Biofouling in the U.S. Pacific States and British Columbia

White Paper Prepared for the Coastal Committee of the Western Regional Panel on Aquatic Nuisance Species by
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SCOPE

This white paper was prepared for the Coastal Committee of the Western Regional Panel on Aquatic Nuisance Species, a regional panel of the Aquatic Nuisance Species Task Force. The geographic focus of this white paper includes the U.S. Pacific states of Alaska, California, Hawaii, Oregon, and Washington, as well as the Canadian province of British Columbia.

The topical focus of this white paper is marine biofouling as a mechanism for the transport, introduction, and spread of nonindigenous species into the coastal and estuarine waters of U.S. Pacific states and the province of British Columbia. The nonindigenous species introduction risks highlighted in this white paper are generally of regional concern. However, specific concerns will vary from one state or province to another based on vector populations and activity levels within and across their borders. Both regionally consistent and state or province-specific concerns are discussed.

The Coastal Committee recognizes that a variety of mechanisms can contribute to the introduction and spread of nonindigenous species via biofouling, however this white paper focuses on the following vector types:

- Commercial merchant and passenger vessels
- Recreational vessels
- Commercial fishing vessels
- Mobile marine infrastructure

EXECUTIVE SUMMARY

Nonindigenous species (NIS) can be introduced into new areas through a variety of different mechanisms or pathways. Some of these pathways have been addressed through regional and global management efforts (e.g., ballast water), while others remain unmanaged. Biofouling is largely unmanaged from a NIS risk minimization perspective, but is perhaps the most potent mechanism, responsible for between 55.5% and 69.2% of the currently established coastal and estuarine NIS globally.

Biofouling is associated with a variety of vector types, including commercial merchant and passenger vessels, recreational vessels, commercial fishing vessels, and mobile marine infrastructure. A common theme among all four of these vector types across the U.S. Pacific states and British Columbia is the lack of regulatory management to minimize the risk of introduction and spread of NIS. In many cases, this lack of regulatory management is underpinned by a lack of knowledge about the vectors themselves, including vector populations (i.e., the number of vectors/vessels that operate in a jurisdictional area) and levels of activity (e.g., movements between bays and states). These data are critical to understanding NIS introduction risks from these vectors and to develop management strategies to minimize those risks.

Progress is being made across the region on developing regulatory strategies for biofouling management for commercial merchant and passenger vessels, but not for other vector types where effective management is needed to reduce NIS introduction risk. Recreational vessel management efforts could benefit from consistent outreach across the region, targeted before and after peak boating seasons. The movement of commercial fishing vessels and mobile marine infrastructure is often tied to permits, licenses, or lease activity. These permission-based activities present an opportunity to incorporate biofouling management requirements into permits or licenses.

There are various opportunities for U.S. Pacific states and British Columbia to improve management of all aquatic vector types, including better inter-jurisdictional coordination and the identification and funding of agencies with regulatory oversight. There are also several opportunities for the Western Regional Panel's Coastal Committee to improve regional consistency and extend environmental protection across the region. These opportunities include:

- Developing regionally consistent best management practices for recreational vessels, commercial fishing vessels, and mobile marine infrastructure that can ensure consistent biofouling management and can be included as requirements in the permitting process for commercial fishing vessels and mobile marine infrastructure
- Developing a regionally consistent commercial merchant and passenger vessel in-water cleaning regulatory model framework to identify and reduce NIS introduction risks

1. INTRODUCTION

1.1. NONINDIGENOUS SPECIES AND BIOFOULING

Nonindigenous species (NIS) are organisms that are introduced by humans into areas where they do not naturally or historically occur. Once established, NIS can pose significant threats to human health, the economy, and the environment. Coastal marine habitats are among the most heavily invaded ecosystems on Earth, largely due to the introduction of NIS from a variety of human activities, including:

- aquaculture (Grosholz et al. 2012)
- aquarium trade (Williams et al. 2012)
- commercial fishing vessels (Davidson et al. 2012)
- commercial shipping (Fofonoff et al. 2003)
- live bait (Fowler et al. 2016)
- live seafood trade (Chapman et al. 2003)
- marine debris (Barnes 2002)
- recreational vessels (Ashton et al. 2012)

While each of the aforementioned activities contributes to aquatic NIS introductions, commercial shipping has been the primary focus of regulatory agencies worldwide (see IMO 2004, USEPA 2013, Brown et al. 2017). More specifically, ships' ballast water has been at the forefront of regional, national, and global regulatory efforts. Progress has been made, and ballast water management is continuing to improve with the impending implementation of international (see IMO 2016a) and U.S. federal (see USCG 2016) ballast water discharge performance standards. Although the global focus has been on ballast water management over the previous 20 years, it is becoming more apparent that major gaps in vector or pathway management still exist, especially gaps related to biofouling.

Biofouling refers to organisms attached to or associated with underwater or wetted surfaces. A variety of surfaces and structures can become fouled, and these surfaces and structures become vectors for transporting NIS when they are moved from one area to another. Nonindigenous species may be introduced into new areas by falling from or being knocked off of their host structures, or as the attached organisms reproduce. Global estimates suggest that biofouling is responsible for between 55.5% and 69.2% of the currently established NIS in coastal waters globally (Hewitt and Campbell 2010).

Regional estimates indicate biofouling is responsible for up to:

- 78% of the established nonindigenous marine (i.e., coastal and estuarine) invertebrates and algae in Hawaii (Davidson et al 2014a)

- 58% of the established nonindigenous marine invertebrates and algae in Puget Sound (Davidson et al. 2014b)
- 60% of the established nonindigenous marine invertebrates and algae in California (Ruiz et al. 2011)

1.2. IMPACTS

Biofouling poses a significant threat to the economy, natural resources, and the health of the people of the U.S. Pacific states and British Columbia.

<u>1.2.1. Economic Impacts</u>

Global shipping industry costs associated with biofouling prevention, vessel maintenance, and fuel consumption are estimated to be in the billions of dollars annually (ACT 2003). For example, biofouling increases drag as a vessel moves through the water, increasing fuel consumption an estimated $56 million annually for the entire fleet of DDG-52 (mid-size) U.S. Naval Destroyers (Schultz et al. 2011). Although not a direct economic impact, biofouling-induced fuel consumption is also responsible for excessive greenhouse gas emissions from vessels (Davidson et al. 2016).

Biofouling increases production costs of aquaculture operations by an estimated five to ten percent, or equal to $1.5 to $3 billion annually (Fitridge et al. 2012). Biofouling impacts European finfish aquaculture specifically between five and ten percent of the industry value, or up to $260 million per year (CRAB 2006). These increased costs and negative impacts are due to a variety of general factors, including:

- Direct fouling of cultured stock causing physical damage. Even when fouled products can be sold, periodic heavy biofouling can reduce the price of a product by 60% - 90% (CRAB 2006)
- Disrupting the mechanics of an aquaculture operation (e.g., valve obstruction in cultured mussels)
- Fouling of infrastructure
- Competition with cultured stock for resources
- Direct and indirect environmental effects to the space occupied by the aquaculture operation (e.g., causing cultured stock to drop from lines due to heavy biofouling)
- Restricting water exchange through net pens
- Increasing the risk of disease
- Causing deformation of cages and structures

Specific examples of negative impacts on shellfish aquaculture productivity include:

- Oyster culture grounds in Samish Bay, Washington, were closed because of an infestation of the polychaete worm *Clymenella torquata* that made the product unsalable (Davidson et al. 2014b)
- The invasive tunicate *Didemnum vexillum* reduced green-lipped mussel production in New Zealand by reducing the density of juvenile mussels (Fletcher et al. 2013)
- *Didemnum vexillum* also negatively affects blue mussel aquaculture by reducing mussel growth rate (Aucker 2010)
- Mollusk aquaculture in New Zealand, the Netherlands, and Ireland was negatively affected by a molluscan parasite (*Bonamia ostreae*) believed to be spread via vessel biofouling (Van Banning 1991, Howard 1994, Culloty and Mulcahy 2007)
- An oyster parasite (*Marteilioides chungmuensis*) is also believed to have been introduced via vessel biofouling into the ports of Darwin (Australia) and Eureka, California (Tubbs et al. 2007), threatening local aquaculture facilities
- The virus responsible for Pacific oyster mortality syndrome (POMS; ostreid herpesvirus microvariant 1) is believed to have been introduced into Australia and New Zealand via vessel biofouling (Fisheries Research and Development Corporation 2011) and has reduced Pacific oyster production in New Zealand by half (Johnston 2014)

<u>1.2.2. Natural Resource Impacts</u>

Biofouling-mediated NIS can impact natural communities and displace native species, for example:

- The invasive tunicate *Didemnum vexillum* infested Georges Bank and has reduced the density of free-living macrofauna, causing shifts in the structure of the benthic community (Lengyel 2013)
- In the Great Lakes, the presence of freshwater dreissenid mussels has facilitated the invasion of a Eurasian amphipod (*Echinogammarus ischnus*) that is replacing a native amphipod and facilitating the expansion of another introduced species, the round goby (*Neogobius melanostomus*) (Ricciardi 2005)
- The blue mussel (*Mytilus galloprovincialis*), introduced via vessel biofouling or ballast water, has excluded the native *M. trossulus* from its southern range on the Pacific coast of the United States (Geller 1999)

Biofouling-mediated NIS can facilitate habitat loss or changes, for example:

- *Watersipora subtorquata* (bryozoan) was documented in offshore waters of California in 1963. It has successfully colonized bays and harbors along the California coast, and can now be found as far north as Yaquina Bay, Oregon. *Watersipora* can cover 100% of the available substrate, resulting in significant changes to both native species and their habitats (BOEM 2015).

