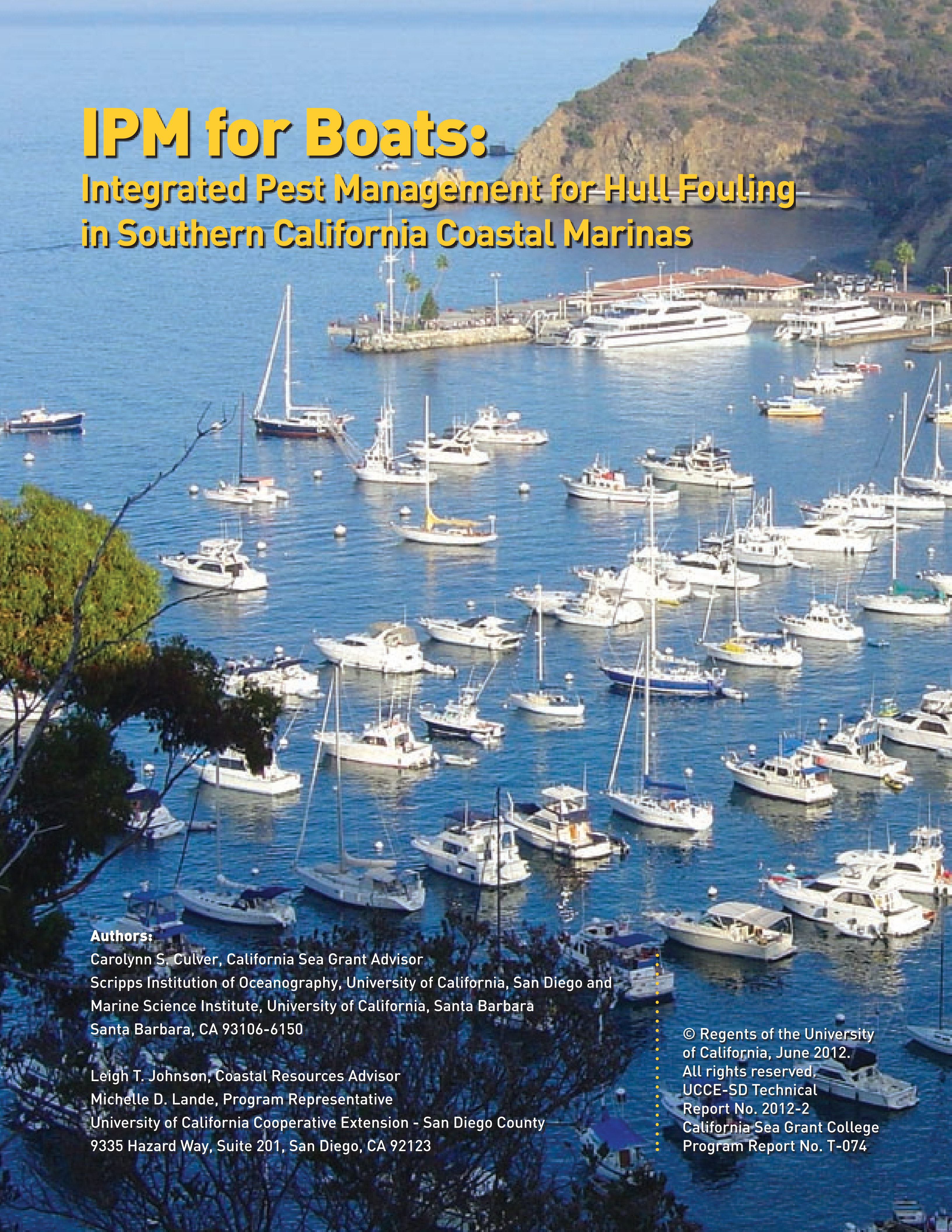

IPM for Boats:
Integrated Pest Management for Hull Fouling in Southern California Coastal Marinas

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PHOTO: R. MATTHEW NEWNHAM

PHOTO: LEIGH JOHNSON

INTRODUCTION

Marine fouling species are organisms that attach and grow on surfaces exposed to salt water, including boats, docks, buoys and lines.[A] They are a nuisance to boaters because they reduce vessel speed and increase fuel consumption. Biofilm (earliest fouling stage) can reduce speed by 3% and increase required shaft power by 10%. Heavy growth can reduce speed by 11% and increase required shaft power by 59%.[1]

Marine fouling species can be transported along coastlines and around the world on the hulls of vessels. Most fouling species begin life as free-swimming larvae in the water column. The larvae grow, age, settle and attach to a submerged surface, such as hulls or docks, where they mature through juvenile stages to adults. Larvae are transported via ballast-water and bait tanks, sea chests, and bilges. Juveniles and adults are transported on hulls or other surfaces (fenders, ropes, etc). Adults that remain on the hull eventually release larvae that attach to other vessels, docks and surfaces.

