et al.* (2017, p. 670) estimated an annual survival rate of adult frogs of 26.3 percent at a pond in Point Reyes National Seashore while Halstead and Kleeman (2017, p. 133) estimated an annual survival rate of 70 percent for adult frogs in a nearby coastal dune area. Halstead and Kleeman (2017, p. 137) attribute this difference in estimated adult survivorship to a lower risk of predation and abundant prey (deer mice, *Peromyscus maniculatus*) in the coastal dune ecosystem. In general, we expect predation to be the most significant cause of mortality to juvenile and adult frogs. In particular, bullfrogs, centrarchid fish, crayfish, and raccoons (*Procyon lotor*) are known to prey on juvenile and adult California red-legged frogs. Additionally, near developed areas we expect mortalities of juvenile and adult California red-legged frogs resulting from vehicle strikes or crushing by equipment.

Overall, we expect that survival of California red-legged frogs at all life stages has decreased relative to historical survival rates. The general trend of a warming and drying climate within the range of the California red-legged frog has reduced the hydroperiod available for larval development and shelter for all life stages, though a reduced hydroperiod may also benefit the species in certain areas by reducing the abundance of invasive predators such as bullfrogs and crayfish. Additionally, relative to historical rates we expect additional mortality of California red-legged frogs near developed areas from vehicle strikes and predation from invasive species.

Sex Ratios

Of studies that report sex ratios in adults, most report female-biased sex ratios and survival (Russel *et al.* 2019, p. 11). Halstead and Kleeman (2017, p. 137) suggest that the sex ratio on their dune study system could be biased towards females because larger female frogs would be capable of preying on the *Peromyscus* deer mice that appear to be the main prey base for the species in their study system. We expect that contemporary sex ratios in California red-legged frogs are similar to historical sex ratios in the species.

Changes in Taxonomic Classification or Nomenclature

The California red-legged frog belongs to the family Ranidae (true frogs). As described by Storer (1925, p. 231), Baird and Girard first described the California red-legged frog (*Rana draytonii*) and the northern red legged frog (*Rana aurora*) as two distinct species in 1852. In 1917, Camp reclassified the frogs into two subspecies of the species *R. aurora*: the California red-legged frog was reclassified as *R. aurora draytonii* and the northern red-legged frog as *R. aurora aurora*.

In 1996, the Service listed the subspecies *R. aurora draytonii* as threatened under the Act (Service 1996, p. 25832). Subsequently, Shaffer *et al.* (2004, p. 2673) used genetic data to differentiate *R. aurora* into two distinct species: northern red-legged frog (*R. aurora*) and California red-legged frog (*R. draytonii*). In 2010, the Service formally recognized full species status for *R. draytonii* in its final rule designating critical habitat for the species (Service 2010, p. 12873).

Genetics

To date, the most comprehensive survey of genetic diversity within California red-legged frogs is Richmond *et al.*'s (2014) survey of microsatellite and mitochondrial DNA data from populations throughout the species range. Frequently, ranid frog species display high amounts of genetic structure between populations caused by philopatry to breeding sites and relatively limited ability to disperse long distances between breeding populations. Richmond *et al.* (2014, p. 134) identified corresponding patterns of strong genetic structure within California red-legged frogs. Specifically, Richmond *et al.* (2014, p. 136) found that Sierra Nevada populations no longer exchange immigrants with each other and are also no longer genetically connected with populations outside the Sierra Nevada. Similarly, Richmond *et al.* (2013, p. 818) found that populations south of Santa Barbara County no longer exchange immigrants with each other and are also no longer genetically connected with populations north of Ventura County. Contrastingly, Richmond *et al.* (2014, p. 134) found that populations in the Bay Area likely continue to retain genetic connectivity with one another.

Additionally, Richmond *et al.* (2014, p. 134) identified a pattern of genetic diversity indicating that Sierra Nevada populations shared most recent common ancestry with Southern California populations rather than Northern California populations. Richmond *et al.* (2014, p. 135) also found that populations in the Sierra Nevada possessed geographic patterns of genetic diversity indicating northwards expansion following the post-Pleistocene glacial retreat.

Overall, we expect that contemporary California red-legged frog populations have reduced genetic diversity relative to the species' historical genetic diversity. The approximately 57 percent reduction in species range likely reflects a proportionate decrease in abundance and a concordant reduction in the genetic diversity of the species. The large reduction in the species' range has severed genetic connectivity between Sierra Nevada populations and the rest of the species range. Similarly, almost all populations south of Santa Barbara County have lost genetic connectivity with the rest of the species range (the Matilija Creek/Ventura River population in Ventura County may be an exception). Accordingly, the coastal populations south of Santa Barbara County and Sierra Nevada populations now have separate evolutionary trajectories from coastal populations north of Ventura County. The loss of gene flow within and between regional populations has likely exacerbated the effect of genetic drift on populations. Accordingly, these populations likely have each suffered substantial stochastic loss of allelic diversity (including beneficial or otherwise adaptive alleles) over time. Artificial translocation of California red-legged frogs between isolated populations (i.e., assisted gene flow) would provide a powerful ameliorating effect on the loss of genetic diversity within these populations.

Species-specific Research and/or Grant-supported Activities

The Service has overseen many California red-legged frog research or other grant-supported activities since the time of the species' listing, we discuss these activities in the Significant Conservation Efforts section below.

THREATS ASSESSMENT (FIVE-FACTOR ANALYSIS)

The following five-factor analysis describes and evaluates the threats attributable to one or more of the five listing factors outlined in section 4(a)(1) of the Act.

The final listing rule for the California red-legged frog (Service 1996, pp. 25824–25830) listed the following factors as threats to the viability of the species: (1) urban encroachment, (2) construction of large and small reservoirs, water diversions and well development, (3) flood control maintenance, (4) road maintenance, (5) placer mining, (6) livestock grazing and feral pigs, (7) off-road vehicle use, and (8) introduction or presence of exotic predators and competitors. Below, we discuss these threats and other threats identified by the Service following the species' listing.

FACTOR A: Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

The Service's 2002 Recovery Plan for the species specifically identifies urbanization, agriculture, impoundments and water management, channelization and flood control, mining, livestock grazing and dairy farming, recreation and off-road vehicles, and timber harvesting activities as contributors to Factor A (Service 2002, pp. 17–23). The effects of timber harvest are largely similar to the effects of agriculture and therefore we have combined our discussion of these effects into a single category. Additionally, the effects of channelization and flood control activities are largely similar to the effects of water impoundments and management projects and therefore we have combined our discussion of these effects into a single category. Furthermore, we have generalized livestock grazing and dairy farming activities to livestock ranching activities. We discuss the status of each of these contributors to Factor A below.

Urbanization

The Service's 2002 Recovery Plan for the species identified urbanization as a significant threat to the California red-legged frog. Urban and suburban developments create isolated habitat fragments and barriers to dispersal (e.g., roads and walls) and consequently reduce connectivity between populations. Furthermore, urbanization can reduce the water available to frogs in the area, contaminate downstream habitat with pollutants and sediment, and facilitate the introduction of predators such as bullfrogs and raccoons. Urbanization remains a significant threat to the California red-legged frog. Urbanization of areas within California red-legged frog habitat continues to occur particularly along aquatic corridors containing suitable breeding habitat.

California red-legged frogs in the Sierra Nevada are under relatively low threat from urbanization because populations are located away from densely populated urban centers and many of these populations are located on protected land. California red-legged frogs in coastal areas north of Santa Barbara County are under moderate threat from urbanization. Some populations in coastal areas north of Santa Barbara County are located near densely populated urban centers but the majority of the species range in coastal areas north of Ventura County (outside of the nine-county San Francisco Bay Area) are located away from urban centers. Additionally, the cooler, wetter climate of the species range north of Ventura County somewhat reduces the negative effect of urbanization on water availability for the species. Furthermore, the greater abundance and connectivity of California red-legged frogs in coastal areas north of Ventura County also somewhat reduces the negative effect of urbanization.

Contrastingly, populations south of Santa Barbara County are under intense threat from urbanization. Almost all known populations south of Santa Barbara County are within 20 miles of a major urban center. Populations south of Santa Barbara County (with the exception of the Matilija Creek/Ventura River population in Ventura County) are separated from neighboring populations by major urban development and roadways. Residential and agricultural use of surface water and groundwater resources in these areas reduces the availability and hydroperiod of suitable aquatic breeding habitat in these hot, dry areas. Similarly, the high human population density in coastal areas south of Santa Barbara County also facilitates introduction of invasive species such as crayfish and giant reed. For example, the sole breeding ponds of the Las Virgenes Creek population in Los Angeles County are on preserved land within 400 m of major urban development and invasive predators and water use issues continue to hinder re-establishment of California red-legged frogs in Malibu Creek.

The Service and its partners have attempted to address the effects of urbanization on the California red-legged frog by establishing conservation banks, permanently preserving areas, creating ponds, and restoring habitat (e.g., removing invasive predators and plants). Nevertheless, urbanization continues to be a threat to the California red-legged frog.

Agriculture

As in the Service’s 2002 Recovery Plan, we distinguish monotypic agricultural activities (e.g., viticulture, row farming, or timber harvest) from ranching and grazing activities. Similar to urbanization, agriculture creates isolated habitat fragments and barriers to dispersal for California red-legged frog. Agriculture can reduce water available to the species in the area, introduce contaminants such as pesticides and sediment into suitable habitat, and facilitate the presence of predators such as raccoons and bullfrogs. Illegal, unpermitted cannabis cultivation sites in particular are known to degrade habitat by converting habitat on protected lands and drafting water from neighboring aquatic habitat. Notably, the habitat fragmentation produced by agriculture is of a lesser magnitude than the fragmentation produced by urbanization because agricultural lands generally remain permeable for dispersing California red-legged frogs and individuals can use water impoundments on agricultural lands such as frost ponds for shelter during movements.

The effect of agriculture on the species can be seen in the near extirpation of the species from the Central Valley region following a century of intense agricultural activities. Fisher and Shaffer (1996, p. 1395) suggested that the declines of native amphibians in the Central Valley and other agricultural regions were due to intense farming practices that rendered the few remaining ponds and pools on these valley floors uninhabitable for native species. The Service’s Recovery Plan for the species (2002, p. 18) in particular singles out the practice of heavy use of fertilizers and pesticides in the region and Davidson (2004, p. 1897) notes a correlation between California red-legged frog population declines and upwind pesticide use. Nevertheless, California red-legged frogs are known to live and breed adjacent to agricultural fields (e.g., near Santa Maria in Santa Barbara County) so the precise effect of heavy use of fertilizers and pesticides on the species in the wild remains unknown.

California red-legged frogs face differing magnitudes of effects from agriculture throughout their range. Many coastal populations north of Ventura County occur nearby agriculture. In particular, populations in Santa Barbara, San Luis Obispo, Monterey, and Santa Cruz Counties occur nearby intensive agricultural activities such as hoop-house row crop farming. Populations south of Santa Barbara County are located away from agriculture with the exception of the Matilija Creek/Ventura River population in Ventura County.

In the Sierra Nevada region, multiple populations are located in close proximity to areas subject to timber harvest operations. Timber harvest operations vary in type and magnitude, from occasional clearcuts of large contiguous areas of forest to removal of individual trees during selective harvest or fuels reduction operations. Timber harvest operations can reduce and degrade California red-legged frog habitat by building and maintaining roads to accommodate vehicle traffic and generating erosion and sedimentation of downstream habitat.

The Service and its partners have attempted to address the effects of agriculture on the California red-legged frog by avoiding, minimizing, and mitigating effects through activities such as establishing conservation banks, permanently preserving areas that contain suitable habitat for the species, creating ponds, and restoring habitat (e.g., removing invasive predators). Nevertheless, agriculture continues to be a threat to the California red-legged frog.

Impoundments and water management projects

As described in the Service’s 2002 Recovery Plan, water impoundment and management projects affect California red-legged frog habitat by removing suitable habitat and altering watershed hydrology and the hydroperiod available to California red-legged frogs. Water impoundment and management projects can also create impassible barriers such as large dams which limit connectivity within watersheds. Additionally, water impoundments can facilitate the presence of invasive predators such as bullfrogs and crayfish. Water impoundment and management projects frequently occur in service to urbanization and agricultural development to ensure year-round water availability for these developments and thus effects on the California red-legged frog from urbanization and agricultural development are frequently compounded by additional effects from water impoundment and management projects.

The range of the California red-legged frog typically has a “Mediterranean” climate characterized by dry summer and mild, wet winters. The life histories of California red-legged frogs align with this “Mediterranean” climate pattern by breeding and dispersing during wet winter weather and sheltering in or near pools during the dry summer. Therefore, the propensity of water impoundment and management projects to alter hydroperiods away from natural patterns can further reduce habitat quality for the species. To date, studies have identified patterns of habitat loss and degradation for California red-legged frogs following construction of water management projects (Hayes and Jennings 1988, p. 154; Kupferberg *et al.* 2012, p. 517).

Nevertheless, water management projects and impoundments may also alter natural hydroperiods for the benefit of the species. For example, the species uses a large artificial pool at the former St. Francis dam site for breeding and shelter in hot, dry Los Angeles County.

The effects of channelization and flood management projects largely are similar to other water management projects in general. However, as noted by the Service's 2002 Recovery Plan, channelization and flood management activities such as dredging channels, placing erosion controls, or applying herbicides typically occur within stream channels and uplands where California red-legged frogs breed and shelter. Therefore, the magnitude of direct effects from channelization and flood management projects on California red-legged frogs may be relatively greater than other types of water management projects.

California red-legged frogs are currently affected by water impoundment and management projects throughout their range. Many of the known remaining populations in the Sierra Nevada region are located at artificial water impoundments created for historical logging or mining activities. Similarly, many of the populations south of Santa Barbara County are located nearby dams and other impoundments. Many coastal populations from north of Ventura County also are located near water impoundment or management projects. In particular, many populations in the nine-county San Francisco Bay Area are located near large reservoirs and other water management projects constructed to service urban and agricultural development. The Service's 2002 Recovery Plan (p. 19) lists these reservoirs near known California red-legged frog populations.

It is likely that agencies will continue to install water management projects (e.g., flood control basins) within the range of the California red-legged frog particularly near areas with urban or agricultural development. Therefore, it is likely that effects on the California red-legged frog from water impoundment and management projects will continue to increase, though at a less rapid pace than seen in the early 20th century.

The Service and its partners have attempted to address the effects of water impoundment and management projects on the California red-legged frog by working with agencies to avoid, minimize, and mitigate effects to natural hydrology and hydroperiod from such projects during the design and permitting processes. Nevertheless, water impoundment and management projects continue to be a threat to the California red-legged frog.

Mining

The Service's 2002 Recovery Plan for the species identifies habitat degradation from gold, sand, and gravel mining as well as oil and gas production activities as a threat to the species. These activities can remove suitable habitat, alter natural stream courses and hydroperiods, and introduce contaminants such as chemicals or sediment into species habitat. Historical mining and quarrying activities have also created artificial ponds on California red-legged frog habitat which can facilitate the presence of predators such as bullfrogs and crayfish. Relative to the other threats to the species discussed in this section, effects from mining and oil and gas production are limited geographically to a few areas. However, effects from these activities can be locally intense.

The Service is aware of no active suction dredge gold mining occurring near California red-legged frog populations. The Service is aware of ongoing sand and gravel mining occurring near California red-legged frog populations at the Sisquoc River and near Lompoc in Santa Barbara County. The Service is aware of ongoing oil and gas production activities occurring within California red-legged frog habitat in San Luis Obispo, Santa Barbara, and Ventura Counties.

The Service and its partners have attempted to address the effects of mining and oil and gas production projects on the California red-legged frog by working with agencies to avoid, minimize, and mitigate effects to natural hydrology and hydroperiod from such projects during the design and permitting processes. Nevertheless, mining and oil and gas production projects continue to be a threat to the California red-legged frog.

Livestock ranching activities

As described in the Service's special rule (Service 2006, p. 19285) exempting routine livestock ranching activities from prohibitions against take under Section 4(d) of the Endangered Species Act (4(d) rule), livestock ranching activities such as grazing and dairy farming can be both detrimental and beneficial to the California red-legged frog (Bobzien *et al.* 2000, p. 18). Specifically, while routine livestock ranching activities can degrade habitat by removing vegetation, introducing contaminants, and facilitating the presence of predators such as bullfrogs these activities also can enhance habitat by removing emergent vegetation that would otherwise overwhelm aquatic habitat. In many areas, livestock stock ponds are used as aquatic breeding habitat by the species.

California red-legged frog populations exist where livestock ranching activities occur throughout their range with the exception of coastal areas south of Santa Barbara County. We expect that these livestock ranching activities in these areas will continue to occur in proximity to California red-legged frog populations. As stated by the Service's 4(d) rule (Service 2006, p. 19286), the Service believes that continued livestock ranching activities near California red-legged frog populations is beneficial for the species.

The Service has worked with its partners to avoid, minimize, and mitigate the effects of livestock ranching activities on the California red-legged frogs. As indicated by the Service's 4(d) rule, there are numerous methods to manage ranching practices for the benefit of the California red-legged frog. To this end, conservation banks for the species frequently include livestock grazing and dairy farming activities to enhance habitat on bank lands for the benefit of the species.

Recreation

As discussed in the Service's Recovery Plan for the species (2002, p. 22), outdoor recreation and its associated infrastructure are known to degrade California red-legged frog habitat quality when occurring in proximity to California red-legged frog populations. Specifically, recreational activities can directly injure or kill California red-legged frogs, introduce contaminants and erosion into suitable habitat, facilitate the presence of predators, and alter hydroperiods in aquatic habitat.

California red-legged frogs exist where recreational activities occur in many locations throughout their range. Populations north of Santa Barbara County frequently occur in recreation areas such as the Golden Gate National Recreational Area, East Bay Regional Parks lands, and Marin County recreational lands. Notably, all populations in coastal areas south of Santa Barbara County and in the Sierra Nevada are on federal lands or are otherwise publicly accessible for recreational activities, other than the Big Gun, Lake of the Cross, and Sailor Flat populations in the Sierra Nevada. For example, the only breeding ponds for the Las Virgenes Creek population in Los Angeles County are located on Los Angeles County lands within 40 m of heavily-used recreational trails. Accordingly, populations in coastal areas south of Santa Barbara County and the Sierra Nevada may be particularly affected by recreation. We expect that recreational activities will continue to affect the species as human populations increase within the range of the species.

The Service has worked with its partners to avoid, minimize, and mitigate effects of recreation on the California red-legged frog. For example, federal agencies consider the presence of the species when siting and managing recreational trails and campgrounds. In general, populations vulnerable to effects from recreation are located on publicly accessible lands managed by governmental agencies. The Service has worked with many of these agencies to develop programs to manage the effects of recreation on the species. Nevertheless, recreation continues to be a threat to the California red-legged frog.

Fire management activities

The Service has not previously identified fire management activities as a threat to the California red-legged frog. The range of the California red-legged frog has suffered a regional drought for the past decade. During this period the frequency and magnitude of wildfires within the range of the species (i.e., coastal areas and the Sierra Nevada range) has increased accordingly (Li and Bannerjee 2021, p. 12). For example, the 2017 Thomas fire burned large portions of the species range in Ventura and Santa Barbara Counties, the 2017 Tubbs fire burned large portions of the species range in Napa and Sonoma Counties, and the 2018 Woolsey fire burned the sole remaining breeding ponds for the species in the Santa Monica Mountains in Los Angeles County. Accordingly, over time both preventative fire management activities such as mechanical thinning or prescribed burns and fire response activities such as cutting dozer lines and aerial retardant drops have likely increased in frequency within the range of the California red-legged frog.

Preventative fire management activities such as mechanical thinning may have some direct effects on California red-legged frog through trampling or crushing of individuals but the intensity of these effects is likely low and relatively small in scale. Contrastingly, large-scale use of aerial retardant for fire response activities may have much broader effects on entire watersheds. According to Pilliod *et al.* (2003, pp. 24–25), there is little evidence for direct effects on amphibians from toxic exposure to aerial retardant. Nevertheless, aerial retardant is primarily nitrogenous and this nitrogen input can cause algal blooms, alter water chemistry, and facilitate the establishment of invasive plants (Zouhar *et al.* 2008, p. 11). We anticipate that use of aerial retardant will continue if not increase over time throughout the species range.

The Service has worked extensively with its agency partners to avoid and minimize the effects of fire response activities on the California red-legged frog. For example, prior to fire season the Service will identify changes to the distribution of listed species (e.g., California red-legged frog) for fire agencies to avoid effects on listed species from fire management activities. Nevertheless, fire response agencies' activities are directed by many State and federal laws and occasionally fire management activities must take place in areas where listed species occur. Following fire response activities, federal agencies evaluate the effects of these activities on listed species in areas of federal responsibility and request consultation on these actions under Section 7(a)2 of the Endangered Species Act. Nevertheless, fire management activities are likely to remain a threat to the California red-legged frog.

FACTOR B: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

The Service evaluated threats to the species from overutilization in its 2002 Recovery Plan for the species and concluded that overutilization in any form was not a threat to the species at that time (Service 2002, p. 23). The status of these threats from overutilization has not changed in the time following the Service's 2002 Recovery Plan and therefore overutilization for any purpose does not appear to be a threat at this time.

FACTOR C: Disease or Predation

Disease

The Service's 2002 Recovery Plan for the species identified disease as a potential threat to the California red-legged frog (Service 2002, pp. 23–24). To the Service's knowledge, *Batrachochytrium dendrobatidis* (chytrid) fungus is the only disease-causing pathogen that could be considered a threat to the California red-legged frog as a species. At the time of the Service's 2002 Recovery Plan for the species, little was known about the extent of chytrid infestation within the range of the species and the effects of chytrid infection on individuals. In the following years, research has shown that chytrid infestation is widespread in California red-legged frog habitats, with few exceptions. Additionally, research has indicated that California red-legged frogs can survive high fungal loads with little apparent effect, especially relative to other ranid frog species such as foothill yellow-legged frog (*Rana boylii*; Adams *et al.* 2020, p. 2). Furthermore, researchers have found that California red-legged frogs have both innate and adaptive immune responses to chytrid fungi. Nevertheless, recently researchers have identified patterns of reduced survival amongst infected California red-legged frogs (Russell *et al.* 2019, p. 8) and an instance of direct mortality of a subadult frog caused by chytrid infection (Adams *et al.* 2020, p. 4).

At present, chytrid fungi is an endemic, range-wide pathogen that appears to have minimal direct effects on California red-legged frogs. However, chytrid fungi are not monotypic and possess substantial genotypic and phenotypic diversity. Accordingly, California red-legged frogs may be vulnerable to introduced chytrid variants from other areas. Introduction of a new chytrid variant may have contributed to mortality of adult California red-legged frogs in Las Virgenes Canyon in Los Angeles County in 2021 (Santa Monica Mountains National Recreational Area 2021, p. 2). Therefore, chytrid fungus may be a potential threat to the California red-legged frog and the Service should continue to monitor the effects of chytrid fungus on the species, particularly from introduced chytrid variants.

Predation, competition, and invasive species

Predation

The Service's 2002 Recovery Plan for the species identified predation as a significant threat to the California red-legged frog (Service 2002, p. 24). Predation of California red-legged frogs by invasive bullfrogs and swamp crayfish (*Procambarus clarkii*) is known to extirpate populations and hinder colonization of otherwise suitable habitat by California red-legged frogs (Hayes and Jennings 1986, pp.154–155; Jennings and Hayes 1990, pp. 19–21; DePalma-Dow *et al.* 2020, p. 45). Accordingly, the presence of these predators in particular can challenge translocation efforts intended to fulfill Recovery Task 10 (i.e., re-establishment of existing populations) described in the Service's 2002 Recovery Plan for the species. Notably, it is possible for California red-legged frogs to coexist with these predators for some period of time (Jennings and Hayes 1990, p. 19; Christopher 2004b, p. 97); however, the presence of these predators should nevertheless be viewed as a significant threat to populations. It remains difficult to remove these predators from California red-legged frog habitat because of their invasive life history traits and continued introduction to habitat near urban areas as sport fishing bait. Raccoons, garter snakes (*Thamnophis* spp.), centrachid fish species such as bass (*Micropterus* spp.) and sunfish (*Lepomis* spp.), mosquitofish (*Gambusia affinis*), signal crayfish (*Pacifastacus leniusculus*), great blue herons (*Ardea Herodias*), cattle egrets (*Bubulcus ibis*), Sierra newt (*Taricha sierrae*), cats (*Felis domesticus*), red and grey foxes (*Vulpes vulpes* and *Urocyon cinereoargenteus*), African clawed frogs (*Xenopus laevis*), and coyotes (*Canis latrans*) also are known to prey on the California red-legged frog.

Predation on California red-legged frogs occurs throughout the species range. Bullfrogs and swamp crayfish in particular are present near almost all populations located near human development. The isolated populations in coastal areas south of Santa Barbara County may be particularly vulnerable to effects of predation because of continued introduction of predators from nearby urbanized areas and the lack of connectivity between populations to allow for re-colonization following extirpation. For example, following years of exhaustive crayfish removal trapping the California red-legged frog population in Las Virgenes Creek in Los Angeles County was able to extend its range 4 km downstream (Mountains Restoration Trust 2018, p. 26). However, following a lapse in trapping from June 2019 to May 2020, crayfish re-infested the formerly trapped areas and the California red-legged frog population's range has receded 400 m upstream (Kirby Bartlett, U.S. Fish and Wildlife Service, pers. comm. 2021).

Predation by bullfrogs is more common in coastal populations north of Ventura County. Bullfrogs have adapted readily to the pond habitat available to California red-legged frogs in this region. Notably, bullfrog tadpoles have a multi-year maturity cycle that can be disrupted by artificially managing hydroperiod of ponds. Bullfrogs also are present in the Sierra Nevada region as well as native predators such as rough-skinned newt (Calef and Waller 1973, p. 751) and centrarchid fish (Alvarez *et al.* 2002, p. 11) which also can voraciously consume California red-legged frogs. However, predator removal in the Sierra Nevada region can be successful. For example, following an extensive multiyear effort, the National Park Service was able to eradicate bullfrogs from Yosemite Valley in Mariposa County and successfully reintroduce California red-legged frog to the Valley (Kamoroff *et al.* 2020, pp. 623–634).

The Service has worked extensively with its partners to address the effects of predation on the California red-legged frog, in particular focusing on threats from bullfrog and swamp crayfish. The Service has worked with partners to eradicate bullfrog and crayfish from California red-legged frog habitat by managing hydroperiods (Jody McGraw Consulting 2020, pp. 7–8) and extensive capture and trapping efforts (Kamoroff *et al.* 2020, p. 618; Mountains Restoration Trust 2018, p. 21). Despite this progress, predation of California red-legged frogs, particularly by bullfrogs and crayfish, continues to be a significant threat to the California red-legged frog.

Competition

The Service's 2002 Recovery Plan for the species identified competition with bullfrogs as a threat to the California red-legged frog (Service 2002, p. 65). Prior to the introduction of bullfrogs, California red-legged frogs were the largest frogs in the Western United States. Therefore, there are few native competitors to the California red-legged frog (e.g., western toads (*Anaxyrus boreas*)). However, bullfrogs are significant competitors to the California red-legged frog. American bullfrogs are larger, more generalized predators, have longer potential breeding seasons, produce around 4 times more eggs than California red-legged frogs per breeding season (up to 20,000), and are unpalatable to predatory fish as tadpoles (Service 1996, p. 25828). Accordingly, D'Amore *et al.* (2009, pp. 538–540) observed direct and indirect effects on California red-legged frogs from competition in addition to predation by bullfrogs. Therefore, competition with bullfrogs continues to threaten the California red-legged frog, though the magnitude of this threat on the species is likely lower than the threat from predation by bullfrogs.

Invasive species

The Service's 2002 Recovery Plan for the species identified threats to the California red-legged frog from habitat degradation by invasive plant and animal species (Service 2002, pp. 24-27, 65-66). Multiple invasive species are known to degrade California red-legged frog habitat quality by ecosystem modification rather than direct predation. Feral pigs (*Sus scrofa*) can degrade habitat by rooting and wallowing in riparian areas and wetlands. The invasive water fern *(Azolla pinnata;* hereafter *Azolla*) is a freshwater floating fern found in suburban and rural ponds and can degrade habitat for the species. An *Azolla* infestation in Ledson Marsh in Sonoma County created anoxic conditions and reduced invertebrate populations to the point that California red-legged frogs abandoned breeding sites in areas of the marsh most invaded by *Azolla* (D. Cook, pers. comm. 2018). Giant reed (*Arundo donax*) is an invasive marsh plant that forms thick, resilient stands in riparian habitat and readily spreads downstream through cane fragments. Giant reed stands can impede California red-legged frog movement in riparian areas and reduce the amount of aquatic habitat available in an area by infilling pools with vegetation. Additionally, giant reed may reduce surface water in infested streams through its relatively high rate of evapotranspiration (Giessow *et al.* 2011, pp. 48 and 56). Therefore, invasive species continue to threaten the California red-legged frog and we anticipate that this threat likely will increase as human populations increase near California red-legged frog populations.

FACTOR D: Inadequacy of Existing Regulatory Mechanisms

At the time of listing, regulatory mechanisms thought to have some potential to protect the California red-legged frog included: (1) Section 404 of the Clean Water Act; (2) the California Environmental Quality Act (CEQA) and the National Environmental Quality Act (NEPA); and

(3) multiple land use management as practiced by national, state, and local land management agencies. The listing rule (Service 1996, pp. 25828–25829) provides an analysis of the level of protection that was anticipated from those regulatory mechanisms. This analysis appears to remain valid.

Aside from the Endangered Species Act (Act), Section 404 of the Clean Water Act remains the primary protective mechanism for the California red-legged frog under Federal law. The U.S. Army Corps of Engineers (Corps) reviews individual and nationwide permit applications under Section 404 of the Clean Water Act that may affect Waters of the United States, which in California frequently are used by the California red-legged frog. The Corps then determines if the permit application's proposed activities may affect the California red-legged frog. If the Corps determines that proposed activities are likely to adversely affect the species, the Corps initiates consultation with the Service on the proposed activities under Section 7(a)(2) of the Act. During this consultation process, the Corps and the Service coordinate on appropriate measures to avoid, minimize, and off-set effects from the proposed activities on the California red-legged frog.

Notably, the jurisdiction of the Corps is limited to the Waters of the United States and occasionally nearby uplands and therefore the Corps cannot require avoidance, minimization, or compensation measures for effects to listed species that occur outside Corps jurisdictional areas. Despite this limitation, the Service and the Corps currently are implementing a "small federal handle" policy that allows the Service to include analysis of incidental take of listed species outside of Corps jurisdiction in biological opinions issued to the Corps under Section 7(a)(2) of the Act. Consequently, under the "small federal handle" policy the Corps can exempt take of listed species from penalties under Section 9 of the Act in areas outside of federal jurisdiction, an exception formerly reserved for permittees under Sections 10(a)1(a) and 10(a)1(b) of the Act. This new exception may encourage development activities on non-federal lands that were formerly inhibited by the presence of California red-legged frogs.

The National Environmental Policy Act (NEPA) is the remaining federal law with the potential to protect the California red-legged frog. Both NEPA and the State of California's California Environmental Quality Act (CEQA) require an intensive environmental review of projects' environmental effects including effects on listed and non-listed wildlife species. However, project proponents are not required under NEPA or CEQA to avoid, minimize, or mitigate effects on wildlife species if the project's effect on a species is not "significant".

The State of California has taken various regulatory steps to protect the California red-legged frog. The California Fish and Game Commission amended its sport fishing regulations in 1972 to prohibit take or possession of California red-legged frog. Additionally, the California Department of Fish and Wildlife banned importation of bullfrogs, a voracious predator of California red-legged frogs, as a food product in 2010 though enforcement of this regulation appears infrequent. The Service has provided the California Department of Forestry and Fire Protection with guidelines to avoid effects on California red-legged frogs during the Department's implementation of Timber Harvest Plans. The State of California designated the California red-legged frog as a ''Species of Special Concern'' and the species may not be taken without an approved scientific collecting permit from the California Department of Fish and

Wildlife. However, designation as a Species of Special Concern provides no legally mandated protection of the species or its habitat.