- The New Zealand isopod, *Sphaeroma quoianum*, was introduced in the late 1800s to the California coast via vessel biofouling and boring (i.e., digging into wooden hulls). It erodes intertidal marsh banks through the creation of burrows (Carlton 2011). As a result of climate change and increases in water temperatures, its range expanded in the 1990s, and it has caused extensive erosion to the banks of Coos Bay, Oregon (Henkel 2014).

1.3. CURRENT SCIENCE

1.3.1. North American West Coast

Four-hundred and fifty marine and estuarine NIS have established populations in the tidal waters of North America, a 51% increase since 1999 (Ruiz et al. 2015). Between 44% and 78% of those 450 established NIS are attributable to shipping as the introduction pathway (either via ballast water or biofouling). A majority of these NIS (310 species) are established on the North American West Coast, more than the East Coast (189 species) and Gulf Coast (88 species) combined.

Along the North American West Coast, most (79%) of the established NIS were first detected in California (Ruiz et al. 2011), including:

- 40% of established NIS in Alaska (i.e., 40% of the currently established NIS in Alaska were detected in California prior to detection in Alaska)
- 50% of established NIS in British Columbia
- 51% of established NIS in Washington
- 64% of established NIS in Oregon
- 89% of established NIS in California

These data suggest that California acts as a regional hub for importing NIS and subsequently spreading them coastwise, most likely through ballast water or vessel biofouling (Ruiz et al. 2011). Although vessel biofouling is a prime mechanism responsible for NIS introductions (up to 60% of established NIS in California), many different types of vessels or mobile structures may be involved. Strategies to manage commercial vessel biofouling may not reduce NIS introduction risks from recreational craft, and vice versa. A comprehensive approach to managing all possible vectors across the region is key to reducing future NIS introduction rates (Williams et al. 2013, Georgiades and Kluza 2014, NZ MPI 2014).

1.3.2. Paradigm Shift – Not Just Hulls

Biofouling on vessel hulls increases drag and fuel consumption as a vessel moves through the water (Schultz et al. 2011, 2015, Hunsucker et al. 2016). This hull biofouling "penalty" provides a strong financial incentive to vessel owners and operators to minimize biofouling on their hulls (Townsin 2003), as reflected in the common industry reference to vessel biofouling as *hull fouling*.

Vessel underwater surfaces are not just uniform hulls and flat bottoms, they are complex structures that include a variety of recesses and appendages, collectively referred to as niche areas (see Figure 1 for example). Niche areas are those areas on a vessel that may be more susceptible to biofouling due to different hydrodynamic forces, susceptibility to preventative antifouling coating (i.e., any paint or coating that prevents or deters the attachment or growth of biofouling organisms on the wetted portions of a vessel) wear or damage, or being inadequately or not painted. Some examples of vessel niche areas are rudders, propellers, and sea chests (i.e., recesses built into the hull to facilitate water intake). Many niche areas do not influence drag and therefore do not carry a financial incentive for biofouling management, often resulting in them being undermanaged (Davidson et al. 2016). Undermanaged niche areas are often hotspots for abundant and diverse biofouling communities (Coutts and Taylor 2004, Sylvester and MacIsaac 2010, Davidson et al. 2016).

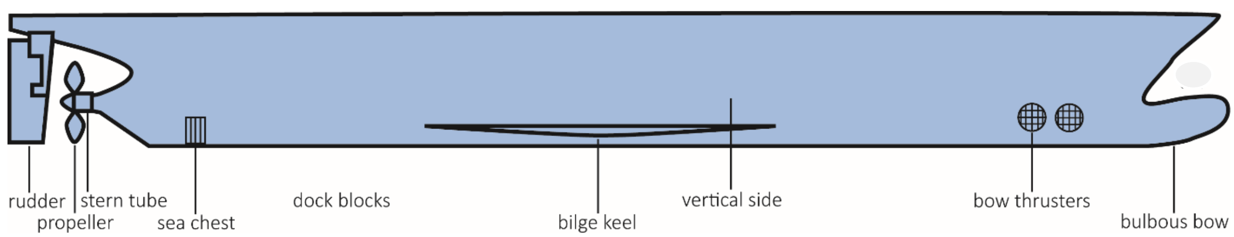

Figure 1. Niche areas on a commercial merchant vessel. Image courtesy of Jeanne Gunther as presented in Davidson et al. 2016.

Sea chests in particular have been shown to harbor extensive biofouling communities (Coutts et al. 2003, Coutts and Dodgshun 2007, Lewis 2016). Frey et al. (2014) found that 80% of sampled vessels on the west and east coasts of Canada had biofouling organisms in their sea chests. Twenty-one percent of identified taxa (i.e., organism groups identified by taxonomists to form a distinct unit) sampled in vessel sea chests in British Columbia were nonindigenous or cryptogenic (i.e., unknown origin), including nine that were nonindigenous and did not yet have established populations in adjacent water bodies (Frey et al. 2014).

Although sea chest biofouling may not necessarily influence drag while a vessel is moving, extensive biofouling on sea chest grates and around intake valves can restrict water flow that is necessary for engine cooling. Pamitran et al. (2016) have estimated that biofouling-induced restriction of cooling water intake could affect the efficiency of heat transfer (i.e., the purpose of cooling water) and could cost a naval vessel with an 8,000 BHP (brake horsepower) engine more than $460,000 per month in excessive fuel.

1.3.3. Paradigm Shift – Not Just Ships

Commercial ships are often the focus of discussions about biofouling management regulations and outreach efforts, mainly because of concerns about:

- Drag-induced fuel consumption and operational efficiency (Shultz et al. 2015)
- The introduction of nonindigenous species (Fofonoff et al. 2003, Davidson et al. 2016)

These concerns about operational efficiency and NIS introduction risk are not, however, specific to commercial ships (Inglis et al. 2010). Many other vessel categories can become fouled and introduce or spread NIS into new environments, including:

- Recreational vessels (Davidson et al. 2010, Inglis et al. 2010, Zabin et al. 2014)
- Fishing vessels (Piola and Conwell 2010, Davidson et al. 2012, 2014)
- Mobile marine infrastructure (e.g., dredges, mobile offshore drilling units) (National System for the Prevention and Management of Marine Pest Incursions 2009, Cawthron Institute 2010)

Regulatory solutions that address only commercial merchant vessels will not address vessel biofouling as a whole, and will not minimize initial NIS introduction into the region nor NIS spread between coastal regions as much as a holistic approach would (Zabin et al. 2014).

1.3.4. Operational Profiles

Vessel biofouling occurs on all vessel types, but the extent and diversity of the organism community can be influenced by numerous activities that make up the vessel's operational profile (Inglis et al. 2010), including:

- Traveling speed: A vessel's traveling speed influences the survivorship of biofouling organisms on a vessel's hull, with observable decreases in species richness and extent at faster speeds, likely due to hydrodynamic stress and organism removal (Coutts et al. 2010).
- Operational period: The amount of time between renewals of antifouling coatings (i.e., the age of the coating) that deter organism attachment can influence a coating's effectiveness.
- Activity level: Vessels that remain stationary at regular or irregular intervals (Coutts 2002, Floerl and Coutts 2009, Dobroski et al. 2015) or travel slowly for short periods of time in a limited geographic range (Hopkins and Forrest 2010) are more likely to accumulate extensive and diverse biofouling communities (Lacoursiere-Roussel et al. 2016) because their antifouling coatings may be less effective.

International guidance on biofouling management (IMO 2011, 2012) recommends that vessel owners or operators develop comprehensive Biofouling Management Plans that account for a vessel's operational profile and select preventative antifouling systems and maintenance strategies that are appropriate for each specific profile.

2. VECTORS

2.1. COMMERCIAL MERCHANT AND PASSENGER VESSELS

Figure 2. Container vessel

Figure 3. Biofouled vessel in dry dock

2.1.1. Current Vector Population and Activity Level

Commercial merchant and passenger vessels include:

- Auto carriers
- Bulk vessels
- Container vessels
- General cargo vessels
- Passenger vessels (i.e. cruise vessels, excluding regional ferries)
- Reefer vessels (i.e. refrigerated cargo vessels)
- Tank Vessels (e.g. liquid or gas cargo carriers)
- Unmanned barges
- Other (e.g. research vessels or government vessels, excluding vessels of the armed forces)

Knowledge of a vessel population (i.e., the number and type of individual or unique vessels that operate in a jurisdictional area) and activity level (i.e., the total number of vessel arrivals over time, or vessel flux) is critical to understanding the potential risk of introducing NIS. The activity level may be indicative of the inflow of biofouling organisms and potential propagule pressure (i.e., a composite measure encompassing the number of individuals in an introduction event and the frequency of these events) (Drake and Lodge 2006, Lo et al. 2012). The vessel population arriving over time may influence outreach or regulatory management strategies (e.g., more individual vessels would likely require a wider outreach approach). The vessel population may also indicate the variety of different vessel types and operating profiles and maintenance histories that can influence biofouling extent (Dobroski et al. 2015).