A Fouling organisms and invasive species are also problems for boats operating in fresh water habitats but they are not the focus of this report. Information on fouling of boats by invasive, Dreissenid mussels in California's fresh water habitats is available at http://www.dfg.ca.gov/invasives/quaggamussel/

Transport of fouling species can be a problem because some species are not native to the areas where they are transported. Non-native (NN) species have caused economic and ecological problems worldwide.[2,3] For example, the marine wood-boring Teredo shipworm is estimated to cost the United States $205 million annually in losses and damages to docks and ships.[4]

Historically, ships have been considered the main vector for moving species across oceans, leading to the establishment of NN species in large ports. Boats are now also recognized as a vector for spreading NN species from major international ports to small craft harbors along the coast.[5] For example a number of invasive species in Elkhorn Slough in Monterey Bay were most likely carried there on hulls of boats returning from the highly invaded, international port, San Francisco Bay.[6] In recognition of these problems, the California Aquatic Invasive Species Management Plan calls for limiting new introductions of aquatic invasive species occurring from recreational boating, fishing and other recreational activities, including introductions from boat hulls.[7]

One goal of this report and the supporting research is to assist boat owners and boating facility managers in addressing invasive species policies when planning boating activities and fouling control programs.

With this in mind and because non-native species can create problems, in this report we identify the origin of the various fouling species relative to the location of our research: south-central and southern California. A native (N) species is believed to have originated in the area where it is found, in this case California. A non-native (NN) species is believed to have originated somewhere other than the area being discussed, in this case outside of California. If the origin of a species is unknown, it is called cryptogenic (C). Some species have not been fully identified by scientists; we refer to them as unresolved (Unr) and no origin can be assigned.

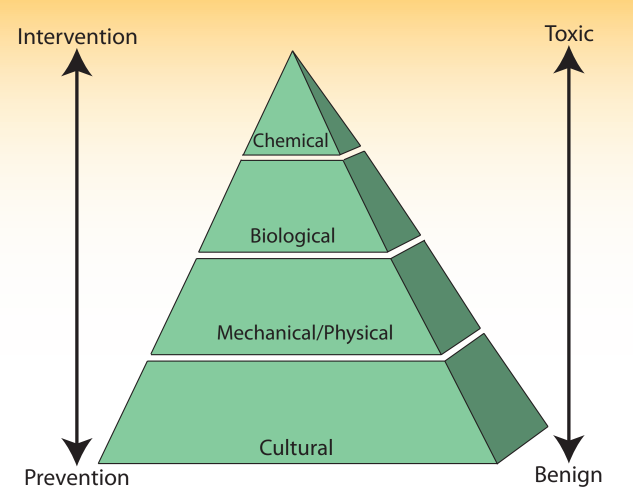
Invasive species typically are NN species that become well established in an area, outcompete N species and/or create problems for boat or harbor infrastructure or operations.[8] They are often referred to as non-native invasive species and in aquatic habitats as aquatic invasive species. They are able to flourish, at least initially, in new areas in part because their natural enemies (parasites, diseases, predators and competitors) are absent.[9,10]

While invasive species are typically NN, not all NN species become invasive everywhere they are introduced. Further, C and Unr species may be considered invasive due to their impacts. Although uncommon, a native species can become invasive, usually as a result of a change in the ecosystem or environment. For example, native sea urchins were considered pests in California giant kelp beds during the 1970s.[11,12]

Antifouling paints are commonly used to deter fouling growth on hulls of recreational and commercial vessels. For many years toxic copper-based paints have been widely applied to ship and boat hulls around the world. However, growing governmental attention to these paints may affect boat owners and boating industries. For example, California regulatory agencies are acting to address accumulation and associated impacts of copper leached from antifouling paints in boat basins.[13,14,15] Washington State passed a bill in 2011 that will restrict copper content of antifouling paints to 0.5% by 2020 for recreational boats up to 65 feet long.[16] Further, scientific literature has reported that some hull fouling species, especially NN, have demonstrated tolerance to copper paints[17] making the paints less effective at reducing fouling.

