

# Effects of Hull Coatings & Hull Cleaning Practices on Fouling Organisms (Southern & South-Central California Ecological Research)

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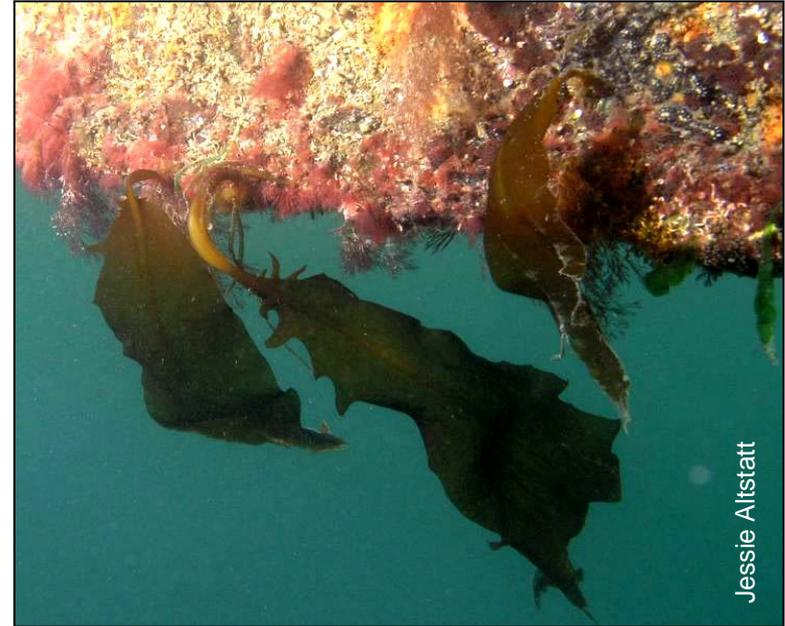
# Changes Facing West Coast Boaters

- CA SWRCB requires that copper discharged from AF paints in Shelter Island Yacht Basin of San Diego Bay be reduced by 75% during 2007-2022 (TMDL Regulatory Program)
- RWQCBs are concerned re: elevated Cu in other San Diego Bay locations, in Newport Bay and Marina Del Rey
- Statewide restrictions may or may not be implemented in CA
- WA law restricts Cu antifouling paint to low level



# California AIS Policy

- The California Aquatic Invasive Species (AIS) Management Plan Strategy 2c: Recreation
- Calls for limiting new AIS introductions through recreational boating, fishing, diving and other water-based activities.



Asian kelp on boat keel

Source: California Department of Fish and Game. 2008. California Aquatic Invasive Species Management Plan and Appendices: 22, 66-67. January 2008. <http://www.dfg.ca.gov/invasives/plan/>

# Transport of AIS



Encrusting bryozoan

*Watersipora subtorquata*

Interfere with boating activities

Potential impacts on natives

Outcompete natives for  
space and food

Often more copper-tolerant

Transport 'hitch-hikers'

Threat to kelp beds &  
Island ecosystems



Sea squirts – *Ciona* spp.



Tube worms – *Hydroides* spp.



Asian kelp

*Undaria pinnatifida*

# Transport of AIS

## *Sargassum horneri*

2003: Long Beach Harbor

Now: Santa Cruz Island south to  
Isla Natividad, Baja California



Research diver, Lindsey Marks,  
next to *S. horneri*



*S. horneri* at Catalina Island



Juvenile, *S. horneri*



Adult, *S. horneri*

# Balanced Approach

## Boat Operations & Ecosystem Health

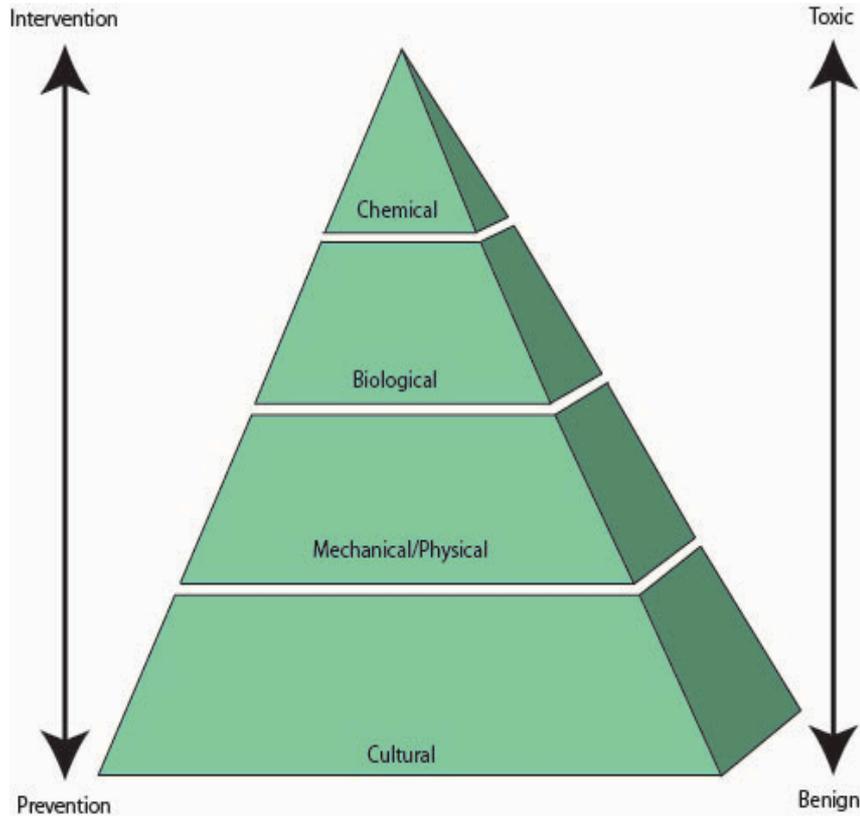


Performance and Efficiency



Water Quality and  
Non-native Invasive Species

# Managing Hull Fouling



## IPM for Boats in Harbors

Use multiple tactics

Target multiple life stages

Adaptively manage

**Not a one size fits all!**  
**Strategy adapted to boater's situation**

# Chemical Control

## Antifouling Paints and Coatings

### Toxic Paints

Reduce fouling (not 100%)

Copper-based

Zinc-based

Short-lived organic

### Biocide-Free Coatings

Restrict water penetration,  
not fouling

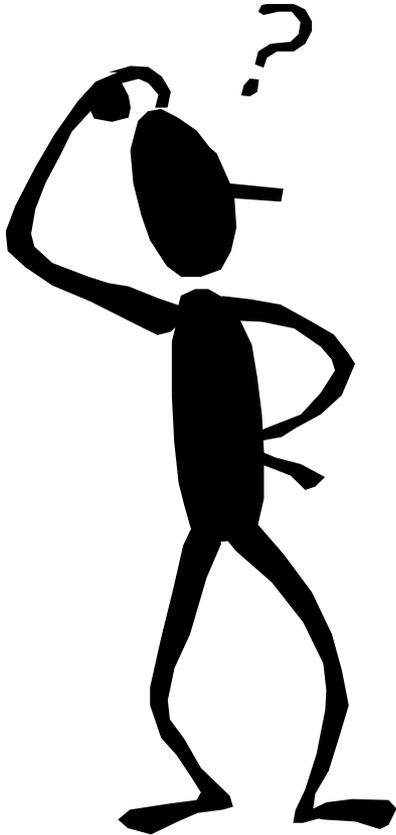
Epoxy ceramic (epoxy)

Siliconized epoxy (slick)

and others



# Research Questions



- How does the **coating type** applied to a boat affect recruitment of fouling organisms, particularly non-native invasive species?
- How effective is **copper**-based AF paint in the **long term**?