The U.S. Pacific states and the Canadian province of British Columbia received a total of 21,470 commercial merchant or passenger vessel arrivals during 2015, with between

288 and 1936 individual vessels per state or province (Table 1). The ratio of these two metrics (arrivals and individual vessels) suggests the prevalence of repeated or multiple visits per vessel. Educational or regulatory outreach is likely to be more effective over time when vessels are making multiple visits to the same location. For example, one educational outreach visit to a passenger vessel in Alaska (with an arrival:individual ratio of 8.51; Table 1) may influence the biofouling management approach of that vessel for the remaining visits it makes during a calendar year. On the other end of the spectrum, a regulatory outreach visit to a bulk vessel in Oregon (with an arrival:individual ratio of 1.41) may not have the same long-term benefits because the vessel is unlikely to return to the state more than one additional time that year. While the overall goal should include as much regulatory alignment as possible between the U.S. Pacific states and British Columbia, these differences in the likelihood of repeat visits may influence the outreach approaches taken by different states and provinces.

Table 1. Commercial merchant and passenger vessel population during 2015.
Note: Data were obtained either through National Ballast Information Clearinghouse (AK, HI) or through individual state or province regulatory agencies (Transport Canada, California State Lands Commission, Oregon Department of Environmental Quality, Washington Department of Fish and Wildlife).

State/ Province	Vessel Arrivals	Individual Vessels	Arrivals:Individual*
AK	2,588	304	8.51
BC	3,663	1,856	1.97
CA	9,038	1,936	4.67
HI	986	288	3.42
OR**	944	669	1.41
WA**	4,251	1,475	2.88

* Ratio of arrivals to individual vessels
** The numbers in the table represent vessels arriving at Oregon or Washington ports during 2015. The combined number of vessels transiting within Columbia River waters of both Oregon and Washington (but not necessarily arriving at ports within both states) was 1438 transits from 768 unique vessels.

Commercial merchant and passenger vessels can be further broken down into vessel-type categories (e.g., container, bulk, passenger; Table 2). Vessels within a vessel-type category often have similar operational profiles. For example, container vessels operating in California during 2015 traveled at an average speed of 16.67 (± 0.08 standard error, S.E.) knots, whereas bulk vessels traveled at an average of 12.2 (± 0.05 S.E.) knots (CSLC, unpublished data). Traveling speed, like many of the practices that contribute to a vessel’s operational profile, influences the accumulation and survival of biofouling organisms (Davidson et al. 2008, Coutts et al. 2010). Slower vessels lack the hydrodynamic stress that may remove organisms and that is typically necessary for the effectiveness of antifouling coatings.

Passenger vessels accounted for 1291 **Alaskan** port arrivals during 2015, approximately half of all arrivals to the state (Table 2). These passenger vessel arrivals represent 33 individual vessels, for an average of 39.1 arrivals per passenger vessel. Educational or regulatory outreach to these 33 passenger vessels would ensure that approximately half of the arrivals receive appropriate outreach, providing maximum benefit to the state for a moderately-sized effort.

Container (27% of 2015 arrivals) and bulk (25%) vessels accounted for most of the arrivals at **Washington** ports during 2015 (Table 2). Container vessels typically have very different operational profiles than bulk vessels, with container vessels typically operating at faster speeds and remaining in port for shorter durations than bulk vessels (Takata et al. 2011). Bulk vessels typically have operational profiles that are often associated with a high likelihood of extensive biofouling accumulation, especially slow speeds (Coutts et al. 2010) and long port residency times (Floerl and Coutts 2009, Hopkins and Forrest 2010). **California** had a very similar vessel-type breakdown to Washington in 2015, with container (41% of 2015 arrivals) and tank (23%) vessels accounting for the majority of arrivals.

Table 2. Vessel type arrivals during 2015.

State/ Province	AK	BC	CA	HI	OR	WA
Bulker	71	1,552	767	39	581	1,047
Container	257	847	3,727	306	33	1,129
General Cargo	30	247	282	14	27	218
Other	229	111	87	110	10	183
Passenger	1,291	436	542	195	19	189
Refrigerated Cargo	199					
Auto	103	248	986	129	139	430
Tanker	408	222	2,115	193	38	429
Unmanned Barge			532		97	626
Total	2,588	3,663	9,038	986	944	4,251

The commercial merchant and passenger vessel population in **Hawaii** was spread more evenly than for any other regional partner during 2015 (Table 2). Container vessels were the most numerous, with 31% of 2015 arrivals. Passenger, tanker, auto, and other vessels all accounted for between 11% and 20% each.

Bulk (62%) and auto (15%) carrier vessels accounted for the majority of **Oregon** arrivals during 2015 (Table 2). The container terminal in the Port of Portland closed in 2014, and as a result only 40 container vessels arrived at Oregon ports in the Columbia River during 2015. Fortunately for Oregon, most of their commercial ports lie within the Columbia River system, minimizing the likelihood that marine biofouling organisms will survive in the river's freshwater habitats. Although the freshwater Columbia River system provides some protection against marine biofouling NIS introduction risks, the brackish water estuarine zones of the lower Columbia River may still be susceptible.

Bulk vessels accounted for the largest portion (42%) of arrivals to **British Columbia** in 2015, with container vessels a distant second at 23% (Table 2). Similar to Oregon (and Washington to a lesser extent), British Columbia arrivals are dominated by a vessel type (bulk) that typically has an operational profile that increases the likelihood of extensive biofouling accumulation.

2.1.2. Current Authorities and Requirements

The International Maritime Organization's (IMO) Marine Environmental Protection Committee adopted the Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species in 2011 (hereafter referred to as the IMO Biofouling Guidelines; see IMO 2011). Developed to provide a globally consistent approach to the management of biofouling, the IMO Biofouling Guidelines recommend that ship owners develop a Biofouling Management Plan for each vessel that takes into account vessel type, size, hull shape and pattern of activity. In 2013, the IMO supplemented the guidance with performance measures (e.g., measuring awareness and dissemination of the IMO Biofouling Guidelines) that could help states and others evaluate different recommendations in the IMO Biofouling Guidelines (see IMO 2013).

U.S. federal biofouling management requirements are implemented and enforced by the U.S. Coast Guard (USCG) and the U.S. Environmental Protection Agency (USEPA). The USCG, under the authority of Title 33 Code of Federal Regulations §151.2050, enforces requirements for vessels to:

- Rinse their anchors and anchor chains when the anchor is retrieved to remove organisms and sediments at their places of origin
- Remove fouling organisms from the vessel's hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, state and federal regulations

The USEPA, under the authority of the Clean Water Act as implemented through the Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels (hereafter referred to as VGP), requires:

- When feasible, sacrificial anodes should be flush-fitted to the hull, or the space between the anode and the hull should be filled to remove the potential for hotspots for biofouling organisms
- Removal of biofouling organisms from seawater piping on a regular basis and dispose of removed substances in accordance with local, state, and federal regulations

- Minimizing the transport of attached living organisms when traveling into U.S. waters from outside the U.S. Exclusive Economic Zone or between Captain of the Port zones
- All in-water biofouling removal activities to minimize the discharge of biofouling organisms and antifouling coatings

Canada has adopted the IMO Biofouling Guidelines as voluntary measures, but has no additional requirements specific to biofouling management. The Canadian province of British Columbia also does not have regulations specifically addressing biofouling management.

The states of Alaska, Oregon, and Hawaii have no statewide requirements in place requiring biofouling management of commercial merchant and passenger vessels. Local requirements for the Hawaiian Papahanaumokuakea Marine National Monument include maintaining all submerged and waterline surfaces free of macro-scale biofouling (PMNM 2014).

Washington's Department of Fish and Wildlife (WDFW) has authority to regulate commercial merchant and passenger vessels, and is currently developing a six-year biofouling management strategic plan (see McClary et al. 2016) to identify an appropriate strategy. Currently, Washington requires all vessels intending to undergo in-water cleaning to contact the Department of Ecology and WDFW at least seven days prior to the proposed cleaning activity. A proposed in-water cleaning activity may be approved only when biofouling is limited to slime and sea grass growth; proposed cleaning of vessels with barnacles, mussels, or tubeworms will not be approved.

California's Marine Invasive Species Act (specifically Public Resources Code section 71204(f)(2)) requires that vessels arriving at California ports remove biofouling from their hulls and other wetted surfaces on a regular basis. Regular basis is defined as no longer than:

- The expiration of the vessel's full-term Safety Construction Certificate
- The expiration of the vessel's full-term USCG Certificate of Inspection
- 60 months since the time of the vessel's last out-of-water drydocking

California has an additional requirement in Title 2 of the California Code of Regulations, Section 2298 for annual submission of the Hull Husbandry Reporting Form to the California State Lands Commission's (CSLC) Marine Invasive Species Program, describing each vessel's maintenance and operational practices. California is in the process of adopting new regulations for biofouling management that will align with the IMO Biofouling Guidelines and that will require vessels to maintain Biofouling Management Plans and Biofouling Record Books (see CSLC 2016).

2.1.3. Current Management Options

The 2011 IMO Biofouling Guidelines (see IMO 2011) include recommendations for minimizing biofouling accumulation on commercial vessels, including:

- Selecting, installing, and maintaining appropriate antifouling systems
- In-water inspection and cleaning
- Design and construction considerations

The primary tool for implementation of the IMO Biofouling Guidelines is a vessel-specific Biofouling Management Plan (BFMP) and Biofouling Record Book (BFRB). The BFMP is intended to describe the vessel-specific biofouling management strategy (including antifouling systems and in-water cleaning). The BFRB is intended to document the implementation of the vessel-specific strategy described in the BFMP. The International Paint and Printing Ink Council (IPPIC) and the Institute of Marine Engineering, Science & Technology (IMarEST) have developed a BFMP template to improve documentation of antifouling coatings (IMO 2016b).