Thus, a second goal of this report is to assist boat owners in addressing water quality policies and scientific findings related to antifouling paints when choosing fouling control strategies.

FIGURE 1. Pyramid of Integrated Pest Management Tactics[18]



Integrated Pest Management (IPM)

Because of the complexity of factors that influence fouling growth, one control tactic may not be sufficient to manage fouling on boats. We propose applying a terrestrial approach to boating: Integrated Pest Management (IPM). IPM has long been employed to control pests in agriculture and buildings, while reducing the need for chemicals that may affect the environment and human health. An IPM program is a strategy, which uses multiple tactics, such as chemical, biological, mechanical, physical, and cultural as shown in the IPM pyramid (Fig. 1). Our explanations of tactics that can be used to create an IPM strategy are based on several sources.[19,20,21,22] We will discuss how to adapt them for controlling hull fouling on recreational boats. Thus, we introduce **IPM for Boats**. We anticipate this approach will continue to evolve with boaters' experiences, as new tactics become available, and as scientific research continues. Basic concepts of IPM include:

Multiple Tactics

- Chemical tactics include pesticides that kill target pests and limit future populations. They should be applied at the pest's most vulnerable life stage.
- Biological tactics use natural enemies, sometimes called "beneficials" or "biological control agents" to help suppress pest populations. If NN species for biological control are to be released, they must be carefully studied beforehand to ensure they themselves will not become invasive or harm non-target species.
- Mechanical/Physical tactics include mechanical pest removal, using barriers or changing physical factors such as light, temperature, moisture, salinity or surface characteristics.
- Cultural tactics prevent or delay pest outbreaks. Examples include choosing sites that do not favor the pest, removing sources of the pest, making changes that favor beneficial native species, and scheduling management practices to achieve pest management goals.

Multiple Pest Life Stages

- Pest life cycles must be considered in an effective IPM program. Methods may be chosen or combined to target larval, juvenile and/or adult stages of the pest.

Plan, Evaluate, Adjust, Improve

- The IPM program (strategy) should be planned and records should be kept on which, when, where and how specific tactics were used for which pests and life stages, as well as their effects on the pest populations.
- Systematic evaluation and record-keeping may show conditions under which a tactic or strategy (combination of tactics) works well versus conditions under which another tactic or strategy may be needed. The information will enable boaters and facility managers to adjust and improve their strategies over time.

INTEGRATED PEST MANAGEMENT FOR BOATS

The goal of **IPM for Boats** is to balance efficient boating operations with ecosystem health (protecting water quality and preventing the spread of non-native invasive species). In accordance with the IPM concept, we propose an integrated control program (strategy) that targets different life stages of hull fouling organisms using multiple tactics.

Specific recommendations are based on our recent research (see Appendices 2-4), earlier studies[23,24,25,26,27] and scientific literature. Details of our research are provided in Appendices 1-4 and they are referred to where appropriate in the discussion. We investigated the biology of hull fouling species and how they respond to the environment, hull coatings, hull cleaning practices and nearby sources of pest populations.

Based on our studies, we consider a small group of common fouling organisms, regardless of origin, to be "species of concern" in southern California due to their impacts on boating activities and harbor operations. They are considered together when discussing management of fouling on boats.

Photographs and descriptions appear in Appendix 1: "Species of Concern."

The principles of **IPM for Boats**, while based on results in coastal waters of south-central and southern California, can be applied widely if they are adjusted to suit local conditions and fouling species. This program has been developed for salt water boating, where boats typically move from location to location without being removed from the water. This differs from fresh water boating where boats are often hauled out of the water and trailered to other locations. Nonetheless, many of our recommendations could be applied to management of fouling in fresh water systems.

IPM for Boats is a new concept that requires review and modification as additional research results become available. As a first step, we concentrated on factors influencing fouling for boats that rarely move, as our earlier research indicated that this represents about half of California boaters.[28] Additional research on the influence of boat use frequency and cruising speed on fouling is critically needed to make the program applicable to more boaters, as we have suggested in Appendices 2-4.