Multiple land use management, as currently practiced by federal agencies, does not necessarily provide long-term protection for the California red-legged frog because protection of the species under the Endangered Species Act is balanced alongside other coequal federal laws. For example, the U.S. Forest Service has created breeding ponds for the species on its lands, but still permits timber harvest, recreational, and infrastructure activities that may affect the California red-legged frog. State, County, and Regional Park lands provide some protection from some threats, however, these parks are also managed for multiple uses. Multiple land use management by local governmental agencies can also threaten local populations of California red-legged frogs. For example, food safety standards promulgated by the US Department of Agriculture and agricultural industry groups recommend removal of riparian vegetation in the vicinity of leafy green (e.g., spinach) production areas in an effort to reduce vectors for *E. coli* contamination. Producers in the Salinas River Valley, which produces 70 percent of all leafy greens grown in the United States, removed approximately 13 percent (2000 hectares) of riparian habitat in the Valley to conform to these guidelines between 2005 and 2009 (Gennet *et al.* 2012, p. 6) including occupied California red-legged frog habitat. Similarly, County ministerial pest control programs, such as the Northern Salinas Valley Mosquito Abatement District, can threaten California red-legged frog populations by introducing mosquitofish and applying pesticides both of which reduce the insect prey available to California red-legged frogs. Mosquitofish are known to attack California red-legged frog tadpoles and delay metamorphosis of tadpoles through behavioral changes and competition for invertebrate prey (Lawler *et al.* 1999, p. 621).

In summary, the Endangered Species Act is the primary Federal law that provides protection for this species since its listing as threatened in 1996. Other Federal and State regulatory mechanisms may provide some discretionary protections for the species but do not guarantee protection for the species absent its status under the Act. Additionally, multiple land use management policies such as food safety regulations or mosquito vector control policy can contribute to threats to local California red-legged frog populations. Therefore, other laws and regulations continue to have limited ability to protect the species in absence of the Endangered Species Act.

FACTOR E: Other Natural or Manmade Factors Affecting Its Continued Existence

Pesticides

The Service's 2002 Recovery Plan for the species described pesticide use as a potential significant threat to the species and attributed in part the species' decline in the Central Valley to heavy use of pesticides in the area (Service 2002, pp. 28 –30). Biologists have continued to observe persistence and breeding of California red-legged frog populations in areas of heavy agricultural pesticide use such as near Santa Maria in Santa Barbara County and Watsonville in Santa Cruz County (CNDDB 2022). Laboratory experiments have observed strong negative effects on amphibians from exposure to glyphosate-based herbicides, a specific class of pesticides with polyethoxylated tallowamine surfactant (e.g., Roundup herbicide; Govindarajulu 2008, pp. 3–8). Nevertheless, California red-legged frogs persist in areas of heavy herbicide use such as recreational parks and golf courses and it appears that nearby pesticide use, including herbicides, do not preclude the presence of California red-legged frogs. However, pesticides may still degrade habitat quality in general by causing algal blooms, reducing the prey base for the species in an area, altering the natural composition of vegetation, or decreasing the cover available to California red-legged frogs. Consequently, the U.S. Environmental Protection Agency has issued regulations prohibiting the application of certain pesticides in and around California red-legged frog habitat (https://www.epa.gov/endangered-species/how-comply-requirements-protect-california-red-legged-frog-pesticides). Accordingly, pesticide use remains a potential threat to the California red-legged frog.

Climate Change

The Service's 2002 Recovery Plan for the species specifically identifies drought as a threat to the species (Service 2002, p. 28) and we have incorporated drought into our more general discussion below of threats to the species from climate change. The scientific consensus is that anthropogenic inputs of carbon dioxide and other greenhouse gases are the primary cause of observed rapid global warming over the past century (i.e., climate change). Rapid global warming over the past century also has changed evaporative patterns which can alter patterns of humidity, the amount of rainfall and snowpack, the frequency of severe storms, and the likelihood of severe drought. Scientists expect higher temperatures and more frequent drought conditions to increase the frequency and intensity of wildfires as well.

To date, scientists have observed over the past century an increase in mean annual temperature between 0.5 and 3 degrees Fahrenheit within the range of the California red-legged frog, with a maximum increase of 3 degrees in coastal areas south of San Luis Obispo County (EPA 2016, p. 1). Swain *et al.* (2018, p. 431) predict that climate change will decrease total statewide precipitation only modestly but will increase the frequency of extreme wet and dry years, particularly in Southern California. Additionally, higher temperatures will increase evaporation rates and reduce the amount of surface water available. McHarry *et al.* (2019, pp. 11–12) studied the potential future effects of climate change on species phenology and survival using a latitudinal gradient of field sites and found that climate influenced all life stages of the species including a correlation between maximum temperature and egg mortality.

We expect that ongoing climate change will continue to reduce and degrade available habitat for the species by inducing generally warmer and drier climate conditions throughout the range of the species. Warmer and drier climate conditions will reduce available habitat for the species by reducing water availability and altering hydroperiods of suitable aquatic habitat. Reduced water availability will reduce the number and extent of areas suitable for breeding and development. Thorne *et al.* (2016, Table S4) expect freshwater marsh habitat in California to decrease by up to 64 percent by 2099 as a result of climate change. Additionally, reduced water availability and less frequent precipitation will limit the distance and frequency of long-distance dispersal events by individuals. These long-distance dispersal events are necessary to maintain genetic connectivity between populations and to recolonize areas of suitable habitat following population extirpation. Changes in precipitation patterns may cause higher flows in stream habitats during egg-laying periods and result in more frequent scouring of egg masses and vegetative cover.

Additionally, climate change likely will increase the frequency and severity of wildfires within the range of the California red-legged frog (Bedsworth *et al.* 2018, p. 30). California red-legged frog populations appear to be resilient to direct effects from wildfire, with populations immediately returning to successful breeding in heavily burned areas following the 2017 Thomas Fire, 2018 Camp Fire, 2018 Woolsey Fire; and 2020 North Complex Fire (P. Lieske, pers. comm. 2021; James Johnson, U.S. Forest Service, pers. comm. 2019; Santa Monica Mountains National Recreational Area 2019, p. 2; James Johnson, pers. comm. 2021). However, habitat degradation from post-fire sedimentation and accumulation of fire-retardant chemicals within inhabited watersheds is likely. We expect these wildfire-related habitat degradation effects on the California red-legged frog will increase over time throughout the species range. Overall, we expect that the threat of habitat degradation from climate change will increase over time on the California red-legged frog throughout the species range.

Combined Effects

The California red-legged frog has suffered wide-scale loss of aquatic, upland, and dispersal habitat as a result of urban, agricultural, rangeland, and water development. The once wide-spread species is now restricted to isolated stock ponds, wetlands, and creeks frequently located near urban or agricultural areas. Urbanization of land within and adjacent to California red-legged frog habitat threatens populations by introduction of predators and reduction of riparian cover (Hayes and Jennings 1988, p. 152). The spread of invasive predatory species has degraded the quality of many remaining areas of breeding habitat. Concurrently, regional climate warming and drying caused by climate change likely will further reduce the amount and quality of suitable aquatic habitat over time.

Significant Conservation Efforts

Conservation Plans

Habitat Conservation Plans (HCPs) permitted under Section 10(a)1(b) of the Act exempt take of listed species in exchange for implementation of sufficient avoidance, minimization, and mitigation measures to provide a conservation benefit to the species as a project outcome. Currently, there are 33 HCPs and one General Conservation Plan that include the California red-legged frog as a covered species. The areas covered by these Conservation Plans total approximately 1,965,493 acres and are located throughout the range of the species including large portions of San Diego, San Joaquin, and Santa Clara Counties. However, large portions of the areas covered by these Conservation Plans, particularly multi-species Conservation Plans in Southern California and the San Joaquin Valley, do not contain suitable habitat for the species. Therefore, these plans together protect some amount less than 1,965,493 acres of the species range.

The Safe Harbor Policy provides incentives for property owners to restore, enhance and maintain habitats for listed species. Because many endangered and threatened species occur exclusively, or to a large extent, on non-Federally owned property, the involvement of non-Federal property owners in the conservation and recovery of listed species is critical to the eventual success of these efforts. There are currently 11 safe harbor agreements that include the California red-legged frog.

The Service's Sacramento Fish and Wildlife Office has developed and implemented the *East Alameda County Conservation Strategy* (EACCS) (EACCS 2011). The EACCS is intended to provide an effective framework to protect, enhance, and restore natural resources in eastern Alameda County, while improving and streamlining the environmental permitting process for impacts resulting from infrastructure and development projects. The EACCS not only addresses project-level mitigation for potential impacts to the California red-legged frog and its habitat throughout the eastern part of the county, but also provides a broader, coordinated approach for local conservation efforts beyond those required by mitigation.

Habitat Restoration

The Service worked with its partners on numerous habitat restoration projects for the California red-legged frog ranging from removal of invasive predators from Las Virgenes Creek in Los Angeles County (Mountains Restoration Trust 2018, p. 26) to construction of ponds on the Eldorado National Forest (US Forest Service 2014, p. 4), Plumas National Forest (US Forest Service 2019, p. 2), Tahoe National Forest (US Forest Service 2020, p. 3), and Bureau of Land Management lands (Service 2004, p. 2; US Bureau of Land Management 2016, p. 3) in the Sierra Nevada. The Service continues to focus its efforts on habitat restoration, particularly as part of translocation projects, and will continue to do so in the future.

Habitat Protection

To calculate the proportion of the species range on protected lands, we compared the species range to areas identified as protected in the California Protected Areas Database (CPAD; GreenInfo Network 2021a) or under a conservation easement in the California Conservation Easement Database (CCED) (GreenInfo Network, 2021b). The CPAD includes national, state, or regional parks forests, preserves, and wildlife areas; large and small urban parks that are mainly open space; land trust preserves; and special district open space lands. CPAD specifically excludes military lands, tribal lands, private golf courses, and public lands not intended for open space such as waste facilities or administrative buildings. The CCED includes easements held by land trusts, nonprofit organizations, local jurisdictions, and State and national governmental agencies. 6,057,310 acres (32.6%) of the total 18,571,388 acres in the species range are on protected lands or lands under a conservation easement. From comparison to the Bureau of Land Management's Land Status Management database (U.S. Bureau of Land Management 2021) an additional 373,740 acres (2.0%) of the species range are on military lands where the species is still protected by the Endangered Species Act Section 7 consultation process to avoid and minimize effects on the species (Cheryl Hickam, U.S Fish and Wildlife Service, pers. comm. 2022).

Reintroductions

The Service and its partners have reintroduced California red-legged frogs to four localities in the Santa Monica Mountains in Los Angeles and Ventura Counties, to Yosemite Valley in Mariposa County, to two localities on the Santa Rosa Plateau in Riverside County, and one locality in San Diego County. The Santa Monica Mountains and Yosemite Valley populations have successfully bred following reintroduction (Santa Monica Mountains National Recreational Area 2021, p. 12; Kamoroff *et al.* 2020, p. 624). Additionally, the Santa Monica Mountains populations have persisted despite the catastrophic 2018 Woolsey fire burning all four reintroduction sites (Santa Monica Mountains National Recreational Area 2019, p. 2). In 2020 and 2021, the Service used egg masses from Baja California and Riverside County populations of the species to establish two adjacent reintroduction sites on State and County lands on the Santa Rosa Plateau in Western Riverside County and another reintroduction site on private land in San Diego County (Simonsen, pers. comm. 2021). The Service is also preparing to reintroduce California red-legged frogs to Gravel Pit and Swamp Lakes in Tuolumne County as well.

III. RECOVERY CRITERIA

The Service completed a recovery plan for the California red-legged frog on May 28, 2002. Recovery plans provide guidance to the Service, States, and other partners and interested parties on ways to eliminate or reduce threats to listed species, and on criteria that may be used to determine when recovery goals are achieved. There are many paths to accomplishing the recovery of a species and recovery may be achieved without fully meeting all recovery plan criteria. For example, one or more criteria may have been exceeded while other criteria may not have been accomplished. For such instances, we may determine that, overall, the threats have been sufficiently addressed, and the species is robust enough to downlist or delist. In other cases, new recovery approaches and/or opportunities unknown at the time a recovery plan was finalized may be more appropriate ways to achieve recovery. Likewise, new information may change the extent that criteria need to be met for recognizing recovery of the species. Overall, recovery is a dynamic process requiring adaptive management, and assessing a species' degree of recovery is likewise an adaptive process that may, or may not, fully follow the guidance provided in a recovery plan. We focus our evaluation of species status in this 5-year review on progress that has been made toward recovery since the species was listed by eliminating or reducing the threats discussed in the five-factor analysis. In that context, progress towards fulfilling recovery criteria serves to indicate the extent to which threat factors have been reduced or eliminated.

The 2002 Recovery Plan for the California red-legged frog provided the following criteria for consideration of species delisting:

1) *Suitable habitats within all 35 core recovery areas designated by the 2002 Recovery Plan are protected and/or managed for the California red-legged frog in perpetuity, and the ecological integrity (e.g., water quality, uplands condition, hydrology) of these areas is not threatened by adverse anthropogenic habitat modification (including indirect effects of upstream/downstream land uses).* ***This criterion addresses listing factors A, C, and E****.*

   This criterion has not been met. To calculate the proportion of the core recovery areas on protected lands, we compared the 35 core recovery areas to areas identified by CPAD (GreenInfo Network, 2021a) as protected or identified by CCED (GreenInfo Network, 2021b) as under a conservation easement. 2,741,278 acres (38.6%) of the 7,087,001 acres within all 35 core recovery areas designated by the 2002 Recovery Plan are identified as protected or under conservation easement. From comparison to the Bureau of Land Management's Land Status Management database (U.S. Bureau of Land Management 2021) an additional 111,066 acres (2.0 %) of the 7,087,001 acres within all 35 core recovery areas are on military lands where the species is protected by the Endangered Species Act Section 7 consultation process to avoid and minimize effects on the species

(Hickam, pers. comm. 2022). The Recovery Plan did not define the amount of suitable habitat that would need protection or management in perpetuity in order to assure the ecological integrity of each core area. To assess this criterion, we would likely need further population viability and habitat modeling analyses which also account for projected climate change effects.

2) *Existing populations, throughout the range, are stable (i.e., reproductive rates allow for long term viability without human intervention). Because population numbers do not necessarily indicate stability, long term evidence of successful reproduction (e.g., presence of juveniles) and survivorship into different age classes provides a better indication of stability, persistence, and population resilience. Therefore, population status will be documented through establishment and implementation of a scientifically acceptable population monitoring program for at least a 15-year period (four to five generations) that includes an average precipitation cycle (a period when annual rainfall includes average to 35 percent above-average through greater than 35 percent below-average and back to average or greater; the direction of change is unimportant in this criterion).* ***This criterion addresses listing factors A, C, D and E***.

   This criterion has not been met. As described above, demonstrating population stability to meet the criterion requires long-term population monitoring programs and the few population monitoring programs currently in place have not yet met the 15-year monitoring period requirement. Fortunately, the introduction of egg mass surveys (Wilcox *et al.* 2017, p. 70) as a less difficult alternative to visual encounter surveys for determining population abundance likely will facilitate implementation of new and existing long-term monitoring programs.

3) *Populations are geographically distributed in a manner that allows for the continued existence of viable metapopulations despite fluctuations in the status of individual subpopulations (i.e., when populations are stable at each core area).* ***This criterion addresses listing factors A, C, and E.***

   This criterion has not been met. Coastal populations south of Santa Barbara County are isolated from one another by impassible distances and therefore cannot exchange migrants with neighboring populations and maintain a metapopulation dynamic (Richmond *et al.* 2013, p. 818). Populations in the Sierra Nevada region also are isolated from one another by impassable distances and cannot maintain a metapopulation dynamic (Richmond *et al.* 2014, p. 134). However, populations in the Bay Area region have retained some amount of genetic connectivity and could potentially maintain a metapopulation structure (Richmond *et al.* 2014, p. 134).

4) *The subspecies is successfully reestablished in portions of its historical range such that at least one reestablished population is stable/increasing in each core area where frogs are currently absent.* ***This criterion addresses listing factors A and E***

   This criterion has not been met. Following listing the Service and its partners have successfully re-introduced the species to core recovery area 32 in San Diego County and the species currently occurs in 30 of 35 core recovery areas. The species remains absent in core recovery area 30 located in San Bernardino County; 31 located in Orange and Riverside Counties; and 33, 34, and 35 all located in San Diego County.

5) *The amount of additional habitat needed for population connectivity, recolonization, and dispersal has been determined, protected, and managed for the California red-legged frog. There will be varying scales of connectivity needed including at the level of a local population (i.e., connectivity of habitat within a drainage) up to the needs of a metapopulation (many linked drainages over large regions such as recovery units). This will provide dispersal opportunities for population viability, genetic exchange, and recolonization.* ***This criterion addresses listing factors A, C, and E****.*

   This criterion has not been met. Populations in coastal areas south of Santa Barbara County remain isolated from one another and the areas necessary for population connectivity are not protected or managed for the California red-legged frog. The Recovery Plan did not define the amount of population connectivity necessary to maintain a metapopulation structure across many linked drainages. Quantifying the required level of connectivity to maintain a metapopulation structure would require population viability analyses and further field study of long-distance dispersal and subsequent gene flow between drainages.

IV. SYNTHESIS

Over the past century, the California red-legged frog has lost 57 percent of its historical range and its remaining range is threatened by anthropogenic development, invasive predators, and climate change effects. Additionally, the formerly contiguous species range is now reduced to three genetically distinct, geographically disjunct areas (coastal areas north of Ventura County, coastal areas south of Santa Barbara County, and the Sierra Nevada region). Coastal populations south of Santa Barbara County and Sierra Nevada populations have lost genetic connectivity among themselves and may be particularly vulnerable to species threats. Climate change effects will reduce habitat quality and quantity throughout the species' range, and further impede connectivity between populations. To date, the species has not met any of the delisting criteria presented in the Service's 2002 Recovery Plan though the species has proven resilient to numerous potential threats such as chytrid fungus and catastrophic wildfires. Approximately 32.6 percent of the species range are in protected areas or land under conservation easement and an additional 2.0 percent of the range is on military lands where activities must undergo a Section 7 consultation process to avoid or minimize effects on the species. Additionally, numerous habitat restoration efforts are underway and translocation efforts have proven consistently successful.

After reviewing the best available scientific information, we conclude that the California red-legged frog continues to meet the definition of a threatened species and recommend no change in its status at this time.

V. RESULTS

RECOMMENDED LISTING ACTION

____ Downlist to Threatened

____ Uplist to Endangered

____ Delist (indicate reason for delisting according to 50 CFR 424.11):

____ *Extinction*

____ *Recovery*

____ *Original data for classification in error*

__X__ No Change

NEW RECOVERY PRIORITY NUMBER AND BRIEF RATIONALE

No change in recovery priority number.

VI. RECOMMENDATIONS FOR ACTIONS OVER THE NEXT 5 YEARS

The following are recommended actions to promote the recovery of the California red-legged frog over the next five years.

1. Develop a range-wide long-term monitoring plan to evaluate if populations are stable and increasing, including specific long-term study sites.

2. Conduct studies to determine population sizes and locations sufficient to maintain metapopulation structures within core recovery areas.

3. Continue to remove non-native predators such as American bullfrog and other invasive species such as giant reed from California red-legged frog habitat throughout the species range.

4. Continue to promote habitat restoration and reintroduction efforts to restore population redundancy and metapopulation structure particularly in coastal populations south of Santa Barbara County to northern Baja California as well as populations within the San Joaquin Valley and adjacent foothills.

5. Work with private landowners to further conservation of California red-legged frog on private lands in the Sierra Nevada. This may include recording conservation easements on non-protected lands that support populations, acquiring occupied private lands from willing landowners, and increasing surveying efforts on private lands to better understand species distribution and recovery opportunities.

6. Continue to research habitat use and movement of California red-legged frog in the Sierra Nevada.

7. Continue to promote habitat protection and conservation in Mendocino County at the northern extent of the species range, and formally standardize a Service-approved protocol for eDNA surveys so the species status can be accurately studied and distinguished from the similar sympatric species, Northern red-legged frogs (*Rana aurora*).

8. Investigate “food safety” policies implemented by agricultural commodity buyers, and subsequently farmers, that result in the removal of natural riparian or terrestrial vegetation adjacent to farm fields for the purpose of stemming contaminate outbreaks.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW

California Red-Legged Frog *(Rana draytonii)*

Current Classification: Threatened

Recommendation Resulting from the 5-Year Review:

_____ Downlist to Threatened
_____ Uplist to Endangered
_____ Delist
__X__ No change needed

Review Conducted By: Sacramento Fish and Wildlife Office

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Sacramento Fish and Wildlife Office

Approve MICHAEL FRIS Digitally signed by MICHAEL FRIS Date: 2022.12.01 13:20:45 -08'00' Date _________

United States Department of the Interior
U.S. FISH AND WILDLIFE SERVICE
Ecological Services
Ventura Fish and Wildlife Office
2493 Portola Road, Suite B
Ventura, California 93003

IN REPLY REFER TO:
08EVEN00-2022-0045260-S7

April 24, 2023

Beatrice L. Kephart
30 CES/CEI
1028 Iceland Avenue
Vandenberg Space Force Base, California 93437

Subject: Biological Opinion on the Construction and Operation of the Phantom Launch Program at Space Launch Complex 5, Vandenberg Space Force Base, Santa Barbara County, California (2022-0045260-S7).

This document transmits the U.S. Fish and Wildlife Service's (Service) biological opinion based on our review of the U.S. Space Force's (Space Force) proposed authorization of the Phantom Space Corporation (Project Proponent) to construct and operate the Phantom Launch Program at Space Launch Complex (SLC)-5, Vandenberg Space Force Base (VSFB), Santa Barbara County, California and its effects on the federally threatened California red-legged frog (*Rana draytonii*) and western snowy plover (*Charadrius nivosus*), in accordance with section 7 of the Endangered Species Act of 1973, as amended (Act) (16 U.S.C. 1531 et seq.). We received your August 1, 2022, request for consultation on August 2, 2022.

We have based this biological opinion on information that followed your original May 18, 2022 request for consultation (Kaisersatt, S., pers. comm., 2022a), including the biological assessment (MSRS 2022a), and further coordination between Space Force and Service staff. These documents, and others relating to the consultation, are located at the Ventura Fish and Wildlife Office.

Definitions Related to Launch Noise Disturbance

The following abbreviations and terms related to launch noise disturbance occur frequently throughout this document. We define them briefly here for clarification and discuss them in more detail below under *Description of the Proposed Action*.

Launch and Static Test Fire Noise

The proposed project would generate engine noise disturbance with the highest sound pressure level (SPL) modeled to be 144 unweighted decibels (dB). The highest sound level measure during a single event is called the L_{max} (MSRS 2022a, p. 44).

Launch Sonic Boom

Each proposed launch would generate a separate sonic boom disturbance event that will not impact terrestrial areas (York, D., in litt., 2022, p. 6). Each sonic boom would produce disturbance in the form of overpressure which is high energy impulsive sound that would last for a fraction of a second. The maximum applicable overpressure produced for the purposes of this analysis would be up to 1.5 pounds per square foot (psf; MSRS 2022a, p. 11).

Not Likely to Adversely Affect Determination

The Space Force's request for consultation also included the determination that the proposed action may affect but is not likely to adversely affect the federally threatened marbled murrelet (*Brachyramphus marmoratus*) and southern sea otter (*Enhydra lutris nereis*), and the federally endangered California condor (*Gymnogyps californianus*), unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*), and tidewater goby (*Eucyclogobius newberryi*).

Marbled Murrelet

There were 23 total observations of marbled murrelets offshore from VSFB between 1995 and 2020 (MSRS 2022a, pp. 40-41; eBird 2022). In 2011, one observation from approximately 2 miles north of SLC-5 indicated presence of a marbled murrelet at an unreported distance offshore. Two additional observations from 1995 each indicated an individual present offshore from Purisima Point. The remaining observations occurred north of Minuteman Beach. Marbled murrelets do not breed on VSFB due to lack of breeding habitat, limiting the impacts of project activities to foraging adults. Marbled murrelet observations in this area have occurred as close as 984 to 6,561 feet from the shore (Strachan et al. 1995, p. 247).

Sound pressure and overpressure levels produced from the project's proposed operations have the potential to affect marbled murrelets in the vicinity of SLC-5. The Launch Noise Effect Area encompasses the Construction Effect Area and extends over the Pacific Ocean (Appendix A, Figures 2a and 2b), and the project area affecting marbled murrelets is a portion of offshore ocean encompassed by a 100 dB L_{max} contour (MSRS 2022a, p. 40). If marbled murrelets were to be present immediately off the coast during the proposed activities, they would be subjected to launch noise levels up to 120 dB L_{max} for launches or 115 dB L_{max} for static fire events (MSRS 2022a, p. 40). However, the further out areas typically inhabited by marbled murrelets would experience much lower noise levels. It is unknown how various noise and overpressure levels can affect marbled murrelet hearing capabilities, but we expect any nearby individuals to exhibit a startle response (i.e., dive and resurface) during launch or static fire events and return to normal behavior post-event (Bellefleur et al. 2009, p. 535).

The Space Force did not produce a strike probability analysis for the proposed action, but the Service assumes there is an extremely low probability of a strike potential due to the scarcity and transitory nature of marbled murrelets occurring in the project vicinity. It is unlikely for marbled murrelets to be present at the exact moment of each launch or static fire event. If a projectile or a component of launches struck a marbled murrelet on the water surface, it could result in injury or death to the individual, but the probability of a direct strike would be extremely low.

After reviewing the information provided, we concur with your determination that the proposed project may affect but is not likely to adversely affect the marbled murrelet on the basis of discountable effects. Our concurrence is based on the following:

1. Marbled murrelets occur irregularly and only as adults foraging offshore. They do not breed within the project area.
2. Monitoring data indicate maximum noise levels produced from launch operations are unlikely to have a significant effect on marbled murrelets. Effects would likely include only temporary behavioral reactions to noise disturbance.
3. The probability of launch debris striking a marbled murrelet individual is extremely low.

Southern Sea Otter

Southern sea otters are irregularly present in transit or foraging off the coast to the west and south of SLC-5. A small breeding colony of southern sea otter is located approximately 4 miles south of SLC-5 at the boat harbor, near Sudden Flats, and is located within the Launch Noise Effect Area (Appendix A, Figures 2a and 2b). Consequently, noise produced from the proposed project's launch operations has the potential to affect southern sea otters in the vicinity of SLC-5. No southern sea otter habitat is available within the launch pad Construction Effect Area (Appendix A, Figure 1). No southern sea otters are known to occur in the Overpressure Effect Area or Vehicle Splashdown Effect Area (Appendix A, Figure 3).

Southern sea otters located offshore at the time of a launch within the vicinity of SLC-5, including the breeding colony at the boat harbor, may be impacted by routine noise levels of less than 120 dB L_{max} and associated visual disturbance during individual launches (MSRS 2022a, p. 15). Monitoring data during space launch activities since 1998 indicate that launch noise and visual disturbances do not substantially affect the number or activities of southern sea otter in the nearshore marine environments of VSFB (Service 2015a, p. 4; MSRS 2022a, p. 69). Southern sea otters adjacent to LF-05 on north base have historically experienced launch noise of 136.6 dB SPL associated with Peacekeeper launches and continue to experience 127.8 dB SPL associated with Minuteman III launches with no observed effects (SRS 1999a as cited in MSRS 2021, p. 55). Consequently, the Service assumes that noise levels and visual disturbance resulting from individual launches associated with the proposed project's launch program would be similar to those already experienced on base and unlikely to result in observable effects to southern sea otter.

The proposed project would introduce novel launch noise disturbance frequency with launch related disturbance event every 2 days. Previous research indicates that sea otters may be capable of some level of acclimatization to noise. Davis, Williams, and Awbrey (1988) conducted a study of northern sea otter's (*Enhydra lutris kenyoni*) response to underwater and in-air noise stimuli utilizing a variety of sounds including air horns and an underwater acoustic harassment device capable of producing 190 dB SPL, for longer period playbacks (sound pulses every 15 seconds over a maximum of 3 hours (Davis et al. 1988, pp. 7 and 14). When exposed to the louder underwater acoustic harassment device, they remained undisturbed (Davis et al. 1988, p. 22). Following noise exposure to the air horn, the northern sea otter exhibited a startle, fleeing response. However, when a specific noise triggered a startle response, individuals only moved between 300 to 600 feet before resuming normal activity and exhibited habituation to the variety of noise stimuli over a short amount of time (Davis et al. 1988, pp. 31 and 35). Consequently, the Service anticipates any southern sea otters within the project area may exhibit a startle response to initial launch noise disturbance which may cause them to move a short distance but that they will likely resume normal behavior soon after. We also anticipate that southern sea otters located off the coast of VSFB may already exhibit a degree of habituation due to the existing launch environment and we do not currently expect the proposed project to result in novel effects.

Permanent and temporary threshold shifts in hearing sensitivity have yet to be determined for the southern sea otter. Based on biological similarities to southern sea otter, the Service has reviewed thresholds developed by U.S. Navy and the National Marine Fisheries Service for otariid pinnipeds as a surrogate (Finneran and Jenkins 2012, p. 5, 19-21; Navy 2017, p. 164). The lower limit for temporary threshold in-air shifts for otariids is 170 dB SPL and the lower limit permanent threshold in-air shift is 176 dB SPL (Navy 2017, p. 164). Being that the Service anticipates these levels would be above the predicted exposure level of 110 dB L_{max} for southern sea otters due to the proposed action and that individual noise occurrences will be of short duration (less than one minute), the Service does not anticipate associated temporary or permanent hearing loss.

If a launch component or associated debris struck a southern sea otter on the water surface, it could result in injury or death to the individual. The Space Force did not produce a projectile strike probability analysis for the proposed action. Without this information, the Service assumes there is an extremely low probability of a strike potential being that sea otters are not known to occur in the Vehicle Splashdown Effect Area which is located a significant distance offshore within the Pacific Ocean to the south of VSFB (Appendix A, Figure 3; Evans, R., Space Force, pers. comm., 2022a). If any debris from launch components fell near shore within the ocean water, it may disturb or injure southern sea otters resting on the water surface being that they occur in small numbers off the coast of VSFB. However, we anticipate that the probability for strike potential would still be unlikely given the extent of the coastline and the presumed small number of generated debris that could fall outside of the Vehicle Splashdown Effect Area.

After reviewing the information provided, we concur with your determination that the proposed action may affect, but is not likely to adversely affect, the southern sea otter on the basis of discountable effects. Our concurrence is based on the following:

1. Monitoring data indicate maximum noise levels produced from launch operations are unlikely to have a significant effect on southern sea otters. Effects would likely be temporary behavioral reactions being that southern sea otters have demonstrated acclimatization to routine noise disturbance.
2. The probability of launch debris striking a southern sea otter individual is extremely low.

California Condor

California condors do not range over VSFB except for one known instance in March 2017, when telemetry data indicated a California condor was within VSFB. This California condor (studbook number 760) was an immature, non-reproductive female hatched in captivity on May 22, 2014, and released in the Ventana Wilderness on November 9, 2016. The individual departed the VSFB area on April 12, 2017, and later died on approximately July 19, 2017, in northern San Luis Obispo County. Under launch monitoring requirements, the Space Force has maintained routine communication with the Service and the Ventana Wildlife Society to monitor California condor locations during launches. California condors have not been present since 2017. However, given the wide-ranging nature of this species, other California condors may occur on VSFB in the future if this species expands into their historical range.