The IMO Biofouling Guidelines are currently voluntary, but several regional and international regulatory bodies are developing (or have developed) regulations based on alignment with the IMO Biofouling Guidelines and the use of BFMPs and BFRBs (see NZ MPI 2014, CSLC 2016).

The biofouling management options that vessel owners or operators may choose fall into two broad categories:

- Proactive measures - intended to prevent biofouling accumulation, including the use of:
    - Biocide-based anti-fouling coatings
    - Biocide-free foul-release coatings
    - Marine growth prevention systems (MGPS) that produce or release small doses of biocides into recesses and internal piping
    - Regular preventative in-water cleaning (or hull grooming)
- Reactive measures - intended to remove biofouling organisms that are already attached or associated with a vessel’s wetted surfaces, including:
    - In-water cleaning (if allowed)
    - In-water treatment (e.g., killing biofouling organisms, such as barnacles, but not necessarily removing them)
        - Chemical dosing of sea chests or other recesses and internal piping
    - Removing the vessel from the water and into a dry dock (i.e., dry docking) for cleaning and application of anti-fouling coating

Appropriate biofouling management regulations should incorporate a holistic approach that includes reliance on both proactive and reactive management measures (when necessary), while also maintaining alignment with the IMO Biofouling Guidelines.

2.1.4. Current Gaps

None of the U.S. Pacific states nor British Columbia have adopted comprehensive (proactive and reactive) biofouling management regulations. However, all states have made different levels of progress towards that goal, including:

- California proposed a set of regulations, with a proposed adoption date of October 1, 2017 (see CSLC 2016)
- Hawaii held discussions with its Aquatic Alien Organism Task Force to begin data collection efforts to inform the future development of biofouling management regulations, and commissioned a study assessing potential management options (see Davidson et al. 2014a)
- Oregon prepared a report evaluating vessel biofouling initiatives and recommendations (see Paul 2011)
- Washington commissioned an assessment of marine biofouling introductions to Puget Sound (see Davidson et al. 2014b) and a Biofouling 6-year Strategic Plan (see McClary et al. 2016)
- Alaska commissioned a report assessing risk associated with vessel biofouling and NIS in Prince William Sound (see Cordell et al. 2011)

Despite this progress, there remains a lack of biofouling management requirements across all jurisdictions. This gap is likely to be partially bridged by California soon, and by several other Pacific states soon after. Regulatory entities in the Pacific states and British Columbia should work together as regional partners to ensure alignment with each other and with the IMO Biofouling Guidelines to ensure better cooperation and therefore better compliance within the commercial maritime shipping industry.

Although the adoption of biofouling management requirements is likely to progress over time across the Pacific states and British Columbia, adoption in one or a few states will likely benefit all of the regional partners. The commercial vessels trading in one state are likely to also trade in others. Efforts to improve biofouling management in Washington are likely to result in improved biofouling management for vessels operating in British Columbia. Likewise, efforts to improve biofouling management in California are likely to provide benefits to all of the other regional partners, as most NIS that become established along the North American Pacific coast are first detected in California before secondary spread northward along the coast (Ruiz et al. 2011). Continual engagement between regional partners is critical to these efforts, including discussions during meetings of interstate working groups (e.g., Pacific Ballast Water Group, Oregon Shipping Taskforce on Aquatic Invasive Species, Washington Ballast Water Working Group).

Another critical gap is the management (or lack of management) of niche areas to prevent or remove biofouling organisms. Although a financial incentive does exist for management of sea chests (Pamitran et al. 2016), most of the shipping industry's biofouling management attention is focused on the hull and flat bottom of a vessel. Without a market-driven financial incentive to manage all niche areas, most remain unmanaged or undermanaged. State or province-level regulation can bridge this gap by providing a regulatory requirement to manage niche areas, similar to the regulatory requirement to manage ballast water in the absence of a clear financial incentive.

In-water cleaning is one of the primary reactive methods for managing vessel biofouling, but the disparate and often overlapping regulation of in-water cleaning hinders effective regulatory management of biofouling-mediated NIS introduction risks. Traditional in-water cleaning activities (i.e., cleaning without capturing or treating the waste stream) increase NIS introduction risk and the risk of heavy metal biocide (e.g., copper, zinc) pollution. However, when conducted responsibly, in-water cleaning can be effective in minimizing the risk of NIS introduction and increasing the operational efficiency of a vessel. Current in-water cleaning rules and regulations vary from state to state and province, and even from water body to water body within a state. For example, existing high levels of copper pollution in one water body may require more stringent copper discharge standards than another water body that has a lower amount of existing copper. Although allowable discharges of copper and other heavy metals are expected to vary based on the existing pollution levels in given water bodies, biological discharge thresholds (i.e. how many organisms are allowed in a discharge) can be aligned across regions. Cooperative development of a regional approach to regulating in-water cleaning activities will bridge the gap of disparate in-water cleaning requirements and reduce the risk of introducing NIS and discharging unacceptable levels of chemical pollutants (see Department of the Environment and New Zealand Ministry for Primary Industries 2015).

2.2. RECREATIONAL VESSELS

Figure 4. Ala Wai Harbor, Hawaii

Figure 5. Biofouled recreational vessel

2.2.1. Current Vector Population and Activity Level

Recreational vessels include vessels such as yachts or power boats that are operated primarily for pleasure, or leased, rented, or chartered for pleasure. There are several important differences between the operational profiles and activity levels of recreational vessels and commercial merchant and passenger vessels (Davidson et al. 2014b), including:

- Typical vessel population size: There are generally more recreational vessels than commercial merchant and passenger vessels per state or province, oftentimes by several orders of magnitude
- Traffic patterns: Recreational vessel traffic is generally more haphazard and covers smaller geographic ranges than commercial merchant and passenger vessels
- Seasonality: Recreational boating activity tends to be highly seasonal, with peaks during the summer and fall months. With the exception of passenger vessels (i.e., cruise ships), commercial merchant vessel traffic is generally consistent throughout the year.

Another important difference between recreational vessels and commercial merchant and passenger vessels is the availability of traffic pattern data. Unlike commercial merchant vessels that must report arrivals to government entities (e.g., National Ballast Information Clearinghouse, Oregon Department of Environmental Quality), recreational vessels are not required to disclose this information. One exception is that recreational vessels arriving from another country or international waters must report to the U.S. Customs and Border Protection (CBP), although anecdotal evidence suggests that international arrivals are under-reported because of the time involved and the lack of repercussions for failure to submit (Ashton et al. 2012).

The lack of an official reporting and tracking entity makes it difficult to obtain useful data on recreational boat population sizes and activity levels. Several academic or research reports of recreational boat traffic patterns exist for the U.S. Pacific states and British Columbia, each relying on small snapshots of boating activity within a localized area or from a series of different data sources that are used to interpret trends, and are summarized in this section. Available data sources included:

- U.S. CPB, only for international arrivals
- Marina/harbor data from mooring permits or guest dock slip rentals
- Boater survey questionnaires

Davidson et al. (2014a) surveyed 60 boaters to identify traffic patterns and recreational vessel usage in **Hawaii**. Eleven of the boaters were out-of-state visitors, with eight coming from west coast states. The other 49 boaters were Hawaii residents, and 34 of those reported that they do not travel outside of their home marina (57% of all surveyed boat owners). The authors also obtained temporary mooring permit data for an additional 618 vessels arriving over a three-year span. The majority (60% to 64%) of these vessels were visitors from other marinas on the same island (Oahu). The remainder of the vessels were split relatively evenly between inter-island, mainland, or international arrivals. A previous study by Godwin et al. (2004) that utilized CPB data indicated that approximately 80 international arrivals occur per year in Hawaii.

Recreational boat traffic in **Alaska** is very seasonal, peaking between May and July (Ashton et al. 2014). Between 60% and 80% of the out-of-state arriving vessels had home marinas in Washington, while more than 90% of the vessels in Ketchikan captured by CPB data had a last port call in British Columbia. Because of its location in southern Alaska, and its proximity to British Columbia, Ketchikan serves as the main entry point for recreational boat traffic into Alaska and therefore acts as the main hub that possibly facilitates the movement of aquatic NIS via recreational vessel biofouling into and throughout southeast Alaska (Ashton et al. 2014).

British Columbia has the largest recreational boating community in Canada, estimated at approximately 400,000 boats (Clarke-Murray et al. 2011). Clarke-Murray et al. (2011) surveyed 616 boaters regarding their boating practices over the previous 12 months indicate that:

- 73% of respondents stored their boats in the water year-round
- 67% of the respondents took local day trips
- 55% of the respondents took overnight weekend trips
- 21% have traveled to the U.S., with most visiting Washington
- 87% moored away from their home marina at least once

Recreational vessel traffic in **Washington** State is also seasonal, with peak traffic occurring in late summer and fall months (Davidson et al. 2014b). Almost all (98%) of the international arrivals to Puget Sound between June 2011 and July 2012 came from 12 ports in British Columbia, most often from Victoria (63%). Most of the international arrivals into Puget Sound landed at Friday Harbor (58%) and Bellingham (28%; Davidson et al. 2014b).