# Coating Type Experiment Methods

## Two Study Sites

Santa Barbara Harbor (Blue dot)

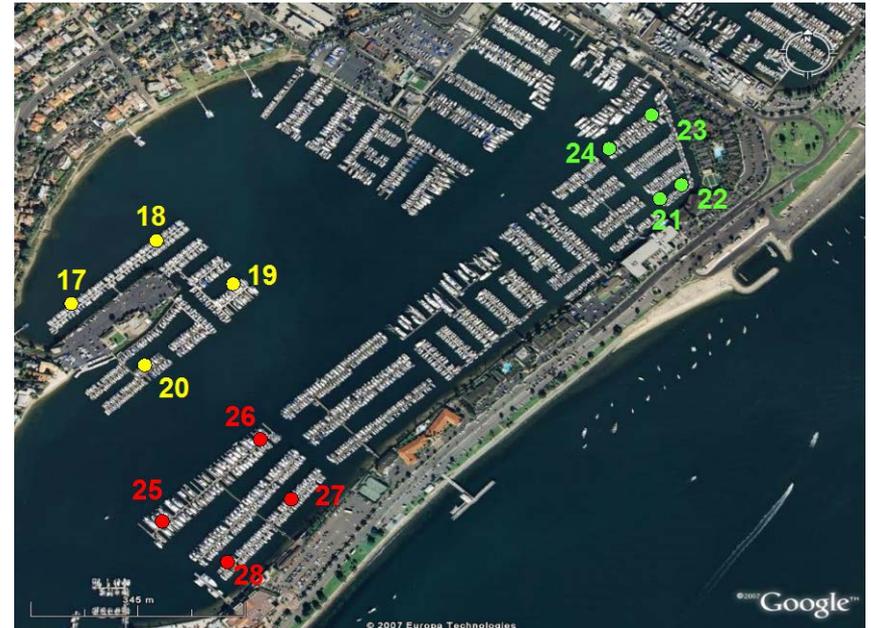
4 locations x 4 replicates = 16 stations

San Diego Bay (Pink dot)

3 locations x 4 replicates = 12 stations



Santa Barbara Harbor



San Diego Bay

# Coating Type Experiment Methods

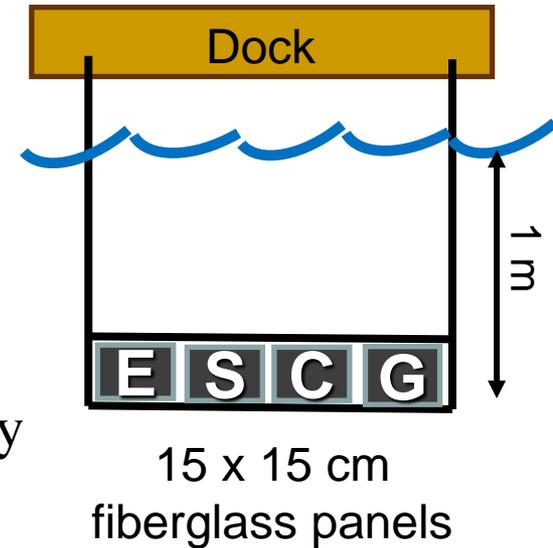
## Coating Types (n=4) (all black)

Gel (G): Cook's Composites Polyester Gel

Epoxy (E): CeRam-Kote Biocide-Free Ceramic-Epoxy

Slick (S): Eco-5 Marine Biocide-Free Siliconized Epoxy

Copper (C): Interlux Epoxy Modified AF



Time Period: monthly intervals, one year (April-March)

Recruitment Measurements: Percentage of cover

Counts (non-colonial)

# Coating Type Experiment Results

More than 30 spp.; 8 phyla

12 non-native, 11 native, 1 cryptogenic, 11 unresolved

- Non-natives

  - Tube worms

  - Tunicates (colonial and non-colonial)

  - Bryozoans (encrusting, branching)

- Several spp. with unresolved taxonomy

  - Encrusting bryozoans

  - Green algae

  - Spirorbid* tube worms

# Coating Type Experiment Results

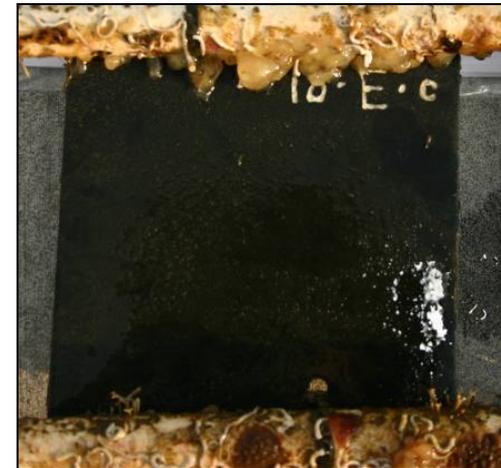
**\*\* All coating types became fouled \*\***

## Copper-based Antifouling Paint

Fouling **extremely low** (1-month intervals on new copper paint)

7 organisms:

- *Hydroides elegans*, *Diplosoma listerianum* (NN)
- Tubes of *Laticorophium baconi* (cryptogenic)
- *Spirorbis* sp., *Cladophora* sp. and *Enteromorpha* sp. (unresolved taxonomy)
- Unidentified sabellid worm (most likely *Pseudopotamilla* sp.)



Copper panels dropped from analyses

# Results

## Biocide-Free Coatings

Location	Effect	Wilks' value	F	P
<b>Santa Barbara</b>	<b>Hull Coating</b>	0.684	1.06	0.395
<b>San Diego</b>	<b>Hull Coating</b>	0.327	2.68	<b>&lt;0.001</b>

<b>San Diego</b>	Coating	
Dependent Variable	F	P
<i>Cladophora</i> sp.	0.51	0.602
<i>Botrylloides violaceus</i>	1.78	0.178
<i>Botryllus schlosseri</i>	2.46	0.095
<i>Diplosoma listerianum</i>	0.87	0.425
<i>Ciona</i> spp.	0.11	0.900
Bugula neritina	1.52	0.229
<b><i>Watersipora subtorquata</i></b>	9.22	<b>&lt;0.001</b>
<i>Cryptosula pallasiana</i>	1.91	0.157
Amphipod tube mat	0.58	0.561
<b><i>Hydroides</i> spp.</b>	4.08	<b>0.022</b>
<i>Filograna implexa</i>	2.04	0.140
Spirorbid worm	1.66	0.200

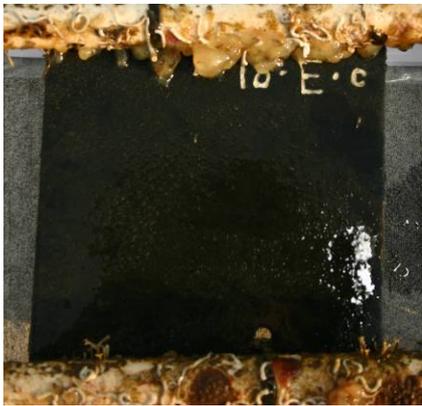
# Results

## Biocide-Free Coatings

*Hydroides* spp.: Higher fouling on epoxy tiles as compared to slick

*Watersipora subtorquata*: Higher fouling on slick and epoxy tiles as compared to gel

Copper



Gel



Epoxy



Slick



# Long-Term **Copper** Exposure Experiment

How effective is **copper**-based AF paint  
in the **long term**?

Do non-native species settle sooner than natives?

Do non-native species occupy more space  
over time than natives?