Sound pressure levels produced from the proposed project’s test firings and launches have a low potential to affect California condors in the vicinity of SLC-5. As described in the recovery plan for California condors, this species appears less tolerant of human disturbances near nesting sites than at roosting sites, and loud noises may alarm them from distances greater than 1.6 miles (Service 1996, p. 5). In addition, the greater the disturbance in either noise level or frequency, the less likely the California condor would be to nest nearby (Service 1996, p. 5). As such, the Service typically recommends isolating roosting and nesting sites from human intrusion when feasible (Service 1996, p. 27). If California condors are present in the project area during the proposed action, they would likely be foraging or roosting, and the noise from a launch or static fire event coupled with visual disturbance could cause a temporary startle response or other minor and temporary behavioral shifts. However, it is unlikely that California condors would be present during these activities or that they would establish nesting on VSFB in the near future.

Avoidance and Minimization Measures

- Prior to any launch, the Space Force will determine if any California condors are present by coordinating with Service and Ventana Wildlife Society personnel (Note: VSFB computers are unable to review the Service’s ‘Daily Snapshot – California Condor Population’ Google Earth imagery). The Space Force will contact the Service if California condors appear to be near or within the area affected by a launch from SLC-5. In the unlikely event that a California condor is nearby, Qualified Biologists will monitor California condor movements in the vicinity of VSFB and coordinate with the Service to analyze data before, during, and after launch events to determine whether any changes in movement occur.

- The Space Force will coordinate with current Service personnel, including Arianna Punzalan, Supervisory Wildlife Biologist, USFWS California Condor Recovery Program, at arianna_punzalan@fws.gov or (805) 377-5471; Joseph Brandt, Senior Biologist, USFWS, at joseph_brandt@fws.gov, 805-677-3324, or 805-644-1766 extension 53324; or Steve Kirkland, California Condor Field Coordinator, USFWS California Condor Recovery Program, at steve_kirkland@fws.gov or 805-766-4630. The Space Force will also coordinate with current Ventana Wildlife Society personnel, including Joe Burnett, Senior Wildlife Biologist, at joeburnett@ventanaws.org or 831-800-7424.

After reviewing the information provided, we concur with your determination that the proposed action may affect, but is not likely to adversely affect, the California condor on the basis of discountable effects. Our concurrence is based on the following:

1. The proposed project is in an area outside the normal range of California condors and the species is not known to breed or roost within the project area.
2. The probability of a California condor being present during project activities is extremely low.

Unarmored Threespine Stickleback and Tidewater Goby

Unarmored threespine stickleback occupy San Antonio Creek from Barka Slough to the lagoon (Swift 1999, p. 17). Tidewater gobies occur in all major drainages of VSFB up to 7.5 miles upstream from the Pacific Ocean (Swift et al. 1997, p. 34). The project area consists of suitable habitat for tidewater goby within Honda Creek and for both species within San Antonio Creek. Neither species has occurred in Honda Creek since 2008 as the creek is becoming shallower and narrower due to drought, making the potential for presence of either species unlikely. In San Antonio Creek, unarmored threespine stickleback occur mostly in the creek channel and tidewater gobies primarily inhabit the lagoon.

The proposed project would not physically impact unarmored threespine stickleback or tidewater goby because SLC-5 launch pads would direct steam, water, and flame away from Honda Canyon where suitable but unoccupied tidewater goby habitat exists. Potential sedimentation during the construction of SLC-5 could result in negative impacts, including injury, death, reduced breeding success, impaired efficiency of gill filaments, and exposure to higher salinities and/or predation as they flee downstream. Additionally, if unarmored threespine sticklebacks or tidewater gobies were present in Honda Creek, launch noise, which could reach up to 130 dB L_{max} at Honda Creek, and vibrations could cause a temporary disruption to individuals. However, using the best available information, the Service anticipates that any perceived disturbance would be temporary and overall unlikely given that neither species occupies Honda Creek, they are unlikely to recolonize in the future, and individuals within San Antonio Creek would be located outside of the Launch Noise Effect Area (Appendix A, Figure 2).

Extending the VSFB water supply line from the source at the San Antonio Creek basin and increasing water usage due to project activities could reduce flow rates, hydration periods, or water levels in San Antonio Creek resulting in negative impacts to unarmored threespine sticklebacks and tidewater gobies. However, the Service reviewed past hydrological assessments (USGS 2019; AECOM 2019) and determined that the estimated 1.69 acre-feet per year (0.06 percent of total annual VSFB water usage) increase in water extraction from the project alone is not anticipated to produce observable effects to these two species.

Avoidance and Minimization Measures

- The Space Force will implement erosion control measures wherever the potential for project-related sedimentation into Honda Creek exists, as described below under section *Avoidance and Minimization Measures* (AM-5).

After reviewing the information provided, we concur with your determination that the proposed action may affect but is not likely to adversely affect the unarmored threespine stickleback or tidewater goby. Our concurrence is based on the following:

1. Unarmored threespine sticklebacks and tidewater gobies do not currently occur in Honda Creek, and there is low likelihood for tidewater goby recolonization.
2. Project-related noise, vibration, and sedimentation are unlikely to impact occupied unarmored threespine stickleback and tidewater goby habitat. The implementation of avoidance and minimization measures will further reduce the potential for effects.
3. Increased water extraction from the San Antonio Creek basin due to proposed project activities in combination with future water use would be negligible.

Our concurrence with the determinations that the proposed action is not likely to adversely affect marbled murrelet, southern sea otter, California condor, unarmored threespine stickleback, and tidewater goby is contingent on the project activities as outlined above being implemented by the Space Force. If the Space Force fails to implement the project as proposed, we will consider our concurrence invalid. If the proposed action changes in any manner, if novel effects associated with the proposed project not previously considered within this concurrence are observed over time, or if new information reveals the presence of listed species in the project area, you must contact our office immediately to determine whether additional consultation is required.

Consultation History

We received your initial May 18, 2022, request for formal consultation in our office on May 18, 2022 (Kaisersatt, pers. comm., 2022a). The Service responded with a request for additional information to clarify the project description and provide effects analyses in relation to the proposed launch frequency and water extraction. The Space Force clarified their original request's effects determination and provided a revised project description and analysis to the Service on August 1, 2022 (Kaisersatt, pers. comm., 2022b). The Service provided a response letter with initial clarifying questions and recommendations on the Space Force's proposed monitoring plan on Sept 26, 2022 (Termondt, S., pers. comm., 2022a). The Space Force responded to comments on November 1, 2022 (Kephart, in. litt., 2022). Both agencies mutually agreed the draft due date of the biological opinion would be on or before January 13, 2023 (Termondt, pers. comm., 2022b). The Space Force provided comments on the draft biological opinion on February 16, 2023 (Kaisersatt, pers. comm., 2023a). Additional minor changes and clarifications to the project description through subsequent phone calls and electronic mails occurred in March 2023 which the Service worked to incorporate into this final biological opinion (Kaisersatt, pers. comm., 2023b).

BIOLOGICAL OPINION

DESCRIPTION OF THE PROPOSED ACTION

Project Overview

The Space Force proposes to authorize the Project Proponent to construct and operate the Daytona-E and Laguna-E space launch program at VSFB. The purpose of the proposed project is to provide Daytona-E and Laguna-E space launch program service from VSFB to support commercial and government customers. The proposed project would include launch pad construction, auxiliary support facilities, and rocket launch operations.

Space Launch Complex-5 Location

The Space Force would authorize the construction of two new concrete launch pads (SLC-5E and SLC-5W, herein referred to collectively as SLC-5). Launch pad construction would occur in the south base of VSFB, 0.1 mile north of Honda Creek, and sited in between existing SLC-6 and SLC-4 facilities, approximately 2 miles from each. The newly proposed SLC-5 would be located on a previously disturbed site that had supported the former Scout Launch Program which is now inactive. The Space Force had removed the vast majority of the Scout Launch Program's associated infrastructure prior to this proposed project.

Construction

Site Construction

The Space Force would authorize the development of SLC-5 (Appendix A, Figure 1). Each pad would be approximately 1,500 square feet in area. Each pad would contain infrastructure including a launch stool (structure that supports the launch vehicle), flame bucket, deluge water containment system and associated basins, and fuel storage areas.

In addition to the pads, the Space Force would authorize the construction of a 7,500-square-foot horizontal integration facility and an instrumentation site. The Project Proponent would also construct multiple above ground water storage tank systems, holding approximately 21,000 gallons, for the purpose of supplying water to the deluge and fire suppression system on site.

Utilities

The Project Proponent would extend new electrical power, fiber communication, water, and sewage lines from existing sources to SLC-5. The Project Proponent would install these utilities within the footprint of Delphy Road and a 100-foot-wide utility corridor immediately south of the road (Appendix A, Figure 1). They would bury electrical and fiber communication lines within this utility corridor or the road to establish new service connections at SLC-5.

The Space Force removed Scout Launch Program infrastructure materials from SLC-5 prior to this proposed project. In the unlikely event that any remnant Scout Launch Program structures or materials are encountered, they would be located entirely within the SLC-5 Right of Entry and the Space Force would authorize their removal if they interfered with the proposed construction footprint (Kaisersatt, pers. comm., 2022c).

Fencing

During construction, the Space Force would implement and maintain a 3-foot-high low porosity (silt) construction barrier fence. The Space Force would also encompass the work site with a permanent security fence (6 to 8 feet high with standard 2-inch spaced chain link with three stands of barbed wire on the top).

Roads, Firebreaks, and Vegetation Management

The Space Force would authorize the installation of paved access roads between the pads and the support facilities. Delphy Road, an existing roadway that connects SLC-5 to Surf Road and Coast Road, would require significant repair including removal of existing pavement and repaving. Avery and Ladd Roads to the north and northeast of SLC-5 would serve as firebreaks and fire access roads and would also require repairs to meet fire safety requirements. The Space Force would authorize the establishment of firebreaks along the western, southern, and eastern perimeters of SLC-5. During initial site clearing for construction, the Project Proponent would remove woody vegetation using a masticator, chainsaws, or similar equipment.

Staging Areas

The Space Force was unable to provide the exact locations of staging areas. However, the Space Force would require that staging areas would be located within the SLC-5 Right of Entry and/or a designated utility corridor (Appendix A, Figure 1).

Construction Schedule

Work would occur during daylight hours at any time of the year and in three phases. Phase I-A would include construction of SLC-5W, site security, roadways, and primary site utility connections and would occur in 2023. Phase I-B would include construction of the horizontal integration facility and instrumentation pad and would occur in 2024. Phase II would incorporate the construction of SLC-5E, supporting roadways, and utility connections and would occur in 2025. Installation of electrical utilities connecting SLC-5 to existing VSFB may be shifted from Phase I-A to Phase I-B or Phase II (Evans, pers. comm, 2022a).

Operations

Launches

Launch Vehicles

The Space Force would authorize launch operations of two vehicles, Daytona-E and Laguna-E vehicles, at SLC-5. Both the Daytona-E and Laguna-E are small launch vehicles. The Daytona-E is a 54.4-foot, two-stage, ground-launched vehicle. The Laguna-E is a slightly larger two-stage vehicle, at 78.7 feet. Both vehicles would achieve altitude within 1 minute.

Launch Schedule

For the purposes of this analysis, the Space Force includes that at full launch tempo the proposed project would conduct launches weekly being separated by at least four days (York, in litt., 2022, p. 3). Launch operations may occur at any time of day with most launches occurring during the daytime between 0700 to 1900 hours.

The Space Force would also authorize a separate associated static fire test for each launch to provide a thorough test of all systems. Static fire test events would occur within 2 days of each individual launch (York, in litt., 2022, p. 3). Individual launch disturbance would last less than 1 minute and static fire launch would last less than 30 seconds.

Following SLC-5 construction, the Space Force proposes the following staggered launch operation schedule until 2028 when the proposed project would attain full launch tempo with 48 launches and 48 static test fires (Table 1). A launch related disturbance event could occur once every two days consecutively across 192 days annually at full launch tempo in 2028 (Evans, pers. comm., 2022a).

Table 1. The proposed launch schedule from 2023 to 2028 when the launch program will attain full launch tempo.

Calendar Year	Number of Launches	Number of Static Fire Tests
2023	1	1
2024	2	2
2025	5	5
2026	12	12
2027	24	24
2028	48	48

Launch Fueling and Combustion

During launch operations, mobile fuel trailers would supply fuel (liquid oxygen (LOX) rocket propellant or Jet-A) to on-site ground support equipment. The Project Proponent would station these over concrete surfaces approximately 150 feet from either launch pad.

Black carbon (soot) can be a biproduct of rocket launches and is largely a factor of running a fuel-rich mixture, such as a fuel-rich gas generator rocket engine. The Space Force has included that the proposed project uses oxidizer-rich staged combustion engines from Ursa Major Technologies that produce a diminutive amount of soot. Assuming the full cadence of 48 launches per year with a 2-minute first stage flight to space, a total of 1.62 pounds per second of soot would be produced which is estimated to be 195 pounds per year (Kaisersatt, pers. comm., 2022d). Referencing previously produced environmental assessments for other launch operations, the Space Force further specifies that the proposed project's exhaust process results in the complete conversion of produced carbon monoxide into carbon dioxide as well as the oxidation of soot from the gas generation exhaust. The Space Force consequently expects that the produced soot would subsequently burn up in the exhaust plume (Kaisersatt, pers. comm., 2022d). The biological assessment did not include any additional discussion of launch combustion biproducts for the purposes of this analysis.

The Space Force would authorize the installation of a 12.5-foot flame bucket under an approximately 12-square-foot launch stool at each pad. The flame bucket is meant to receive and channel combustion (hot exhaust gases) from a rocket during lift-off. The Project Proponent would connect the flame bucket to a concrete catchment with an underground tank that contains up to 10,000 gallons of water deluge. The *Deluge Water System and Water Usage* section discusses this in more detail below.

Launch Noise

The Space Force provided modeling of individual launches and associated static test fire events for the purposes of this analysis using the L_{max} noise metric. L_{max} is the highest sound level measure during a single launch event. Although it provides some measure of the event, L_{max} does not fully describe the noise disturbance because it does not account for the duration of the sound. Sound exposure level (SEL) considers the length of time a noise occurs and provides a measure of the net impact of the entire acoustic event. In previous analyses, the Service has considered the SEL metric; however, for the purposes of this analysis, the biological assessment did not include SEL information and consequently the Service will use the L_{max} metric.

Variability in noise level between the two vehicle types is approximately 5 dB SPL. The biological assessment did not specify vehicle type use in the proposed schedule and consequently the Service will use the larger Laguna-E vehicle to provide a conservative analysis. The Space Force includes that engine noise would reach as high as 144 dB L_{max} on SLC-5 during launch events with noise level attenuating outward. Noise produced by launch operations to terrestrial areas would last approximately one minute during launches and approximately 30 seconds during static fire events.

Appendix A, Figures 2a and 2b depict the Launch Noise Effect Area, which is the modeled L_{max} footprint of the proposed project generated by noise modeling software (RUMBLE 4.1, Rocket Propulsion Noise and Emissions Simulation, developed by Blue Ridge Research and Consulting). Noise modeling conducted for the proposed project did not consider topography and how topographical features may attenuate or enhance actual noise levels. The modeling does account for the attenuation of sound by the ground surface when estimating the received noise. The model assumes a 5-foot receiver height and a variable ground impedance to account for grass (soft) or water (hard) ground surfaces.

Launch Sonic Boom (*Overpressure*) *and Vehicle Splashdown*

Each proposed launch would generate a sonic boom resulting in overpressures of high energy impulsive sound. Sonic booms are low frequency, impulsive noise events with durations lasting a fraction of a second (BRRC 2020, p. 32). The maximum applicable overpressure produced for the purposes of this analysis would be up to 1.5 psf, occurring entirely within the Pacific Ocean for each vehicle type, typically to the south and west of San Miguel Island. The Space Force has clarified that overpressure would not impact any terrestrial areas, including the Northern Channel Islands (York, in. litt., 2022, p. 4). Appendix A, Figure 3 depicts the modeled sonic boom footprint, or Overpressure Effect Area, provided in the biological assessment. The Space Force utilized PCBoom 6.7b software to calculate the magnitude, waveform, and location of sonic boom overpressures on the ground from supersonic flight operations. Overpressure modeling conducted for the project did not consider topography and how topographical features may attenuate or enhance actual overpressure levels.

Both Laguna-E and Daytona-E launch vehicles would be expendable rockets with equipment that drops into the Pacific Ocean following delivery of payloads into orbit. The biological assessment includes a depiction of various azimuths associated with both vehicle types. The Vehicle Splashdown Effect Area is located entirely within the Pacific Ocean, to the south and west of San Miguel Island (Appendix A, Figure 3). The Space Force does not expect any land mass or shoreline to be present in the Vehicle Splashdown Effect Area.

Deluge Water System and Water Usage

The proposed project would include the development of a deluge water system. The intention of the deluge water system involves spraying water in large volumes to reduce vibration, heat, and energy produced during launch and static test fire operations. The Project Proponent would add deluge water for approximately 10 seconds before and 10 seconds after each launch and static test fire event for a total of 20 seconds.

The Space Force would also authorize the associated construction of multiple water features to support the deluge water system. Features would include two deluge containment basins meant to collect deluge water runoff and four infiltration areas referred to as Storm Water Management areas. The deluge containment basins would have an outlet structure to allow manual discharge of the basin water through a valved discharge pipe. The Project Proponent would screen the outlet pipe with 1/8-inch mesh. After each launch, the Project Proponent would inspect stored water within the basin for any contamination. The Space Force anticipates this inspection process would take up to 3 days in total. If the Project Proponent encounters contamination, they would pump out and dispose of the basin contents per relevant state, Federal, and local regulations. If there is no contamination and it meets relevant state, Federal, and local regulations, the Project Proponent would discharge it from the retention basin to the Stormwater Management Areas for infiltration into the ground. Similarly, the Project Proponent would test any stormwater that accumulates within the flame deflector or water deluge catchment system for any contamination prior to potential release into the Stormwater Management Areas.

The proposed project would use a combined total of 2,100 to 10,000 gallons (0.006 to 0.03 acre-feet) of potable water in the proposed deluge water system during each launch and associated static test fire. At full launch tempo of 48 launch events and 48 static test fire events per year, the Space Force would authorize a maximum of 480,000 gallons (1.47 acre-feet) annually of water usage for the deluge water system. The proposed project would require an additional 72,000 gallons (0.22 acre-feet) annually to support personnel and operational activities at SLC-5 (Kaisersatt, pers. comm., 2022c). Consequently, the Space Force would authorize a maximum of 552,000 gallons (1.69 acre-feet) of water per year to support the project. The current water source for VSFB consists of four water wells located within the San Antonio Creek Basin.

SLC-5 Facility Lighting

The Space Force would authorize the installation of 36 light poles around the perimeter of SLC-5 for security and support of night operations. The light poles would have a maximum height of 40 feet which the Project Proponent would place in holes dug down to approximately 20 feet below the surface. The Space Force provided a preliminary lighting plan within the biological assessment (MSRS 2022a, p. 21). The proposed project would include lighting levels between 1- to 4-foot candle within the SLC-5 facility (MSRS 2022a, p. 59, Figure 5.1–4).

Road maintenance and Associated Vegetation Management

The Space Force would authorize annual routine vegetation clearance on Honda Canyon Road as well as a connected former access road to enable emergency access for fire equipment. Vegetation maintenance would occur within 15 feet of either side of these roadways. Honda Canyon Road is currently paved and the former access road that serves as the connection to SLC-5 consists of gravel. There would be no improvements or repairs to Honda Canyon Road (Kaisersatt, pers. comm., 2023). The improvements to the abandoned access road would involve similar vegetation maintenance and light grading (Kaisersatt, pers. comm., 2022c, p. 4)

Additional vegetation management at SLC-5 would involve routinely mowing the SLC-5 fence line and surrounding firebreaks.

AVOIDANCE AND MINIMIZATION MEASURES

Biologist Definitions

Avoidance and minimization measures included in this biological opinion require various levels of biological competency from personnel completing specific tasks, as defined below:

- Permitted Biologist: Biologist with a valid and current Section 10(a)(1)(A) Recovery Permit issued by the Service or specifically named as a Service Approved Biologist in a project-specific biological opinion. The Space Force will coordinate with the Service prior to assigning Permitted Biologists to a specific project.
- Service Approved Biologist: Biologist with the expertise to identify listed species and species with similar appearance. The Space Force will review and approve the resumes for each individual, and then submit them to the Service for review and approval no less than 15 days prior to the start of the project. A Service Approved Biologist could train other biologists and personnel during surveys and project work; in some cases, a Service Approved Biologist could also provide on-site supervision of other biologists.
- Qualified Biologist: Biologist trained to accurately identify specific federally listed species and their habitats by either a Permitted or Service Approved Biologist. This person could perform basic project monitoring but would need to have oversight from a

Permitted or Service Approved Biologist. Oversight will require a Permitted or Service Approved Biologist to be available for phone/electronic mail consultation during the surveys and to have the ability to visit during monitoring/survey activities if needed.

General Project Avoidance and Minimization Measures

The following protection and monitoring measures would apply to all aspects of the proposed action to protect and minimize effects on biological resources. The Space Force will ensure the Project Proponent takes all identified applicable actions as listed below.

AM-1. The Space Force will require the Permitted or Service Approved Biologists to be responsible for delineating areas where special status species are located or concentrated, relocating special status species during construction activities, and inspecting equipment and equipment staging areas for cleanliness and gas and oil leaks daily. The Space Force will require that contractors immediately address any unanticipated leaks or spills.

AM-2. The Space Force will require a Permitted or Service Approved Biologist to brief all project personnel prior to participating in construction activities. At a minimum, the training will include a description of the listed species and sensitive biological resources occurring in the project area, the general and specific measures, restrictions necessary to protect these resources during project implementation, the provisions of the Act, the necessity of adhering to the provisions of the Act, and the penalties associated with violations of the Act.

AM-3. The Project Proponent will keep disturbances to the minimum extent necessary to accomplish project objectives.

AM-4. The Project Proponent will remove and transport all excess excavated materials to a designated waste or fill site.

AM-5. The Project Proponent will implement erosion control measures wherever potential for project-related sedimentation into Honda Creek exists. The Project Proponent will use all erosion control materials from weed-free sources and, if left in place following project completion, constructed from 100 percent biodegradable erosion control materials (e.g., erosion blankets, wattles, etc.).

AM-6. The Project Proponent will dispose of all human generated trash at the project site properly at the end of each workday with specific attention concerning food waste. Proper waste disposal is deposition of material into a trash receptacle with a lid that will not blow open in the wind. The Project Proponent will not overfill trash receptacles to the point that the lid does not fit properly. Large dumpsters are appropriate for waste disposal which the Project Proponent can maintain within a staging area for this purpose. The Project Proponent will remove all construction debris and trash from the work areas upon completion of the project and will dispose of all waste at a designated waste or fill site approved by 30 CES.

AM-7. The Project Proponent will clean equipment vehicles (dozers, mowers, etc.) of weed seeds prior to use in the project area to prevent the introduction of weeds. A Qualified Biologist will inspect equipment vehicles to verify weed free status prior to use. Prior to site transport, the Project Proponent will remove and clean any skid plates and will clean equipment vehicles of weed seeds daily especially wheels, undercarriages, and bumpers. Prior to leaving the project area, the Project Proponent will clean equipment vehicles with caked-on soil or mud with hand tools such as bristle brushes and brooms at a designated exit area and may subsequently wash vehicles at an approved wash area. The Project Proponent will thoroughly brush equipment vehicles with dry dusted soil (not caked-on soil or mud) prior to leaving a site at a designated exit area; vehicles may alternatively be air blasted on site.

AM-8. The Project Proponent will conduct fueling of equipment in a pre-designated location within the staging area and will place spill containment materials around the equipment before refueling.

AM-9. The Space Force will require a Qualified Biologist to inspect any equipment left overnight prior to the start of work and to check equipment for the presence of special status species in the vicinity and for fluid leaks.

AM-10. The Project Proponent will not leave holes or trenches open overnight and may use plywood sheets or steel plates to cover holes or trenches. A Qualified Biologist will inspect these locations before the resumption of work.

Species-specific Avoidance and Minimization Measures

California Red-legged Frog

AM-11. The Space Force will require Permitted or Service Approved Biologists to be present and monitor activities during construction when project activities are likely to encounter California red-legged frogs that require relocation.

AM-12. Prior to construction activities, the Space Force will require a Qualified Biologist to conduct a training session for all construction personnel. At a minimum, the training will include a description of the California red-legged frog and its habitat, the specific California red-legged frog measures implemented for the current project, and project boundaries.

AM-13. The Space Force will require that a Service Approved Biologist conducts pre-project surveys for California red-legged frog. If no Service Approved Biologist is determined to be available, the Space Force will require a Qualified Biologist to complete these surveys on an as needed basis. Biologists may also conduct additional surveys as needed at their discretion. The Space Force will require that all biologists adhere to the following measures:

a. From November 15 to March 31, the Space Force will require a Service Approved Biologist (or Qualified Biologist, as needed) to conduct a pre-construction survey of project areas within suitable aquatic, adjacent upland, or dispersal habitat (690 feet from aquatic habitat or other distance as determined by a Service Approved Biologist) immediately before the onset of all work activities.

b. From April 1 to November 14, the Space Force will require that a Service Approved Biologist (or Qualified Biologist, as needed) conduct a pre-construction survey of project areas within suitable aquatic or upland habitat (140 feet from aquatic habitat or other distance as determined by a Service Approved Biologist) to identify potential artificial water or shelter resources that may contain California red-legged frogs.

c. A Service Approved Biologist (or Qualified Biologist, as needed) will repeat surveys following any precipitation event greater than 0.2 inch during a 24-hour period.

d. A Service Approved Biologist (or Qualified Biologist, as needed) will monitor any initial ground disturbance or vegetation removal within suitable aquatic, adjacent upland, or dispersal habitat as determined above. After the initial ground disturbance/vegetation removal is complete, the Space Force would not require further monitoring within bare-dirt areas.

AM-14. During construction of the launch site, the Space Force and the Project Proponent will implement the following measures:

a. The Project Proponent will encircle the launch construction site with a minimum of 3-foot-tall silt fencing, anchored with metal T-posts, and buried along the bottom edge to inhibit terrestrial wildlife, including California red-legged frogs, from entering the site. The Space Force will require a Qualified Biologist to inspect the fence daily and direct maintenance to ensure its efficacy.

b. The Project Proponent will conduct all work during daylight hours during periods when there is no rainfall.

c. The Project Proponent will cover any open holes or trenches with plywood or metal sheets if left overnight to minimize the risk of entrapment of California red-legged frogs.

d. The Project Proponent will not conduct construction activities until 24 hours after an actual precipitation event greater than 0.2-inch accumulating within a 24-hour period.

  e. The Project Proponent will not stage equipment or supplies overnight within 0.10 mile of California red-legged frog aquatic habitat (see Appendix A, Figure 1). The Project Proponent will implement measures that preclude California red-legged frog from accessing the staging area (e.g., install drift fence barrier).

  f. The Space Force will require that a Qualified Biologist surveys the site, including any open holes or trenches, each day prior to initiation of work.

AM-15. The Space Force will require that a Service Approved Biologist conduct any necessary California red-legged frog relocation. If biologists find California red-legged frogs of any life stage within the project area during pre-project surveys, daily monitoring where required, or at any other time, the Space Force will require that all construction activity within the vicinity of the California red-legged frog occurrence cease and will adhere to the following measures:

  a. If the Service Approved Biologist is satisfied that work in a different area of the project can continue with no threat to California red-legged frogs, the Space Force may permit work to continue after workers have received a briefing on the area to avoid.

  b. The Space Force will require that construction activities within the vicinity of the California red-legged frog occurrence not begin or resume until a Service Approved Biologist relocates the individual(s) or contacts the Service for alternate guidance.

  c. Using the Declining Amphibians Task Force Fieldwork Code of Practice (DAPTF 2019), the Space Force will require that the Service Approved Biologist relocate all life stages of California red-legged frog the shortest distance possible to a location that is (1) within the same drainage, (2) contains suitable aquatic/upland habitat, and (3) is outside of the project impact area.

AM-16. The Project Proponent will design retention basins and water storage features to prevent access by California red-legged frogs (York, in. litt., 2022, p. 4) . If total exclusion is not possible, and water is present in retention basins overnight, the Space Force will require that a Qualified Biologist check daily for California red-legged frogs prior to pumping. The Project Proponent will screen the pump with 1/8-inch mesh.

AM-17. The Project Proponent will design deluge containment basins to minimize the amount of stormwater received into the basin (MSRS 2022a, p. 5).

AM-18. The Project Proponent will design Stormwater Management Areas to prevent the presence of standing water, other than immediately after a rainstorm, by using design features similar to a French drain.

AM-19. The Project Proponent will design pads at SLC-5 to prevent discharge of deluge water into surrounding drainages and will divert any overland flow to the deluge containment basins.

AM-20. The Project Proponent will design the position of the flame buckets and deluge system to direct flames and associated steam to the north of SLC-5, away from Honda Canyon, to minimize potential impacts to California red-legged frog.

AM-21. Except when necessary for the performance and safety of launch operations or maintenance, the Project Proponent will minimize artificial lighting at SLC-5 to provide site security during the hours of darkness. For the purposes of this analysis, the Service understands this will include no lighting during construction operations being that the Project Proponent will conduct all work during daylight hours (AM-14).

AM-22. The Space Force will require the development of a lighting plan for the proposed project. The Space Force will design this plan such that the Project Proponent will direct all light away from Honda Canyon and shield it to reduce scatter into natural, undeveloped areas to the maximum extent possible. The Space Force will require that the Project Proponent shield any installed lighting ensuring that illumination lighting levels of 1-foot candle would not extend beyond the SLC-5 facility into natural habitats (MSRS 2022a, p. 59). The Space Force will require that the lighting design includes use of the minimum number of lumens necessary to accomplish lighting requirements. This requirement will be accomplished through strategic placement of lights, and the use of shields, timers, and motion sensors wherever possible to minimize potential effects associated with novel persistent artificial light at night (York, in litt., 2022, p. 6).

AM-23. The Space Force will conduct quarterly night surveys and spring tadpole surveys for California red-legged frog in lower Honda Creek within the 120 dB L_{max} Laguna-E noise contour (Figure 2a). The Space Force will use existing California red-legged frog protocol level survey data collected at lower Honda Creek between 2013 through 2023 prior to construction and launch operations to serve as an existing baseline in coordination with the Service. Comparison of post-launch operation data with the established baseline will allow the Space Force to assess if there are any changes in California red-legged frog habitat occupancy, breeding behavior (calling), and breeding success (egg mass and tadpole densities) in lower Honda Creek as Phantom's launch and static fire tempo gradually increases over six years to reach full cadence (Table 1). The Space Force will record and measure the following during the surveys:

a. California red-legged frog detection density (number of frogs per survey hour) following the same survey methods conducted previously at these sites and throughout VSFB;

b. California red-legged frog locations and breeding evidence (e.g., calling, egg masses);

c. environmental data during surveys (temperature, wind speed, humidity, and dewpoint) to determine if environmental factors are affecting California red-legged frog detection or calling rates;

d. annual habitat assessments to measure flow rates, stream morphology, depths, and sediment to determine if any changes in California red-legged frog metrics are associated with other environmental factors, such as drought;

e. and locations and densities of co-occurring anurans including bullfrogs (*Lithobates catesbeianus*) and Baja California tree frogs (*Pseudacris hypochondriaca*).

AM-24. The Space Force will conduct passive bioacoustic monitoring annually during California red-legged frog breeding season (typically November through April) to characterize the baseline noise environment and determine if there are changes in calling behaviors as launch and static fire tempo gradually increase over six years. Passive bioacoustic recording would occur throughout the entirety of the breeding season using the Wildlife Acoustics Song-Meter 4 (or similar technology) with software that enables autodetection of California red-legged frog calling (Kephart 2022, p. 2). The Space Force will place these passive noise recorders and environmental data loggers (temperature, relative humidity, dew point) at two suitable breeding locations in lower Honda Creek within the 120 dB L_{max} Laguna-E noise contour (Appendix A, Figure 2a) as well as at two suitable breeding locations in San Antonio Creek to serve as a control site. The Space Force will use bioacoustic monitoring to characterize and analyze any impacts of launch and static fire events during the breeding season on calling behavior to assess whether Phantom’s gradual increase in launch and static fire tempo affects California red-legged frog calling frequency. The Space Force will report on monitoring results within an annual report.