Although there are many freshwater marinas within the Columbia River system, **Oregon** has 19 coastal marinas that have direct access to the ocean. These 19 marinas include a total of 4,066 recreational vessel slips. Approximately 80% of these recreational vessels are primarily used for day trips out and back into the ocean (Dolphin, G., pers comm, 2016).

California boating activity also appears to follow a strong seasonal pattern, with CPB data indicating a primary peak between March and June and a secondary peak in October, and marina data indicating a peak between May and September (Ashton et al.

2012). Marina arrival data indicate that 79% of arrivals to California were from west coast states and British Columbia, including (70%) from other California marinas. Survey data from 316 resident vessels showed that 81% of 8,320 total trips taken by survey respondents were within the vessel's home bay, and 42% took less than 12 trips per year (Ashton et al. 2012). Specifically within San Francisco Bay (SFB), 76% of the surveyed vessels never left the SFB (Davidson et al. 2010). Of those vessels that did take trips outside of the SFB, three-quarters stayed within 31 miles of the Golden Gate Bridge (Davidson et al. 2010). Zabin et al. (2014) also found strong connectivity between SFB and nearby coastal bays.

Common themes that emerged from the Pacific regional recreational vessel literature described above include:

- Seasonal patterns: Most recreational vessel traffic within the U.S. Pacific states and British Columbia occurs during the summer and fall months
- Lack of central reporting authority: Across all U.S. Pacific states and British Columbia, there is no centralized agency that collects arrival or traffic information from recreational vessels. The closest approximation to a centralized dataset is maintained by U.S. CBP, but only for international arrivals. Anecdotal evidence suggests that CPB data is underreported.
- Connectivity to nearby water bodies or states/province: There is strong connectivity between Alaska and British Columbia, between British Columbia and Washington, and between the SFB and nearby coastal bays.

2.2.2. Current Authorities and Requirements

The International Maritime Organization's Marine Environmental Protection Committee approved and circulated the Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft in 2012 (hereafter referred to as IMO Recreational Guidance; see IMO 2012). Developed to provide a globally consistent approach to the management of biofouling, this IMO Recreational Guidance applies to all owners and operators of recreational craft less than 24 meters in length.

The USEPA released and implemented a Small Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels less than 79 feet (hereafter referred to as sVGP; see USEPA 2014) in 2014. However, federal legislation was adopted to exempt small vessels from the requirement to obtain coverage under the sVGP until December 18, 2017. As a result, there are no regulations implemented or enforced at the national level in the U.S. There are also no federal requirements for recreational vessel management of biofouling in Canada.

At the state or province level, there are no existing regulations requiring biofouling management for recreational vessels in marine environments. Requirements exist for trailered vessels moving across state borders or into certain freshwater bodies.

Although these trailered vessel requirements to minimize the risk of transporting dreissenid mussels (i.e., Zebra and Quagga mussels) are of interest to the greater Western Regional Panel, they are beyond the scope of this white paper.

Both the Hawaii Department of Land and Natural Resources (HI DLNR) and the Washington Department of Fish & Wildlife have regulatory authority to require biofouling management of recreational vessels, but no regulations have been developed.

2.2.3. Current Management Options

The 2012 IMO Recreational Guidance includes recommendations for minimizing biofouling accumulation on recreational craft, including:

- Selecting, installing, and maintaining appropriate antifouling systems (e.g., anti-fouling coatings, MGPS)
- Cleaning the wetted surfaces when appropriate, either by hauling out (preferable) or while in-water (if allowed)
- Maintaining a craft logbook to document the antifouling systems used and cleaning activities

Similar to commercial merchant and passenger vessels, most biofouling options available to a recreational boat owner include:

- Proactive measures that are intended to prevent biofouling accumulation, including:
    - The use of biocide-based anti-fouling coatings
    - The use of biocide-free foul-release coatings
    - The use of marine growth prevention systems (MGPS)
    - Regular preventative in-water cleaning (or hull grooming)
    - Storage of the craft out of water when not in use, either on land or on floating platforms
    - Regularly cleaning anchor and chain wells or lockers

- Reactive measures that are intended to remove biofouling organisms that are already associated with a vessel's wetted surfaces (Inglis et al. 2012), including:
    - In-water cleaning (if allowed)
        - Preferable if cleaned prior to transiting to a new area, also referred to as "Clean before you leave"
    - In-water treatment (e.g., killing biofouling organisms, such as barnacles, but not necessarily removing them), including:
        - Wrapping the vessel with a plastic barrier with or without the use of freshwater or chlorine
        - Heat treatment (using heated water, if allowed)
        - Disinfect seawater pipes, inlets, outlets, and pumps (Northern Territory 2017)

- Hauling out or dry docking
  - Cleaning and drying mooring lines that have biofouling attached
  - Removing biofouling organisms, other biological material, and mud/sand from anchors as they are hauled

2.2.4. Current Gaps

Unlike commercial merchant and passenger vessels that generally fall under clear regulatory authority (e.g., Washington Department of Fish and Wildlife, Oregon Department of Environmental Quality), there is a lack of an official recordkeeping or regulatory authority for recreational craft across all U.S. Pacific states and British Columbia. Several states (e.g., Washington, Hawaii) have agencies with regulatory authority, however regulations have yet to be developed or proposed. **The unmanaged and undocumented recreational vessel traffic into and throughout each state and province remains a large gap in effective management strategies to minimize the risk of NIS introduction and spread.**

The lack of an official recordkeeping or data collection regime limits the ability of each state and province to quantify vessel populations and activity levels - critical information to assess NIS introduction risk and to develop sound regulatory and educational management strategies. Without a dedicated central authority in each state or province, recordkeeping will continue to be sparse and outreach efforts will likely continue to be splintered among groups.

2.3. COMMERCIAL FISHING VESSELS

Figure 6. Commercial fishing vessels in B.C.

Figure 7. Commercial crab fishing vessel in CA

2.3.1. Current Vector Population and Activity Level

Commercial fishing vessels are vessels that are used to harvest fish and other aquatic organisms, either whole or in part, that are intended to enter commerce.

Fishing vessel population and activity level data are more available than recreational vessel data, but not as accessible as commercial merchant and passenger vessel data. Fishing vessel data are typically available from:

- Permit or licensing agencies at the state or province level
- Vessel monitoring or tracking services, generally only for large fishing vessels
- Fish landing data

Hawaiian longline fishing permit data indicate that 140 vessels operated in the Hawaii longline fishery in 2016, similar to the 140 permitted vessels in 2015 and 139 in 2014 (NOAA 2016a). No other types of commercial fishing vessels (e.g., trawlers and purse seiners) operate legally in Hawaiian waters.

Thesing et al. (2006) conducted a commercial marine inventory in 2002 and found that there were 2,316 individual vessels operating in **Alaska** that were tracked by the Alaska Commercial Fisheries Commission through issuing of fish landing tickets. The top three arrival ports (Ketchikan, Valdez, and Kodiak) each had about 21% of the arrivals. Dutch Harbor (13%) and Homer (12%) were fourth and fifth in arrivals, respectively. A more recent profile from the North Pacific Fishery Management Council indicated that there were 2,736 fishing vessels operating in federal waters offshore of Alaska, including 1,646 commercial fishing vessels and 1,090 chartered recreational fishing vessels (Witherell et al. 2012). An additional study suggested that there were 500-900 fishing vessels that operate annually within the Cook Inlet (Cape International 2012). Hundreds of other fishing vessels are likely to operate solely in state waters but were outside the scope of this report because they are recreational and not commercial fishing vessels.

British Columbia fishing vessel licensing data indicate that there were 2,440 vessels that obtained licenses to operate in west coast Canadian waters in 2016 (Fisheries and Oceans Canada 2016). These data did not include home port or landing port information, but a 2013 study prepared for the British Columbia Ministry of Environment used vessel monitoring data to track vessel movements across beacon lines throughout the provincial coastline (Nuka Research and Planning 2013). These data are incomplete because they only capture vessels with monitoring software installed, but the relative proportions of traffic at different locations is still useful to understand fishing vessel itineraries. Forty-four percent of the transits captured occurred at the outer mouth of Neah Bay. Twenty percent of the transits crossed the Alaska Inside Passage line (separating southeast Alaska from British Columbia), indicating traffic to or from southeast Alaska. Approximately ten percent of the transits occurred at each of the borders of Queen Charlotte Sound and the North Georgia Strait (Nuka Research and Planning 2013).

Between 2005 and 2008, there were 105,494 total arrivals by 1,584 individual fishing vessels in **Washington** (Zabin et al. 2011, Davidson et al. 2014b). Approximately 41% of the individual fishing vessels reported that they operated out of only one port during the four-year span. Westport was the most trafficked arrival port by fishing vessels, with 14,709 arrivals. When evaluated by region, the arrivals are allocated as follows:

- Northern ports (Bellingham, Anacortes, Blaine): 33% of all arrivals
- West coast ports: 27%
- Puget Sound ports: 17%
- Columbia River ports: 13%
- Strait of Juan de Fuca Coast: 10%

There were 93,582 arrivals made by 1,684 individual commercial fishing vessels in **Oregon** between 2005 and 2008 (Zabin et al. 2011). Homeport affinity was high during the four-year period, with approximately 58% of the individual fishing vessels operating out of only one port. Four ports (Newport, Astoria, Coos Bay, and Port Orford) accounted for the majority (55%) of the arrivals during the four-year period (Zabin et al. 2011). More recently, the Oregon Department of Fish and Wildlife indicated that 1,199 individual fishing vessels made 30,703 arrivals during 2014, and 1,129 vessels made 27,021 arrivals in 2015 (The Research Group 2016).