IPM PROGRAM COMPONENTS

Chemical Tactics

Chemical tactics include pesticides that kill target pests and limit future populations. Because they are the most toxic tactics used in pest control, they appear at the top of the IPM pyramid (Fig. 1). IPM programs seek to limit toxic chemicals by applying them only when needed, at the pest's most vulnerable life stage, and in a way that minimizes their impacts on people and the environment.[29,30,31,32] Therefore, we will suggest ways to reduce toxic chemical use while balancing issues of boating operations, water quality and transport of invasive species.

Toxic hull coatings are the most widely used chemical tactic for fouling control. Much less common are legally permitted liquid chlorine products, used with a slip liner and according to label directions (see below). These tactics target the larval stage, inhibiting settlement and early survival of fouling organisms. Liquid chlorine in slip liners may also kill other life stages of some fouling organisms, including juveniles and adults.[33,34]

When deciding whether to use chemical tactics in an IPM program, boat owners and boating businesses first need to consider regulations and policies regarding use of toxic substances (e.g., antifouling paints and liquid chlorine products). Marina/harbor authorities should be consulted on policies regarding slip liners, as some do not permit them.

Toxic Hull Coatings:[B] When considering toxic hull coatings, a boat owner should take into account travel patterns and slip location. Those who travel regularly over longer distances, and whose boats thus spend less time in the slip, pose a lower risk for leaching antifouling toxins into the water of harbors and marinas. However, because of their frequent travel, they pose a higher risk for transporting invasive species to new areas. Boat owners who fit this profile may wish to include toxic hull coatings in their fouling control strategy, because of reduced impacts on water quality in boat basins. Further, a toxic hull coating will reduce the likelihood of carrying species of concern because fewer organisms will settle on them than on nontoxic coatings (see Appendix 2). Given regulatory concerns and evidence that some species tolerate copper, boat owners may want to consider an alternative toxic coating.

Boats with toxic hull coatings should be located in slips with high water circulation to reduce accumulation of toxins in the harbor. Further, boaters using this strategy should consider only applying toxic coatings to underwater areas that are critical for boat operations and difficult to clean (e.g. water intakes, housing for outdrives). Reducing the amount of toxic coating on the boat will help to reduce water quality impacts.

In contrast, boat owners who travel infrequently or only short distances may want to avoid toxic hull coatings. Because these boats stay in the slip for extended periods, they would be a source of leached toxins if toxic hull coatings were applied. Even though they will become more highly fouled if they use nontoxic coatings

B We refer to metal-based antifouling paints (e.g. copper) as toxic and we refer to epoxy, slick (siliconized) and gel hull coatings that lack such toxins as nontoxic. Our choice of terminology is discussed in, "Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California and Baja California," available at http://ucanr.org/sites/coast/publications.

(see Appendix 2) boats that travel short distances are more likely to carry the same hull fouling species that are already present in nearby areas, posing less risk of introducing new species elsewhere. Such boats represent substantial numbers, as half of California's coastal boats rarely or never leave the home marina[35] and half of California's boats rarely travel more than 100 miles from home.[36] An important and notable exception is short distance travel to offshore islands that are especially vulnerable to invasions.[37,38]

Chlorine Treatment: A legally permitted liquid chlorine product, used with a slip liner and according to label directions, is another chemical tactic for boats with nontoxic hull coatings. An advantage to this method is that the chemical treatment can penetrate hard-to-reach areas where mechanical removal would be difficult. As noted, this method may kill juvenile and adult stages that may already be attached to the boat. Label directions for the liquid chlorine product must be followed closely to ensure that the correct concentration has been achieved and that the concentration has fallen below a specified level before the slip liner is opened to avoid water quality impacts.[C] Poorly maintained slip liners that allow chlorine to leak are a hazard to marine life in the surrounding waters.[39,40]

Biological Tactics

Biological tactics use natural enemies, sometimes called beneficial species or biological control agents, to help suppress pest populations. They may be predators, parasites, pathogens or competitors. If biological control agents, especially those that are non-native, are to be released into the environment, they must be evaluated carefully beforehand to ensure they will not become invasive or harm non-target species. While they are generally less harmful than chemical methods, biological controls still present some risks and are near the top of the IPM pyramid.

Using biological tactics to reduce fouling on boats has received little attention. Applying biological control agents directly to boat hulls is logistically complicated and potentially harmful because they would need to be removed and reapplied or could cause damage to the hull coating. However, predators that consume larvae, juveniles and/or adult fouling organisms could potentially be used as a control tactic for minimizing sources of fouling on docks, piers and other structures. This application would be similar to biological control tactics used to reduce fouling on aquaculture nets and cages at sea.[41,42,43] Careful research would be needed to develop a safe and effective biological control for hull fouling.