AM-25. The Space Force will conduct monitoring to detect changes in calling frequency and declines in the abundance, distribution, or tadpole densities of California red-legged frog. The Space Force will utilize existing survey data for Honda Creek to establish the California red-legged frog baseline (Kephart 2022, p. 1). To address potential declining trends that may be a result of the proposed project, the specified threshold criteria is described below.

a. Annual protocol survey efforts conducted in the same area of Honda Creek document fewer adult frog detections than baseline average two years consecutively;

b. egg mass or tadpole densities decrease by 15 percent from baseline average;

c. and/or surveys document average call-rate changes (decrease) with increasing disturbance level.

If any of these threshold criteria are met and cannot confidently be attributed to other natural- or human-caused catastrophic factors, not related to the proposed action, that may eliminate or significantly degrade suitable habitat (see potential scenarios described below), the Space Force will mitigate for these impacts (Kephart 2022, p. 3) as discussed under the *Habitat Mitigation and Monitoring Plan* section. Examples of potential catastrophic scenarios include the following:

a. Fire, unrelated to project activities or launch operations, that directly impacts Honda Canyon and is demonstrated to degrade or eliminate breeding habitat.

b. Landslides or significant erosion events in Honda Canyon, unrelated to project activities or launch operations, that result in the elimination or degradation of California red-legged frog breeding habitat.

c. Drought or climate impacts that quantifiably reduces available aquatic habitat further than what was available during existing baseline.

d. Flash flood events during the breeding season that are more significant than what was experienced during the existing baseline.

The Space Force will review the supported cause of decline with the Service and reach agreement. If cause of declines is determined to be inconclusive, the Project Proponent will implement proposed mitigation.

AM-26. The Space Force will discontinue monitoring after concurrence from the Service if California red-legged frog occupancy, calling frequency, or tadpole densities do not demonstrate adverse effects after three years of monitoring once Phantom has achieved full or near full tempo.

Western Snowy Plover

AM-27. The Space Force will augment the current western snowy plover monitoring program on VSFB by performing acoustic monitoring and geospatial analysis of nesting activity on South Surf Beach to assess potential adverse effects from Daytona-E and Laguna-E launch and static fire activities (Kephart 2022, p. 2).

a. The current basewide western snowy plover monitoring program estimates breeding effort, nest fates, and fledging success while recording patterns of habitat use throughout the season. The Space Force will augment this program for the proposed project by placing sound level meters (SLMs) immediately inland of South Surf Beach within the Daytona-E and Laguna-E noise footprint to characterize the noise environment (Appendix A, Figure 2b).

b. Acoustic monitoring will begin during the first calendar year of launch operations and continue annually during the breeding season as Phantom’s program gradually increases over six years to full cadence (Table 1).

AM-28. The Space Force will conduct monitoring to detect declines in the abundance, distribution, and nest success of western snowy plover. To address potential declining trends that may be a result of the proposed project, the specified threshold criteria is described below.

a. The Space Force will require geospatial analysis to show the decline is a statistically significant reduction in breeding effort or nest success that continues over two consecutive years within the areas impacted by noise from the Daytona-E and Laguna-E launch vehicles.

b. The Space Force defines a statistically significant reduction as a decline greater than the baseline annual variation in these variables over the past 10 years at South Surf Beach. The Space Force may calculate baseline annual variation in a variety of ways but likely will use 95 percent confidence intervals (Kephart 2022, p. 2).

c. The Space Force will perform geospatial analysis annually to assess whether noise from the proposed project negatively impacts patterns of nesting activity, nest fates, or fledgling success as Phantom’s launch and static fire tempo increases to full cadence. The Space Force will report on monitoring results within an annual report.

If any of these threshold criteria are met and cannot confidently be attributed to other natural- or human-caused catastrophic factors, not related to the proposed action, that may eliminate or significantly degrade suitable habitat (see potential scenarios described below), the Space Force will mitigate for these impacts (Kephart 2022, p. 3) as discussed under the *Habitat Mitigation and Monitoring Plan* section below. Examples of potential catastrophic scenarios include the following:

a. Significantly higher levels of tidal activity, predation, etc. as compared with the existing baseline and demonstrable across remainder of base population.

b. Significant avian disease demonstrable across the recovery unit.

c. Separate work activities (i.e., restoration efforts) not related to project.

The Space Force will review the supported cause of decline with the Service and reach agreement. If cause of declines is determined to be inconclusive, the Project Proponent will implement proposed mitigation.

AM-29. The Space Force will discontinue monitoring after concurrence from the Service if they do not document adverse effects attributable to the proposed project after three years of monitoring once Phantom has reach full or near full tempo.

Habitat Mitigation and Monitoring Plan

The Space Force proposes a mitigation and monitoring plan in the event the proposed project's monitoring detects a change in the baseline of species populations (AM-23, 28). In the event the Space Force detects declines and declines meet threshold trigger criteria, the Space Force will implement mitigation activities as detailed below.

The potential mitigation actions for California red-legged frog include the creation of new breeding habitat at a 2:1 ratio (habitat enhanced: habitat affected) within the San Antonio Creek Oxbow Restoration "expansion area" (Appendix A, Figure 4a). The Oxbow Restoration site is an abandoned tract of agricultural land that riparian vegetation historically occupied. The Space Force initiated compensatory mitigation restoration work at this site associated with a separate previous project (San Antonio West Bridge; 2016-F-0103; Service 2018) in the fall of 2019 to improve California red-legged frog habitat within San Antonio Creek (MSRS 2020, p. 2). Specifically, potential mitigation actions associated with the proposed project within the Oxbow Restoration include site preparation via herbicide application, plowing, container plant installation, seeding, willow pole planting, and watering via water truck. The existing biological opinion (2016-F-0103; Service 2018) includes potential mitigation actions for California red-legged frog and the Space Force will implement all required avoidance, minimization, and monitoring measures. The Space Force will track and report on restoration efforts and success within an annual report.

The potential mitigation actions for western snowy plover consist of increasing predator control to include the non-breeding season, which includes trapping, shooting, and tracking known western snowy plover predators with particular focus on raven removal at and adjacent to VSFB beaches (Appendix A, Figure 4b). Predator control efforts are intended to increase wintering adult snowy plover survival and control predators prior to the breeding season. An existing biological opinion (8-8-12-F-11R; Service 2015b) permits these actions, and the Space Force will implement all required avoidance, minimization, and monitoring measures. The Space Force also maintains a depredation permit issued by the Service. The Space Force will report on predator removal efforts and success within an annual report. Additionally, the Space Force will continue pursuing other beneficial actions including recovery opportunities outlined in the western snowy plover recovery plan (Service 2007) and 5-year review (Service 2019) following mutual agreement by the Service and the Space Force annually, supporting the Space Force's goals to ensure no net loss (Kephart 2022, p. 3).

ANALYTICAL FRAMEWORK FOR THE JEOPARDY DETERMINATIONS

Jeopardy Determination

Section 7(a)(2) of the Act requires that Federal agencies ensure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of listed species. "Jeopardize the continued existence of" means "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (50 CFR 402.02).

The jeopardy analysis in this biological opinion relies on four components: (1) the Status of the Species, which describes the current rangewide condition of the California red-legged frog and western snowy plover, the factors responsible for that condition, and its survival and recovery needs; (2) the Environmental Baseline, which analyzes the condition of the California red-legged frog and western snowy plover in the action area, the factors responsible for that condition, and the relationship of the action area to the survival and recovery of the California red-legged frog and western snowy plover; (3) the Effects of the Action, which determines all consequences to the California red-legged frog and western snowy plover caused by the proposed action that are reasonably certain to occur in the action area; and (4) the Cumulative Effects, which evaluates the effects of future, non-Federal activities, that are reasonably certain to occur in the action area, on the California red-legged frog and western snowy plover.

In accordance with policy and regulation, the jeopardy determination is made by evaluating the effects of the proposed Federal action in the context of the current status of the California red-legged frog and western snowy plover, taking into account any cumulative effects, to determine if implementation of the proposed action is likely to reduce appreciably the likelihood of both the survival and recovery of the California red-legged frog and western snowy plover in the wild by reducing the reproduction, numbers, and distribution of that species.

STATUS OF THE SPECIES AND ITS CRITICAL HABITAT

California Red-legged Frog

Legal Status

The California red-legged frog was federally listed as threatened on May 23, 1996 (61 Federal Register (FR) 25813). Revised critical habitat for the California red-legged frog was designated on March 17, 2010 (75 FR 12816, Service 2010). The Service issued a recovery plan for the species on May 28, 2002 (Service 2002, entire).

Natural History

The California red-legged frog uses a variety of habitat types, including various aquatic systems, riparian, and upland habitats. They have been found at elevations ranging from sea level to approximately 5,000 feet. California red-legged frogs use the environment in a variety of ways, and in many cases, they may complete their entire life cycle in a particular area without using other components (i.e., a pond is suitable for each life stage and use of upland habitat or a riparian corridor is not necessary). Populations appear to persist where a mosaic of habitat elements exists, embedded within a matrix of dispersal habitat. Adults are often associated with dense, shrubby riparian or emergent vegetation and areas with deep (greater than 1.6 feet) still or slow-moving water; the largest summer densities of California red-legged frogs are associated with deep-water pools with dense stands of overhanging willows (*Salix* spp.) and an intermixed fringe of cattails (*Typha latifolia*) (Hayes and Jennings 1988, p. 147). Hayes and Tennant found juveniles to seek prey diurnally and nocturnally, whereas adults were largely nocturnal (Hayes and Tennant 1985, p. 604).

California red-legged frogs breed in aquatic habitats; larvae, juveniles, and adult frogs have been collected from streams, creeks, ponds, marshes, deep pools and backwaters within streams and creeks, dune ponds, lagoons, and estuaries, and frequently breed in artificial impoundments such as stock ponds, given the proper management of hydroperiod, pond structure, and control of exotic predators, and can proliferate in a wide range of edge and emergent cover amounts, including ponds devoid of emergent vegetation (Service 2002, p. 12). While frogs successfully breed in streams and riparian systems, high spring flows and cold temperatures in streams often make these sites risky egg and tadpole environments. An important factor influencing the suitability of aquatic breeding sites is the general lack of introduced aquatic predators. Accessibility to sheltering habitat is essential for the survival of California red-legged frogs within a watershed and can be a factor limiting population numbers and distribution.

California red-legged frogs are “irruptive” breeders where their breeding capacity is highly dependent on local environmental conditions, specifically the availability of cool water for egg deposition and larval maturation (Jennings and Hayes 1994, p. 62). California red-legged frogs breed from November to May and breeding activity typically begins earlier at southern coastal than northern coastal localities (Storer 1925, p. 2; Alvarez et al. 2013, pp. 547-548). Breeding may start as late as March or April in Sierra Nevada localities, due to low temperatures at these sites in January and February (Tatarian 2008, p. 16). Breeding in southern California localities may start as late as April, as exemplified in Matilija Canyon following the 2017 Thomas Fire (P. Lieske, pers. comm., 2021). High water flows in the winter and spring also can delay breeding in streams and rivers (Fellers et al. 2001, p. 157). Adult males call at night in the air and underwater. Calls can be easily missed because of their low volume and calling lasts only one to two weeks at a location (Nafis 2020). Eggs will hatch after approximately 4 weeks and tadpoles will typically metamorphose between 4-7 months, although they have been reported to overwinter at some sites (Nafis 2020). Female California red-legged frogs lay only one egg mass in a breeding year and each egg mass contains between 300 to 4,000 eggs (Storer 1925, p. 240). Egg masses typically hatch after approximately 4 weeks (Nafis 2020). Frogs typically deposit egg masses in relatively shallow water (approximately 1.6 to 2 feet deep) on emergent vegetation within 4 feet of shore (Storer 1925, p. 239; Jennings and Hayes 1994, p. 64). However, the species can deposit eggs on a wide variety of substrates including boulders and cobbled substrate and submerged tips of overhanging branches, and egg masses have been documented 39 feet from shore and in water up to 10.5 feet deep (Alvarez et al. 2013, pp. 544-545; Wilcox et al. 2017, p. 68).

California red-legged frog tadpoles hatch from egg masses after 6 to14 (Storer 1925, p. 241). Tadpole development and growth rates are variable and likely temperature dependent (Fellers 2005, pp. 552-554). Occasionally, tadpoles may overwinter and then metamorphose the following spring, a phenomenon so far observed in Santa Clara, Marin, Contra Costa, and San Luis Obispo Counties (Fellers et al. 2001, entire). The juvenile California red-legged frog life stage is defined as the time after an individual undergoes metamorphosis (when they lose their tails and become small froglets) which typically occurs four to five months after hatching and it spans to when an individual is able to breed (Storer 1925, p. 241; Wright and Wright 1949, p. 422). On average, the juvenile life stage is from about five months of age to three years in California red-legged frogs. Immediately after metamorphosis, juveniles shelter near their natal pond. However, some juveniles may disperse in the fall to nearby moist uplands or different aquatic habitat to avoid predation by larger, older frogs. Hayes and Tennant (1985, p. 604) found juveniles to seek prey diurnally and nocturnally, whereas adults were largely nocturnal.

During periods of wet weather, starting with the first rains of fall, some individual California red-legged frogs may make long-distance overland excursions through upland habitats to reach breeding sites. In Santa Cruz County, Bulger et al. (2003, p. 90) found marked California red-legged frogs moving up to 1.74 miles through upland habitats, via point-to-point, straight-line migrations without regard to topography, rather than following riparian corridors. Most of these overland movements occurred at night and took up to 2 months. Similarly, in San Luis Obispo County, Rathbun and Schneider (2001, p. 1302) documented the movement of a male California red-legged frog between two ponds that were 1.78 miles apart in less than 32 days; however, most California red-legged frogs in the Bulger et al. (2003, p. 93) study were non-migrating frogs and always remained within 426 feet of their aquatic site of residence (half of the frogs always stayed within 82 feet of water). Rathbun et al. (1993, p. 15) radio-tracked three California red-legged frogs near the coast in San Luis Obispo County at various times between July and January; these frogs also stayed close to water and never strayed more than 85 feet into upland vegetation. Scott (2002, p. 2) radio-tracked nine California red-legged frogs in East Las Virgenes Creek in Ventura County from January to June 2001, which remained relatively sedentary as well; the longest within-channel movement was 280 feet and the farthest movement away from the stream was 30 feet.

After breeding, California red-legged frogs often disperse from their breeding habitat to forage and seek suitable dry-season habitat. Cover within dry-season aquatic habitat could include boulders, downed trees, and logs; agricultural features such as drains, watering troughs, spring boxes, abandoned sheds, or hayricks, and industrial debris. California red-legged frogs use small mammal burrows and moist leaf litter (Jennings and Hayes 1994, p. 64; Rathbun and Schneider 2001, p. 15); incised stream channels with portions narrower and deeper than 18 inches may also provide habitat (Service 2002, p. 14). This type of dispersal and habitat use, however, is not observed in all California red-legged frogs and is most likely dependent on the year-to-year variations in climate and habitat suitability and varying requisites per life stage.

Although the presence of California red-legged frogs is correlated with still water deeper than approximately 1.6 feet, riparian shrubbery, and emergent vegetation (Jennings and Hayes 1994, p. 64), California red-legged frogs appear to be absent from numerous locations in its historical range where these elements are well represented. The cause of local extirpations does not appear to be restricted solely to loss of aquatic habitat. The most likely causes of local extirpation are thought to be changes in faunal composition of aquatic ecosystems (i.e., the introduction of invasive predators and competitors) and landscape-scale disturbances that disrupt California red-legged frog population processes, such as dispersal and colonization. The introduction of contaminants or changes in water temperature may also play a role in local extirpations. These changes may also promote the spread of predators, competitors, invasive plants, parasites, and diseases.

Rangewide Status

The historical range of the California red-legged frog extended coastally from southern Mendocino County and inland from the vicinity of Redding, California, southward to northwestern Baja California, Mexico (Storer 1925, p. 235; Jennings and Hayes 1985, p. 95; Shaffer et al. 2004, p. 2673). The California red-legged frog has sustained a 70 percent reduction in its geographic range because of several factors acting singly or in combination (Davidson et al. 2001, p. 465).

Over-harvesting, habitat loss, non-native species introduction, and urban encroachment are the primary factors that have negatively affected the California red-legged frog throughout its range (Jennings and Hayes 1985, pp. 99-100; Hayes and Jennings 1988, p. 152). Habitat loss and degradation, combined with over-exploitation and introduction of exotic predators, were important factors in the decline of the California red-legged frog in the early to mid-1900s. Continuing threats to the California red-legged frog include direct habitat loss due to stream alteration and loss of aquatic habitat, indirect effects of expanding urbanization, competition or predation from non-native species including the bullfrog, catfish (*Ictalurus* spp.), bass (*Micropterus* spp.), mosquito fish (*Gambusia affinis*), red swamp crayfish (*Procambarus clarkii*), and signal crayfish (*Pacifastacus leniusculus*). Chytrid fungus (*Batrachochytrium dendrobatidis*) is a waterborne fungus that can decimate amphibian populations and is considered a threat to California red-legged frog populations.

A 5-year review of the status of the California red-legged frog was initiated in May 2011 but has not yet been completed.

Recovery

The 2002 final recovery plan for the California red-legged frog (Service 2002, entire) states that the goal of recovery efforts is to reduce threats and improve the population status of the California red-legged frog sufficiently to warrant delisting. The recovery plan describes a strategy for delisting, which includes: (1) protecting known populations and reestablishing historical populations; (2) protecting suitable habitat, corridors, and core areas; (3) developing and implementing management plans for preserved habitat, occupied watersheds, and core areas; (4) developing land use guidelines; (5) gathering biological and ecological data necessary for conservation of the species; (6) monitoring existing populations and conducting surveys for new populations; and (7) establishing an outreach program. The California red-legged frog will be considered for delisting when:

1. Suitable habitats within all core areas are protected and/or managed for California red-legged frogs in perpetuity, and the ecological integrity of these areas is not threatened by adverse anthropogenic habitat modification (including indirect effects of upstream/downstream land uses).
2. Existing populations throughout the range are stable (i.e., reproductive rates allow for long-term viability without human intervention). Population status will be documented through establishment and implementation of a scientifically acceptable population monitoring program for at least a 15-year period, which is approximately 4 to 5 generations of the California red-legged frog. This 15-year period should coincide with an average precipitation cycle.
3. Populations are geographically distributed in a manner that allows for the continued existence of viable metapopulations despite fluctuations in the status of individual populations (i.e., when populations are stable or increasing at each core area).
4. The species is successfully reestablished in portions of its historical range such that at least one reestablished population is stable/increasing at each core area where California red-legged frog are currently absent.
5. The amount of additional habitat needed for population connectivity, recolonization, and dispersal has been determined, protected, and managed for California red-legged frogs.

The recovery plan identifies eight recovery units based on the assumption that various regional areas of the species’ range are essential to its survival and recovery. The recovery status of the California red-legged frog is considered within the smaller scale of recovery units as opposed to the overall range. These recovery units correspond to major watershed boundaries as defined by U.S. Geological Survey hydrologic units and the limits of the range of the California red-legged frog. The goal of the recovery plan is to protect the long-term viability of all extant populations within each recovery unit.

Within each recovery unit, core areas have been delineated and represent contiguous areas of moderate to high California red-legged frog densities that are relatively free of exotic species such as bullfrogs. The goal of designating core areas is to protect metapopulations that combined with suitable dispersal habitat, will support long-term viability within existing populations. This management strategy allows for the recolonization of habitat within and adjacent to core areas that are naturally subjected to periodic localized extinctions, thus assuring the long-term survival and recovery of the California red-legged frog.

Western Snowy Plover

Legal Status

The Service listed the Pacific Coast population of the western snowy plover as threatened on March 5, 1993 (Service 1993). We designated critical habitat in 1999 (Service 1999) and redesignated it in 2005 (Service 2005). In 2012, we issued a revised critical habitat designation which included a change in taxonomic nomenclature (Service 2012). We issued a recovery plan in August 2007 (Service 2007) and completed 5-year status reviews in 2006 and 2019 (Service 2006, 2019).

Natural History

The western snowy plover is a small shorebird in the family Charadriidae, a subspecies of the snowy plover (*Charadrius nivosus*). It is pale gray/brown above and white below, with a white collar on the hind neck and dark patches on the lateral breast, forehead, and behind the eyes. The bill and legs are black.

Foraging Behavior

Western snowy plovers are primarily visual foragers, using the run-stop-peck method of feeding typical of most plover species. They forage on invertebrates in the wet sand and amongst surf-cast kelp within the intertidal zone, in dry sand areas above the high tide, on saltpans, on spoil sites, and along the edges of salt marshes, salt ponds, and lagoons. They sometimes probe for prey in the sand and pick insects from low-growing plants (Service 2007, pp. 17–18).

Breeding

The Pacific Coast population of the western snowy plover breeds primarily on coastal beaches from southern Washington to southern Baja California, Mexico. The main coastal habitats for nesting include sand spits, dune-backed beaches, beaches at creek and river mouths, and saltpans at lagoons and estuaries (Wilson 1980, p. 23; Page and Stenzel 1981, p. 12). Western snowy plovers nest less commonly on bluff-backed beaches, dredged material disposal sites, salt pond levees, dry salt ponds, and gravel river bars (Wilson 1980, p. 9; Page and Stenzel 1981, pp. 12, 26; Tuttle et al. 1997, pp. 1–3; Powell et al. 2002, pp. 156, 158, 164).

Their nests consist of a shallow scrape or depression, sometimes lined with beach debris (e.g., small pebbles, shell fragments, plant debris, and mud chips). As incubation progresses, western snowy plovers may add to and increase the nest lining. Driftwood, kelp, and dune plants provide cover for chicks that crouch near objects to hide from predators. Because invertebrates often occur near debris, driftwood and kelp are also important for harboring western snowy plover food sources (REPEATPage et al. 2009, Breeding).

Along the west coast of the United States, the nesting season of the western snowy plover extends from early March through late September. Generally, the breeding season may be 2 to 4 weeks earlier in southern California than in Oregon and Washington. Fledging (reaching flying age) of late-season broods may extend into the third week of September throughout the breeding range (Service 2007, p. 11).

The approximate periods required for western snowy plover nesting events are: 3 days to more than a month for scrape construction (in conjunction with courtship and mating), usually 4 to 5 days for egg laying, and incubation averaging 28.4 days in the early season (before May 8) to 26.9 days in the late season (Warriner et al. 1986, pp. 23–24). The usual clutch size is three eggs with a range from two to six (REPEATPage et al. 2009, Breeding). Both sexes incubate the eggs with the female tending to incubate during the day and the male at night (Warriner et al. 1986, pp. 24–25). Adult western snowy plovers frequently will attempt to lure people and predators from hatching eggs and chicks with alarm calls and distraction displays.

Western snowy plover chicks are precocial, leaving the nest with their parents within hours after hatching (Service 2007, p. 14). They are not able to fly for approximately 1 month after hatching; fledging requires 29 to 33 days (Warriner et al. 1986, p. 26). Broods rarely remain in the nesting area until fledging (Warriner et al. 1986, p. 28; Lauten et al. 2010, p. 10). Casler et al. (1993, pp. 6, 11–12) reported broods would generally remain within a 1-mile radius of their nesting area; however, in some cases would travel as far as 4 miles.

Wintering

In winter, western snowy plovers use many of the beaches used for nesting, as well as beaches where they do not nest. They also occur in man-made salt ponds and on estuarine sand and mud flats. In California, most wintering western snowy plovers concentrate on sand spits and dune-backed beaches. Some also occur on urban and bluff-backed beaches, which they rarely use for nesting (Page and Stenzel 1981, p. 12; Page et al. 1986, p. 148). South of San Mateo County, California, wintering western snowy plovers also use pocket beaches at the mouths of creeks and rivers on otherwise rocky points (Page et al. 1986, p. 148). Western snowy plovers forage in loose flocks. Roosting western snowy plovers will sit in depressions in the sand made by footprints and vehicle tracks, or in the lee of kelp, driftwood, or low dunes in wide areas of beaches (REPEATPage et al. 2009, Behavior). Sitting behind debris or in depressions provides some shelter from the wind and may reduce their detectability by predators.

Rangewide Status

Historical records indicate that nesting western snowy plovers were once more widely distributed and abundant in coastal Washington, Oregon, and California (Service 2007, p. 21). In Washington, western snowy plovers formerly nested at five coastal locations (WDFW 1995, p. 14) and at over 20 sites on the coast of Oregon (Service 2007, p. 24). In California, by the late

1970s, nesting western snowy plovers were absent from 33 of 53 locations with breeding records prior to 1970 (Page and Stenzel 1981, p. 27).

The first quantitative data on the abundance of western snowy plovers along the California coast came from window surveys conducted during the 1977 to 1980 breeding seasons by Point Reyes Bird Observatory (Page and Stenzel 1981, p. 1). Observers recorded an estimated 1,593 adult western snowy plovers during these pioneering surveys. The results of the surveys suggested that the western snowy plover had disappeared from significant parts of its coastal California breeding range by 1980 (Service 2007, p. 27).
Breeding and winter window survey data from 2005 to 2022 includes approximately 250 sites in Washington, Oregon, and California, with most sites located in California (Table 2). In California, biological monitors counted 1,830 western snowy plovers during the 2022 breeding window survey, and 4,196[1] western snowy plovers during the 2021 to 2022 winter window survey (Service 2022a, entire). Across the Pacific Coast range, the 2022 breeding window survey estimated 2,371 western snowy plovers, and the 2021 to 2022 winter window survey estimated 4,803 western snowy plovers in Washington, Oregon, and California (Service 2022a, entire). These numbers demonstrate that monitors counted a large percentage of all western snowy plovers in the Pacific Coast range in California during both winter and breeding window surveys.

Table 2. Pacific Coast western snowy plover breeding window survey results, in descending order from 2022 to 2005, for each recovery unit (RU1 through RU6) and the U.S. Pacific Coast (excludes the Baja California peninsula). All counts are breeding age adults and are uncorrected (raw). Recovery Units are RU1: Washington and Oregon; RU2: Northern California (Del Norte to Mendocino Counties); RU3: San Francisco Bay; RU4: Monterey Bay area (Sonoma to Monterey Counties); RU5: San Luis Obispo area (San Luis Obispo to Ventura Counties); RU6: San Diego area (Los Angeles to San Diego Counties) (Service 2019, p. 3).

Year	***RU1***	***RU2***	***RU3***	***RU4***	***RU5***	***RU6***	***TOTAL (U.S. Pacific Coast)***
2022	541	71	281	281	804	393	2,371
2021	624	84	263	292	737	358	2,358
2020	469	46	147	308	855	484	2,309
2019	479	41	190	303	807	397	2,217
2018	402	52	235	361	874	451	2,375
2017	342	56	246	369	856	464	2,333
2016	477	46	202	366	820	373	2,284
2015	340	38	195	348	963	376	2,260

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[1] This number likely includes wintering inland birds that are not part of the listed Pacific Coast population.

2014	269	27	178	374	822	346	2,016
2013	260	23	202	261	754	326	1,826
2012	234	21	147	324	771	358	1,855
2011	202	28	249	311	796	331	1,917
2010	196	19	275	298	686	311	1,785
2009	182	15	147	279	707	257	1,587
2008	147	18	133	257	717	269	1,541
2007	175	26	207	270	676	183	1,537
2006	158	45	102	357	917	298	1,877
2005	137	41	124	337	969	209	1,817

Recovery and Threats

The primary objective of the recovery plan (Service 2007, p. vi) is to remove the Pacific Coast population of the western snowy plover from the list of endangered and threatened wildlife and plants by:

1. Increasing population numbers distributed across the range of the Pacific Coast population of the western snowy plover;
2. Conducting intensive ongoing management for the species and its habitat and developing mechanisms to ensure management in perpetuity; and
3. Monitoring western snowy plover populations and threats to determine success of recovery actions and refine management actions.

Outlined below are the delisting criteria for the Pacific Coast population of the western snowy plover (Service 2007, p. vii):

1. An average of 3,000 breeding adults has been maintained for 10 years, distributed among 6 recovery units as follows: Washington and Oregon, 250 breeding adults; Del Norte to Mendocino Counties, California, 150 breeding adults; San Francisco Bay, California, 500 breeding adults; Sonoma to Monterey Counties, California, 400 breeding adults; San Luis Obispo to Ventura Counties, California, 1,200 breeding adults; and Los Angeles to San Diego Counties, California, 500 breeding adults. This criterion also includes implementing monitoring of site-specific threats, incorporation of management activities into management plans to ameliorate or eliminate those threats, completion of research

necessary to modify management and monitoring actions, and development of a post-delisting monitoring plan.

2. A yearly average productivity of at least one (1.0) fledged chick per male has been maintained in each recovery unit in the last 5 years prior to delisting.
3. Mechanisms have been developed and implemented to assure long-term protection and management of breeding, wintering, and migration areas to maintain the subpopulation sizes and average productivity specified in Criteria 1 and 2. These mechanisms include establishment of recovery unit working groups, development and implementation of participation plans, development and implementation of management plans for Federal and State lands, protection and management of private lands, and public outreach and education.

Our current estimate (2,371 breeding adults) remains below the population size of 3,000 birds listed as a recovery objective in the recovery plan (Service 2007), although some local population sizes have surpassed recovery objectives for some areas (e.g., Monterey Bay, Oregon, Washington). Yearly average productivity (Criterion 2; number of fledglings per male) are not compiled annually for the entire U.S. Pacific Coast; however, the best available information indicates that the yearly average productivity has not been met (Service 2019, p. 6).

Threats have not changed significantly since the 2006 5-year review. Evidence of habitat loss and degradation remains widespread; while the degree of this threat varies by geographic location, habitat loss and degradation attributed to human disturbance, urban development, introduced beachgrass, and expanding predator populations remain the management focus in all six recovery units. Efforts to improve habitat at current and historic breeding beaches, and efforts to reduce the impacts of human recreation and predation on nesting plovers, have improved western snowy plover numbers. Active vegetation and predator management and habitat restoration should be continued. Because of active management efforts, including increased monitoring, use of predator exclosures at some sites, predator management, and expanded beach closures, western snowy plover population numbers have increased at some locations. However, despite active vegetation and predator management, we expect ongoing and projected changes in sea level and climate to affect coastal habitat suitability, nest survival, overwinter survivorship, and quality of nesting and roosting habitats (Service 2019, p. 7).

ENVIRONMENTAL BASELINE

The implementing regulations for section 7(a)(2) (50 CFR 402.02) define the environmental baseline as “the condition of the listed species or its designated critical habitat in the action area, without the consequences to the listed species or designated critical habitat caused by the proposed action. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process. The consequences to listed species or designated critical habitat from ongoing agency activities or existing agency facilities that are not within the agency's discretion to modify are part of the environmental baseline."

Action Area

The implementing regulations for section 7(a)(2) of the Act (50 CFR 402.02) define the "action area" as all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action. The action area for this biological opinion includes all areas subject to temporary and permanent ground-disturbing activities required to prepare the SLC-5 site; areas subject to noise generated from individual launches; areas subject to overpressure as a result of sonic booms generated from launches breaking the sound barrier; areas subject to launch vehicle disposal; four water extraction wells located within the San Antonio Creek Basin and the 9.5 miles of San Antonio Creek downstream habitat; and areas subject to potential mitigation/restoration efforts that may occur as a result of the proposed project.

Appendix A, Figure 1 depicts the Construction Effect Area, Figure 2 (a, b) depicts the Launch Noise Effect Area of potential disturbance, Figure 3 depicts the Sonic Boom Overpressure Effect Area and Vehicle Splashdown Effect Area of potential disturbance, and Figure 4 (a, b) depicts potential mitigation areas associated with the proposed project. The Service considers all areas within the construction, noise, overpressure, vehicle splashdown, water extraction within the San Antonio Creek Basin, as well as potential mitigation/restoration areas to encompass the entirety of the action area.