# Long-Term Copper Exposure Experiment Methods

1 Site, 2 Locations, 8 Stations

San Diego Bay (Pink dot)

Half Moon Anchorage (inner)

Kona Kai Marina (outer)



San Diego Bay

Dissolved copper  
levels substantially  
higher at inner  
location

# Long-Term Copper Exposure Experiment Methods

## Exposure Times (n=3)

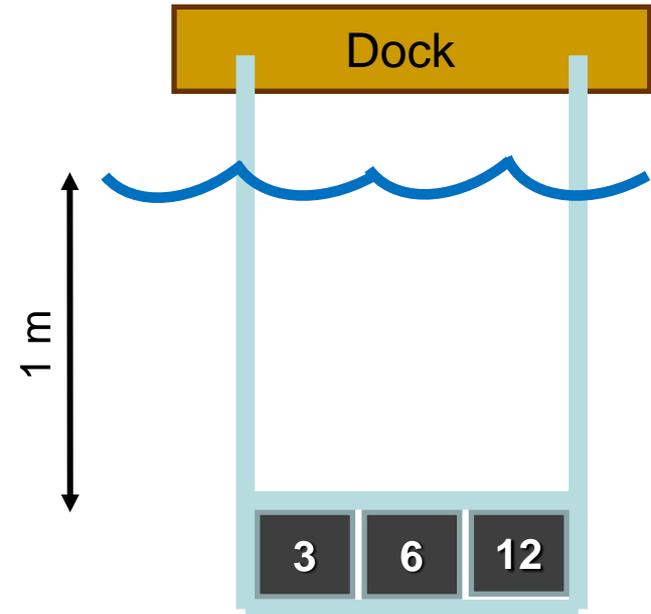
3, 6, 12 months

## Time Period

One year (July-June)

## Recruitment Measurements

Percentage of cover, counts (non-colonial organisms)

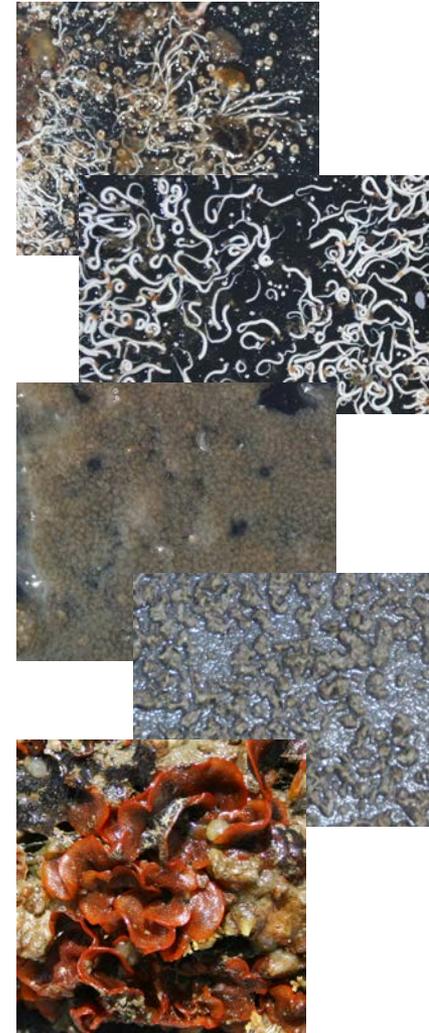


15 x 15 cm fiberglass panels

# Long-Term Copper Exposure Experiment Results

Many more organisms (22 spp.; 6 phyla) than on new copper exposed for 1 month  
Common: 5 non-native (O), 2 native (G), 1 cryptogenic (Y), 1 unr (P)

Taxa	Species	Origin	1 mo	3 mo	6 mo	12 mo
<b>Algae</b>	*Cladophora sp.	Unr	x			
	*Colpomenia sp.	Unr			x	
	*Enteromorpha sp.	Unr	x			
	*Green monofilament	UnID		x		
	Rhodymenia californica	N			x	x
<b>Polychaeta</b>	Filograna implexa	NN		x	x	x
	Hydroïdes spp. complex H. elegans, H. gracilis	NN/N	X	x	x	x
	Sabellid	Unr	x			
	Spirorbid sp.	Unr	x	x	x	x
<b>Chordata</b>	Aplidium californicum	N				x
	*Botrylloides diegensis	N				x
	*Botrylloides violaceus	NN				x
	*Ciona sp. C. intestinalis or C. savignyi	NN		x		x
	Diplosoma listerianum	NN	x	x		x
<b>Crustacea</b>	Laticorophium baconi (tubes)	C	x	x	x	x
<b>Ectoprocta</b>	Bowerbankia sp.	Unr		x	x	x
	Bugula californica	N				x
	Bugula neritina	NN			x	x
	*Celleporaria brunnea	N			x	
	*Crisulipora occidentalis	N				x
	*Cryptosula pallasiana	NN				x
	*Thalamoporella californica	N			x	
	Watersipora subtorquata	NN			x	x
<b>Porifera</b>	*Sponge	UnID				x