Mechanical Tactics

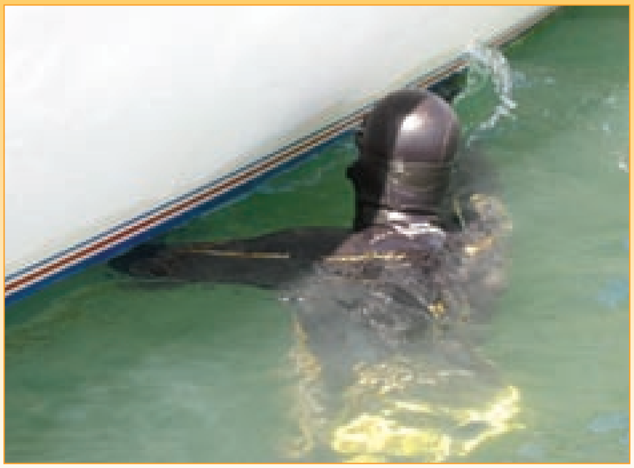
Mechanical tactics include removal of the target pest from the target location (boat hulls in this case) by mechanical means. Hull cleaning that removes juvenile and adult fouling organisms is a fairly benign (and therefore close to the base of the IPM pyramid) yet effective strategy that is widely used in California. Hull cleaning may be performed on land or in the water.

Land-based Hull Cleaning: This tactic could help to reduce risks of introducing invasive species by boats with fouled hulls that are arriving from other regions, as well as for heavily fouled boats that are leaving the home port and traveling to islands or locations far away. The boat is hauled from the water and, typically, washed with a high-pressure water sprayer. It is important to get the small, hard-to-reach areas. Wash waters should be contained and filtered to remove larvae or older stages that may regenerate or release larvae. Removed debris should be disposed in a land fill that does not drain to surface waters. The boat should be left on a stand for several days to dry thoroughly and allow any remaining fouling growth to die.

In-water Hull Cleaning: This tactic is typically performed periodically by certified hull cleaning professionals as part of routine hull maintenance. To clean hull coatings divers typically use hand tools, such as 3M™ pads, or hydraulically powered, rotating brushes. For metal parts they may use scrapers. Best management practices (BMPs) developed by the California Professional Divers Association include cleaning frequently enough to use the gentlest cleaning tool and least amount of effort to remove fouling species.[44] Such practices are beneficial for: 1) extending the life of a hull coating by avoiding the need for more aggressive tools and effort levels; 2) reducing transport of non-native organisms that are reproductively

C Information on liquid chlorine products for slip liners from the April 2007 County of San Diego Department of Agriculture, Weights and Measures, "Official Notice to Dock Masters and Marine Suppliers," is excerpted in our "Alternative Antifouling Strategies Sampler" at http://ucanr.org/coast/Nontoxic_Antifouling_Strategies/. Other regulations may apply in other areas.

PHOTO: LEIGH JOHNSON



Diver uses a soft pad to clean boat hull in water

mature; 3) decreasing survivorship of removed organisms; 4) preventing stimulation of new fouling growth (Appendix 3); and 5) removing algal growth to reduce risk of staining the hull coating (Appendix 4). Research is needed to determine whether fouling organisms survive after being cleaned off the hull. If so, systems for removing and disposing them should be considered.

In California and Baja California, in-water hull cleaning by divers is more cost effective than land-based cleaning as an ongoing tactic. Our economic research found that average costs to haul a boat and clean its hull ranged from about $11 per foot for boats 15-20 feet long to about $13 per foot for boats 51-60 feet long. In contrast, average costs for in-water hull cleaning by professional divers ranged from $1.03 per foot for sailboats up to 25 feet long in Mexico to $2.59 per foot for powerboats 26-40 feet long in California.[D,45]

Another in-water hull cleaning tactic involves driving or towing a boat through a facility that is outfitted with powered brushes. No such facilities were found in California during our economic research.

Physical Tactics

Physical tactics include using barriers or changing physical factors such as light, temperature, salinity, moisture, oxygen or hull coating surface characteristics. They are lower on the IPM pyramid because they are often fairly benign. Thus, they should be considered before tactics that are higher on the pyramid.