In **California**, 2,464 individual fishing vessels made 204,488 arrivals between 2005 and 2008 (Zabin et al. 2011). Homeport affinity was also high in California, with approximately 53% of the individual fishing vessels operating out of only one port. Although homeport affinity was high, each port/bay was connected by fishing vessel activity to an average of 18 other bays, with San Francisco Bay and Bodega Bay both connected to 25 of the 26 other bays (Davidson et al. 2012). Fishing vessel arrivals were spread across 27 ports throughout California during the four-year period, with the most trafficked arrival ports including Los Angeles/Long Beach (15.4% of all arrivals), Santa Barbara (11%), and San Diego (8%; Davidson et al. 2012).

Zabin et al. (2011) evaluated **interstate fishing vessel traffic between Washington, Oregon, and California**. An overwhelming majority (86%) of the 4,920 individual commercial fishing vessels operating across the contiguous U.S. Pacific coast remained within a single state between 2005 and 2008. Most of the remaining fishing vessels (8% of the total) operated in both Oregon and Washington, not surprising given that the two states share the Columbia River. Four percent of the 4,920 fishing vessels operated in both Oregon and California, while approximately one percent operated within all three states.

2.3.2. Current Authorities and Regulations

While there are no IMO NIS management guidelines specific to commercial fishing vessels, the same recommended practices for recreational (see IMO 2012) and commercial merchant and passenger (see IMO 2011) vessels can be applied as best management practices for fishing vessels. Canada has adopted the IMO Biofouling Guidelines as recommended management for commercial fishing vessels operating in Canadian waters.

At the U.S. federal level, there are no additional biofouling management requirements that specifically target commercial fishing vessels. If a commercial fishing vessel is under the jurisdiction of the USCG (i.e., non-recreational vessels that are equipped with ballast tanks), then it is subject to the same requirements as commercial merchant and passenger vessels, specifically requiring:

- Rinsing of anchors and anchor chains when the anchor is retrieved to remove organisms and sediments at their places of origin
- Removal of fouling organisms from the vessel's hull, piping, and tanks on a regular basis and disposal of any removed substances in accordance with local, state and federal regulations

If a commercial fishing vessel meets the criteria for coverage under the USEPA VGP (i.e., greater than 79 feet in length), then it is subject to the requirements of the VGP, specifically requiring:

- When feasible, sacrificial anodes should be flush-fitted to the hull, or the space between the anode and the hull should be filled to remove the potential for hotspots for biofouling organisms
- Removal of fouling organisms from seawater piping on a regular basis and disposal of removed substances in accordance with local, state, and federal regulations
- Minimizing the transport of attached living organisms when traveling into U.S. waters from outside the U.S. economic zone or between Captain of the Port zones
- All in-water biofouling removal activities to minimize the discharge of biofouling organisms and antifouling coatings

If a commercial fishing vessel is under 79 feet in length, then it is exempt from the requirement to obtain coverage under the sVGP until December 18, 2017 (USEPA 2016).

There are no biofouling management regulations specific to commercial fishing vessels in any of the U.S. Pacific states or British Columbia.

2.3.3. Current Management Options

Biofouling management options for commercial fishing vessels are similar to options for recreational and commercial merchant and passenger vessels (Commonwealth of Australia 2009a, Inglis et al. 2012, Davidson et al. 2012), and include:

- Proactive measures that are intended to prevent biofouling accumulation, including the use of:
    - Preventative antifouling coatings that are appropriate for the vessel's:
        - Operating profile (e.g., speed, routes, activity level)
        - Operating location
        - Construction type (e.g., wood, steel, aluminum)
    - Marine growth prevention systems (MGPS) that produce or release small doses of biocides into recesses and internal piping
    - Regular preventative in-water cleaning (or hull grooming)
    - Dry storage, either on land or on floating platforms
    - Wrapping the vessel with a plastic barrier with or without the use of freshwater or chlorine
- Reactive measures that are intended to remove biofouling organisms that are already attached to or associated with a vessel's wetted surfaces, including:
    - In-water cleaning (if allowed)
    - In-water treatment (e.g., killing biofouling organisms, such as barnacles, but not necessarily removing them)
    - Hauling out or dry docking
    - Wrapping the vessel with a plastic barrier with or without the use of freshwater or chlorine

The fishing activities occurring on a commercial fishing vessel can also present NIS introduction risk (Commonwealth of Australia 2009a). To manage these risks, fishing vessels can:

- Clean and dry mooring lines that have biofouling attached
- Remove biofouling organisms, other biological material, and mud/sand from anchors as they are hauled
- Regularly clean anchor and chain wells or lockers
- Ensure that nets, lines, and tackle are dried out between use in different areas

2.3.4. Current Gaps

Although commercial fishing vessel population data are more readily available (often indirectly through permit, license, or fish landing databases) than recreational vessels, there is still a lack of useful movement data for commercial fishing vessels (i.e. commercial fishing vessel data are generally sparse and inconsistent). In some states, fish landing data are publicly available, allowing the tracking of the ports at which individual vessels arrive. It is important to know how many fishing vessels operate within a state or province, but it is more important to know where those vessels travel and if they operate in more than one geographic area. Better access to these types of data is a critical step towards characterizing NIS introduction risk and developing management strategies.

Even if NIS introduction risk can be determined through commercial fishing vessel population and movement data, the lack of clear regulatory authority to minimize NIS introduction risk from commercial fishing vessels in each of these states and British Columbia is another important gap that must be overcome before outreach or management strategies can be developed to minimize biofouling species introductions.

2.4. MOBILE MARINE INFRASTRUCTURE

Figure 8. Jackup rig *Randolph Yost* being transported on a heavy lift vessel

2.4.1. Current Vector Population and Activity Level

Mobile marine infrastructure (MMI) includes a variety of non-traditional vessels or non-vessel floating structures that can be moved from one area to another, along with its biofouling community (Cawthron Institute 2010). Mobile marine infrastructure typically remains stationary or moves slowly within the same geographic location for lengthy, irregular time periods. Vector activity or population-level data are rare to nonexistent because of the lack of movement tracking by institutions or agencies. Projects that involve MMI are typically local and infrequent, and require permits for the projects themselves (e.g., dredging permits), but not necessarily for the equipment used. Projects utilizing MMI often include additional support vessels (e.g., tugs, heavy lift vessels) that also can introduce and spread NIS and may not be regulated for biofouling management.

The categories of MMI considered in this white paper include:

- Mobile offshore drilling units (MODUs)
- Long-term work vessels (e.g., dredges, crane/construction barges)
- Non-vessel infrastructure (e.g., docks, wave energy structures, floating wind farms, buoys)

New offshore oil and natural gas operations that utilize MODUs only occur regionally in waters surrounding Alaska; new drilling is prohibited in all other U.S. Pacific states and British Columbia (Myers and Finney 2004, BOEM 2016). Mobile offshore drilling units that operate along the Alaskan coast include jackup rigs, semi-submersibles, drill ships, and drill barges. These drilling units typically arrive after long transits, generally weeks to months, atop heavy lift vessels (i.e., transported out of the water), likely reducing NIS introduction risk through desiccation. Although these MODUs only drill offshore of Alaska, they do spend time in other states (primarily Washington) during the drilling offseason and during the initial transit or at the termination of their Alaskan operations. The movement of these MODUs between states and between bays, often after lengthy stationary periods, can facilitate the spread of NIS between these areas.

Six MODUs have arrived and operated in Alaskan waters since 2011, including:

- *Spartan 151*: A jackup rig that arrived at Cook Inlet in 2011 and is still in operation there. This MODU winters at Port Graham, Alaska (Quinn 2014)
- *Endeavor – Spirit of Independence*: A jackup rig that also operated within Cook Inlet; it arrived in August 2012 and left Alaskan operations in November 2014 (Armstrong 2014)
- *Kulluk*: A drill ship that arrived in Seattle in 2012 en route to Alaska. This MODU ran aground in Unalaska on December 31, 2012, and was removed from Alaskan operations in 2013 (DOJ 2014)
- *Noble Discoverer:* A drill barge that arrived in Seattle in 2012 en route to Alaska. This MODU was cited with multiple USCG environmental violations and was removed from Alaskan operations in 2013 (DOJ 2014)
- *Polar Pioneer*: A semi-submersible that arrived at several Puget Sound ports en route to Alaska in April 2015 and again after it was removed from Alaskan operations in October 2016 (Shell 2014)
- *Noble Discoverer*: The same drill barge that operated in Alaska in 2012-2013 was brought back to Alaska in May 2015, after arriving to several ports within Puget Sound. This MODU visited Puget Sound again in October 2016 after being removed from Alaskan operations (Shell 2014)

- *Randolph Yost*: A jackup rig that arrived at Cook Inlet in April 2016 and is still in operation (DeMarban 2016)

Two of these MODUs were inspected for biofouling and NIS after arrival in Alaskan waters. The *Endeavor – Spirit of Independence* was dry docked for maintenance in Singapore and was transported dry to Alaska atop a heavy lift vessel. The rig was inspected after arrival because of the presence of biofouling on the underwater surfaces. The survey revealed heavy biofouling accumulation, but none of the sampled organisms were alive (URS 2012). Prior to its transit to Alaska, the operators of the *Randolph Yost* contacted the Coordinator of the Alaskan Department of Fish and Game's Invasive Species Program about the biofouling organisms on the rig's underwater surfaces. Organisms were collected and sent to Alaska for identification, and the rig was further inspected upon arrival in Alaska to assess NIS introduction risk (KBNERR 2016). There was extensive biofouling accumulation on the rig, but all of the sampled organisms were dead, likely the result of the four-month dry docking in Singapore prior to transit and the month-long dry transit to Alaska atop a heavy lift vessel.