# Results

## Key

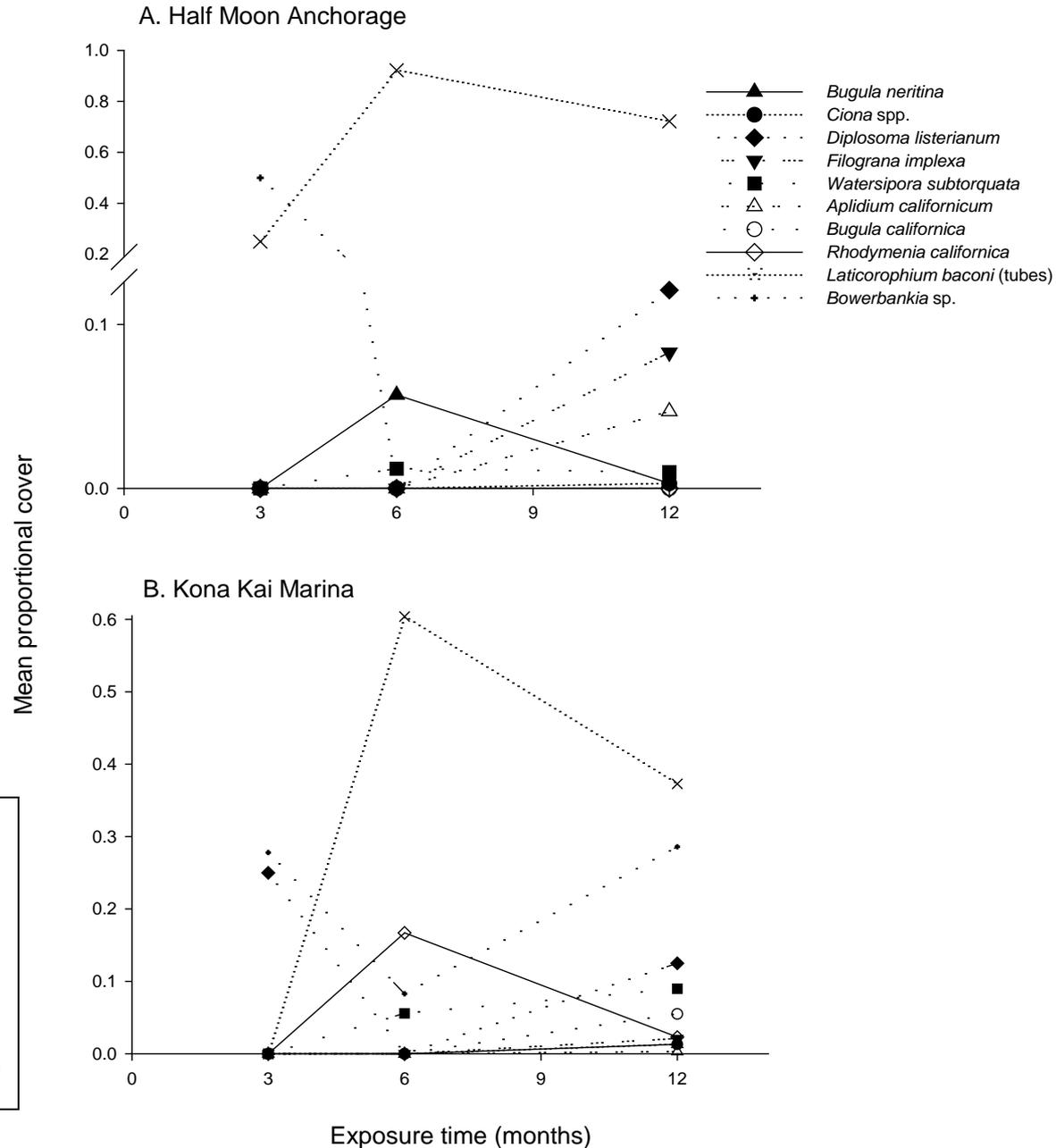
Closed symbols, non-natives

Open symbols, natives

'x' symbol, cryptogenic

'+' symbol, unresolved taxonomy

Non-native tube worms showed up early but not detected with percentage of cover, only with counts



# Long-Term Copper Exposure Experiment Results

Increased fouling at longer exposures (6, 12 months)

- Non-natives appear sooner
- Non-natives occupy more space



Panel with **copper** antifouling paint after 12 months in San Diego Bay

# Copper-Tolerant Species

- Selectivity of non-native species  
Attach directly to **copper** antifouling paint
- Provide biocide-free refuge for sensitive species  
Facilitate transport of other species



Other supporting evidence in the scientific literature

# Conclusions

- There are risks of transporting AIS via boats with copper-based paints, particularly w/ increased time (selectivity, persistence)
- Higher risk of transporting AIS on boats with biocide-free coatings
- Higher risk for transporting **certain** AIS on boats with **certain** biocide-free coatings (e.g., *Hydroïdes* tube worms)



# NIS Risks from Recreational Boat Traffic: CA and Baja CA Peninsula\*

## Overnight Visitors

➤ Races, tournaments, holidays, vacation

➤ 3,000 mi (5,000 km) coast

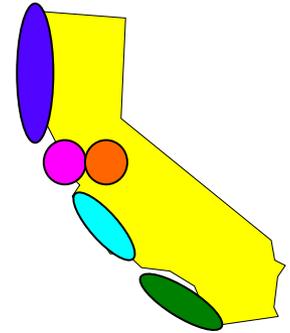
➤ Heaviest boat traffic

So. Cal ↔ Baja Cal Peninsula, SF Bay

Central Coast → SF Bay

Delta → SF Bay (salinity change, less risk)

North Coast → Central Coast, Delta, So. Cal



## Resident Boats

➤ Yet, **48%** of boats **rarely leave** marina

\*Johnson & Fernandez. 2011. A binational, supply-side evaluation for managing water quality and invasive fouling species on California's coastal boats. J. Env. Mgt. 92:3071-3081.

# Recommendations

For boats **often** used that travel **far** from home port

- Consider copper-based or alternative toxic paints, especially for hard to clean areas
- Keep boat in well flushed area of harbor

For boats **seldom** used that stay **near** home port

- Consider biocide-free coatings
- **Exception: travel to nearby islands!**

For **ALL** Boats

Need to use **additional tactics** (e.g., hull cleaning) to improve boat operations and to reduce potential spread of non-native invasive species

# “Beyond Paint” – Other Tactics for Fouling IPM

## ➤ Physical:

- Trailer: OK for small boats
- Boat “barn”: rare CA coast – waterfront space \$\$\$\$
- Boat lift: OK in 45% CA & 38% Baja CA marinas\*
- Slip liner: OK in 47% CA & 88% Baja CA marinas\*



## ➤ Mechanical

- In-water hull cleaning

## ➤ Cultural

- Timing & frequency of cleaning re: fouling recruitment

\*Johnson & Fernandez. 2011. A binational, supply-side evaluation for managing water quality and invasive fouling species on California’s coastal boats. J. Env. Mgt. 92:3071-3081.

## Part II: The Role of Hull CLEANING



# GOAL: Balanced Approach

**Ecosystem Health\* & Boat Operations\*\***

\*Water quality & Aquatic invasive species (AIS)

\*\*Fouling control & Cost effectiveness

Research-based information is needed to support:  
Sound decisions  
Sustainable policies

# “Beyond Paint” – Other Tactics for Fouling IPM

## ➤ Physical:

- ✧ Trailer: OK for small boats
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- ✧ Boat lift: OK in 45% CA &  
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## ➤ Mechanical

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\*Johnson & Fernandez. 2011. A binational, supply-side evaluation for managing water quality and invasive fouling species on California’s coastal boats. J. Env. Mgt. 92:3071-3081.

# Research Questions

- ① Does **in-water hull cleaning**, using California Best Management Practices (BMPs), stimulate fouling growth?
- ② Do fouling organisms, particularly non-native invasive species have **recruitment peaks** that could be useful in scheduling control tactics?

# Hull Cleaning Experiment

Australian research:<sup>1,2</sup>

In-water hull cleaning increases the susceptibility of vessel hulls to fouling

- Disturbance Hypothesis (space)
- Settlement Cues

Methods:

- Fouled 7 months
- Cleaned with a paint scraper
- Some sterilized, some not
- Returned to water for 2 and 6.5 wks
  - (visiting boat residence times)

1. Floerl O. 2002. Intracoastal spread of fouling organisms by recreational vessels. Dissertation. James Cook University, Townsville, Australia.
2. Floerl O, Inglis GJ, Marsh HM. 2005. Selectivity in vector management: an investigation into the effectiveness of measures used to prevent transport of non-indigenous species. *Biological Invasions* 7: 459-475.



# California Hull Cleaning BMPs

## California Professional Divers Association (CPDA):

Clean frequently with least abrasive tool possible

- **San Diego Bay** – CPDA-recommended hull cleaning frequencies
  - ✧ *Copper-based paints* – 13 times/year
  - ✧ *Biocide-Free hull coatings* – 26 times/year
- Mean **regional** hull cleaning frequencies for *Copper-based paints*:\*
  - ✧ 4 times/year in northern CA
  - ✧ 12 times/year in southern CA
  - ✧ 16 times/year in Baja CA

\* Johnson LT, Fernandez LM, Lande MD. 2012. Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California & Baja California.