Barriers: A slip liner acts as a barrier (when properly employed and maintained) that isolates the boat hull from larval, juvenile and adult stages of fouling species in the surrounding harbor water and on docks. The liner's bag and seals should be inspected for leaks and supporting lines should be taut enough to prevent water from lapping over the sides. Because the outside of the liner can become fouled, it should be cleaned regularly to prevent the liner from sagging and eventually sinking. Consult the vendor for cleaning instructions. Before selecting this tactic, consult harbor or marina management to determine whether slip liners are allowed and policies for using and maintaining them.

Reduced Salinity: Decreasing the salinity of water surrounding the boat to a level that kills fouling pests can be achieved by using a slip liner and adding fresh water. Substituting fresh water for liquid chlorine reduces risks to marine life in nearby waters. Water quality and natural resource agencies should be consulted to determine whether it is permissible to add fresh water to a slip liner.

Desiccation: Desiccation, or the elimination of moisture, kills fouling larvae and, over time, juveniles and adults. This can be applied to boats by allowing the hull to dry for an appropriate amount of time, depending on temperature and humidity, after the boat is used. Examples include storing a boat on a trailer or raising it above the water on a boat lift until fouling organisms die. Wet gear and areas where water accumulates, such as bilges and bait tanks, should be drained and allowed to dry. It may also be advisable to flush the engine cooling

PHOTO: LEIGH JOHNSON

Slip liner creates a barrier around boat hull

D For more economic research results see, "Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California and Baja California," at http://ucanr.org/sites/coast/publications.

PHOTO: SCOTT PARKER

Boat lift isolates hull from water

system.[E] Removing the boat from the water also prevents fouling larvae from reaching the hull between trips. While highly effective and quite benign, these tactics are most feasible for smaller boats. Boat lifts may be cost prohibitive, especially for larger boats,[46] and may not be permitted in some marinas or harbors.

Hull Coating Surface Characteristics: Surface characteristics of nontoxic hull coatings differ from those of copper paints. They do not deter fouling, must be combined with another tactic, and currently require special hull preparation. Thus, a longer service life may be needed to make them cost effective within an IPM strategy.[47] As they are not pesticides,[48] they likely have less impact on water quality than toxic coatings. For more information on nontoxic hull coatings see *Alternative Antifouling Strategies Sampler*.[49]

Nontoxic epoxy coatings are simply very durable. Boat owners who participated in our earlier research reported that nontoxic epoxy coatings lasted for up to 8 years. Copper paints are replaced on average every 2.5 years in San Diego Bay. Owners of a sail boat that received a nontoxic epoxy coating in our earlier research reported that they had saved $2940 versus anticipated costs for a copper paint over an 8-year period.[50,51,52,53]

Surface qualities of "slick" (silicone, siliconized epoxy) coatings cause fouling organisms to attach loosely.[54] They are often called "foul release" coatings because fouling may be removed more easily or, if the boat regularly exceeds 12 knots, they may slough off.[55]

E For more information on dessication and cleaning tactics for recreational boats, see "What boaters can do to help," and, "Boat cleaning guide book," available at http://www.dfg.ca.gov/invasives/quaggamussel/

Cultural Tactics

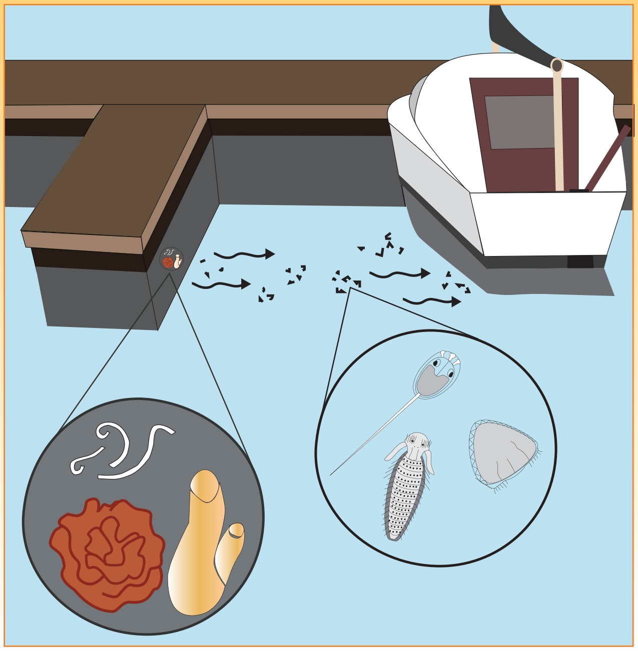
Cultural tactics prevent or delay pest outbreaks. They include choosing sites that do not favor the pest, removing sources of the pest, making changes that favor beneficial native species, and scheduling (timing) management practices to achieve pest management goals. They are the most benign tactics, and therefore appear at the base of the IPM Pyramid.