Long-term work vessels include dredges and crane or construction barges that operate within a small geographic range over lengthy time periods. These vessels are irregularly moved from bay to bay or from state to state or province for specific projects (e.g., dredging navigation channels in Puget Sound, construction of the Bay Bridge in the San Francisco Bay). Data on population size or activity level are sparse and sporadically kept. Construction and dredging projects are permitted activities, but permits and contracts are typically awarded to companies, not necessarily to a specific vessel. The outcome of this arrangement is that agency records do not typically indicate the actual vessels that are used for projects. For example, approximately 57 navigation dredging projects were permitted in California during 2016. Multiple projects could involve the same equipment (dredges and barges), and each project could involve multiple barges. Therefore, the total number of dredge vessels and barges used in California during 2016 and their prior movement and maintenance history are unknown (Scianni, M., pers comm, 2016). The actual number and movement of long-term work vessels operating in the U.S. Pacific states and British Columbia is unknown.

Non-vessel MMI can include floating docks, alternative energy structures (e.g., wave or offshore wind energy), dry docks, buoys, and aquaculture gear. These types of mobile infrastructure are typically moved irregularly, and movements are often project-based. Similar to other types of mobile marine infrastructure, quantifying the population and activity level of these non-vessel MMI is difficult to assess across a large geographical area because there is no central information clearinghouse to capture these data.

2.4.2. Current Authorities and Regulations

Regulatory authority over MMI is limited and often local. Unless MMI meet the criteria for coverage under the jurisdiction of federal, state, or province rules for commercial merchant and passenger vessels, there are no national (U.S. or Canada), statewide, or province-wide requirements for biofouling management.

Most types of MMI are moved around for specific projects, most likely involving the issuance of a permit (e.g., drilling permit, dredging permit). The permitting agency or agencies can place requirements in the permit language or leases for biofouling management of the MMI to be used for the project, but it is unclear if that is the current practice.

2.4.3. Current Management Options

The operational profiles of most MMI are consistent with a high likelihood of extensive biofouling accumulation. MODUs, long-term work vessels, and non-vessel MMI all remain stationary or move slowly within a small geographic range for lengthy time periods. These operational practices are consistent with high accumulation of vessel biofouling and elevated NIS introduction risk when the structure is transported from one area to another.

The selection of appropriate antifouling systems is important for MMI. Owners or operators should obtain technical advice from an antifouling coating manufacturer or distributor to ensure that selected coatings and systems are appropriate for the operational profile of the MMI (Commonwealth of Australia 2009b).

Regardless of the antifouling coating used, the operational profiles of MMI will likely result in some amount of biofouling accumulation. Managing the existing biofouling community on or in a vector before transport is critical to minimizing the NIS introduction risk during the transit and upon arrival at the new location. Management options include:

- Dry docking to remove biofouling organisms and apply new antifouling systems
- Indirect biofouling management through dry docking for maintenance purposes (i.e., not necessarily to physically remove organisms) that will remove the biofouling community from water for lengthy time periods
    - Note: biofouling organisms within internal seawater systems can survive lengthy periods out of water
- In-water cleaning prior to transit to a new area (i.e., in the location where it remained for lengthy time period), also referred to as “Clean before you leave”
- Dry transit atop a heavy lift vessel
    - Note: Splash and spray during transit can increase the likelihood of organism survival because it may prevent them from drying out

2.4.4. Current Gaps

Similar to recreational and commercial fishing vessels, there are few sources of data on MMI population and activity levels. Local or regional permitting agencies may collect data on permitted projects, but not necessarily on vessels or structures involved in the projects. High-profile projects (e.g., MODU operations in Alaska) are relatively easy to track because they are infrequent and prone to wide exposure through news media. Low-profile projects (e.g., navigation dredging, buoy deployment) can also be relatively infrequent, but external documentation of their activities is minimal. Oftentimes, permitting agencies do not track the vectors that are used for certain projects, as permits typically are awarded to companies that operate multiple vessels or other infrastructure. For those vectors that are quantified by local or regional agencies, those data may be contained within individual permit applications or reports and not housed within a searchable or available database.

The lack of clear regulatory authorities with NIS oversight is also a critical gap limiting management of MMI. There are no agencies with NIS authority overseeing any of the MMI categories across any of the U.S. Pacific states and British Columbia, with the exception of the Papahanaumokuakea Marine National Monument in Hawaii.

In the absence of regulatory authority, *ad-hoc* risk assessment and management can reduce NIS introduction risk. Proactive biofouling assessments of MODUs (e.g., *Randolph Yost* operators sending samples ahead of time for identification) are useful but not mandatory. Reactive assessments of MODUs (e.g., post-arrival surveys of *Endeavor – Spirit of Independence* and *Randolph Yost*) can help to quantify NIS introduction risk, but are conducted after arrival and submersion of parts of the rig structure (i.e., after the risks may have materialized). While dry transport atop heavy lift vessels is likely to reduce overall NIS introduction risk, it should not be assumed to always be completely effective. Splash and spray during transit can increase the likelihood of survival of exposed organisms, and organisms within internal pipes and seawater systems, where water may still be present, may be able to survive long periods of vessel emersion (Commonwealth of Australia 2009b).

2.5. OTHER BIOFOULING PATHWAYS

There are other biofouling pathways in operation across the region, but they are not the focus of this white paper and are not discussed in detail. A brief description of two other pathways is included in this subsection, along with references for more information if desired.

Marine debris includes any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment (NOAA 2016b). Marine debris can also include debris released into the ocean via tectonic and tsunami activity and transported across ocean basins (Barnea et al. 2012). Because marine debris consists of solid materials, they can accumulate biofouling organisms and facilitate their transfer across ocean basins and into new areas. For more information on management of biofouling associated with marine debris, see the *Response Protocols for Biofouled Debris and Invasive Species Generated by the 2011 Japan Tsunami* (Barnea et al. 2012).

In addition to biofouling impacts on **aquaculture** facilities and productivity, the movement of fouled aquaculture stock and gear can also facilitate the transport of NIS if not properly managed prior to being placed into a new environment. For more information about the NIS introduction risks, and management options, related to aquaculture activities, see:

- *An Analysis of Aquaculture as a Vector for Introduced Marine and Estuarine Species in California* (Grosholz et al. 2012)
- New Zealand's *Options to Strengthen On-farm Biosecurity Management for Commercial and Non-commercial Aquaculture* (Georgiades et al. 2016)

3. DISCUSSION

Nonindigenous species are being moved into and throughout the U.S. Pacific states and British Columbia by commercial merchant and passenger vessels, recreational vessels, commercial fishing vessels, and mobile marine infrastructure. This movement of species is largely unregulated and, without effective management requirements and outreach, is likely to facilitate successful introductions of NIS into and throughout the region.

At the scale of an individual vector (e.g., vessel), the likelihood of extensive and diverse biofouling communities is dependent on the vessel's operational profile and maintenance practices, many of which are influenced by financial incentives or regulatory requirements for biofouling management. Estimating a categorical level of NIS introduction risk (e.g., high, medium, low) from a single vector prior to arrival is achievable, based on knowledge of that vessel's operational profile, maintenance history, and biofouling survey results (if available).

At the scale of a vector group (e.g. commercial merchant and passenger vessels), NIS introduction risk is dependent on the vector population size and their activity levels (e.g., where and how often they move). The available data for vector population and activity levels vary along a spectrum by vector type, from very little available information for mobile marine infrastructure to abundant information for commercial merchant and passenger vessels (Figure 9).

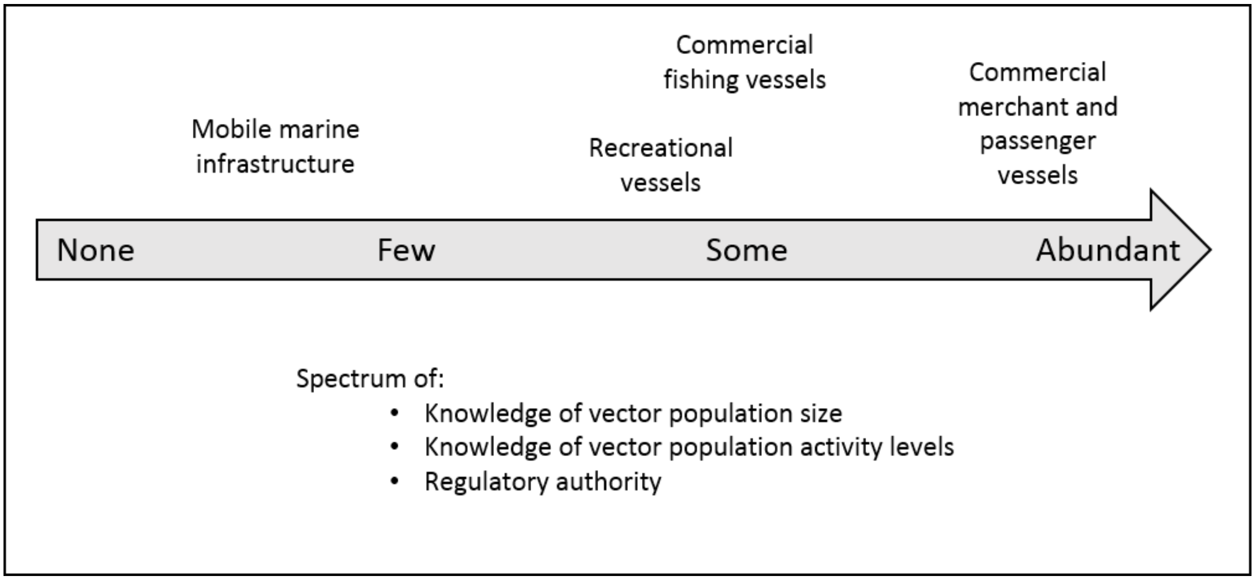

Figure 9. Generalized spectrum of our knowledge of vector population size, knowledge of vector activity levels, and existing regulatory authority for four categories of vector types.