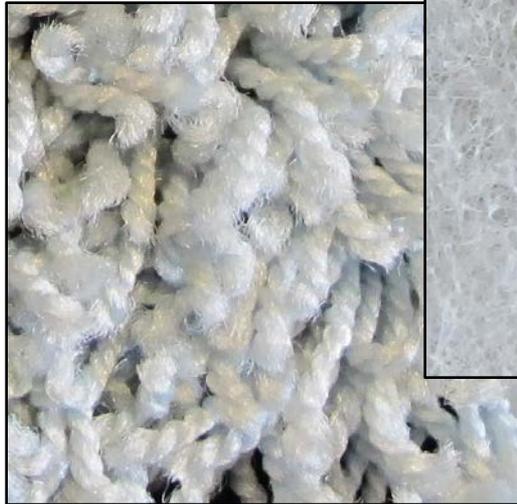


# Gentle Hull Cleaning Tools

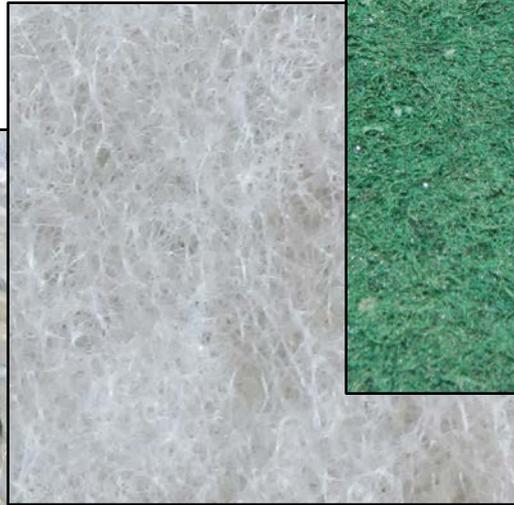


**Soft-bristled, powered brushes**

**Hand-held pads**



Shag Carpet - Level 1



White 3M™ pad - Level 1



Green 3M™ pad - Level 2

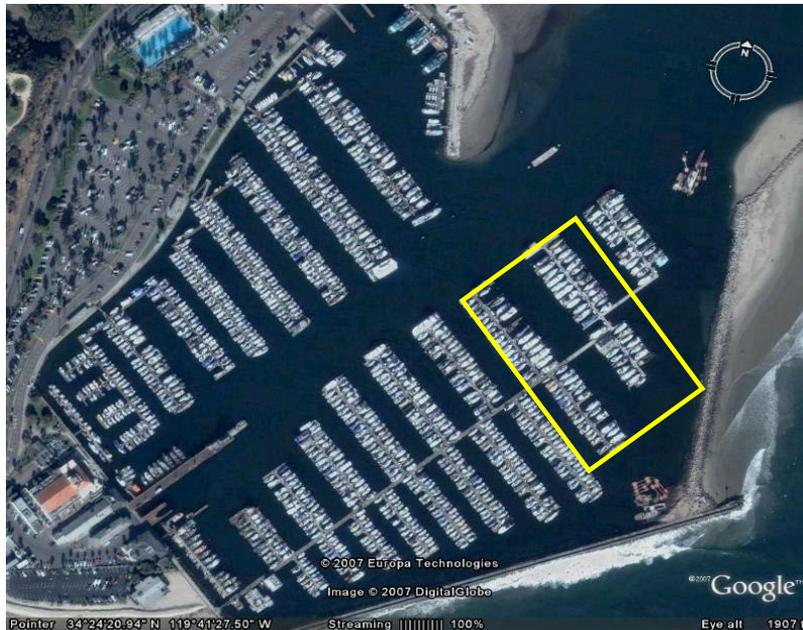
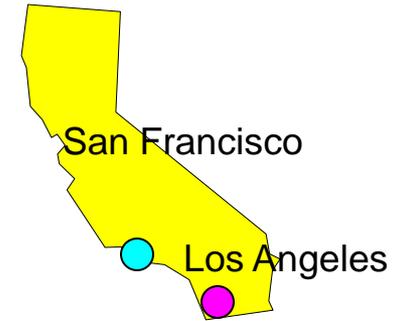
# Study Locations

Three Sites:

Santa Barbara Harbor (4 stations)

San Diego Bay (8 stations)

Half Moon Anchorage and Kona Kai Marina



Santa Barbara Harbor



San Diego Bay

# In-Water Hull Cleaning Experiment - Methods

## 3 panel types:

- ✧ **Biocide-Free** epoxy coating
- ✧ **Biocide-Free** slick coating
- ✧ **Copper** antifouling (AF) paint

## 3 cleaning treatments:

### First 3 months:

- **Frequently** cleaned (BMPs)
  - Biocide-Free** coatings – every 2 weeks
  - Copper** AF paint – every 3 weeks
- **Not** cleaned in first 3 months

### 4<sup>th</sup> month:

- **All cleaned and returned to water**
- **New** (never cleaned) **added**

**Tools:** Carpet; White or Green hand-held pads

## **Time Period:**

Peak “recruitment” period (July-Oct)



Installing experimental frames



Cleaning at end of 3<sup>rd</sup> month

# In-Water Hull Cleaning - Results

Fouling Biomass:

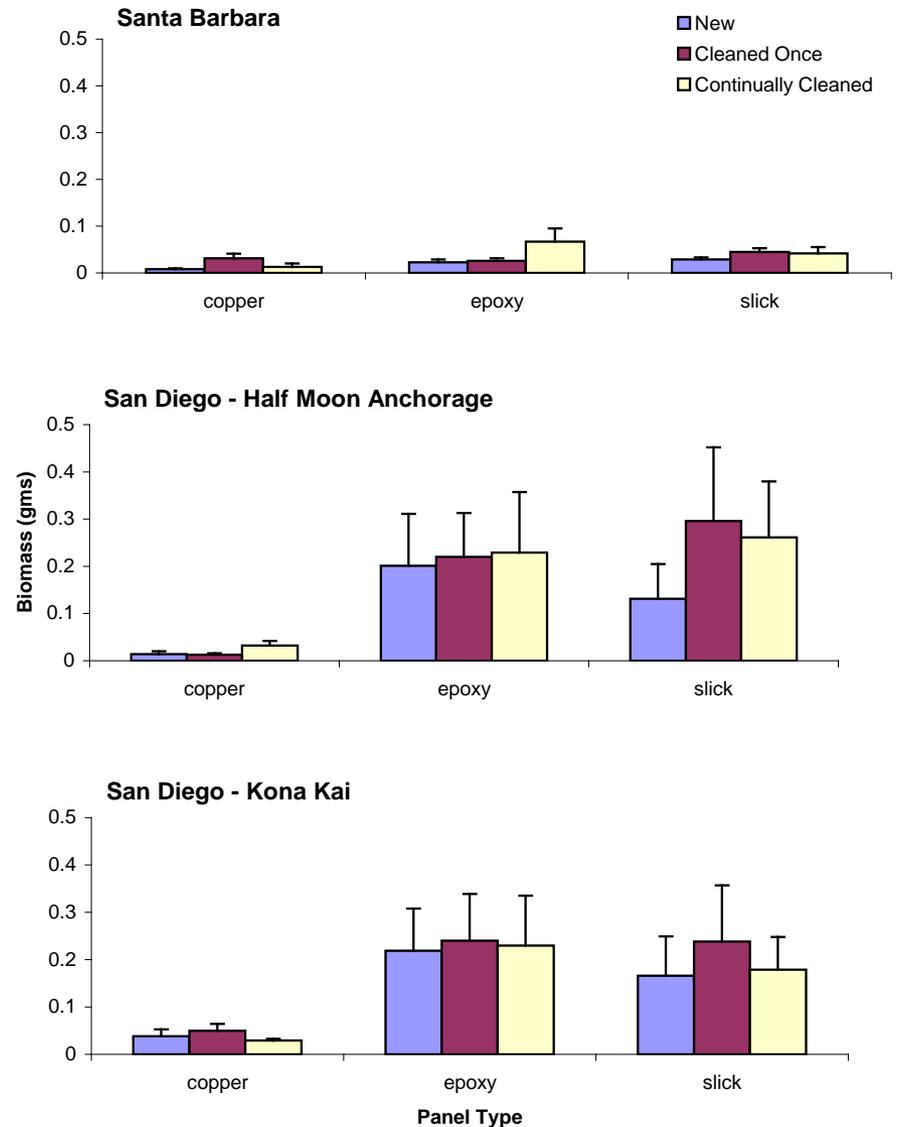
- ✓ Coating type & geography matter
- ✓ Cleaning does not matter

ANOVA

Variable	F Value	prob
*Location	28.51	<0.0001
*Panel type	50.84	<0.0001
Cleaning treatment	2.56	0.0829