Removing Sources of the Pest: Fouling growth on docks provides a source of larvae to re-infest cleaned boat hulls (Fig. 2). The harbor or marina manager should periodically inspect dock floats and pilings for "hot spots" where species of concern are abundant. Boat owners and hull cleaners may identify hot spots if they notice fouling species that are especially prevalent on their boats or nearby docks. If so, they should advise the harbor or marina manager, who could inspect the dock.

Understanding the harbor's environmental conditions may help in identifying hot spots. For example, we found that the NN bryozoan *Watersipora subtorquata* was more abundant where water flow was faster and the NN tunicate (sea squirt) *Ciona* spp. was more abundant where it was slower (see Appendix 4).

If hot spots are found, the marina or harbor manager may consider cleaning dock floats, pilings and other submerged structures periodically. The goal is to remove reproductively mature organisms to reduce the amount

FIGURE 2. Fouling species of concern on docks release larvae that settle and grow on boat hulls.



GRAPHIC: CHRISTINA WEBB

of fouling species' larvae in and near boat slips.

Cost-effective methods for removing fouling organisms from docks are needed. Focusing on cleaning hot spots will help to contain costs. Research is also needed to determine whether organisms scraped from docks into the water survive and continue to reproduce once released into the harbor. If so, systems for removing and disposing them should be considered.

Boat owners can address other sources of fouling pests in the harbor. They can employ this tactic by: 1) keeping the hulls of their boats cleaned to prevent fouling species from maturing and reproducing; 2) cleaning the outsides of slip liners according to the vendor's instructions; 3) cleaning and flushing bilge and bait tanks;[E] and 4) removing trash, lines and other objects from the water.

Favoring Native Species: Promoting beneficial native species can reduce the success of the pest species.[56] For example, removing NN species when larvae of N species are highly abundant could reduce competition for the N larvae. Further, some NN invasive species are more tolerant than N species of copper antifouling paint.[57] Thus, reducing copper pollution in a harbor may allow non-tolerant N individuals to outcompete copper-tolerant NN individuals on docks and other surfaces. Although reducing copper pollution would not reduce fouling as a whole, it would improve water quality and could help reduce the abundance and potential spread of copper-tolerant, NN invasive species.

Scheduling (Timing) of IPM Tactics: The time of year affects the amount of larvae available to recruit[F] to surfaces on a boat. In our research, more larvae were available from the late spring through early fall (May-October) (Appendix 4). Timing control tactics in accordance with the recruitment of larvae can improve the effectiveness of the overall IPM strategy.

Scheduling Application of Toxic Hull Coatings: A copper antifouling paint may be most effective if it is applied just before this peak recruitment season for many fouling species. However, this may not suffice to control copper-tolerant "species of concern" or species such as *Watersipora subtorquata* that recruit earlier (January-March) than other species in southern California (see Appendix 4). Additional tactics should be applied to control these species where they are abundant.

Scheduling Hull Cleaning: Boat owners should also consider scheduling hull cleaning to improve the effectiveness of control efforts. In particular, our research indicates that hull cleaning frequency should be adjusted for the following factors:

- Type and Age of Hull Coating
- Time of Year
- Harbor and Slip Locations and Conditions
- Travel Plans

Boat use frequency and cruising speed may also affect the hull cleaning schedule. Investigating these factors was beyond the scope of our research discussed in the Appendices.

Type and Age of Hull Coating: In general, boats with newly applied (less than six months) toxic copper coatings will need to be cleaned less often than boats with nontoxic coatings. However, cleaning frequency for copper coatings will need to increase as they age (Appendix 2).

Nontoxic coatings require frequent cleaning regardless of age, as they do not inhibit fouling growth. Further, boats with epoxy and slick nontoxic coatings may require more frequent cleaning in areas where species that recruit strongly to these coatings are abundant. Examples are the NN tube worms *Hydroides* spp. and the NN bryozoan *Watersipora subtorquata* (Appendix 2).