Habitat Characteristics of the Action Area

The proposed action includes development of a new launch site at SLC-5, located in south VSFB, immediately north (450 feet) of Honda Creek. The area incorporates previously developed areas (5.68 acres) and includes a large portion of native habitat types (27.37 acres) with some non-native habitat (11.08 acres) present (Kaisersatt, pers. comm., 2022e). ManTech SRS Technologies (MSRS) conducted biological surveys in November 2019, March 2020, and August 2021 to characterize and map vegetation communities within the portions of the terrestrial action area subject to physical impacts (MSRS 2022a, p. 30). During surveys, biologists mapped any special status species and their habitat detected, including potential wetlands, wetland vegetation, standing water, or defined channels. Biologists delineated all vegetation communities within the survey area using a combination of survey data and aerial photo interpretation (MSRS 2022a, p. 30).

The majority of the Construction Effect Area is comprised of central coastal scrub/iceplant (9.5 acres) and Venturan coastal sage scrub/herb (10.54 acres) with portions of ruderal vegetation (Kaisersatt 2022e). Within the Construction Effect Area, Honda Canyon Road is located within Honda Canyon and the riparian canopy-associated floodplain of Honda Creek running parallel to the ordinary high-water mark of Honda Creek (between 50 to 550 feet) for approximately 1 mile (Google Earth Pro, 2022; Kaisersatt, pers. comm., 2023). Honda Creek contains aquatic habitat with deep ponded features as well as Central Coast Arroyo Willow Riparian Forest and Scrub (30 CES 2021, Appendix A, Figure 2). Immediately to the north of SLC-5 is a mix of Monterey cypress (*Hesperocyparis macrocarpa*) and coastal scrub (Kaisersatt 2022e). The Launch Noise Effect Area also includes portions of central dune scrub, maritime chapparal, live oak woodland, and pine forest (30 CES 2021, Appendix A, Figure 2).

Existing Conditions in the Action Area

SLC-5 is a decommissioned launch site occupying approximately 18 acres in the south base of VSFB (Appendix A, Figure 1). The National Aeronautics and Space Administration (NASA) originally used this site between 1962 and 1994 to launch Scout space vehicles. Upon completion of the Scout Launch Program, the Space Force deactivated and demolished all facilities at SLC-5 between 2009 and 2012.

Previous Consultations in the Action Area

On May 14, 2021, Vandenberg Air Force Base (VAFB) changed its name to Vandenberg Space Force Base. Consultations prior to this date refer to the U.S. Air Force (Air Force).

1. August 23, 2022: The Service issued a draft biological opinion to the Space Force for the Terran 1 Launch Program (Relativity Space, Inc.) at SLC-11 project. We determined that the proposed action was not likely to jeopardize the continued existence of the western snowy plover and the California red-legged frog. This action has not yet occurred to date.

2. November 18, 2020: The Service issued a biological opinion to the Air Force for the Blue Origin Orbital Launch Site at SLC-9 project. We determined that the proposed action was not likely to jeopardize the continued existence of the California least tern (*Sterna antillarum browni*), beach layia (*Layia carnosa*), western snowy plover, and California red-legged frog. This action has not yet occurred to date.

3. November 21, 2018: The Service issued a reinitiation of a biological opinion to the Air Force on routine mission operations and maintenance activities at VAFB for changes to California red-legged frog-specific avoidance and minimization measures. We concluded the proposed action was not likely to jeopardize the continued existence of the California red-legged frog or alter effects of the proposed activities on the beach layia, Gaviota tarplant (*Deinandra increscens* ssp. *villosa*), Lompoc yerba santa (*Eriodictyon capitatum*), Vandenberg monkeyflower (*Diplacus vandenbergensis*), vernal pool fairy shrimp (*Branchinecta lynchi*), El Segundo blue butterfly (*Euphilotes battoides allyni*), tidewater goby, unarmored threespine stickleback, California least tern, and western snowy plover.

4. December 12, 2017: The Service issued a biological opinion to the Air Force for the proposed launch, boost-back, and landing of the Falcon 9 first stage at Space Launch Complex 4 (SLC-4). We concluded that the proposed action was not likely to jeopardize the continued existence of the El Segundo blue butterfly, California red-legged frog, California least tern, and western snowy plover. This project began in spring of 2018 and is currently ongoing. This consultation was reinitiated due to an increase in launch cadence with the associated final biological opinion issued on March 22, 2023.

5. February 4, 2015: The Service issued a biological opinion to the Air Force for the proposed beach management plan for VAFB. We concluded that the proposed action was not likely to jeopardize the continued existence of the El Segundo blue butterfly, California red-legged frog, California least tern, and western snowy plover.

6. December 3, 2015: The Service issued a programmatic biological opinion to the Air Force for routine mission operations and maintenance activities at VAFB. We concluded that the proposed action was not likely to jeopardize the continued existence of the Vandenberg monkeyflower, beach layia, Gaviota tarplant, Lompoc yerba santa, vernal pool fairy shrimp, El Segundo blue butterfly, California red-legged frog, tidewater goby, unarmored threespine stickleback, California least tern, and western snowy plover.

Condition (Status) of the Species in the Action Area

California Red-legged Frog

California red-legged frogs have been documented in nearly all permanent streams and ponds on VSFB as well as most seasonally inundated wetland and riparian sites (MSRS 2022a, p. 33). Biologists have consistently documented a moderately sized population of California red-legged frogs over the last 10 years across variable survey efforts within Honda Creek adjacent to SLC-5. Using protocol night California red-legged frog survey information between 2013 and 2022, adult frogs encountered ranged between 1 to 12 adult individuals, with the current average annual high number being 7.2 within the anticipated 120 dB contour of the Launch Noise Effect Area. Honda Creek includes multiple deep pond features that biologists have documented regularly support breeding. In 2017, biologists observed 68 juvenile California red-legged frogs within the Honda Pond area. In 2022, 50 California red-legged frog tadpoles and 13 egg masses were observed in a single day in the westernmost portion of Honda Creek (USSF, unpublished data, 2022a).

Suitable upland dispersal habitat exists throughout VSFB between the various riparian zones and ponds, but dispersal into these upland habitats is not likely to be as common as biologists have observed in more mesic parts of the range of this species. However, due to the proximity to aquatic habitat within Honda Creek, upland habitat within the proposed project's Construction Effect Area is likely to support dispersing California red-legged frog individuals. The proposed SLC-5 site is within 450 feet of occupied California red-legged frog breeding habitat within

Honda Creek (CNDDB 2022, Occurrence #1442). Honda Canyon Road runs parallel to Honda Creek for approximately 1 mile, at points is located approximately 50 feet from occupied breeding habitat in Honda Creek (CNDDB 2022, Occurrence #1442), and supports areas of dense riparian vegetation that likely provides shelter for California red-legged frog.

The Launch Noise Effect Area extends approximately 5 miles from SLC-5 in all directions. This includes approximately 6.5 miles of occupied California red-legged frog habitat within Honda Creek with modeled noise levels between 100 to 120 dB as well as the entirety of Bear Creek with modeled noise levels of 100 dB.

The Space Force provided approximate estimates of the number of California red-legged frog life stages present within each noise level contour of the Launch Noise Effect Area (Table 3; Appendix A, Figure 2a).

Table 3. California red-legged frog life stage estimates within each noise level contour of the Launch Noise Effect Area.

Unweighted dB L_{max}	**Adult**	**Metamorph**	**Larvae**	**Egg Mass**
100	19	2	90	13
110	12	1	50	13
120	2	0	0	3
130	0	0	0	0

The Space Force includes that these numbers are likely conservative when estimating adults as these are the largest number of individuals observed during surveys. Conversely, the estimated number of metamorphs, larvae, and eggs masses should be considered a less accurate approximation as not all locations have received equal survey effort for these life stages within each noise contour; stochastic events (flash storms) may have resulted in detection difficulty due to survey timing and drought has likely resulted in the failure of many cohorts over the past ten years (USSF, unpublished data, 2022a; Kaisersatt, pers. comm., 2022c). Similarly, an above average level of rainfall has occurred throughout the winter of 2023 and will likely have rehydrated aquatic habitat previously impacted by drought. This may increase population numbers and impact the establishment of the associated California red-legged frog population baseline (AM-25) in these areas in the immediate future.

No California red-legged frogs are known or expected to occur within the Overpressure Effect Area which is located entirely in the Pacific Ocean.

California red-legged frogs are well documented within the portions of the action area that include San Antonio Creek (MSRS 2022a, p. 34). This includes the potential Oxbow mitigation area and 9.5 miles downstream of the well water extraction in Barka Slough to the estuary.

Annual VSFB water use between 2019 and 2021 has averaged 2,794 acre-feet (MSRS 2022a, p. 51). However, the Space Force is planning to expand additional launch programs that will contribute to this average water extraction in the future years. Consequently, the Service considers the current average water use in addition to what has been permitted to constitute the existing water extraction baseline.

Western Snowy Plover

VSFB provides important nesting and wintering habitat for western snowy plovers, which includes all sandy beaches and adjacent coastal dunes from the rocky headlands at the north end of Wall Beach on north VSFB to the rock cliffs at the south end of Surf Beach on south VSFB (approximately 12.5 miles). VSFB has consistently supported one of the largest populations of breeding western snowy plovers along the west coast of the United States.

The nearest observation of western snowy plover nesting to the action area (Launch Noise Effect Area) is on the southern end of Surf Beach, approximately 3.5 miles north of SLC-5 (Appendix A, Figure 2b). Numerous known western snowy plover nesting areas are located across Surf Beach, the majority of which are located within the anticipated Launch Noise Effect Area (Appendix A, Figure 2b). Between 2012 to 2021, a total of 1,083 known western snowy plover nests fell within the Launch Noise Effect Area with an average of 108.3 nests per year (Table 4; USSF 2021, 2022b).

Table 4. Number of known western snowy plover nests per year from 2012 to 2021 within the Launch Noise Effect Area.

Year	Nest Count
2021	102
2020	111
2019	103
2018	138
2017	129
2016	91
2015	117
2014	120
2013	80
2012	92

Recovery

California Red-legged Frog

In the recovery plan for California red-legged frog, the Service revised recovery units and identified core areas that are watersheds, or portions thereof, that biologists determined essential to the recovery of the California red-legged frog. VSFB is located within the Northern Transverse Ranges and Tehachapi Mountains Recovery Unit and Core Area 24, Santa Maria River-Santa Ynez River. This core area is important because it is currently occupied, contains a source population, and provides connectivity between source populations (Service 2002, pp. 6, 146).

In this recovery unit, biologists consider the lower drainage basin of San Antonio Creek, the adjacent San Antonio Terrace, and San Antonio Lagoon to be among the most productive areas for California red-legged frogs in Santa Barbara County (Christopher 1996, as cited in Service 2002, p. 10). Most of this area occurs on VSFB.

Recovery task 1.24 identifies that the conservation needs in Core Area 24 are (1) to protect existing populations; (2) reduce contamination of habitat (e.g., clean contaminated ponds on VSFB); (3) control non-native predators; (4) implement management guidelines for recreation; (5) cease stocking dune ponds with non-native, warm water fish; (6) manage flows to decrease impacts of water diversions; (7) implement guidelines for channel maintenance activities; and (8) preserve buffers from agriculture (e.g., in lower reaches of Santa Ynez River and San Antonio Creek) (Service 2002, p. 75).

Western Snowy Plover

In the recovery plan for western snowy plover, the Service designated six recovery units across the range. VSFB is located within Recovery Unit (RU) 5, which includes San Luis Obispo, Santa Barbara, and Ventura Counties. RU5 supports the greatest number of western snowy plovers in the range (approximately half of the U.S. population) and has the greatest amount of available suitable habitat (Service 2007, p. 142).

The population trajectory of RU5 since 2007 is stable, positive, and has had minimal annual fluctuation (Service 2019, p. 5). The population has not attained or exceeded the recovery target in any survey year. Annual monitoring reports from several of the larger sites, including VSFB, report fecundity results that exceed the recovery criterion in most years (Service 2019, p. 5).

In 2022, VSFB comprised approximately 26 percent of breeding adults in RU5, 12 percent of California’s breeding population, and 10 percent of breeding adults rangewide (Service 2022b, entire). Table 5 outlines average numbers of breeding adults counted during breeding window surveys from 2014 to 2022. Percentages illustrate the numbers of breeding western snowy plovers at VSFB relative to numbers rangewide, across California, and within RU5.

Table 5. 2014–2022 breeding adult averages from uncorrected (raw) breeding window survey numbers for the Pacific Coast range of western snowy plover, California, RU5, and VSFB with relative percentages (Service 2022b).

Area Surveyed	2014–2022 Averages	Percent of Range	Percent of CA	Percent of RU5
Rangewide	2,283	100	-	-
California Only	1,843	81	100	-
RU5	857	38	47	100
VSFB	226	10	12	26

EFFECTS OF THE ACTION

The implementing regulations for section 7(a)(2) define effects of the action as "all consequences to listed species or critical habitat that are caused by the proposed action, including the consequences of other activities that are caused by the proposed action. A consequence is caused by the proposed action if it would not occur but for the proposed action and it is reasonably certain to occur. Effects of the action may occur later in time and may include consequences occurring outside the immediate area involved in the action" (50 CFR 402.02).

In conducting this analysis, we have considered factors such as previous consultations, 5-year reviews, published scientific studies and literature, and the professional expertise of Service personnel and other academic researchers with aspects directly related to the sensitive species involved in determining whether effects are reasonably certain to occur. We have also determined that certain consequences are not caused by the proposed action, such as the increase or spread of disease, poaching, or collecting, because they are so remote in time, or geographically remote, or separated by a lengthy causal chain, so as to make those consequence not reasonably certain to occur.

Effects of the Proposed Action on the California Red-legged Frog

Construction

The Service assumes that project construction would take place at any point of the year. Due to the proposed project's close adjacency to Honda Creek, SLC-5 site construction, ground disturbance, and vegetation removal activities may result in the injury or mortality of California red-legged frogs due to entrapment, trampling, or crushing by work equipment, materials, and vehicles, at any point of the year. Injury or mortality levels would likely be higher when California red-legged frogs are expected to be moving across the landscape during the wet season (between November 15 and March 31). The Space Force will minimize these effects by conducting work activities during daylight hours and in dry conditions (AM-14). The Space Force will install exclusion fencing to help inhibit terrestrial wildlife, including California red-legged frogs, from entering work areas (AM-14). A Qualified Biologist will survey the site and associated fencing during any activity that has the potential to impact California red-legged frog to minimize associated effects to this species (AM-14). The Qualified Biologist will relocate any California red-legged frogs encountered during work activities that are in harm's way to the nearest suitable habitat (AM-15). Work activities may create open holes or trenches that could entrap California red-legged frogs if left open overnight and lead to subsequent work-related injury or mortality. The Space Force will minimize the potential for effects by securely covering any open holes or trenches with plywood or metal sheets if left overnight, as well as having a Qualified Biologist search any open holes and trenches the following morning for entrapped animals (AM-10).

The proposed project's construction may produce temporary and persistent elevated noise levels during the construction of SLC-5 features. The Space Force did not produce a specific construction noise analysis for the project. We assume that construction noise levels may disturb California red-legged frogs and has the potential to alter California red-legged frog behavior and induce physiological effects. California red-legged frogs are known to occur within 0.1 mile of the proposed SLC-5 Construction Effect Area. Using guidance provided by the Federal Transit Administration (FTA), the Service assumes the proposed project's construction would result in intermittent noise produced by pile driving equipment of 101 dB and persistent noise with average levels of 85 dB (at 50 feet from the source) across an 8-hour period (FTA 2006, p. 12-6, 12-8). We assume noise levels would attenuate to some degree from the construction source at SLC-5 within Honda Canyon. We have no specific data on the response of California red-legged frogs to varying levels or duration of construction noise exposure and consequently use research conducted on related anurans as a surrogate. Traffic noise playback experiments using noise levels between 75 to 87 dB have demonstrated physiological responses including increased level of stress hormone in *Hyla* and *Lithobates* (Tennessen et al. 2014; Troïanowski et al. 2017). Prolonged elevated stress hormone concentrations can have deleterious effects on survival and subsequent reproduction (reviewed in Tennessen et al. 2014). Cases of anuran spatial displacement in response to traffic noise playback experiments have been documented (Caorsi et al. 2017, pp. 9, 14) with different movement effects depending on land cover type (Nakano et al. 2018, entire). Exposure to persistent traffic noise, averaging 70 dBA (A-weighted decibels), significantly reduced the amount of food consumed by Cuban treefrog (*Osteopilus septentrionalis*) tadpoles and also increased the activity level of both Southern toad (*Anaxyrus terrestris*) and Cuban treefrog tadpoles (Castaneda et al. 2020, p. 249). It is possible that increased tadpole activity in response to noise may increase their risk to predation as previous work has shown (Lawler 1989 as cited in Castaneda et al. 2020, p. 251). Adult and sub-adult California red-legged frogs may face increased risk of predation if they move away from noisy construction areas with increased activity potentially making them more noticeable to predators. During the breeding season most adult male anurans, including California red-legged frog, rely on auditory specific advertisement calls which can be critical to female choice of a mate. Consequently, associated effects of construction noise may also include auditory cue masking and loss of signal content. The Space Force will minimize potential noise related impacts on California red-legged frogs by limiting work activities associated with the proposed new facility construction to occur outside of peak vocalization periods during daylight hours and dry weather (AM-14).

The Service also assumes that construction activity has the potential to create associated ground vibration within Honda Creek due to the near adjacency of SLC-5. We cannot anticipate the level or duration of substrate vibration that the proposed project may produce at this time but assume conservatively that low levels of vibration may occur routinely for extended periods of the day during the construction of SLC-5. The Service assumes that potential construction related vibration may be of low frequency which attenuates less readily than high frequency (Norton et al. 2011, p. 658). We have no specific data on the response of California red-legged frogs to varying levels or duration of exposure to construction vibration. We consequently use available research on the effects of vibration on related anurans as a surrogate. In a laboratory study, researchers investigated the effects of low frequency vibrations on early embryonic development of African clawed frog (*Xenopus laevis*). The study demonstrated that vibrating embryos in petri dishes overnight during the embryo development process at 3 low frequency levels (7, 15, and 100 hertz) induced significant levels of physiological effects (heterotaxia, defined by the abnormal position of the heart, gall bladder, and/or gut loop), with some treatments inducing neural tube defects as well as bent tail morphology (Vandenberg et al. 2012, pp. 3-5). Other research has demonstrated negative effects of anthropogenic vibration on anuran communication. Researchers carried out field based vibratory playbacks during 13 days from sunset until dawn when male common midwife toads (*Alytes obstetricans*) were calling. During vibratory playback stimuli, call-rate of the common midwife toad significantly decreased with a smaller number of toads ceasing calling activity completely or abandoning their calling sites (Caorsi et al. 2019, p. 2). Being that construction on SLC-5 would occur within 0.1 mile of California red-legged frog breeding habitat, these findings suggest that if routine construction related vibration occurs during the breeding season, routine exposure to low frequency vibration may adversely affect California red-legged frogs and has the potential to negatively impact breeding success during construction. However, the Space Force did not perform vibration modeling for the purposes of this assessment. The Service cannot anticipate the specific levels or duration of any construction vibration that the project may cause and consequently is unable to predict the magnitude of potential effects. Although more information is needed, the Service conservatively assumes that the project may generate routine construction vibration levels that could result in adverse effects to adjacent California red-legged frog breeding habitat which may include tadpole developmental effects, adult communication, and overall breeding success. Until more information is available, and the effects of the project activity are studied, we are unable to anticipate the specific response at this time.

In the event that construction related vibration causes small scale erosion into Honda Creek, the quality of California red-legged frog breeding habitat may degrade if sedimentation of the creek occurs. The Space Force will conduct annual habitat assessments to measure stream characteristics, including sediment level, to monitor that no unanticipated changes to sedimentation are occurring as a result of the proposed project (AM-23). The Project Proponent will implement erosion control measures wherever potential for project related sedimentation into Honda Creek exists using weed-free biodegradable materials (AM-5). Implementation of erosion control materials has the potential to injure individual California red-legged frogs or disturb their habitat. However, the Service expects these effects to be temporary and minimized by the presence of a Qualified Biologist that will attempt to capture and relocate any California red-legged frogs encountered within the project area (AM-1, 14, 15).

Capture and relocation of California red-legged frogs could result in injury or death as a result of improper handling, containment, transport, or release into unsuitable habitat. Although we do not have an estimated survivorship for translocated California red-legged frogs, intraspecific competition, lack of familiarity with the location of potential breeding, feeding, and sheltering habitats, and increased risk of predation reduces survivorship of translocated wildlife in general. The Space Force will minimize effects by using Qualified Biologists as proposed, limiting the duration of handling, requiring proper transport of individuals, and identifying suitable relocation sites (AM-1, 15). The Service expects the relocation of individuals from work areas to greatly reduce the overall level of injury and mortality, if any, which would otherwise occur. The Space Force will also reduce any associated risk of spreading chytrid fungus during capture and relocation activities by requiring the implementation of DAPTF (AM-15).

Accidental spills of hazardous materials, careless fueling or oiling of vehicles and equipment, and associated runoff could impact California red-legged frogs if materials enter adjacent aquatic habitat. Vehicle and worker movement within staging areas may also injure or crush any California red-legged frogs that enter these areas. The Space Force includes that although the exact locations of laydown and staging areas are unknown at this time, they will limit potential locations to within the SLC-5 Right of Entry or designated utility corridors. Additionally, the Space Force will require that these areas and individual equipment or supplies staged overnight will be located at least 0.1 mile away from California red-legged frog aquatic habitat (AM-14). The Space Force will also ensure that the Project Proponent implements measures to deter California red-legged frogs from accessing designated staging areas (e.g., drift fence barriers). The Space Force will require that the Project Proponent conducts any fueling of equipment in a pre-designated location within the staging areas as well as place spill containment materials around equipment before refueling (AM-8). The Space Force will ensure that Permitted or Service Approved Biologists inspect equipment and staging areas for cleanliness and gas and oil leaks on a daily basis and require that contractors immediately address any unanticipated leaks or spills (AM-1).

During construction, open standing water may be present within excavation areas of SLC-5 infrastructure features (e.g., detention basins, other open site features) for an unknown period of time. Consequently, the Service must assume that features within the proposed construction area have the potential to serve as ephemeral breeding habitat, particularly for California red-legged frogs that may be competing for resources within adjacent habitat in Honda Creek. If filled with storm or construction-related water, these features may attract California red-legged frogs for breeding. Work activities and any associated water drainage during construction activities have the potential to result in the injury or death of any present California red-legged frogs or their egg masses through crushing or desiccation. During construction the Space Force will decrease risks by ensuring the Project Proponent covers all holes or trenches and places wildlife exclusionary fencing around the project area (AM-10). The Space Force will require that a Qualified Biologist survey the site, including any open holes or trenches, each day prior to initiation of work (AM-14) and attempt to capture and relocate any California red-legged frogs encountered within the project area (AM-1, 15).

Operations

The Space Force would authorize routine operational vegetation clearance on Honda Canyon Road as well as an abandoned former access road. Operational vegetation management would also involve routinely mowing the SLC-5 fence line and surrounding firebreak. The Space Force did not provide a project end date and consequently the Service assumes these activities would occur into perpetuity. Due to the proposed project's close adjacency to Honda Creek, routine vegetation management activities may result in the injury or mortality of California red-legged frogs due to entrapment, trampling, or crushing by work equipment, materials, and vehicles, at any point of the year. Injury or mortality levels would likely be higher if the Space Force conducts activities when California red-legged frogs are expected to be moving across the landscape during the wet season (between November 15 and March 31). The Space Force will minimize effects by conducting work activities during daylight hours and in dry conditions (AM-14). The Space Force will continue to require that a Qualified Biologist survey the vegetation maintenance work areas to minimize associated effects to California red-legged frogs (AM-14). The Qualified Biologist will relocate any California red-legged frogs encountered during work activities out of harm's way to the nearest suitable habitat (AM-15). Operational capture and relocation effects would be similar to those described above under Construction.

The Space Force would authorize a maximum of 552,000 gallons (1.69 acre-feet) of water per year to support the project. The current water source for VSFB consists of four water wells located within the San Antonio Creek Basin. Water withdrawal from the San Antonio Creek wells has the potential to reduce streamflow and water levels within San Antonio Creek. This could adversely affect all life stages of California red-legged frog downstream of Barka Slough by reducing associated wetland and riparian habitats supported by the existing groundwater level and extent of inundated area. Annual VSFB water use between 2019 through 2021 has averaged 2,794 acre-feet (MSRS 2022a, p. 51). Utilizing available data for purposes of comparison, a previous analysis for a separate project involving groundwater extraction within the Barka Slough estimated that a 5.1 percent decrease in average annual base flow (up to 0.07 cubic feet per second) in near normal precipitation years could occur within the associated downstream creek channel as a result of pumping a maximum of 921 acre-feet (USGS 2019, p. 5). When using this provided ratio for reference, the Service assumes that pumping 1.47 acre-feet annually would likely result in less than an approximate 0.01 percent decrease in average annual base flow with a correspondingly low level of associated aquatic habitat within the creek channel. Discussion with hydrologists involved with the previously generated hydrological modeling indicate that a 1.47 acre-feet extraction amount is not anticipated to result in measurable decline of streamflow or aquatic habitat considering current water usage at this point in time (C. Faunt and G. Cromwell, USGS, pers. comm. 2021). The Service considers the extraction level of 1.47 acre-feet to be insignificant at this time based on the information provided. Factors including future surrounding water usage (e.g., collective existing and future launch program water needs, surrounding agriculture, etc.) as well as increased variability of annual precipitation due to climate change, including shorter wet seasons and longer dry periods, may influence true effects (Myers et al. 2017, p. 15, 59). An additional hydrological model incorporating various precipitation scenarios predicts that an extraction amount of 921 acre-feet would decrease inundated area between 0.14 and 10.14 percent (AECOM 2019, p. 6). Similarly, given that the maximum annual extraction amount of 1.69 acre-feet is less than 1 percent of the 921 acre-feet used for the supplemental model analysis, it is not reasonably foreseeable that it would result in a discernable reduction of inundated area. Although potential impacts to associated riparian terrestrial habitat were not initially characterized, based on the best available information (USGS 2019; AECOM 2019), the Service does not anticipate measurable decline in the quality or overall extent of these associated habitats as a result of the proposed quantity of 1.69 acre-feet to be extracted annually at this time referencing available information. However, the Service understands that there has been a level of habitat change within Barka Slough driven by increasing groundwater withdrawals from the San Antonio Creek groundwater basin for agriculture on and off VSFB. Since the 1980s, withdrawals have exceeded the recharge rate for the basin (Public Works 2020 as referenced in MSRS 2022b, p. 5). Since the 1950's, ground water levels have dropped between 10 to over 30 meters (USGS 2019 as referenced in MSRS 2022b, p. 5). The Service also understands that there are additional launch programs currently permitted but not yet operational that represent the true existing water extraction baseline. However, the Space Force did not provide the total permitted extraction amounts. Without this information, the Service is unable to make clear quantifiable reference for how the proposed project would contribute to the existing baseline of water extraction. Consequently, additional monitoring and analysis would be necessary to confirm preliminary assumptions and understand the impacts of the proposed project's extraction levels in the event ground water overdraft continues to occur over time.

The proposed project would include the development of a deluge water system. The Space Force has not provided specific design plans for features involved within this system. The Service anticipates water would be present within the retention basin up to three days during the described inspection process to test deluge water quality following static fire and launch events. The Service also assumes rainstorm events could also fill these features with stormwater held for a short period until actively drained. Being that the Project Proponent would remove wildlife exclusionary fencing (AM-10) following construction, there is the potential that California red-legged frogs may enter basins more easily. California red-legged frogs frequently breed in artificial impoundments and consequently the Service must assume that the proposed deluge water retention basin features, when filled, may serve as ephemeral breeding habitat for California red-legged frogs. Deluge water drainage from basins has the potential to result in the injury or death of any individuals or present egg masses through desiccation. The Space Force would transport tested deluge water that does not meet permit water criteria to an offsite facility.

This action may injure any life stages of California red-legged frog present within basins if not relocated prior to water transport. The Project Proponent will design retention basins and water storage features to prevent access by California red-legged frogs. However, the Space Force indicates that if total exclusion is determined impossible, the Space Force will require that the Project Proponent screen all pumps with a 1/8-inch mesh and that a Qualified Biologist check daily for California red-legged frogs prior to pumping (AM-16). To minimize impacts associated with stormwater, the Project Proponent will design deluge containment basins to minimize the amount of stormwater they receive (AM-17). The Project Proponent will also design stormwater management areas to prevent the presence of standing water (other than immediately after a rainstorm) by using design features similar to a French drain. Consequently, the Service assumes stormwater would not fill retention features to an adequate depth or hydroperiod to support the potential for breeding. Based on the implemented avoidance and minimization measures, the Service assumes that all SLC-5 water features will passively drain in less than 24 hours following a storm event and not serve as an attractive nuisance.

The Space Force indicates they would test stored deluge water for chemicals to see if it meets permit water quality criteria before releasing water into the deluge water infiltration pond. The Service does not know what chemicals or elements the Space Force would be testing for that may contaminate deluge water temporarily stored in the basin. Amphibians, including California red-legged frogs, have highly permeable skin and are thought to be particularly susceptible to poor water quality or waterborne pollutants (Jung 1996, p. i; Llewelyn et al. 2019, p. 1). Consequently, the Service must assume that this deluge water has the potential to injure or kill any California red-legged frogs that contact it. The Service also assumes that the deluge water retention features may require maintenance including sediment and associated vegetation removal. Basin maintenance activities could result in the injury or death of adult California red-legged frogs if present. To minimize effects, the Project Proponent will design retention basins and water storage features to prevent access by California red-legged frogs. However, if total exclusion is determined not to be possible, the Space Force will require that a Qualified Biologist check daily for California red-legged frogs prior to pumping (AM-16).

Similarly, the Space Force anticipates the proposed project’s launches will produce soot biproduct that also has the potential to impact California red-legged frogs. Conservatively, assuming the full cadence of 48 launches per year, a total of 1.62 pounds per second of soot would be produced, which is estimated to be 195 pounds in total per year (Kaisersatt, pers. comm., 2022d). In the event enough soot or other similar launch related biproducts contact dispersing California red-legged frogs or enter Honda Creek and other adjacent occupied waterbodies, the Service must assume it has the potential to injure or kill California red-legged frogs. However, the Space Force references a comparable launch assessment (FAA 2020, entire) and expects that the actual amount of soot produced would be diminutive being that it would subsequently burn up in the exhaust plume (Kaisersatt, pers. comm., 2022d). Consequently, the Service assumes that the proposed project’s launch biproducts are not likely to impact dispersing California red-legged frog or their aquatic habitats.

The project's associated flame bucket and deluge system may produce temporary high intensity flame and steam that could result in the injury or mortality of any California red-legged frogs within the project area during launch or test fire events. To minimize potential impacts to California red-legged frogs, the Project Proponent will design the position of the flame buckets and deluge system to direct flame and associated steam to the north of SLC-5, away from Honda Canyon, to minimize potential impacts to California red-legged frog (AM-20). The Space Force will also maintain exhaust ducts to be free of water between launches to help minimize the potential to attract California red-legged frogs to the immediate area.

The Service also assumes that launch and static test fire events have the potential to create associated ground vibration within Honda Creek due to the near adjacency of SLC-5. We cannot anticipate the level of substrate vibration that the proposed project may produce at this time but assume conservatively that low levels of vibration may occur routinely for a short period (up to 1 minute every 2 days) during the operation of SLC-5. The Service assumes that potential construction related vibration may be of low frequency which attenuates less readily than high frequency (Norton et al. 2011, p. 658). We have no specific data on the response of California red-legged frogs to varying levels or duration of exposure to launch operation vibration. Although it is likely that vibration level and duration would differ, we anticipate effects of potential launch vibration could be similar to those previously described for construction-related vibration. The Service considers that although the project has the potential to result in effects from launch related vibration to California red-legged frog's tadpole development, communication, and breeding success, until the novel effects of this project activity are studied, we are unable to anticipate the specific response at this time.