\*statistically significant results

Biomass Accumulation



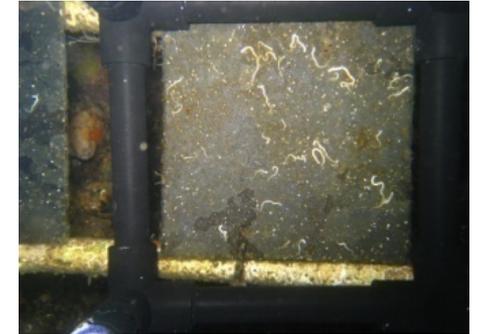
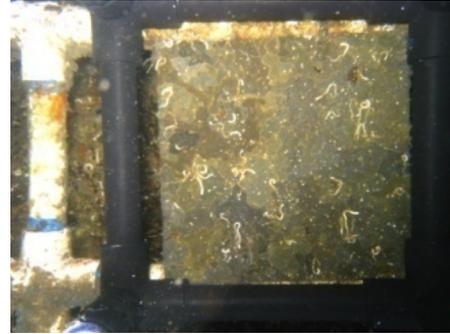
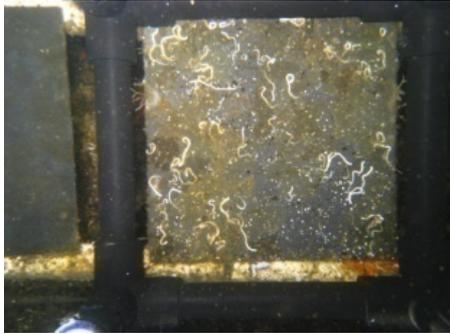
# Frame #34 - Kona Kai Marina, San Diego, CA

Multiple cleanings for 3 mos.

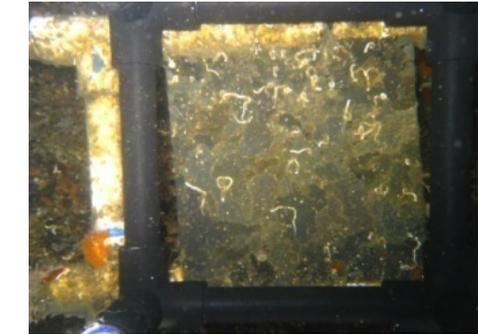
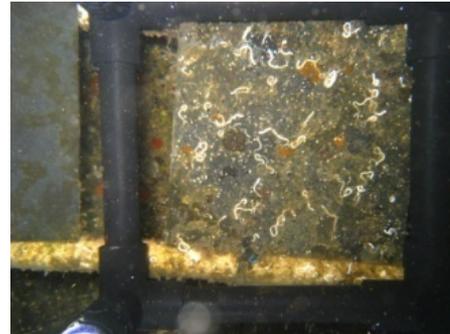
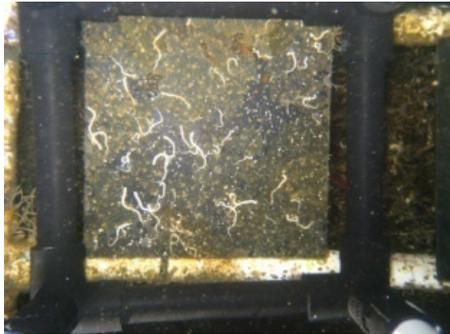
Single cleaning after 3 mos.

Never cleaned/new for mo. 4

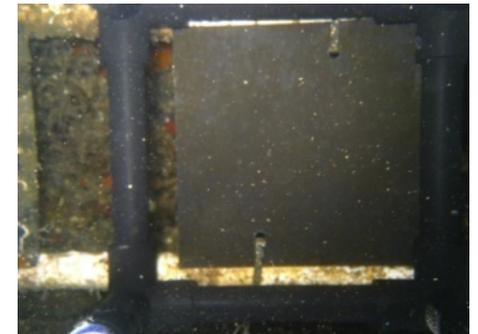
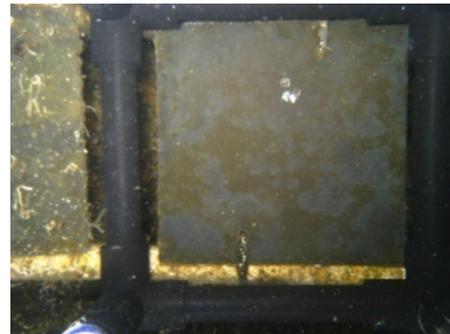
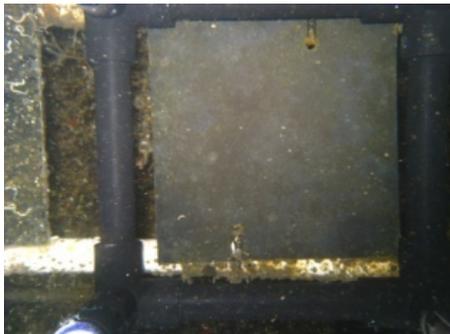
**Ceramic  
Epoxy**



**Siliconized  
Epoxy  
(Slick)**



**Copper**





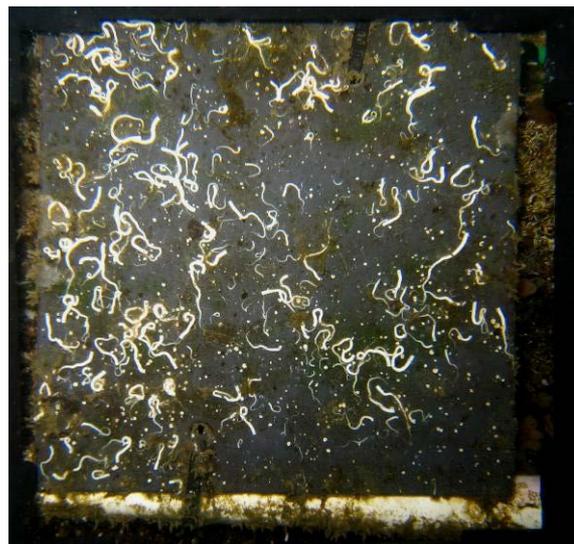
# All Locations

## Epoxy - Multiple Cleanings

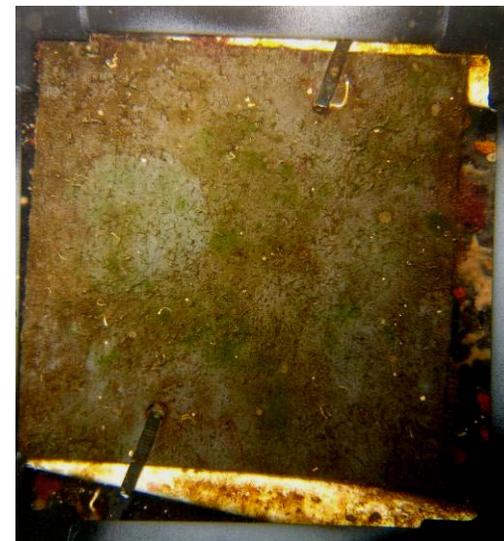
Kona Kai Marina, San Diego



Half Moon Anchorage  
San Diego



Santa Barbara Harbor



# CA Hull Cleaning BMPs

## Frequent cleanings:

- Less effort (fewer, smaller organisms)
- Less abrasive tool → Longer life of coatings
- Fewer deep scratches and chipping; left over 'parts'
- Fouling growth less developed, so less risk of transporting reproductive individuals:



1 month



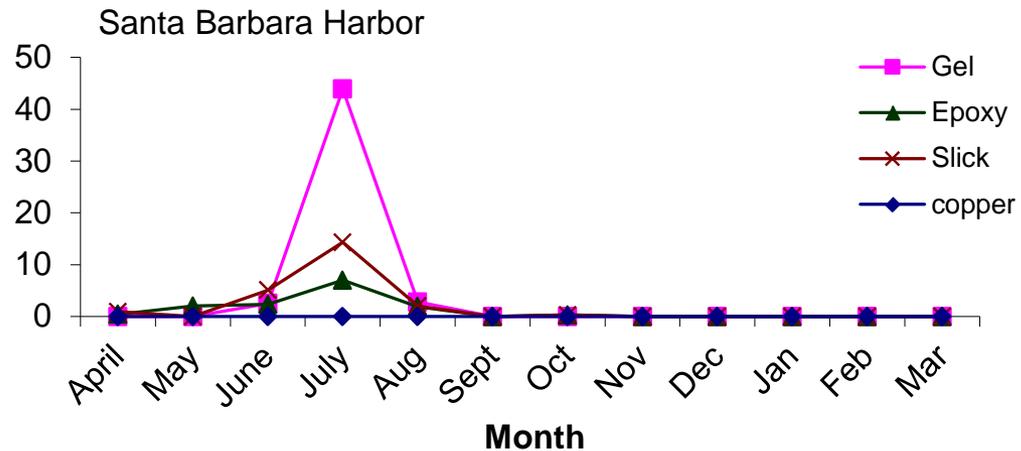
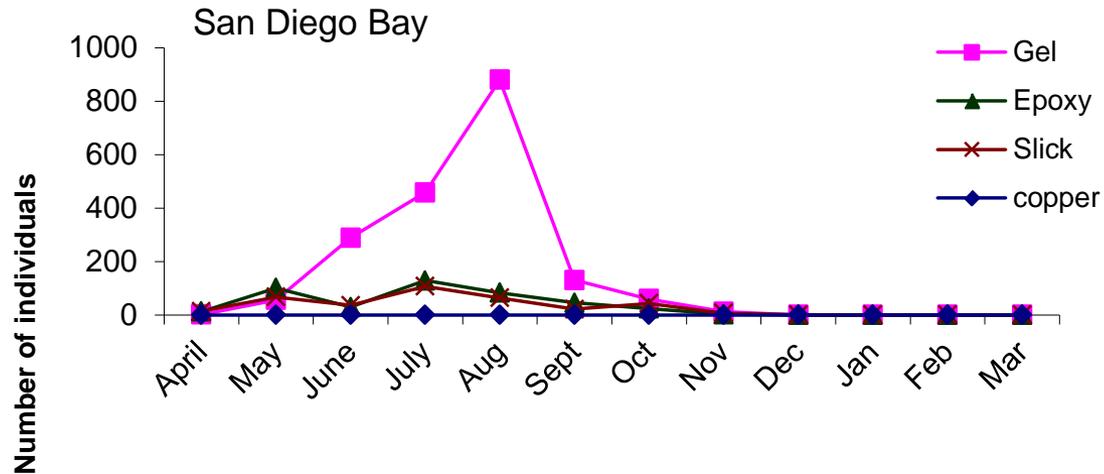
3 months



12 months

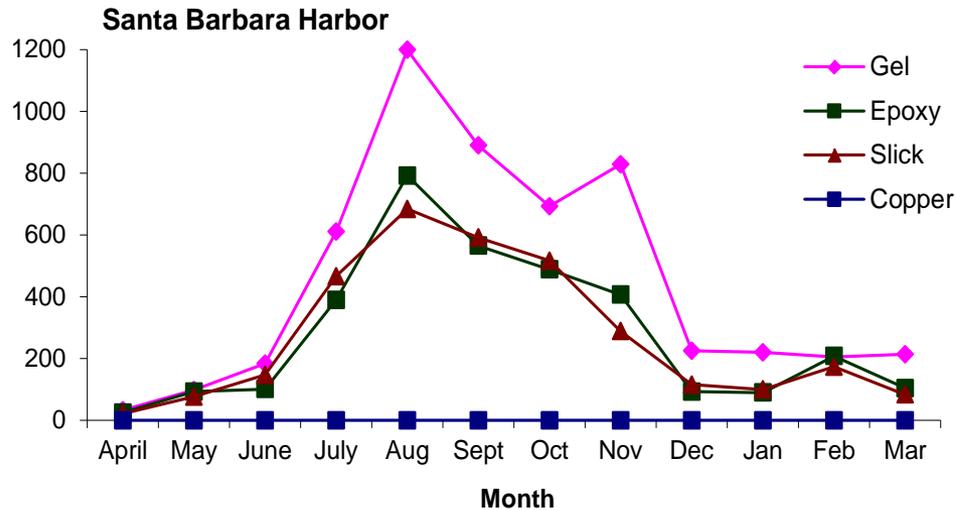
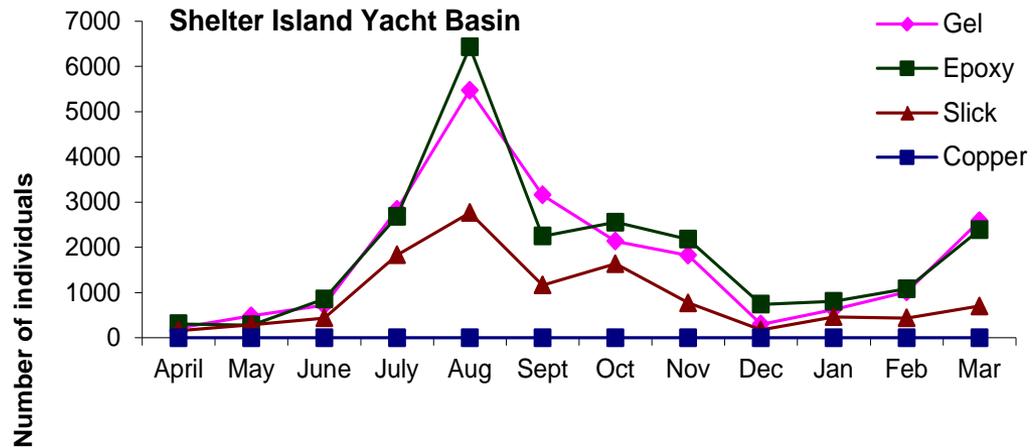
# Recruitment Patterns - Pulse

## Filograna implexa Note Scale



# Recruitment Patterns – Year-Round

## *Spirorbid* sp. Note Scale



# Other Factors to Consider in Integrated Approach

- Time of the Year (Season)
- Harbor Location (geography)
- Slip Location
  - Water flow
  - Sunny vs shady
  - Nearby sources of fouling species



# Summary of Coating & Cleaning Results

- Paint/coating type and age important
- Location important
- California hull cleaning BMPs (frequent and gentle) do not stimulate new fouling
- Fouling recruitment peaks matter when scheduling toxic hull coating applications and cleaning

# Recommendations

**Create Integrated Pest Management (IPM) strategy via a suite of fouling control tactics**

**Choose hull coating to suit boat's travel pattern**

- **Biocide-Free** hull coatings for boats that rarely leave home (50%)
- **Toxic** hull coatings for boats that go far or often

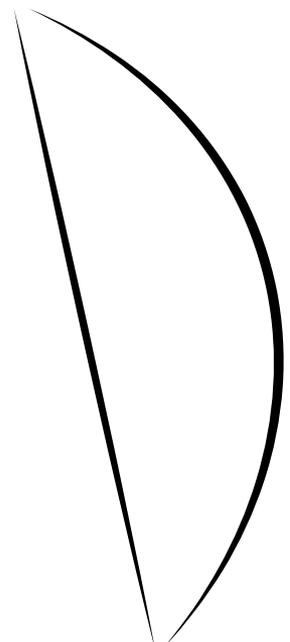
**Locate boat according to hull coating**

- **Toxic** hull coatings in well-flushed areas

# Recommendations

## Clean before you leave/Clean before you return!

- Clean hull before departing to other region, island, or event
- Clean hull again before moving on or returning home
  - ✧ Consider location, exposure time, season
- If boat is kept in or visits a major port, be especially diligent about cleaning the hull before departing
- Upon arrival, haul and clean heavily fouled hulls
  - ✧ Contain and dispose removed fouling on land
- In other words.....