Much is known about **commercial merchant and passenger vessels** operating in the U.S. Pacific states and British Columbia. The existence of federal or state invasive species programs that track commercial merchant and passenger vessel movements for compliance with ballast water management requirements provides easily accessible data on vessel populations, activity levels (e.g., last port and next port), vessel-type (e.g., container, bulk), and connectivity with other states and British Columbia. Some states also collect hull husbandry and operational practice data from these vessels to identify the prevalence of maintenance and operational practices that influence biofouling extent and survival. Hull husbandry data collection occurs or has occurred in the following states:

- California: Annual mandatory submission of a Hull Husbandry Reporting Form since 2008
- Oregon: Voluntary submission of a Hull Husbandry Reporting Form in 2008 and 2009
- Hawaii: Voluntary submission of a Hawaii DLNR Hull Husbandry Reporting Form in 2013 and 2014

State or provincial regulatory authority is also mostly clear and defined for commercial merchant and passenger vessels, a fortunate byproduct of existing ballast water management authority over these vessels. Two exceptions to clear state or provincial authority over commercial merchant and passenger vessels exist in British Columbia and Alaska. In both cases, federal regulations provide some level of protection regarding NIS introduction risks related to ballast water, but minimal biofouling management protection. *Establishing clear authority to manage NIS introduction risks from commercial merchant and passenger vessel biofouling is an obvious first step to protect the regional coastline*.

Information on **recreational vessel** population size and activity levels is sparse and limited when compared to commercial merchant and passenger vessels. Aside from U.S. Customs and Border Patrol data on international arrivals, there are very few available sources for recreational vessel population size and no agencies or authorities that collect standardized data on transit patterns. This lack of population and activity data limits our understanding of statewide, province-wide, or region-wide NIS risk from recreational vessel biofouling. The limited data that are available indicate that recreational boat activity is very seasonal, with peaks in activity during the summer and fall months. In addition to the lack of available information on recreational vessel population and activity level, *most U.S. Pacific states and British Columbia have no clear regulatory authority over these vessels.* Washington and Hawaii both have authority over these vessels, but no statewide management actions have been proposed.

Commercial fishing vessel population and some activity level data are available through a variety of sources, including permit and fish landing data. This availability allows for vector population estimates and a limited amount of activity level information (e.g., arrivals). These data, however, do not reveal any information about where these vessels go during off-seasons or their maintenance histories (e.g., antifouling system use). *Similar to recreational vessels, there is no clear biofouling and NIS management authority over commercial fishing vessels throughout the region*.

Mobile marine infrastructure as a vector category is at the low end of the spectrum of our knowledge of vector population size, vector activity levels, and regulatory authority. Many of these structures or vessels are moved infrequently for project-specific purposes. If the projects are high-profile (e.g., mobile offshore drilling unit operations in the Chukchi Sea), then identifying the vectors and their activity level may be possible through news media. If the projects are low-profile (e.g., maintenance dredging of navigation channels in the San Francisco Bay), the activities often go unnoticed by regulatory agencies charged with reducing the risk of NIS introduction and useful data may not be widely available. Knowledge of region-wide NIS introduction risk for these vectors is limited by the wide variety of, and often unavailable, data. *This category of mobile marine infrastructure is also so wide and varied (anything from MODUs to offshore buoys), that regulatory oversight for the purposes of minimizing NIS introduction risk is nonexistent at present.*

Although the availability of vector population and activity level data varies across these four vector types, the risk of NIS introduction and spread via vessels (large and small) and MMI is widely acknowledged (Cawthron Institute 2010, Inglis et al. 2012, Davidson et al 2014a, 2014b, NZ MPI 2014). Efforts should be made to increase data availability. Efforts should also be made to develop and implement regulatory or outreach programs. Coordinating regional consistency with these regulatory or outreach programs should be the ultimate goal for the Coastal Committee, to ensure cooperation, compliance and environmental protection.

4. RECOMMENDATIONS TO REDUCE THE RISK OF BIOFOULING-MEDIATED NIS INTRODUCTION AND SPREAD IN THE U.S. PACIFIC STATES AND BRITISH COLUMBIA

4.1. COMMERCIAL MERCHANT AND PASSENGER VESSELS

- Continue to develop and adopt biofouling management requirements at the state or provincial level
    - Regional partners should work together through task forces, advisory groups, and the Pacific Ballast Water Group to align policies as much as possible
    - Regional partners should work together to ensure that all policies are consistent with IMO Biofouling Guidelines
- Develop and implement a regionally consistent in-water cleaning model framework to identify and reduce NIS introduction risks
    - Note: Although organism discharge thresholds can be aligned across the region, heavy metal discharge thresholds will vary from state to state to province and from one water body to another

4.2. RECREATIONAL VESSELS

- Identify or work with state or provincial legislature to designate an agency with regulatory or oversight authority over biofouling management of recreational vessels within each state and British Columbia
- Establish outreach programs to provide targeted biofouling management education before and during seasonal activity peaks
- Develop regionally consistent best management practices (BMPs), including a “clean before you leave” strategy, collaboratively through the WRP Coastal Committee
    - Note: Regionally consistent outreach and BMPs are likely to be effective because of the strong vessel transit connectivity between regional bays and states (and British Columbia). Synergistic efforts are more likely to be effective if boaters hear the same message when they travel.
- Investigate the feasibility of state or provincial data collection on vessel arrivals

- If necessary, investigate the feasibility of regulation development and implementation

4.3. COMMERCIAL FISHING VESSELS

- Identify or work with state or provincial legislatures to designate an agency with regulatory or oversight authority within each state and British Columbia (e.g., existing commercial fishing permitting agencies)
- To understand commercial fishing vessel transits between jurisdictions (state to state/province), existing data held by the USCG, states, and organizations must be analyzed to detect overlaps and inconsistencies, and identify mechanisms to align datasets to the greatest extent possible
  - Effort should be collaborative and should be endorsed by the Pacific States Marine Fisheries Commission.
- Develop regionally consistent BMPs that must be followed and documented to obtain or maintain a permit
  - Consistent BMPs should be developed collaboratively through the WRP Coastal Committee and the Pacific States Marine Fisheries Commission
  - Homeport affinity was high across the region, regulatory or oversight attention could be focused on vessels moving between ports

4.4. MOBILE MARINE INFRASTRUCTURE

- Identify and conduct outreach to appropriate permitting agencies for projects involving mobile marine infrastructure (and associated support vessels) within each state and British Columbia
- Develop regionally consistent BMPs for biofouling management that must be followed and documented to obtain or maintain a permit
  - Consistent BMPs should be developed collaboratively through the WRP Coastal Committee

4.5. GENERAL RECOMMENDATIONS

- Continue regional collaboration to ensure consistent biofouling management policies across the region
  - Include participation of Western Regional Panel Coastal Committee, Pacific Ballast Water Group, and state-specific task forces, working groups, and advisory groups

    - Ensure that vessel owners, operators, and other interested stakeholders are included in policy development discussions
- Identify and designate agencies for outreach or regulatory authority within each state and British Columbia
    - Identify possible funding sources, including add-ons to permit or license fees

4.6 RECOMMENDED ACTION ITEMS FOR THE WRP COASTAL COMMITTEE

Although some of the recommendations in this white paper are targeted at individual states or British Columbia (e.g., identify possible funding sources for outreach or regulatory oversight), several are suggested specifically for the Coastal Committee to act on. Two Coastal Committee action items, in particular, are necessary, practical, and achievable, as detailed below:

- Develop regionally consistent best management practices (BMPs) for biofouling management of recreational vessels, commercial fishing vessels, and mobile marine infrastructure. Clear and consistent messaging across jurisdictions is important for managing vectors that move between bays, states, and provinces. BMPs can also be tied to permitting language or leases to ensure that commercial fishing vessels and mobile marine infrastructure are managed appropriately.

- Develop a regionally consistent in-water cleaning regulatory model framework for commercial merchant and passenger vessels to identify and reduce NIS introduction risks. Water quality-based restrictions on in-water cleaning vary from water body to water body and state to state to province, so a comprehensive (chemical and biological pollution) and consistent regional framework is not practical for the region. However, it is practical to develop a regionally consistent regulatory model framework focused on reducing NIS introduction risks that can be employed throughout the region (if adopted and implemented within each state and province). The practical result of an effort like this would be that in-water cleaning permitting agencies in individual jurisdictions would consider applications from two perspectives, one would be the local water quality perspective and the other would be the regionally consistent bioinvasion perspective.

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