The proposed project's launch operations will produce noise levels that may adversely affect California red-legged frogs. There are no studies on the effects of noise on California red-legged frogs, but available literature on the effects of noise disturbance on anurans in general has grown in recent years (Zaffaroni-Caorsi et al. 2022, entire). A previous study reviewed the effects of noise exposure on American bullfrogs (*Lithobates* (*Rana*) *catesbeianus*), which are closely related to California red-legged frogs. Although no specific acoustic thresholds were determined during the study, American bullfrogs were exposed to sound levels greater than 150 dB SPL for 20 to 24 hours straight, which produced observable damage to their inner ears (Simmons et al. 2014a, p. 1629). American bullfrogs' inner ears showed physical signs of recovery nine days after noise exposure (Simmons et al. 2014b). A moderately large population of breeding California red-legged frogs are known to occur approximately 0.1 mile south of proposed SLC-5 within Honda Creek. Any California red-legged frogs present in upland habitat near SLC-5 may experience modeled noise levels of 144 dB L_{max}. California red-legged frogs distributed throughout the western most approximate 6.5 miles of Honda Creek will experience routine (up to 1 minute every 2 days) noise levels between 100 to 130 dB as a result of the proposed project. The entirety of Bear Creek which also supports a moderate population of breeding California red-legged frog is also within the noise action area and would routinely experience modeled noise levels of 100 dB. Although the proposed project's maximum noise levels are only slightly lower than those documented to produce observable damage to American bullfrog ears, the duration of the noise events would be much shorter than the exposure duration used in this study. However, the specific acoustic thresholds of California red-legged frog are unknown. In the event that the proposed project's noise levels did result in hearing damage to California red-legged frogs, it may temporarily deafen them. The Service assumes the California red-legged frog inner ear recovery period may be similar to the 9-day recovery period exhibited by American bullfrogs. In the event the proposed project's noise levels physically damage California red-legged frog's inner ears and given that project's noise events may occur every 2 days, this may lead to routine deafening. Routine deafening of a substantial portion of the Honda Creek breeding population may alter California red-legged frog's ability to effectively communicate across the breeding season when frogs are calling with the potential to result in overall lower likelihood of reproductive success. California red-legged frogs that exhibit hearing loss may have a decreased ability to detect danger which increases their risk of predation.

However, without refined specific acoustic threshold information, the Service is unable to determine if the proposed project will result in routine deafening of the California red-legged frog population. The Service considers that although specific acoustic thresholds are not available, the American bullfrog surrogate study used higher noise levels (greater than 150 dB) with significantly longer exposure duration (20 to 24 hours). The same study reported that shorter duration (4 hours) of levels below 150 dB did not produce observable morphological damage (Simmons et al. 2014b). Further, noise modeling for the proposed action did not account for topography, and it is likely that surrounding topographic features may serve to attenuate noise levels produced from the proposed project (Bermingham 2013, pp. 19–21). The incised topography associated with Honda Canyon may influence the received noise levels produced by the proposed action within Honda Creek. This may result in lower levels within the action area than was predicted within noise modeling (MSRS 2021, p. 51). Consequently, although the acoustic thresholds for California red-legged frog are unknown, the Service does not anticipate physiological effects to California red-legged frog's inner ears at this time due to the short duration and lower noise levels of the project's anticipated noise disturbance events. Observed call-rate changes could be correlated with hearing loss as frogs may logically call more often if they are unable to perceive responses. The Service has reviewed previous short-term California red-legged frog call-rate monitoring conducted following a single launch event (MSRS 2023, pp 12, 15-16). Short term monitoring documented a significant increase in call-rate following previous Falcon-9 launch activities in December 2022 (MSRS 2023, pp 12, 15-16) . However, data was collected over an insufficient time period (6 days) to be able to analyze results in a meaningful manner. The Service has determined that significantly more data is necessary to begin to understand potential effects. To address the need for better information, the Space Force will implement annual long-term, passive bioacoustics monitoring during the California red-legged frog breeding season to characterize the baseline noise environment and determine if there are unanticipated changes to calling behaviors that may indicate inner ear damage (AM-23).

In addition to call-rate, introduction of novel noise disturbance may result in changes to other signal characteristics including amplitude, frequency, duration, and complexity. Changes (increases or decreases) to an individual's signal characteristics may represent energetic and vocal performance trade-offs. Receiver interpretation of altered signals may influence assessment of signaler quality. This may have implications on the long-term fitness of anuran populations which rely heavily on acoustic signals to attract females and to defend resources against rivals. Previous research looking at traffic noise has demonstrated a trade-off between call-rate and call duration in *Hyla versicolor* (Schwartz et al. 2002). Females were found to prefer calls that were delivered at high rates with longer durations (Gerhardt et al. 1996; Gerhardt and Brooks 2009), suggesting that environmental factors that influence the tradeoff of call-rate and call duration may potentially impact overall fitness over the long-term. Multiple related frog species have been shown to alter call amplitudes during motorbike noise exposure (Cunnington and Fahrig 2010). The energetic costs of calling increases exponentially with call amplitude with an approximate doubling in energetic cost for each 3 dB increase in amplitude (Parris 2002). Previous work suggests that increased energetic costs of calling may inhibit growth rate as a result of allocating more energy towards call effort (Given 1988). This may result in lower reproductive output (Gibbons and McCarthy 1986) and increased risk of desiccation (Heatwole et al. 1969 as referenced in Yi and Sheridan 2019) both of which can lead to decreases in population size. Potential changes in signal frequency could also reduce transmission distance and overall reduce signal efficiency. In bird species, adjustments in signal frequency can decrease song complexity which can profoundly affect reproductive success (Montague et al. 2013). Few studies have considered the long-term implications of adjusted signaling performance in anurans and more information is needed to understand how changes in signal characteristics may impact anuran populations over the long term.

California red-legged frogs may react to individual project related launch noise by startling or remaining immobile, making them more susceptible to predation or desiccation; they may also react to noise by diving into water or retreating away from the affected areas. In our 2017 SpaceX Falcon 9 boost-back biological opinion, we did not expect project-related noise to induce a behavioral response greater than momentary startling or freezing by individual frogs from noise levels as high as 146 dB, which are higher than the proposed project's levels (Service 2017a, p. 49). However, subjecting California red-legged frogs to more frequent and routine noise disturbance may result in novel adverse effects. The Service continues to review the growing body of available literature on the effects of noise pollution to surrogate species. The U.S. Army conducted a study on the response of Colorado checkered whiptail (*Aspidoscelis neotesselatus*) when exposed to intermittent noise disturbance from aircraft flyover noise. When exposed to a week of intermittent flyover noise up to 112.22 dB in comparison to a control week of no noise disturbance, the Colorado checkered whiptail was found to modify its behaviors by spending less time moving and more time eating, and also exhibited higher levels of corticosterone and ketone bodies (markers of stress) (Kepas et al. 2023). The study also suggests that noise disturbance that occurs during the breeding season may induce higher levels of impact when energy would otherwise be invested into developing offspring. Other available research documents cases of anuran spatial displacement in response to traffic noise playback experiments (Caorsi et al. 2017, pp. 9, 14), with different movement effects depending on land cover type (Nakano et al. 2018, entire). Somewhat conversely, it has been suggested that noise can trigger tonic immobility, a paralysis-like fear response, in anurans as a result of increased stress levels (Tennessen et al. 2014, p. 6), which may make them more vulnerable to predation. The proposed project will create frequent noise disturbance throughout the year, including the wet season, when California red-legged frogs are more active and breeding. Induced stress during this period may magnify effects of potential behavioral responses. However, no specific thresholds of disturbance level or frequency are known. The Service considers that although the project has the potential to result in routine stress production and associated effects on behavior, including feeding, reproduction, and dispersal behaviors, until the novel effects of the project activity are studied, we are unable to anticipate the specific response at this time.

The proposed project has the potential to contribute to long-term adverse effects that result from routine intermittent acute noise disturbance. The Service understands that the proposed project would contribute to the frequency of an existing launch disturbance baseline. Over the past five years, VSFB has supported an average of 4.4 rocket launches per year with a maximum of 7 launches in both 2017 and 2018. Other proponents have recently initiated several adjacent launch programs within the vicinity of SLC-5. Of these, those that will have noise impacts on Honda Creek of at least 100 dB include SpaceX Falcon 9 (SLC-4), Minotaur (SLC-8), ULA Vulcan (SLC-3), Blue Origin New Glenn (SLC-9), Relativity Terran 1 (SLC-11), and Phantom Daytona-E (SLC-8). If all these programs, including the proposed project, achieve full launch tempo by 2028, a combined total of up to 157 launch disturbance events of at least 100 dB L_{max} would impact Honda Creek each year as a result of launch and static fire. The proposed project would contribute to over half of this total. The Service understands the adjacent SLC-4 that now supports 36 SpaceX launches would have additional associated terrestrial sonic booms that would also contribute to the existing disturbance baseline within Honda Creek. Although no specific information is available on California red-legged frog response to specific launch disturbance thresholds at certain temporal frequency, using the best available information, the Service considers that related amphibians demonstrate sensitivity to noise disturbance at certain thresholds.

In certain frog species, acute stress has been shown to induce an immediate increase in stress hormone (corticosterone) production (Hammond et al. 2018). Chronic stress, such as frequent exposure to noise disturbance, can cause chronically high levels of stress hormone (Troïanowski et al. 2017). Prolonged elevated stress hormone concentrations can have deleterious effects on growth, survival, reproduction, and immune function (Sapolsky et al. 2000; Tennessen et al. 2014). Relatively recent research demonstrates that increases in advertisement calling rate may be correlated with stress hormone production, which can result in an overall tradeoff in energy otherwise allocated for immunocompetence (Troïanowski et al. 2017; Park and Do 2022). Collectively, if California red-legged frogs were startled at least once every 2 days as a result of the proposed project with the possibility of being disturbed even more frequently as a result of the collective 157 proposed launches annually, using the best available information, the Service anticipates the potential for long-term effects from chronic stress caused by routine intermittent acute noise disturbance. These may include long-term population level effects including reduced reproduction success, survival, and fitness. However, it is unknown how California red-legged frogs would specifically react to repetitive launch events of variable disturbance level with increasing frequency. There are no thresholds in the literature that quantify what level of noise or frequency of disturbance would elicit stress hormone responses that may lead to impacts to breeding and reproduction or other negative population level effects.

The Space Force provided preliminary audiogram analysis which suggests there would not be overlap in the species' hearing sensitivity and low frequency noise produced by rocket launches. Specifically, the provided audiogram analysis suggests that California red-legged frog may only be able to perceive a portion of the launch noise, hearing less than 25 dB across the entire launch event (MSRS 2022a, pp. 55-56). However, subject matter expert review indicates the provided hearing curve and corresponding weighting function are not established and there is still significant uncertainty around the hearing capabilities of California red-legged frog (J. Tennessen, pers. comm., 2022). Referencing current best available information, specific disturbance levels and frequency thresholds that may impact California red-legged frogs are unknown. Consequently, the Service cannot adequately determine the anticipated effects of the proposed project's 96 disturbance events on the residential and breeding California red-legged frog populations within Honda Creek. In addition, the Service cannot adequately determine how the proposed project's 96 disturbance events would contribute to the existing baseline of 61 permitted launch disturbance events annually. The Service considers that although the project has the potential to significantly contribute to the collective effects of the existing launch disturbance baseline and result in long-term population level effects, until the novel effects of the project activity are studied, we are unable to anticipate the specific response at this time.

Newly introduced persistent artificial night lighting associated with SLC-5 operations could have adverse physiological and behavioral effects on California red-legged frogs. The Space Force would authorize the installation of 36 light poles around the perimeter of SLC-5 for security and support of night operations. The light poles would have a maximum height of 40 feet. The Service assumes permanent operational site lighting will include ultra-violet artificial night lighting features that may newly illuminate some amount of adjacent natural habitat around SLC-5. The Space Force provided a preliminary lighting plan within the biological assessment. The proposed project would include lighting levels between 1- to 4-foot candle within SLC-5 facility (MSRS 2022a, p. 59; Figure 5.1-4). The Space Force indicates that newly introduced light will be contained within the work area (Evans, pers. comm., 2022b). Although we have no specific data on the response of California red-legged frogs to artificial night lighting exposure, laboratory and field studies of related anurans indicate artificial lighting can result in changes in hormone production and growth, as well as altered activity levels including movement and foraging (Baker and Richardson 2006; Wise 2007; Hall 2016; May et al. 2019). The introduction of artificial night lighting may consequently increase anuran predation rates if predators are able to better detect dispersing adult frogs that may move more in newly lit environments.

Numerous anurans have been shown to increase foraging activity surrounding permanent light sources (reviewed in Buchanan 2006), likely attributed to increased concentrations of prey levels resulting from insects' attraction to the presence of ultraviolet light (Longcore and Rich 2017a, p.

25). The number of insects attracted to a lamp is disproportionally affected by the emission of ultraviolet light, regardless of the proportion of ultraviolet radiation emitted (Barghini and Augusto Souze de Medeiros 2012, entire; B. Seymoure, pers. comm., 2023), indicating that even ‘low-UV’ lighting options attract insects. Permanent ultraviolet lighting adjacent to roadways or parking areas associated with SLC-5 launch facility may result in higher likelihood of vehicle strikes if California red-legged frogs increase foraging in these areas. Launch operations may physically injure or destroy California red-legged frog individuals if lighting surrounding the launch pad attracts them and they come within close vicinity of features including the flame bucket. Being that SLC-5 is only 0.1 mile north of the Honda Creek which is known to contain a consistently moderately sized population of California red-legged frogs, the Service reasonably anticipates that the introduction of artificial lighting associated with the project has the potential to result in sustained adverse effects. To attempt to minimize these effects, the Space Force will require development of a lighting plan for the proposed project (AM-22). This plan will require that the Project Proponent directs all light away from Honda Canyon and shield it to reduce scatter into natural, undeveloped areas. The Space Force will ensure that illumination lighting levels of 1-foot candle do not extend beyond the SLC-5 facility into natural habitats (MSRS 2022a, p. 59). The Space Force will require that the lighting plan design uses the minimum lumens necessary to accomplish lighting requirements. This requirement will be accomplished through strategic placement of lights, and the use of shields, timers, and motion sensors to the maximum extent possible to minimize potential effects associated with novel persistent artificial light at night (York, in litt., 2022, p. 6). The Project Proponent will limit all persistent artificial lighting at SLC-5 to the needs of providing site security during the hours of darkness (AM-21). Provided this language and that the Space Force will limit construction work to occur only during daylight hours (AM-14), the Service assumes that there will be very minimal or no construction lighting as a part of the proposed project, effectively avoiding the potential for associated lighting effects. The Project Proponent will also design the position of the flame buckets to direct flame and associated steam north of SLC-5, away from Honda Canyon, to help minimize potential direct physical injury to California red-legged frog that may be attracted to the area by lighting (AM-20).

Capture and relocation of California red-legged frogs during project operations (vegetation maintenance) could result in injury or death as a result of improper handling, containment, transport, or release into unsuitable habitat. Although we do not have an estimated survivorship for translocated California red-legged frogs, intraspecific competition, lack of familiarity with the location of potential breeding, feeding, and sheltering habitats, and increased risk of predation reduces survivorship of translocated wildlife in general. The Space Force will minimize effects by using Qualified Biologists as proposed, limiting the duration of handling, requiring proper transport of individuals, and identifying suitable relocation sites (AM-1, 15). The Service expects the relocation of individuals from work areas to greatly reduce the overall level of injury and mortality, if any, which would otherwise occur. The Space Force will also reduce any associated risk of spreading chytrid fungus during capture and relocation activities by requiring the implementation of DAPTF (AM-15).

Somewhat similarly, the proposed project's disturbance frequency has the potential to displace California red-legged frog populations, potentially stimulating migration away from noisy areas or attraction towards newly lit adjacent habitat as described above. Although we do not have an estimated survivorship of displaced California red-legged frog, this could result in injury or death to individuals as a result of increased intraspecific competition, lack of familiarity with new locations of potential breeding, feeding, and sheltering habitats, and increased risk of predation. All of which reduces survivorship of translocated wildlife in general.

Following review of the effects of the proposed action, the Service anticipates the proposed project would result in the sustained degradation in the quality of adjacent California red-legged frog aquatic habitat due to associated sensory pollutants caused by routine launching. In the event the Space Force observes California red-legged frog population declines from the established baseline within Honda Creek, the potential mitigation actions would include the creation of new breeding habitat at a 2:1 ratio (habitat enhanced: habitat affected) within the San Antonio Creek Oxbow Restoration 'expansion area' (Appendix A, Figure 4a). Mitigation actions that may occur as result of the project include site preparation via herbicide application, plowing, container plant installation, seeding, willow pole planting, and watering via water truck. These activities have the potential to effect California red-legged frog. An existing biological opinion (2016-F-0103; Service 2018) addresses the associated effects of this portion of the proposed action for California red-legged frog, and the Space Force will implement all required avoidance, minimization, and monitoring measures. The Space Force has formerly conducted restoration work over the past three years at the existing San Antonio Creek Oxbow Restoration site to improve San Antonio Creek California red-legged frog habitat. The Space Force indicates that restoration methods have proven successful at creating deep water aquatic habitat, suitable for California red-legged frog breeding and riparian woodland that simulate naturally occurring high-flow channels. However, previous survey efforts have not yet detected California red-legged frog at this site or demonstrated that California red-legged frog will newly colonize these areas for breeding (Evans 2022a, p. 4; Kephart 2022, p. 2). The Service considers that the Space Force will continue to develop restoration methods to ensure the objectives of proposed mitigation are met and able to clearly demonstrate that no net loss in occupied California red-legged frog habitat and population size will result from project activities (Kephart 2022, p. 2-3).

Effects of the Proposed Action on the Western Snowy Plover

Construction

Western snowy plovers do not occur within or adjacent to the proposed SLC-5 facility. The nearest observation of western snowy plover nesting is approximately 3.5 miles north of SLC-5, at the southern end of Surf Beach. Additionally, the proposed SLC-5 construction area is approximately 325 feet above sea level and out of sight of western snowy plover habitat. Based on these reasons, we do not anticipate adverse effects to western snowy plover from site construction activities.

Operations

Known western snowy plover nesting locations are located approximately 3.5 miles north of the proposed SLC-5 facility and extend within the northern portion of the Launch Noise Effect Area (Appendix A, Figure 2b). Western snowy plovers in this area would experience launch operation noise levels between approximately 100 to 108 dB L_{max} during Laguna-E launches and between approximately 100 and 104 dB L_{max} during Daytona-E launches. Static fire levels would reach less than 100 dB L_{max} for both launch vehicles. The Space Force proposes a staggered launch operation schedule until 2028 when the proposed project would attain full launch tempo with 48 launches and 48 static test fires (Table 1). Using the information provided, the Service assumes a launch related disturbance event would occur once every two days consecutively across 192 days annually at full launch tempo in 2028.

The Space Force conducted prior monitoring of western snowy plovers during individual launches to understand immediate impacts from launch related noise events. Biologists monitored nesting western snowy plovers on April 17, 2022, during a SpaceX Falcon 9 NROL-85 with boost-back at 137 dB SEL from SLC-4 East (4E), located approximately 0.9 mile from western snowy plover habitat. Although behavioral responses were not captured, the biologists reported no detectable effects on abundance or nest attendance of western snowy plover after this single launch (Point Blue Conservation Science 2022, p. 1). Biologists also monitored western snowy plovers during a Titan IV launch at 130 dBA from SLC-4E and observed no adverse reactions from western snowy plovers due to the launch (SRS 2006 as cited in Tetra Tech 2020, p. 40). However, after a launch event during the 1998 western snowy plover breeding season of a Titan II from SLC-4W at 119 dB, monitors found one of three eggs broken in the nest located closest to the launch facility. The cause of the damaged egg was not determined (Applegate and Schultz 1998, as cited in MSRS 2021, p. 54).

More recently, biologists monitored western snowy plover for the June 18, 2022 Falcon 9 SARah-1 mission with boost-back and first stage recovery at SLC-4 (Robinette and Rice 2022, entire). They noted that incubating western snowy plovers reacted to both the launch and sonic boom produced by the return flight of the first-stage with more intense reactions to the sonic boom (Robinette and Rice 2022, p. 1). They observed a startle effect in response to the sonic boom for all five western snowy plover nests with cameras, and two of the five incubating birds hunkered down on their eggs in response to the sonic boom. Biologists note that it is possible the startle and hunker behavior observed can lead to damage to one or more eggs. One western snowy plover egg at north Wall Beach (outside of the monitoring area) showed signs of potential damage in which it had a long crack. The damaged egg had an approximately three-week-old embryo that may have stopped developing around the time of the launch. However, it is common for one or more eggs from a successful nest to fail to hatch and there currently is no data on how often eggs undergo damage under normal (i.e., non-launch) circumstances. The nest with the damaged egg did not have a camera set on it, so biologists could not determine what caused the damage. Biologists reported no difference in nest attendance or bird abundance before and after launch and boost-back, and they concluded that this launch and boost-back did not significantly affect western snowy plover nesting on VSFB (Robinette and Rice 2022 pp. 1–2, 13).

Physiological responses of western snowy plover to launch noise disturbance may include an increased heart rate, altering of metabolism and hormone balance, and behavioral reactions, such as head raising, body shifting, moving short distances, and flapping of wings. These responses may cause energy expenditure, reduced feeding, habitat avoidance, reproductive losses, and bodily injury resulting in increased vulnerability to predation (Radle 2007, p. 5). Although more information is needed on specific noise level and frequency thresholds that may impact western snowy plover at various stages during the breeding season, the proposed project's noise disturbance is anticipated to be of short duration (1 minute during launches and 30 seconds during static test fire). Considering past monitoring results, we do not expect the proposed project's individual launch and static test fire events to result in short term observable effects, such as birds flushing from the nest. However, non-observable effects, such as increased heart rate or increased stress hormone levels could routinely occur. Consequently, the proposed project has the potential to contribute to long-term adverse effects that result from routine intermittent acute noise disturbance. The Service assumes a launch related disturbance event would occur once every two days consecutively across 192 days annually, at full launch tempo in 2028. Proposed project launch operations would consequently expose populations to routine intermittent acute noise disturbance at levels between 100 to 108 dB for 1 minute during launches and 30 seconds during static test fire. The Service understands that the proposed project would contribute to the disturbance frequency of the existing launch noise disturbance baseline. Existing noise disturbance events of at least 100 dB L_{max} currently occur across Surf Beach within the proposed project's Launch Noise Effect Area that affect the same populations of western snowy plover. This includes the SpaceX launch complex at SLC-4, approximately 1.8 miles north of SLC-5 (2017-F-0480; Service 2017b); the ULA Vulcan launch complex at SLC-3, approximately 3 miles north (2013-F-0430; Service 2015c); the Blue Origin New Glenn launch complex at SLC-9, approximately 4 miles north (2020-F-0427; Service 2020); and the Relativity Terran 1 launch complex at SLC-11, approximately 2.5 miles south (2022-0032755-S7; Service 2022c). The proposed project in combination with other planned and permitted launch programs would produce a total of 154 noise disturbance events of at least 100 dB annually that would impact South Surf Beach (estimated for 2028 to 2030; MSRS 2022a, p. 67).

Although no information is available on western snowy plover response to specific noise disturbance thresholds at certain temporal frequency, western snowy plovers do appear to demonstrate sensitivity to frequent noise disturbance. Biological monitors reported that a 20-minute fireworks display (lower levels of frequent acute noise; variable intermittent disturbances that ranged from 59 dB to 80 dB for 20 minutes) at Coal Oil Point Reserve in Goleta, California, visibly agitated western snowy plovers (BRC 2018, entire). Camera footage captured western snowy plovers displaying stress responses (i.e., shallow breathing, frantic head turning, flushing) during the noise events. Chronically elevated stress hormone concentrations can have deleterious effects on species. Responses may cause energy expenditure, reduced feeding, reproductive losses, bodily injury resulting in increased vulnerability to predation, and habitat avoidance

(Radle 2007, p. 5). Referencing current best available information, the Service cannot adequately determine the anticipated impacts of the proposed project's 96 disturbance events annually on the western snowy plover population at Surf Beach. Similarly, the Service cannot adequately determine how the proposed project's 96 disturbance events would contribute to the existing baseline of 61 permitted launch disturbance events annually. The Service considers that although the project has the potential to significantly contribute to the collective effects of the existing launch disturbance baseline and result in long term population level effects, until the novel effects of the project activity are studied, we are unable to anticipate the specific response at this time.

The proposed project's disturbance frequency has the potential to displace western snowy plover populations, potentially stimulating migration away from noisy areas. Although we do not have an estimated survivorship of displaced western snowy plover, this could result in injury or death to individuals as a result of increased intraspecific competition, lack of familiarity with new locations of potential breeding, feeding, and sheltering habitats, and increased risk of predation. All of which reduces survivorship of translocated wildlife in general.

Potential mitigation actions for western snowy plover include predator control, including trapping, shooting, and tracking known western snowy plover predators with particular focus on raven removal at and adjacent to VSFB beaches. An existing biological opinion (8-8-12-F-11R; Service 2015b) analyzes and permits these actions, and the Space Force will implement all required avoidance, minimization, and monitoring measures. Additionally, the Space Force will continue pursuing other beneficial actions including recovery opportunities outlined in the western snowy plover recovery plan (Service 2007) and 5-year review (Service 2019) following mutual agreement by the Service and the Space Force annually (Kephart 2022, p. 3). The Service considers that the Space Force will continue to develop restoration methods to ensure the objectives of the mitigation are met and that no net loss in occupied western snowy plover habitat and population size has resulted from project activities (Kephart 2022, p. 3).

Due to the distant location of the proposed SLC-5 facility in relation to the subject western snowy plover nesting habitat on Surf Beach, we do not expect any significant visual disturbance from launch operations on western snowy plover. If western snowy plovers are able see launch operations, we expect effects would not be greater than the noise disturbance effects described above.

Effects on Recovery

California Red-legged Frog

We do not anticipate the proposed project to interfere with the specific recovery goals for Core Area 24 (Santa Maria-Santa Ynez River) provided in the Service's 2002 recovery plan for the species. Although the function of Honda Creek is not specified within the recovery plan, the recovery plan states the goal to protect existing California red-legged frog populations within

Core Area 24 (Service 2002, p. 75). Direct effects from SLC-5 construction would impact approximately 60 acres of suitable dispersal and non-breeding aquatic habitat, a very small amount (less than 0.00009 percent) of the approximately 673,288 acres within Core Area 24. However, project operations create the potential for long-term effects that may result in overall habitat degradation across a larger portion of occupied California red-legged frog breeding habitat within Honda Creek. We are unable to anticipate the magnitude of potential effects of increased launch frequency at this time with the available information.

We expect that adverse effect are likely to occur to California red-legged frogs as a result of the proposed project. Construction activities, routine vegetation removal, routine and frequent launch operations, deluge water storage and release, and capture and relocation efforts may cause injury or mortality. However, based on the available information and minimization measures, including potential mitigation and the Space Force's commitment to ensure no net loss to the species, we expect adverse effects to the recovery of California red-legged frogs would be low. Although adverse effects are likely to occur as a result of the proposed action, we do not anticipate they will dimmish the contribution the population at VSFB makes to the recovery of the California red-legged frog at this time.

Western Snowy Plover

We do not currently anticipate that the proposed project would interfere with the recovery goals provided in the 2007 recovery plan for the species (Service 2007). Construction of SLC-5 will not remove any western snowy plover habitat; however, project operations create the potential for long-term effects that may result in overall habitat degradation across occupied western snowy plover breeding habitat at South Surf Beach. Although potential long-term effects of increased launch noise disturbance frequency may occur, we are unable to anticipate the magnitude of potential effects at this time with the available information. With mitigation actions ensuring no net loss in place if the Space Force detects a population decline, we do not anticipate the proposed action will diminish the VSFB population's contribution to the recovery of the western snowy plover.

Summary of Effects

California Red-legged Frog

In summary, we expect adverse effects to California red-legged frog are likely to occur due to the proposed action. During the proposed project's construction activities, California red-legged frogs may become entrapped, injured, or crushed. The Space Force will decrease risks by ensuring all holes or trenches are covered and by placing fencing around the project area during construction to prevent dispersing California red-legged frogs from entering the area (AM-10, 14). Furthermore, a Service Approved biologist will monitor all construction activities that may impact California red-legged frogs and attempt to capture and relocate any California red-legged frogs from the project area (AM-15).

Construction noise and vibration may result in behavior and physiological effects. Prolonged elevated stress hormone concentrations can have deleterious effects on survival and subsequent reproduction. The Service considers that although the project has the potential to result in effects to breeding success, until the novel effects of the project activity are studied, we are unable to anticipate the specific response at this time. The Space Force will attempt to minimize potential construction noise related effects by limiting work activities outside of peak vocalization periods during daylight hours and dry weather (AM-14). The Space Force will also implement erosion control measures wherever potential for project related sedimentation, potentially caused by vibration, into Honda Creek exists using weed-free biodegradable materials (AM-5).

Accidental spills of hazardous materials, careless fueling or oiling of vehicles and equipment, and associated runoff could impact California red-legged frogs if material enters adjacent aquatic habitat. The Space Force will ensure the work equipment and refueling occurs at least 0.1 mile away from California red-legged frog aquatic habitat, that spill containment equipment is present at all times on site, and daily inspections of equipment (AM-1, 8, and 14).

Construction site features that fill with storm or work water may attract California red-legged frogs for breeding which has the potential to result in the injury or death of any present California red-legged frog individuals or egg masses through crushing or desiccation. The Space Force will minimize effects by ensuring holes are covered (AM-10) and that a Qualified Biologist survey the site to capture and relocate any California red-legged frogs encountered (AM-1, 14, and 15).

During project operations, routine vegetation clearance that may be conducted at any point of the year may result in the injury or mortality of California red-legged frogs. Injury or mortality levels would likely be higher if the Space Force conducts activities when California red-legged frogs are expected to be moving across the landscape during the wet season (between November 15 and March 31). The Space Force will minimize effects by conducting work activities during daylight hours and in dry conditions, and by requiring that a Qualified Biologist survey work areas and relocate any encountered individuals (AM-14 and 15).

The Space Force would authorize a maximum of 552,000 gallons (1.69 acre-feet) of water per year to support the project sourced from four water wells located within the San Antonio Creek Basin. Using existing hydrological modeling, the Service does not anticipate measurable decline in the quality or overall extent of these associated habitats as a result of the annual extraction at this time based on existing water usage.

When filled, deluge water retention basins may serve as ephemeral breeding habitat for California red-legged frogs and water drainage has the potential to result in injury or death to any individuals or present egg masses. California red-legged frogs that come into contact with operational contaminated deluge water may also be injured or killed. The Service also assumes any required water basin feature maintenance could result in the injury or death of any life-stages of California red-legged frogs if present. However, the Space Force will require that the Project Proponent design retention basins and water storage features to prevent access by California red-legged frogs and minimize the amount of stormwater they receive (AM-17). The Space Force indicates that if total exclusion is determined not possible, the Space Force will require that all pumps be screened and that a Qualified Biologist check for California red-legged frogs prior to pumping daily (AM-16). Consequently, the Service assumes with implementation of avoidance and minimization measures, the SLC-5 water features will not serve as an attractive nuisance.

The proposed project’s launches will produce soot biproduct that also has the potential to impact California red-legged frogs. The Space Force expects that the actual amount of soot produced would be diminutive being that it would subsequently burn up in the exhaust plume (Kaisersatt, pers. comm., 2022d). Consequently, the Service anticipates that the proposed project’s launch biproducts are not likely to impact dispersing California red-legged frogs or their aquatic habitats.

The project’s associated flame bucket and deluge system may produce temporary high intensity flame and steam that could result in the injury or mortality of any California red-legged frogs within the project area during launch or test fire events. To minimize potential impacts, the Project Proponent will design the position of the flame buckets and deluge system to direct flame and associated steam to the north of SLC-5 (AM-20) and maintain exhaust ducts to be free of water between launches.