The logo of the University of California, featuring a stylized sun or arc shape.

**University of California**  
Agriculture and Natural Resources

A decorative banner with a wavy, ribbon-like border, containing the main text.

**CLEAN** *then* **CRUISE**

# Online Resources

**Coastal Resources website <http://ucanr.edu/sites/coast>**

- **IPM for Boats: Integrated Pest Management for Hull Fouling in Southern California Coastal Marinas (28p)**  
(IPM strategies & tactics + ecological, coatings & cleaning research)
- **Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California and Baja California (16p)**  
(supplies/services; costs/availability; boater behavior)
- **Hull Fouling and Copper Tolerance – 2011 Scientific Review (4p)**  
(English y Español)
- **And many short publications in English y en Español**

**Boating Environmental Forum blogsite**  
**<http://ucanr.edu/blogs/BoatingEnvironmentalForum/>**

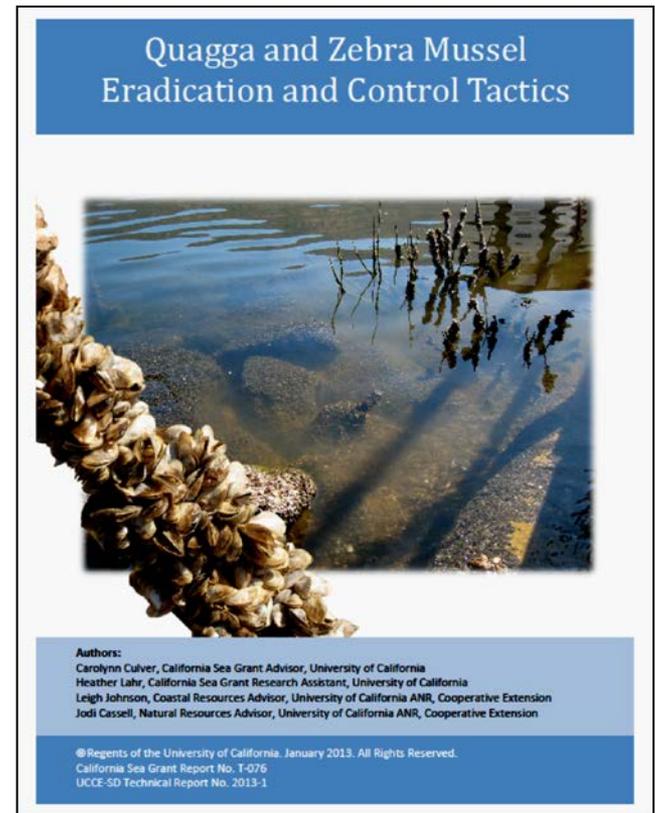
**Leigh Johnson [ltjohnson@ucanr.edu](mailto:ltjohnson@ucanr.edu)**

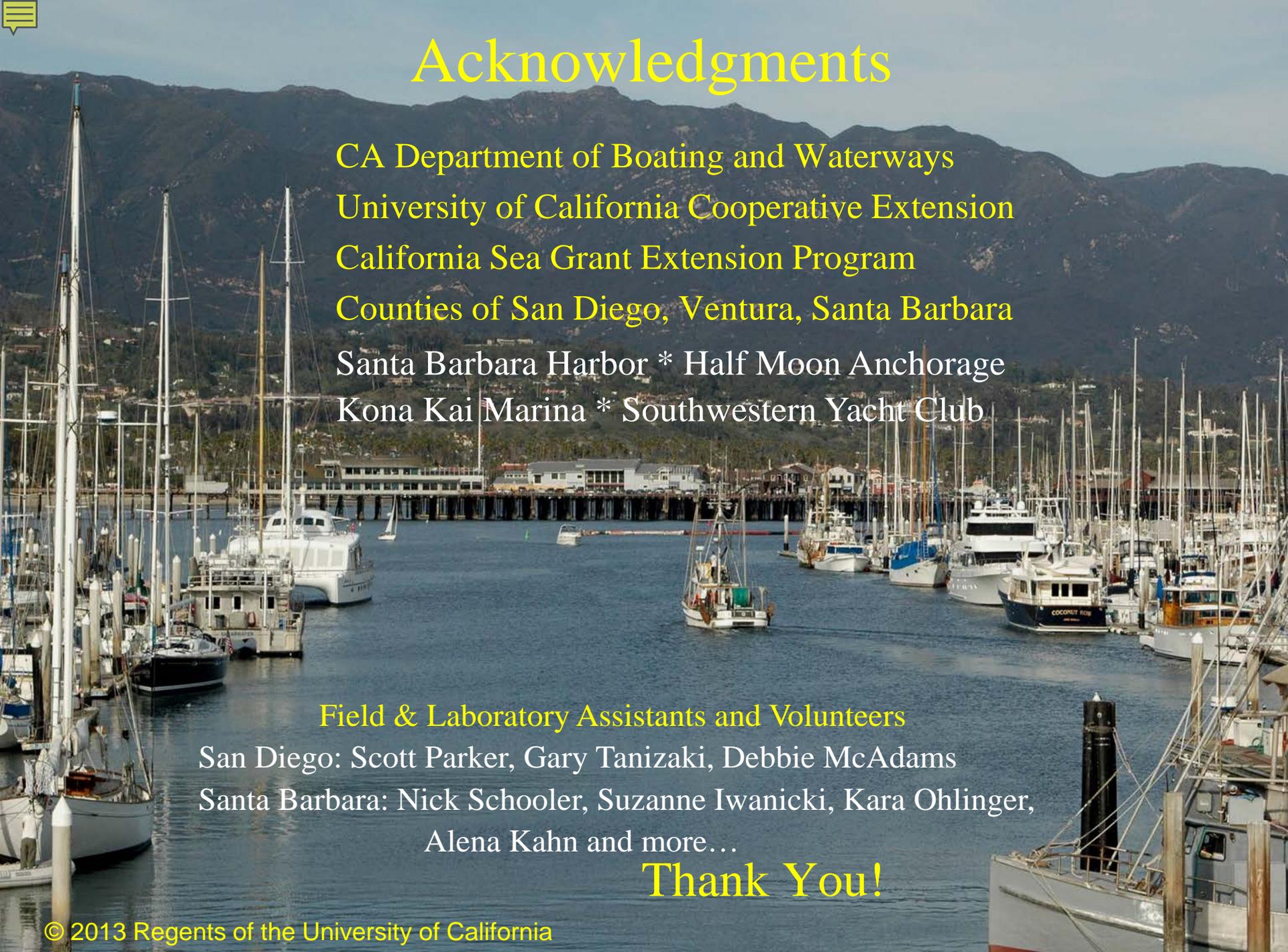
# Aquatic Invasive Species Eradication & Control Web Site for Lake Managers

- Focus: QZM (broadly applicable to AIS eradication & control)
- Workshop materials
  - Agenda
  - Extended abstracts
- Information Sheets
  - Individual strategies & other info
  - Combined in Technical Report
  - References & Weblinks

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[http://ca-sgep.ucsd.edu/quaggazebra\\_mussel\\_control](http://ca-sgep.ucsd.edu/quaggazebra_mussel_control)





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## Thank You!