Project operational noise and vibration from routine launching may induce long-term behavioral and physiological responses in California red-legged frog that may be present in the action area. The proposed project constitutes 96 disturbances events that would contribute to the disturbance frequency of the existing launch noise disturbance baseline. A current total of 61 existing permitted launch noise disturbance events of at least 100 dB occur within the proposed project’s Launch Noise Effect Area. With the addition of the proposed project this would collectively total 157 disturbance events. Therefore, the proposed project would represent more than a twofold increase in overall potential annual launch disturbances on the residential and breeding California red-legged frog populations within Honda Creek. The proposed project would contribute to over half of this total. Using the best available information, the Service does not anticipate routine deafening of California red-legged frog population within Honda Creek but considers the population could experience negative effects that develop over the long term from routine exposure to sensory pollutants and subsequent stress. The Service cannot adequately determine the anticipated impacts of how the proposed project’s noise disturbance events in combination with the existing launch related disturbance baseline in the near vicinity may affect residential and breeding California red-legged frog populations within features including Honda Creek. However, the Space Force will implement a phased approach prior to reaching full launch tempo to provide opportunity to detect any unanticipated effects. In the event that population or call-rate declines are observed, the Space Force would implement proposed mitigation and has ensured that no net loss of occupied California red-legged frog habitat and population size (Kephart 2022, p. 2-3).

Newly introduced persistent artificial night lighting associated with SLC-5 construction and operations could have adverse physiological and behavioral effects on California red-legged frogs. Migrating California red-legged frog may be affected by newly introduced artificial night lighting, which may also serve as an attractive nuisance. To attempt to minimize these effects, the Space Force will require the development of a lighting plan for the proposed project (AM-22) which requires that illumination lighting levels of 1-foot candle do not extend beyond the SLC-5 facility into natural habitats and that lighting design uses the minimum lumens necessary to accomplish lighting requirements.

Following review of the effects of the proposed action, the Service anticipates the proposed project has the potential to result in the sustained degradation in the quality of adjacent California red-legged frog aquatic habitat due to construction and launch associated sensory pollutants. In the event the Space Force detects an unanticipated decline in California red-legged frog distribution and abundance across Honda Creek not directly attributed to other factors (e.g., drought or wildfire), they will implement mitigation actions for California red-legged frog by creating new breeding habitat at a 2:1 ratio (habitat enhanced: habitat affected) within the San Antonio Creek Oxbow Restoration ‘expansion area’. The Service considers the Space Force’s commitment to ensure the objectives of proposed mitigation are met and able to clearly demonstrate that no net loss in occupied California red-legged frog habitat or population size have resulted from project activities (Kephart 2022, p. 2-3).

Based on the available information and minimization measures, including potential mitigation ensuring no net loss, we expect adverse effects to the recovery of California red-legged frogs would be low. Although adverse effects are likely to occur as a result of the proposed action, we do not anticipate they will dimmish the contribution the population at VSFB makes to the recovery of the California red-legged frog at this time.

Western Snowy Plover

In summary, we expect adverse effects to western snowy plover may occur due to the proposed project operations. We do not anticipate adverse effects to western snowy plover from site construction activities.

Project operation noise from routine launching may induce behavioral and physiological responses in western snowy plover that may be present in the action area. The Service cannot adequately determine the anticipated impacts of how the proposed project’s noise disturbance events in combination with the existing noise disturbance baseline from other launch operations in the near vicinity may affect breeding western snowy plover populations located across Surf Beach until the novel effects of the project activity are studied. However, with mitigation actions in place ensuring no net loss if the Space Force detects a population decline, we do not anticipate the proposed action will diminish the VSFB population’s contribution to the recovery of the western snowy plover at this time.

CUMULATIVE EFFECTS

Cumulative effects include the effects of future State, tribal, local or private actions that are reasonably certain to occur in the action area considered in this biological opinion. We do not consider future Federal actions that are unrelated to the proposed action in this section because they require separate consultation pursuant to section 7 of the Act. We are unaware of any future State, tribal, local or private actions that are reasonably certain to occur in the action area.

CONCLUSION

The regulatory definition of "to jeopardize the continued existence of the species" focuses on assessing the effects of the proposed action on the reproduction, numbers, and distribution, and their effect on the survival and recovery of the species being considered in the biological opinion. For that reason, we have used those aspects of the California red-legged frog and the western snowy plover status as the basis to assess the overall effect of the proposed action on the species.

California Red-legged Frog

Reproduction

The proposed project would not result in the physical loss of California red-legged frog breeding habitat. However, the proposed project would likely constitute sustained degradation of breeding habitat within Honda Creek due to sensory pollutants (e.g., lighting, noise, vibration) associated with the proposed action's construction and operations. Until the novel effects of the project activity are studied, the Service is unable to anticipate the specific response at this time using available information. If the proposed project's increased launch frequency demonstrates a reduction in reproductive success in Honda Creek, the Space Force indicates they will implement mitigation as described at the San Antonio Creek Oxbow Restoration expansion area to ensure no net loss in California red-legged frog occupied breeding habitat and overall population size occurs. We expect the Space Force will demonstrate successful colonization and breeding within the San Antonio Creek Oxbow Restoration expansion area to offset potential project impacts to the portion of Honda Creek within the action area at a 2:1 ratio. Should the Oxbow Restoration site not meet mitigation acreage requirements depicted in the project description, we expect that the Space Force will implement other recovery objectives coordinated with the Service that quantifiably demonstrate no net loss to be consistent with this effects analysis. We consequently conclude that the proposed project would not reduce overall California red-legged frog reproduction on VSFB, in the Northern Transverse Ranges and Tehachapi Mountains Recovery Unit, or rangewide.

Numbers

We are unable to determine the exact number of California red-legged frogs that could occur in the action area that may be affected by proposed project because existing survey data are insufficient to estimate population numbers, and the numbers of individuals in the action area likely vary from year to year. Proposed project activities could affect individual California red-legged frogs to the point of injury or death. Project operations may result in sustained stress on the California red-legged frog population within Honda Creek that may reasonably cause cumulative sublethal effects that lead to gradual decline over the long term. Until the novel effects of the project activity are studied, the Service is unable to anticipate the specific response at this time using available information. However, the number of California red-legged frogs we expect may be affected at this point in time by the proposed activities is small relative to the total VSFB population and those across the entirety of the species' range. Additionally, if the proposed project's increased launch frequency demonstrates a reduction in California red-legged frog numbers in Honda Creek, the Space Force will implement mitigation as described at the San Antonio Creek Oxbow Restoration expansion area to ensure no net loss in the species abundance occurs. We expect the Space Force will demonstrate successful colonization and subsequent species abundance within the San Antonio Creek Oxbow Restoration expansion area to offset potential project impacts to the portion of Honda Creek within the action area at a 2:1 ratio. Should the Oxbow Restoration site not meet mitigation acreage requirements depicted in the project description, we expect that the Space Force will implement other recovery objectives coordinated with the Service that quantifiably demonstrate no net loss to be consistent with this effects analysis. Therefore, we conclude that the proposed project would not appreciably reduce the number of California red-legged frog on VSFB, in the Northern Transverse Ranges and Tehachapi Mountains Recovery Unit, or rangewide.

Distribution

The proposed project would likely constitute sustained degradation of occupied aquatic California red-legged frog habitat within Honda Creek due to sensory pollutants (e.g., lighting, noise, vibration) associated with the proposed action's construction and operations. Until the novel effects of the project activity are studied, the Service is unable to anticipate specific response in potential distribution of California red-legged frog at this time using available information. If the proposed project's increased launch frequency demonstrates a reduction in species abundance and distribution in Honda Creek, the Space Force indicates they will implement mitigation as described at the San Antonio Creek Oxbow Restoration expansion area to ensure no net loss in occupied habitat occurs. However, the proposed mitigation site is located in north base over ten miles from Honda Creek. In the event the proposed project results in reduced occupation of California red-legged frog within Honda Creek, this would constitute a reduction in the overall distribution of the species across south base and across the VSFB population as a whole. However, any observed reduction would not appreciably reduce the distribution across the Northern Transverse Ranges and Tehachapi Mountains Recovery Units, or rangewide. We consequently conclude that the proposed project may reduce California red-legged frog distribution in the action area and across VSFB but would not appreciably reduce distribution within the Northern Transverse Ranges and Tehachapi Mountains Recovery Unit, or rangewide.

<u>Recovery</u>

The proposed project is not anticipated to interfere with the specific recovery goals for Core Area 24 (Santa Maria-Santa Ynez River) provided in the Service's 2002 recovery plan for the species. Although the function of Honda Creek is not specified, the recovery plan states the goal to protect existing California red-legged frog populations within Core Area 24 (Service 2002, p. 75). Using the available information and considering minimization measures, including potential mitigation ensuring no net loss, we expect adverse effects to the recovery of California red-legged frogs on VSFB would be low. Therefore, we conclude that the proposed action would not appreciably reduce the likelihood of recovery of the California red-legged frog on VSFB, in the Northern Transverse Ranges and Tehachapi Mountains Recovery Unit, or rangewide.

<u>Conclusion</u>

After reviewing the current status of the California red-legged frog, the environmental baseline for the action area, the effects of the proposed action and the cumulative effects, it is the Service's biological opinion that the action, as proposed, is not likely to jeopardize the continued existence of the California red-legged frog, because:

1. We anticipate that project effects could reduce the reproductive success of California red-legged frogs at the local population level. However, due to the Space Force's commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss, the project would not appreciably reduce numbers of the California red-legged frog locally across VSFB, or rangewide.
2. We anticipate that project effects could reduce the number of California red-legged frogs at the local population level. However, due to the Space Force's commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss, the project would not appreciably reduce numbers of the California red-legged frog locally across VSFB, or rangewide.
3. The project may reduce the species' distribution locally across VSFB but is not anticipated to appreciably reduce the distribution rangewide.
4. We do not anticipate the proposed project would interfere with the specific recovery goals for Core Area 24 because of the Space Force's commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss. Consequently, the project would not cause any effects that would appreciably preclude our ability to recover the species.

Western Snowy Plover

Reproduction

Monitoring of nesting western snowy plovers for past individual launches have reported no difference in nest attendance or hatching rates compared to previous years when no launches occurred. Construction of SLC-5 will not remove any western snowy plover habitat; however, project operations create the potential for long-term effects that may result in overall habitat degradation across occupied western snowy plover breeding habitat at South Surf Beach. Although potential long-term effects of increased launch noise disturbance frequency may occur, the Service is unable to anticipate the magnitude of potential effects at this time with the available information. In the event the Space Force detects a population decline, we expect the Space Force's proposed mitigation actions ensuring no net loss will demonstrate successful offset of impacts to reproductive success. Should the proposed predator management not meet mitigation objectives depicted in the project description, we expect that the Space Force will implement other recovery objectives coordinated with the Service that quantifiably demonstrate no net loss to be consistent with this effects analysis. Consequently, we do not anticipate the proposed action will appreciably reduce the reproductive capacity of western snowy plover populations locally on VSFB or rangewide.

Numbers and Distribution

RU5 comprises nearly 40 percent of breeding western snowy plovers rangewide, and we expect the Space Force to continue managing and monitoring the VSFB population within RU5. Monitoring of nesting western snowy plovers for past individual launches have not reported notable differences in abundance or distribution. Although potential long-term effects of increased launch noise disturbance frequency may occur, the Service is unable to anticipate the magnitude of potential effects at this time with the available information. In the event the proposed project results in reduced occupation of western snowy plover at South Surf Beach, this would constitute a reduction in the overall distribution of the species across south base and across the VSFB population. However, with mitigation actions ensuring no net loss in place, any observed reduction would not appreciably reduce the numbers or distribution within RU5 or rangewide. Should the proposed predator management not meet mitigation objectives depicted in the project description, we expect that the Space Force will implement other recovery objectives coordinated with the Service that quantifiably demonstrate no net loss to be consistent with this effects analysis. We consequently conclude that the proposed project may reduce western snowy plover distribution in the action area and across VSFB, but we do not anticipate the proposed action will appreciably reduce the numbers or distribution of western snowy plover populations within RU5 or rangewide.

Recovery

When reviewing breeding window survey numbers from 2014 to 2022, VSFB contributed an average of approximately 216 breeding adults, which is approximately 26 percent of RU5 and 10 percent of the range. Several sites do not record productivity data (fledglings per breeding male); however, larger sites within the range, including VSFB, meet or exceed the criteria of 1.0 fledgling per breeding male in most years. VSFB being a military installation is likely to continue having additional natural resource benefits as part of their Integrated Natural Resource Management Plan. The shape of the population trajectory of RU5 since 2007 is linear, positive, and gradual, with minimal annual fluctuation. With mitigation actions ensuring no net loss in place, we expect effects of the proposed action would not diminish these trends at VSFB, and consequences of the proposed action would not appreciably interfere with recovery goals or overall recovery of the western snowy plover. Should the proposed predator management not meet mitigation objectives depicted in the project description, we expect that the Space Force will implement other recovery objectives coordinated with the Service that quantifiably demonstrate no net loss to be consistent with this effects analysis.

Conclusion

After reviewing the current status of the western snowy plover, the environmental baseline for the action area, the effects of the proposed action, and the cumulative effects, it is the Service’s biological opinion that the action, as proposed, is not likely to jeopardize the continued existence of the western snowy plover, because:

1. We anticipate that project effects could reduce the reproductive success of western snowy plover at the local population level. However, due to the Space Force’s commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss, the project would not appreciably reduce numbers of the western snowy plover locally across VSFB, or rangewide.
2. We anticipate that project effects could reduce the number of western snowy plover at the local population level. However, due to the Space Force’s commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss, the project would not appreciably reduce numbers of the western snowy plover locally across VSFB, or rangewide.
3. The project may reduce the species’ distribution locally across VSFB but is not anticipated to appreciably reduce the distribution in RU5 or rangewide.
4. We do not anticipate the proposed project would interfere with the specific recovery goals for western snowy plover because of the Space Force’s commitment to monitor and mitigate reductions of individuals to meet their proposed goal of no net loss. Consequently, the project would not cause any effects that would appreciably preclude our ability to recover the species.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act and Federal regulation pursuant to section 4(d) of the Act prohibit the take of endangered and threatened wildlife species, respectively, without special exemption. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harm in the definition of "take" in the Act means an act which actually kills or injures wildlife. Such [an] act may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering (50 CFR 17.3). Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not the purpose of the agency action is not considered to be prohibited taking under the Act provided that such taking is in compliance with the terms and conditions of this incidental take statement.

AMOUNT OR EXTENT OF TAKE

California Red-legged Frog

We anticipate that some California red-legged frogs could be taken as a result of the proposed action. We expect the incidental take to be in the form of capture, injury, harm and mortality. We cannot quantify the precise number of California red-legged frogs that may be taken as a result of the actions that Space Force has proposed because California red-legged frogs move over time; for example, animals may have entered or departed the action area since the time of pre-construction surveys. The protective measures proposed by Space Force are likely to prevent mortality or injury of most individuals during construction. In addition, finding a dead or injured California red-legged frog is unlikely. Consequently, we are unable to reasonably anticipate the actual number of California red-legged frogs that would be taken by the proposed project; however, we must provide a level at which formal consultation would have to be reinitiated. The Environmental Baseline and Effects Analysis sections of this biological opinion indicate that adverse effects to California red-legged frog would likely be low given the implementation of proposed avoidance and minimization measures and moderate detected abundance of California red-legged frog in the vicinity of SLC-5. We, therefore, anticipate that take of California red-legged frogs would also be relatively low. We also recognize that for every California red-legged frog found dead or injured, other individuals may be killed or injured that are not detected, so when we determine an appropriate take level, we are anticipating that the actual take would be higher, and we set the number below that level.

Similarly, for estimating the number of California red-legged frog that would be taken by capture, we cannot predict how many may be encountered for reasons stated earlier. While the benefits of relocation (i.e., minimizing mortality) outweigh the risk of capture, we must provide a limit for take by capture at which consultation would be reinitiated because high rates of capture may indicate that some important information about the species in the action area was not apparent (e.g., it is much more abundant than thought). Conversely, because capture can be highly variable, depending upon the species and the timing of the activity, we do not anticipate a number so low that reinitiation would be triggered before the effects of the activity were greater than what we determined in the Effects Analysis.

Therefore, the Space Force must contact our office immediately to reinitiate formal consultation if they observe any of the following scenarios during Construction (Table 6) and Operations (Table 7):

i. 3 adult or juvenile California red-legged frogs are found killed or wounded, including during capture and relocation, annually over the course of construction;
ii. 20 adults or juveniles are captured annually over the course of construction;
iii. the California red-legged frog established baseline (AM-23) within Honda Creek is more than 15 individuals and a greater than 15 percent (up to 5 frogs) decline is observed from the established baseline two years consecutively or on average across 5 years across operations;
iv. the California red-legged frog established baseline (AM-23) within Honda Creek is less than 15 individuals and a greater than 25 percent decline is observed from the established baseline two years consecutively or on average across 5 years of operations;
v. 3 years of consecutive negative finding of tadpoles of normal physiological condition across construction or operations;
vi. 2 adult or juvenile California red-legged frogs are found killed or wounded, including during capture and relocation, annually over the course of operations;
vii. and/or, 5 adults or juveniles are captured annually over the course of operations.

We do not anticipate any take of egg mass or tadpole life stage in association with basin features being that we assume these features will hold water for less than a day. Project activities that are likely to cause additional take should cease as the exemption provided pursuant to section 7(o)(2) may lapse and any further take could be a violation of section 4(d) or 9.

Construction

Table 6. Summary of incidental take for California red-legged frog life stages during the Construction phase of the proposed project.

Life Stage	*Quantity (per calendar year) during Construction*	*Type of Take*
Adults or juveniles	3	Killed or wounded (including during capture and relocation)
Adults or juveniles	20	Captures
Tadpoles	3 years of consecutive negative finding of tadpoles of normal physiological condition	Harm – Habitat modification impairing breeding success

Operations

Table 7. Summary of incidental take for the California red-legged frog life stages during the Operations phase of the proposed project.

Life Stage	*Quantity during Operations*	*Type of Take*
Adults or juveniles	Scenario 1- If the Established Baseline* greater than 15 individuals: 15% decline (up to 5 frogs) from established baseline two years consecutively or on average across 5 years. OR Scenario 2 – If the Established Baseline* is less than 15 individuals: 25% decline from established baseline two years consecutively or on average across 5 years.	Harm – Habitat modification disrupting sheltering
Tadpoles	3 years of consecutive negative finding of tadpoles of normal physiological condition	Harm – Habitat modification impairing breeding success
Adults or juveniles	2 per year	Killed or wounded (including during capture and relocation)
Adults or juveniles	5 per year	Captures and relocation

*Established Baseline within monitoring plan described in AM-24.

Western Snowy Plover

We anticipate that all western snowy plovers present in the action area could be taken as a result of the proposed action. We expect the incidental take only to be in the form of harm from the potential degradation of suitable habitat resulting from increased frequency of noise disturbance associated with routine launch activities. We cannot quantify the precise number of individuals that may be harmed due to fluctuations in population. Take may rise to a statistically significant level of decreased western snowy plover occupancy, nesting establishment, or nesting success from the established baseline across the entirety of Surf Beach. We anticipate that if the Space Force observes any decline that proposed mitigation efforts will be effective in offsetting the impact and will result in no net loss to the species.

However, in the event that mitigation efforts are not successful, the Space Force must contact our office immediately to reinitiate formal consultation if they observe any of the following scenarios:

i. Available western snowy plover monitoring data indicates that in any single year western snowy plover nesting establishment exhibits fewer than 80 nests within the Launch Noise Effect Area on Surf Beach without showing similar declines outside of the Launch Noise Effects Area on base;

ii. the Space Force observes a 10 percent reduction from the prospective 10-year baseline (AM-28b) of nest establishment consecutively across 3 years (see Term and Condition #4b below); or

iii. if more than 5 western snowy plovers of any life stage (egg, chick, or adult) are injured or killed as a result of project activities, including any camera-monitored nests on Surf Beach that indicate nest abandonment, injury, or mortality to eggs or chicks immediately following launch activities (see Term and Condition #6 below).

The Service considers a nest abandoned if the attending western snowy plover adults documented via camera monitoring do not return to the nest for more than eight hours. Project activities that are likely to cause additional take should cease as the exemption provided pursuant to section 7(o)(2) may lapse and any further take could be a violation of section 4(d) or 9.

REASONABLE AND PRUDENT MEASURES

The measures described below are non-discretionary and must be undertaken by the Space Force or made binding conditions of any grant or permit issued to the applicant, as appropriate, for the exemption in section 7(o)(2) to apply. The Space Force has a continuing duty to regulate the activity covered by this incidental take statement. If the Space Force (1) fails to assume and implement the terms and conditions or (2) fails to require the applicant to adhere to the terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, the protective coverage of section 7(o)(2) may lapse. To monitor the impact of incidental take, the Space Force must report the progress of the action and its impact on the species to the Service as specified in the incidental take statement [50 CFR 402.14(i)(3)].

The Service believes the following reasonable and prudent measures are necessary and appropriate to minimize the impacts of the incidental take of California red-legged frog and western snowy plover:

1. The Space Force must ensure that biologists used for survey, monitoring, training, and capture and relocation tasks are skilled and experienced.
2. The Space Force must reduce potential for injury or mortality of California red-legged frogs and western snowy plover.
3. The Space Force must monitor effects to ensure they are consistent with this analysis.

TERMS AND CONDITIONS

To be exempt from the prohibitions of section 9 of the Act, the Space Force must comply with the following terms and conditions, which implement the reasonable and prudent measures described above and outline reporting and monitoring requirements. These terms and conditions are non-discretionary.

The following term and condition implements reasonable and prudent measure 1:

1. The Space Force must request Service approval of any biologist who will conduct activities related to this biological opinion at least 30 days prior to conducting any such activities. The Space Force must provide biologist resumes listing their experience and qualifications to conduct specific actions that could potentially affect listed species and their habitats (please refer to and use Appendix B, Biologist Authorization Request Field Experience Tracking Form). A Qualified Biologist(s) is more likely to reduce adverse effects based on their expertise with the covered species. Please be advised that possession of a 10(a)(1)(A) permit for the covered species does not substitute for the implementation of this measure. Authorization of Service Approved biologists is valid for this consultation only.

The following terms and conditions implement reasonable and prudent measure 2:

2. The Space Force must reduce the effects of ultraviolet lighting on California red-legged frogs on all external permanent site lighting. As referenced in the effects analysis, to accomplish this, the Space Force may choose lighting with either no ultraviolet emissions or equip fixtures with an ultraviolet filter on external permanent site lighting. These actions will help avoid attracting insects and subsequent California red-legged frog individuals to SLC-5 (refer to lighting best management practices in Longcore and Rich 2017b, entire).

3. The Space Force must attempt to reduce the potential for effects of frequent vibration on California red-legged frog breeding success. Options may include implementing minimization measures (refer to CalTrans Transportation and Construction Vibration Guidance Manual 2013; Chapter 8, p. 41) or proactively designing systems to attenuate vibration to the maximum extent possible. In the event the Space Force detects declines or physical abnormalities to the California red-legged frog population within Honda Creek, then the Space Force must conduct vibration monitoring next to occupied breeding habitat during construction activities if they are still occurring. If declines or physical abnormalities are observed during operations, the Space Force must conduct vibration monitoring to obtain experienced levels at least once during a launch event for each vehicle type within Honda Creek next to occupied breeding habitat.

The following terms and conditions implement reasonable and prudent measure 3:

4. The Space Force must implement long-term monitoring of annual population and distribution trends associated with western snowy plover along Surf Beach and California red-legged frog populations within Honda Creek to ensure they can detect novel effects of increased launch frequency across the action area over time. The Space Force must develop a comprehensive monitoring plan that adequately addresses potential short and long-term project effects that may develop from sensory pollutants. The Space Force must provide the Service the monitoring plan for review and approval at least 90 days prior to the construction of SLC-5 to ensure that potential project related short and long-term effects are detectable and clearly defined.
    a. The California red-legged frog monitoring plan must at a minimum clearly establish baseline California red-legged frog average population level prior to the start of the proposed project. The Space Force must conduct annual surveys with consistent methodology within the same sections of Honda Creek during the breeding season when California red-legged frogs are most likely to be encountered. The plan must provide a depiction of the survey area and a tentative survey schedule. The plan must also clearly state the established decline threshold criteria that would trigger proposed mitigation (refer to AM-25). During annual surveys, the Space Force must also monitor California red-legged frog egg masses and tadpoles to ensure no physiological effects may be occurring.
        i. As part of the proposed monitoring plan, the Space Force must include the bioacoustics monitoring design for review and approval by the Service. The Space Force must clearly define how they will establish California red-legged frog calling behavior baseline within Honda Creek using any necessary appropriate control sites (e.g., sites located outside of areas exposed to launch impacts) for purposes of comparison 90 days prior to project implementation. California red-legged frog calling behavior baseline must include applicable call characteristics (e.g., changes in signal rate, call frequency, amplitude, call timing, call duration, etc.). The Space Force must ensure that bioacoustic

monitoring is designed to address confounding factors in order to appropriately characterize impacts of frequent launch disturbance events on calling behavior. The Space Force must analyze results in conjunction with long term population data to help understand if observed changes in signal characteristics are correlated with observable declines.

   b. The western snowy plover monitoring plan must include a clear, established baseline annual variation and decline threshold that would trigger proposed mitigation. AM-28b indicates the Space Force may calculate baseline annual variation in a variety of ways but likely will use 95 percent confidence intervals (Kephart 2022, p. 2).
   c. The Space Force must also conduct noise monitoring during construction at Honda Creek and at least once for each vehicle type during a launch event at Surf Beach and Honda Creek to ensure noise levels assumed for the purposes of this analysis are equal to or less than experienced levels.

5. The Space Force must submit a comprehensive mitigation plan and provide it to the Service for approval prior to the construction of the project. The plan must include specific quantifiable success criteria the Space Force will obtain within 5 years' time from when the proposed project triggers mitigation that will serve to address the Space Force's goal of no net loss in species' distribution and abundance. In the event the Space Force does not obtain the success criteria, the Space Force must reduce project effects to align with our analysis until they achieve alternative effective mitigation.
   a. Within the California red-legged frog mitigation plan (AM-25), to determine mitigation acreages needed to meet proposed no net loss, the Space Force must clearly depict how they will calculate impacted acreages across unsurveyed portions of Honda Creek within the action area in the event they observe population declines within surveyed areas. In the event the Oxbow restoration area alone does not meet mitigation acreage required, the Space Force must include additional options where mitigation acreage needs would be met.
6. If the proposed project schedules 4 disturbance events over a 4-week period during the western snowy plover breeding season (March 1 through September 30), the Space Force must camera monitor at least 10 percent of the southernmost active western snowy plover nests located on Surf Beach within the Launch Noise Effect Area to assess potential novel effects that may result from frequent launching. The Space Force must employ camera technology that is capable of long-term recording and time marking the moment of disturbance events. The Space Force must review western snowy plover nest video recordings as soon as possible. The Space Force may discontinue nest camera monitoring if they observe no response within 2 years of full launch tempo.
7. The Space Force must rescue any western snowy plover eggs abandoned on Surf Beach during disturbance events. The Space Force must develop and/or fund a program to incubate any rescued abandoned eggs and release fledglings.

8. In the event the Space Force observes declines in the California red-legged frog population within Honda Creek over the course of the project, the Space Force must conduct water quality sampling in lower Honda Creek to ensure no project related biproducts (i.e., launch combustion residue, construction- and operations-related run-off, etc.) have entered the waterway in a manner not previously considered in this analysis. The Space Force must design water quality sampling to reasonably detect potential project related biproducts and any resulting associated changes in aquatic habitat (i.e., salinity, pH, etc.). Sampling must consider and utilize the most recent applicable advances in water quality sampling technology. The plan must include at least 1 annual sampling event for 3 years of project operations with maps depicting sampling locations. The Space Force must collect and clearly present data including any associated chemical and nutrient presence, dissolved oxygen, water temperature, turbidity, and any other pertinent observations regarding ecosystem condition for purposes of annual comparison.
9. Prior to project operation the Space Force must establish a pre-project baseline for hydrodynamic data within San Antonio Creek. During project operations the Space Force must collect hydrodynamic data annually using consistent data collection methodologies for purposes of comparison against the established baseline. The Space Force must use these data to ensure that the proposed project’s water extraction is not measurably affecting flow rate or water level within San Antonio Creek.
10. If the Project Proponent cannot design water features to preclude California red-legged frog entry, then the Space Force must ensure SLC-5 water features, including deluge containment basins, passively or actively drain within 24 hours of a storm event to avoid the creation of an attractive nuisance.

REPORTING REQUIREMENTS

The Space Force must provide a written report due by January 30 for each fiscal year (October through September) that activities are conducted pursuant to this biological opinion. The annual report must include:

1. Documentation of the impacts of the proposed activities on California red-legged frog and western snowy plover; results of biological surveys and observation records; documentation of the number of individuals of California red-legged frogs or western snowy plovers captured, injured, or killed; the date, time, and location of any form of take; approximate size and age of those individuals taken; and a description of relocation sites or rehabilitation outcomes for captured individuals.
2. The schedule of launches and static test fires that occurred annually.
3. A discussion of annual monitoring of the populations of California red-legged frog within Honda Creek and western snowy plover within Surf Beach. This discussion must address any observed changes in population and distribution trends over time that may be associated with long-term effects of the project. The discussion must also address any potential improvements to the monitoring plan design efficacy, including advances in

technology that may aid in sublethal effects detection for consistency with the above analysis. The Space Force must include results requested within all term and condition requirements above including:

a. The California red-legged frog portion of the report must also include: (*i*) noise and vibration exposure levels in Honda Creek as depicted in T&C 3, 4c; (*ii*) documentation and analysis of any observed effects on California red-legged frog that occur during the experienced frequency of launching and may be related to the project's routine disturbance (effects may include, but are not limited to, changes to habitat use pattern, reproduction, or behavior over the long-term); (iii) discussion of bioacoustics monitoring results (T&C 4ai) conducted within Honda Creek and at appropriate control site(s) located outside of areas impacted by routine launching, software analysis methods (can refer to Higham et al. 2020, Kruger et al. 2016) used to analyze changes in signal characteristics and generate annual estimation of chorus size, and the results and discussion of any observed changes to California red-legged frog calling behavior (e.g., changes in signal rate, call frequency, amplitude, call timing, call duration, etc.) in conjunction with California red-legged frog annual population data within Honda Creek.

b. The western snowy plover portion of the report must also include: (*i*) date and times of launches and static test fires that impacted Surf Beach; (*ii*) visual or video monitoring results of birds and nests as well as acoustic monitoring results at Surf Beach colonies; (*iii*) documentation and an analysis of effects by the activities evaluated in this biological opinion, including observed effects that occur during the experienced frequency of launching; (*iv*) discussion of effects that result in take of western snowy plover as well as any observed changes to habitat use pattern or behavior of birds; and (*v*) any other pertinent information as required by this biological opinion.

c. Results from the annual habitat assessment and any supplemental water quality sampling performed.

d. Pre-project baseline comparison with annual hydrodynamic data results for San Antonio Creek water extraction.

e. In the event mitigation is triggered as a result of the project, implemented restoration methods, habitat acreages, and a discussion of mitigation success criteria.

f. If the Project Proponent cannot design water features to preclude California red-legged frog entry, the Space Force must include how many days in which they found deluge water retention basins held water and if water quality failed to pass RWQCB permit requirements.

The Space Force must submit federally listed species observations over the course of the project to the CNDDB. The report should also include a discussion of any problems encountered implementing the terms and conditions and other protective measures or recommendations to enhance the conservation of federally listed species, and any other pertinent information.

DISPOSITION OF DEAD OR INJURED SPECIMENS

As part of this incidental take statement and pursuant to 50 CFR 402.14(i)(1)(v), upon locating a dead or injured California red-legged frog or western snowy plover, initial notification within 3 working days of its finding must be made by telephone and in writing to the Ventura Fish and Wildlife Office (805-644-1766). The report must include the date, time, location of the carcass, a photograph, cause of death or injury, if known, and any other pertinent information.

The Space Force must take care in handling injured animals to ensure effective treatment and care, and in handling dead specimens to preserve biological material in the best possible state. The Space Force must transport injured animals to a qualified veterinarian. Should any treated California red-legged frog or western snowy plover survive, the Space Force must contact the Service regarding the final disposition of the animal(s).

The remains of California red-legged frogs and western snowy plovers must be placed with educational or research institutions holding the appropriate State and Federal permits, such as the Santa Barbara Natural History Museum (Contact: Paul Collins, Santa Barbara Natural History Museum, Vertebrate Zoology Department, 2559 Puesta Del Sol, Santa Barbara, California 93460, (805) 682-4711, extension 321), Western Foundation of Vertebrate Zoology (Contact: Linnea S. Hall, Ph.D., Executive Director, Western Foundation of Vertebrate Zoology, 439 Calle San Pablo Camarillo, CA 93012, (805) 388-9944), or the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) (CCBER, Herpetological Collection, University of California, Santa Barbara, Harder South, Building 578, MS-9615 Santa Barbara, CA 93106-9615.

CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the Act directs Federal agencies to use their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. The conservation recommendations below are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information and can be used by the Space Force to fulfill their 7(a)(1) obligations.

1. Due to the likelihood for sustained effects from sensory pollutants that will occur within Honda Creek during project operations, we recommend the Space Force proactively implement proposed mitigation. Advanced mitigation will provide assurances that restoration efforts will be successful at attaining no-net loss of California red-legged frog occupied habitat and population.

2. We recommend that the Space Force proactively conduct a small-scale California red-legged frog egg-mass relocation study into the existing Oxbow Restoration site. Previous survey efforts have not yet detected California red-legged frog at this site or demonstrated that California red-legged frog will newly colonize these areas for breeding (Evans 2022a, p. 4; Kephart 2022, p. 2). This study could help determine whether manual facilitation of California red-legged frog establishment to ensure no-net loss of species abundance is achievable.
3. We recommend that the Space Force proactively require their project proponents to design launch vehicles to attenuate sensory pollutants, similar to what is being done with aircraft at other installations (e.g., Edwards Air Force Base, X-59 Quiet SuperSonic Technology; NASA 2022, entire). Design considerations in combination with new sensory pollutant attenuation technologies may prove to be critical over the long-term based on a growing body of evidence that suggests light, noise, and vibration can have detrimental impacts on natural ecosystems as previously discussed.
4. We recommend that the Space Force coordinate with researchers familiar with study design involving short- and long-term ecological effects of sensory pollutants in the development of the effects monitoring plan for the project. We also recommend that the Space Force implement a basewide monitoring strategy to address the potential for compounding impacts of collective launches across the base.
5. We recommend that the Space Force work with researchers to develop a habitat suitability model that addresses launch disturbance frequency. The Space Force could use a model to inform the number, spacing, and distribution of collective launch scheduling to avoid altering the existing baseline of ‘intermittent acute noise disturbance’ to what would be more akin to ‘chronic acute’ noise disturbance. We also would recommend that sensitive time windows, such as breeding seasons, be strongly considered when scheduling launches in order to promote recovery goals.
6. We recommend that the Space Force install approved mufflers on mechanized equipment (particularly when using impact/pile drivers capable of generating over 100 dB noise levels) or install absorptive (non-reflective) sound walls during construction and operation to help reduce noise and vibrational disturbance to California red-legged frogs, western snowy plover, and other wildlife in the near vicinity.
7. We recommend that the Space Force install permanent fencing to exclude wildlife for the duration of project operations. We also recommend that the Space Force utilize fencing material that inhibits climbing and report on its efficacy.
8. We recommend that the Space Force survey for and lethally remove introduced non-native predatory species, including American bullfrog (*Lithobates catesbeianus*) and crayfish (*Cambarus* spp.), found within California red-legged frog habitat during surveys and other project related inspection activities.
9. We recommend that the Space Force advise Service Approved biologist(s) to relocate all wildlife and attempt to transplant or collect seed from non-federally listed (California

Native Plant Society) sensitive plants observed within the work areas to suitable habitat outside of project areas if such actions are in compliance with State laws and report all observations to CNDDB. Such relevant species with documented records within the Construction Effect Area and immediate vicinity may include *Erysimum suffrutescens, Lilium humboldtii* ssp. *ocellatum, Monardella undulata* ssp. *crispa, Mucronea californica,* and *Senecio blochmaniae* (Calflora 2022, entire).

10. We recommend that the Space Force install bat roost boxes or similar structures to encourage bat roosting outside of the project area if such actions are in compliance with State laws. We also recommend that the Space Force design project buildings to deter roosting.
11. We recommend the Space Force investigate the efficacy of capture and relocation of California red-legged frogs to determine if use of this minimization measure reduces adverse effects of project actions on the species. As part of this, the Space Force should note information on repeat capture and behavior of individuals post-movement.
12. We recommend the Space Force minimize movement of work equipment to the degree possible across the project area to further reduce transport of weeds. We recommend the Space Force designate equipment to work in specific areas and stage vehicles in laydown areas as close as possible to respective work areas.
13. We recommend the Space Force advise Qualified Biologists to relocate other native reptiles or amphibians found within work areas to suitable habitat outside of project areas if such actions are in compliance with State laws. Specifically for the southwestern pond turtle, we recommend following these suggested avoidance and minimization measures and reporting to the Service their efficacy:
    a. Service Approved Biologist(s) will be present on site during all construction activities occurring in southwestern pond turtle habitat.
    b. Prior to the start of daily construction activities, Service Approved Biologist(s) will survey the work sites for southwestern pond turtles, checking beneath all parked vehicles and heavy equipment before project activities commence.
    c. If biologist(s) observe a southwestern pond turtle within a designated work area and construction activities cannot avoid it, all work will stop in the immediate area (within 164 feet of the individual) until a Service Approved Biologist(s) can relocate the animal or until it has left the work area of its own accord.
    d. Service Approved Biologist(s) will relocate southwestern pond turtles captured during surveys or construction activities to the nearest suitable habitat outside of the project area but within the Honda Creek watershed and no more than 2 miles from the capture site. Service Approved Biologists may only capture southwestern pond turtles by hand or dip net and transport in buckets separate from other species. When capturing and removing southwestern pond turtles from the project area, the Service Approved Biologist(s) must minimize the amount of

time they hold animals in captivity. In addition, Service Approved Biologist(s) must maintain southwestern pond turtles in a manner that will not expose them to temperatures or any other environmental conditions that could cause injury or undue stress.

e. The Space Force will follow the Declining Amphibian Populations Task Force fieldwork code of practice to avoid conveying diseases between work sites (DAPTF 1998) and will clean all equipment between use following protocols that are also suitable for aquatic reptiles.

The Service requests notification of the implementation of any conservation recommendations so we may be kept informed of actions minimizing or avoiding adverse effects or benefitting listed species or their habitats.

REINITIATION NOTICE

This concludes formal consultation on the action(s) outlined in the request. As provided in 50 CFR 402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of incidental take is exceeded (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion; (3) the agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not considered in this opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action. In instances where the amount or extent of incidental take is exceeded, the exemption issued pursuant to section 7(o)(2) may have lapsed and any further take could be a violation of section 4(d) or 9. Consequently, we recommend that any operations causing such take cease pending reinitiation.

If you have any questions about this biological opinion, please contact Sarah Termondt and Erin Arnold of my staff by electronic mail at sarah_termondt@fws.gov and erin_arnold@fws.gov.

Sincerely,

Stephen P. Henry
Field Supervisor

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APPENDIX A

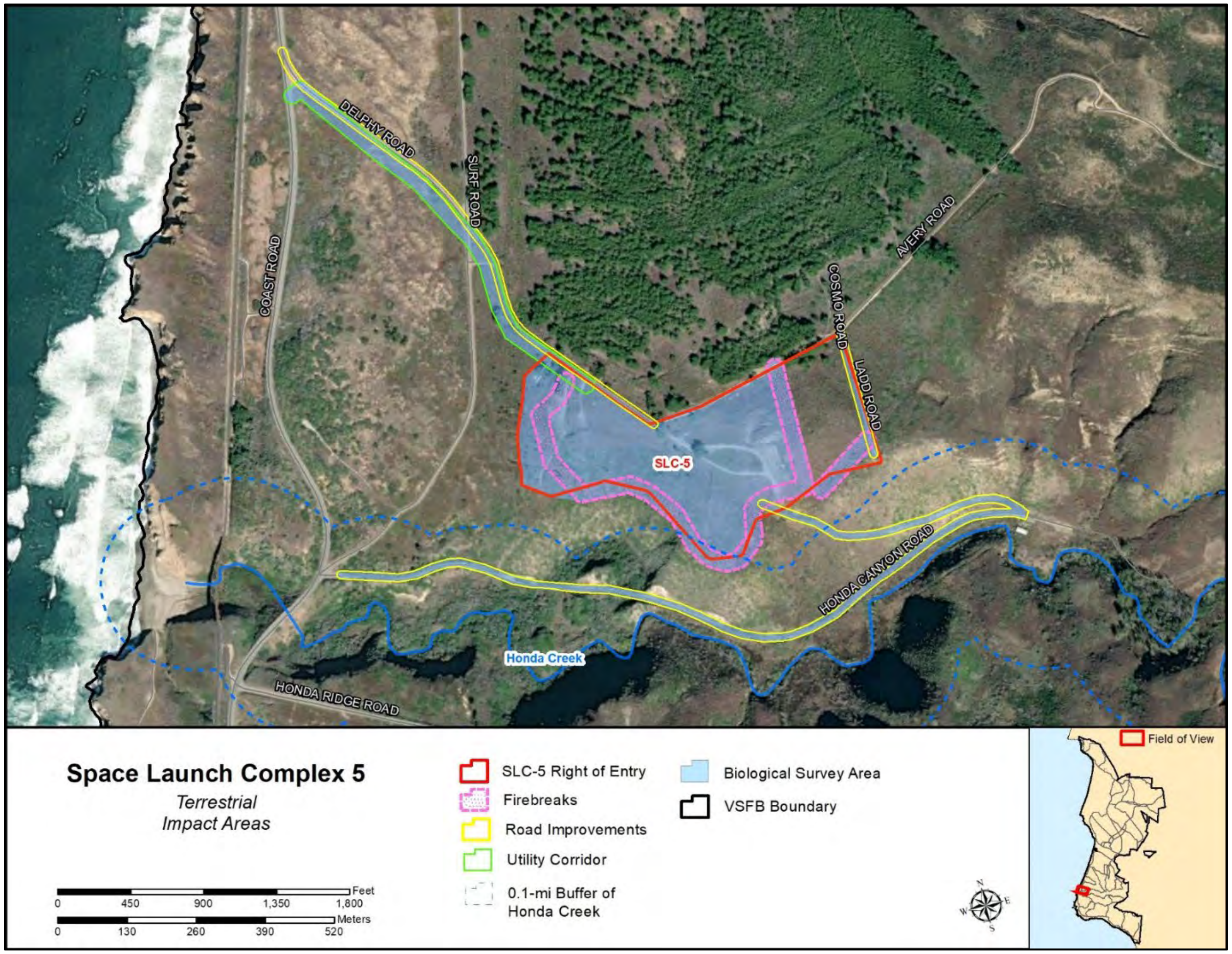


Figure 1. Construction Effect Area at SLC-5 within the South Base of VSFB.

Figure 2a. California red-legged frog occurrences and project Launch Noise Effect Area.

Figure 2b. Western snowy plover nesting occurrences and project Launch Noise Effect Area.

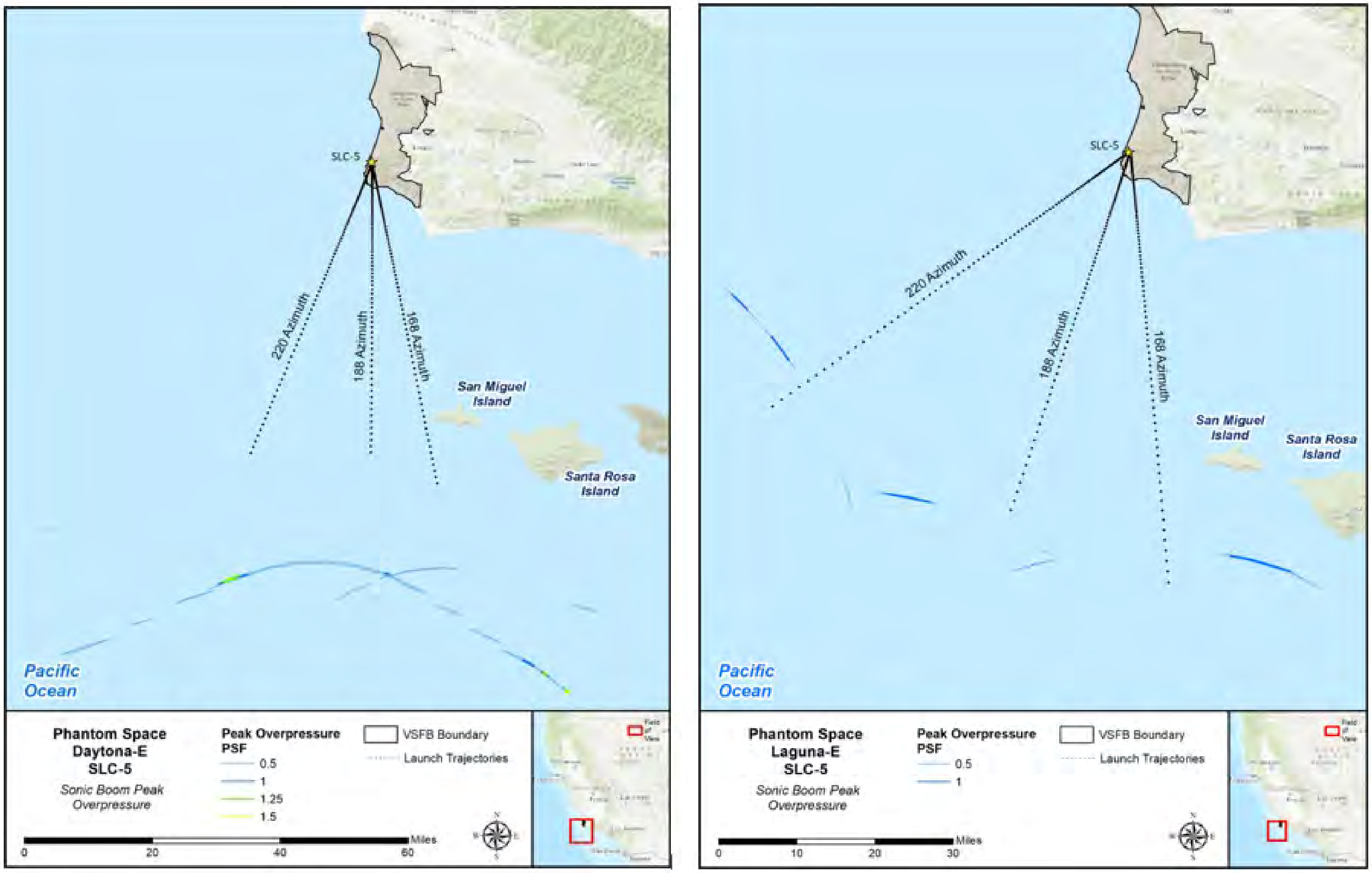


Figure 3. Sonic Boom Overpressure Effect Area and Vehicle Splashdown Effect Area (along azimuths) by vehicle type.

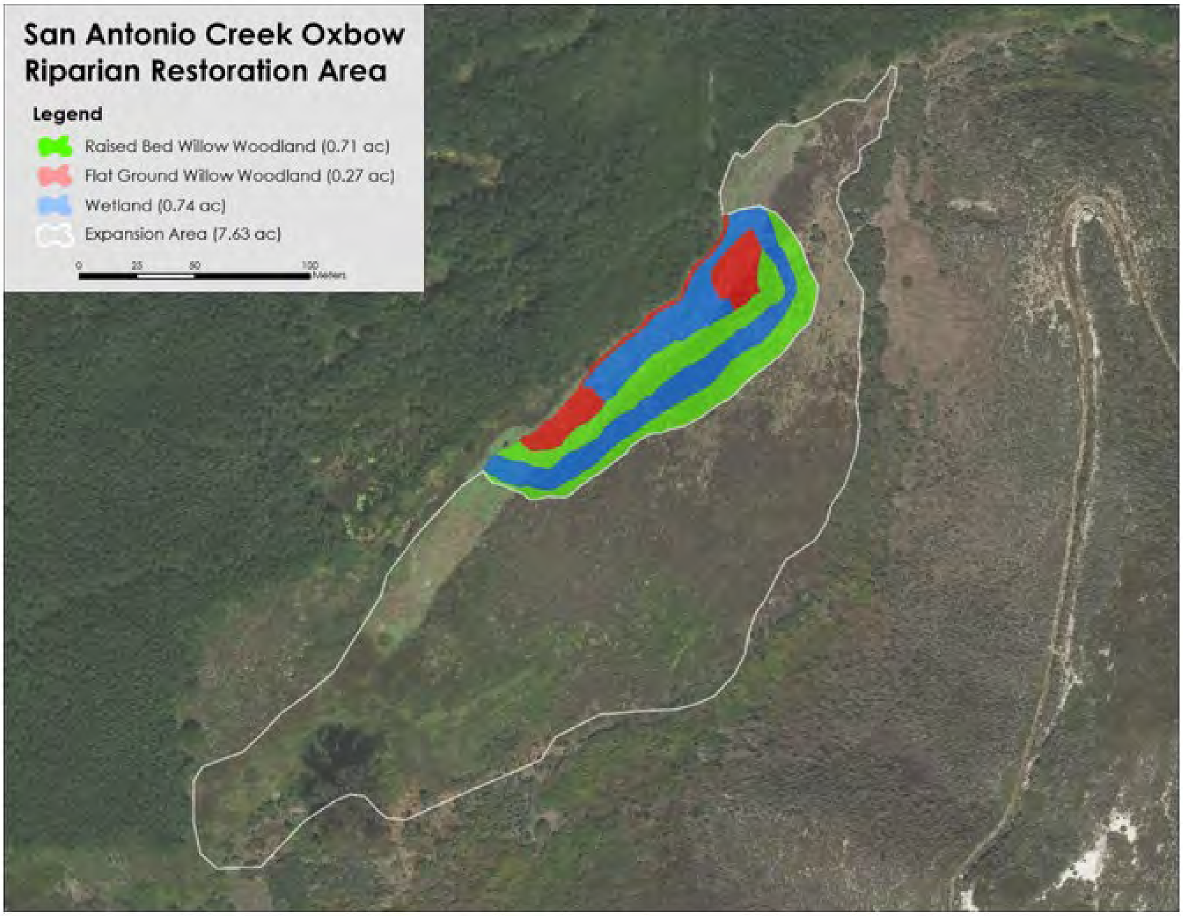


Figure 4a. Potential mitigation area (San Antonio Creek Oxbow Restoration Area) for California red-legged frog. Current restoration efforts depicted in green, red, and blue.

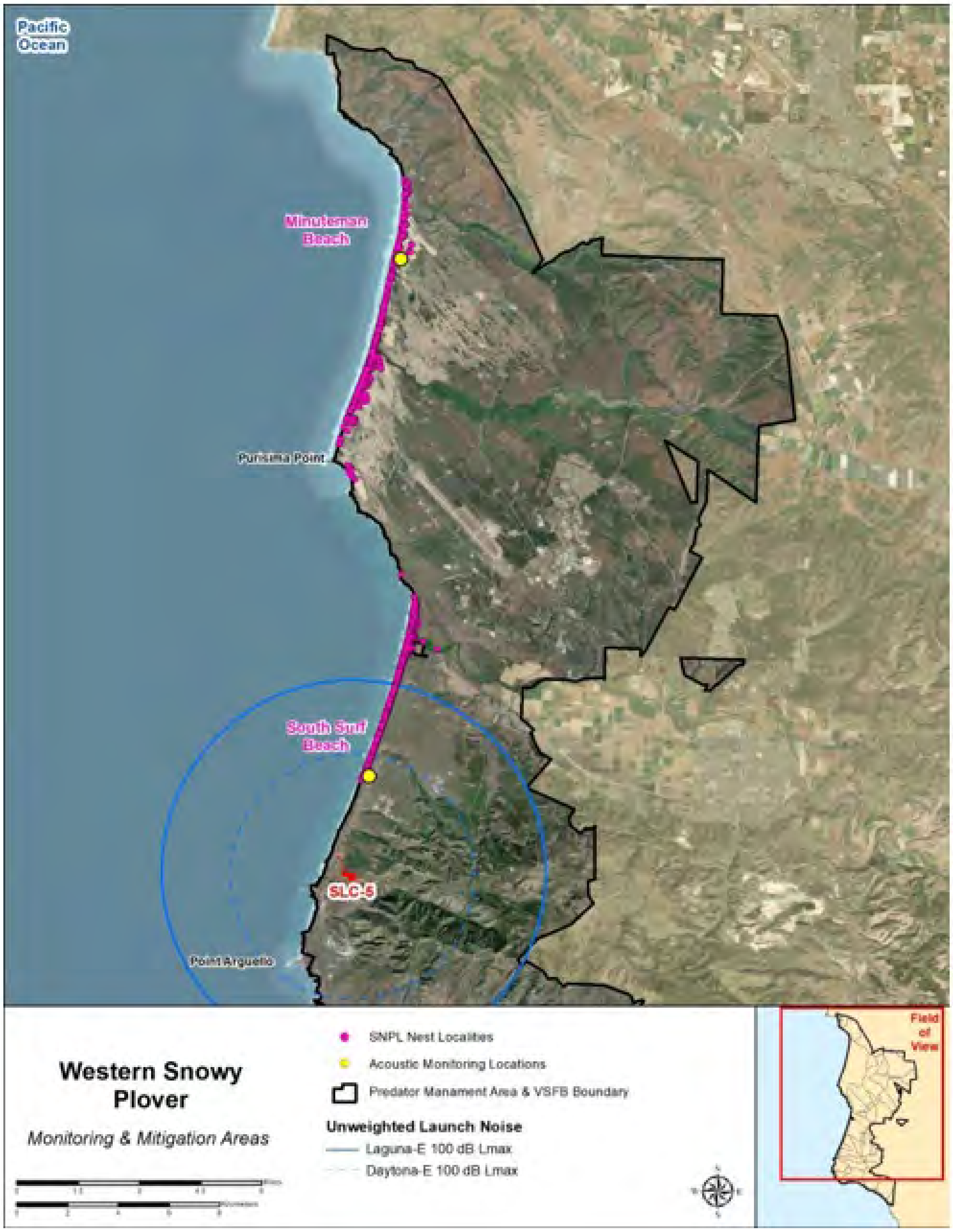
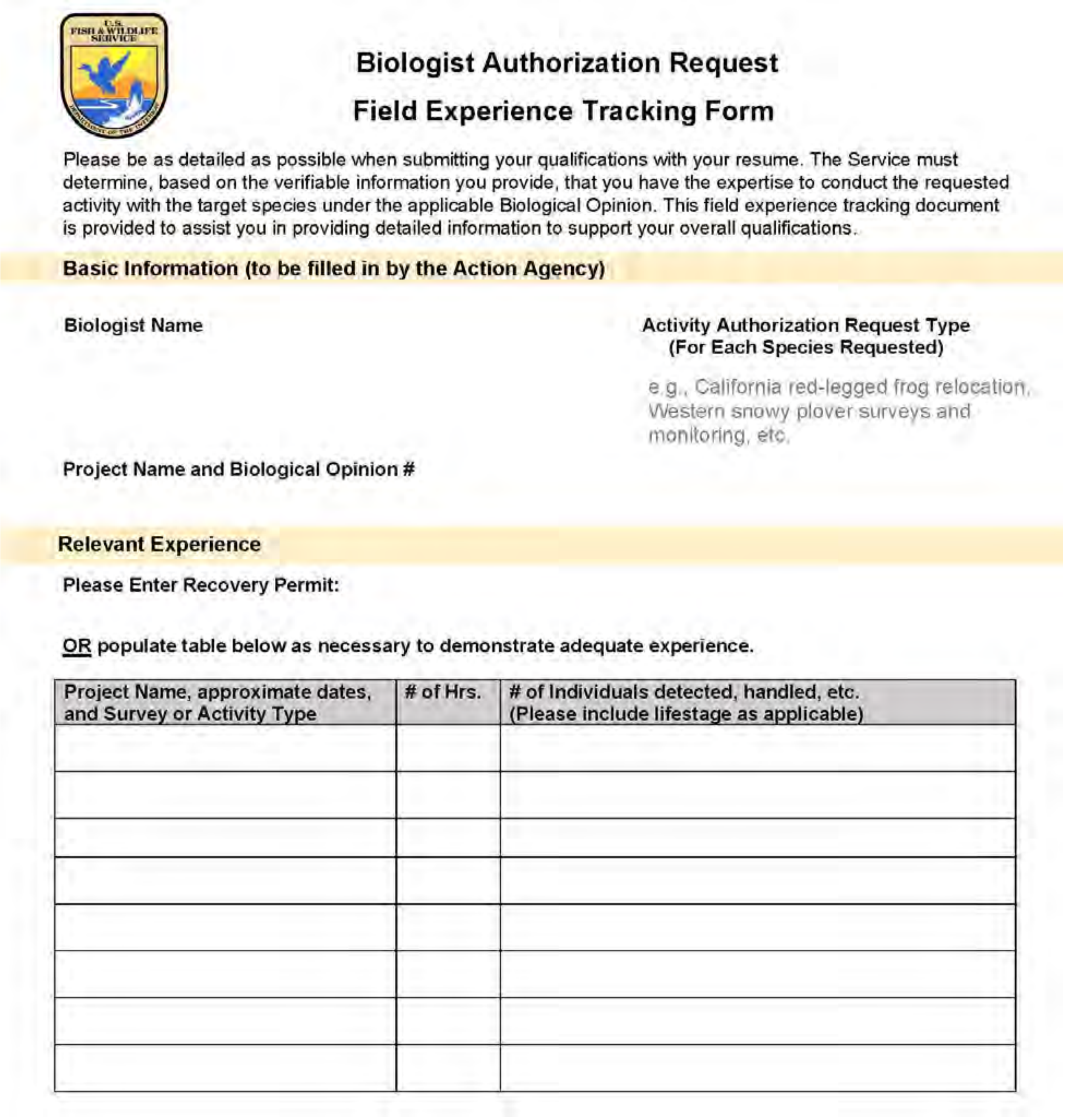


Figure 4b. Potential mitigation area (Predator Management Area) for western snowy plover.

APPENDIX B



Biologist Authorization Request

Field Experience Tracking Form

Please be as detailed as possible when submitting your qualifications with your resume. The Service must determine, based on the verifiable information you provide, that you have the expertise to conduct the requested activity with the target species under the applicable Biological Opinion. This field experience tracking document is provided to assist you in providing detailed information to support your overall qualifications.

Basic Information (to be filled in by the Action Agency)

Biologist Name

Activity Authorization Request Type (For Each Species Requested)

e.g., California red-legged frog relocation, Western snowy plover surveys and monitoring, etc.

Project Name and Biological Opinion #

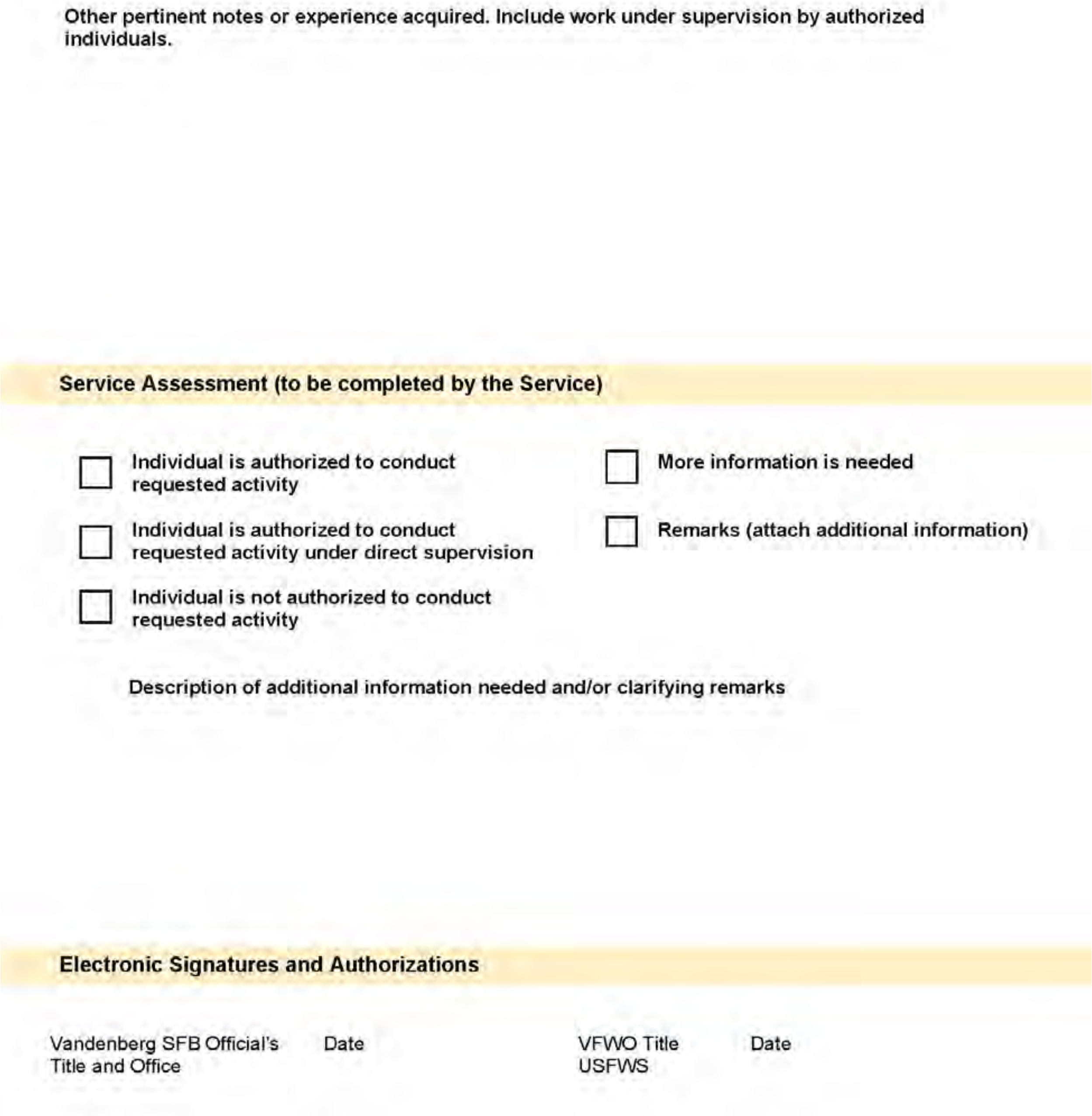
Relevant Experience

Please Enter Recovery Permit:

OR populate table below as necessary to demonstrate adequate experience.

Project Name, approximate dates, and Survey or Activity Type	# of Hrs.	# of Individuals detected, handled, etc. (Please include lifestage as applicable)

Picture of the first page of the Biologist Authorization Request Field Experience Tracking Form.



Other pertinent notes or experience acquired. Include work under supervision by authorized individuals.

Service Assessment (to be completed by the Service)

☐ Individual is authorized to conduct requested activity

☐ Individual is authorized to conduct requested activity under direct supervision

☐ Individual is not authorized to conduct requested activity

☐ More information is needed

☐ Remarks (attach additional information)

Description of additional information needed and/or clarifying remarks

Electronic Signatures and Authorizations

Vandenberg SFB Official's Title and Office

Date

VFWO Title USFWS

Date