Time of Year: More frequent cleaning is required during the peak recruitment period (May-October in southern California). However some species of concern, such as the copper tolerant NN bryozoan *W. subtorquata*, recruited more heavily during January-March in our study. Where this species is abundant in southern California, hull cleaning should also be frequent during the winter.

Harbor and Slip Locations and Conditions: Both harbor and slip location should be considered when determining cleaning frequency. In temperate climates, boats docked in harbors in warmer water regions will require more frequent cleaning than boats docked in harbors in cooler water regions.[58] This was quite evident during our study, as much less fouling occurred at our northern site (Santa Barbara) than our southern site (San Diego) (Appendices 2–4).

F "Settle" and "recruit" mean that a fouling organism has begun to live on a surface. Although we use the terms interchangeably, settlement technically occurs first.

In a shaded area, the hull may need more frequent cleaning, as invertebrates recruit more heavily to darker areas (Appendix 4). Because most of the NN species identified in our study were invertebrates, frequent cleaning would likely remove them before they could reproduce. Also, some invertebrates become hardened as they mature, requiring more aggressive cleaning tools that increase risk of damage to the hull coating.

Travel Plans: Hull cleaning schedules also should consider travel plans. For example, boats should be cleaned before departing on a trip to a different region, an island or an event attended by boats from many regions. Hulls should also be cleaned before returning from extended stays at other regions or events. This is especially important from May through October in southern California when more fouling larvae are in the water. These actions will help to minimize transport of invasive species.

GRAPHIC: RYAN KRASON AND MICHELLE LANDE

CONCLUSIONS

IPM for Boats can help to minimize impacts on boating and facility operations, costs and ecosystem health by reducing fouling (especially by species of concern), use of toxic materials, and the risk of spreading NN invasive species. This integrated approach recognizes and addresses the complexities associated with the recruitment of fouling organisms on boat hulls and the diversity of boating activities.

IPM for Boats is not a "one size fits all" approach; it should be tailored to local conditions and individual boating patterns. Boat owners and facility managers will improve their abilities to manage fouling by developing an integrated pest management program (strategy) that takes into consideration location of the facility or slip within the facility, travel patterns, feasibility of various control tactics for the specific situation, and other factors discussed in this report. Implementing a combination of control tactics that target all life stages (larvae, juveniles, adults) can improve effectiveness of the IPM strategy. Further, the IPM program should be evaluated and updated as the boat owner or the boating facility manager learns from experience, from IPM program records, and as additional research becomes available.

APPENDICES

APPENDIX 1. HULL FOULING SPECIES OF CONCERN

During our series of field studies (see Appendices 2-4), we found over 40 fouling organisms at our two study sites in California (Table 1). Seven of them were common, often abundant, and are especially troublesome for boaters or coastal ecosystems. Thus, we consider them to be top marine fouling "species of concern" in southern California.

PHOTO: CAROLYNN CULVER

Adult fouling organisms on dock are a source of larvae to infest boats

Most of these species of concern rapidly colonize surfaces, forming very dense accumulations. They are tolerant of copper antifouling paints. They typically outcompete native (N) species for space, thereby reducing survival chances for the N species. All these species of concern compete with N species for microscopic food in the water; some filter food from the water very rapidly and efficiently. When mature, some are difficult to remove, requiring more abrasive cleaning that can reduce the life of the hull coating. Further, the calcareous (calcium carbonate or limestone) tubes of tube worms are a white, gritty material that can scratch hull coatings during cleaning, even when soft pads are used.

PHOTO: CAROLYNN CULVER, LEIGH JOHNSON, MICHELLE LANDE

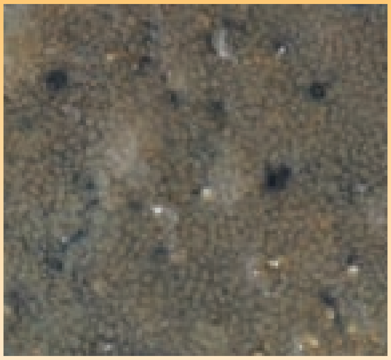
Scars and scratches left by removing *Hydroides* tubes illustrate that removing such hardened structures can damage the hull coating.

Most of these species of concern are non-native (NN), two have unknown origins (C, Unr) and one is native (N). The NN tube worm *Hydroides elegans* and the N tube worm *Hydroides gracilis* can only be distinguished by careful dissection and microscopic evaluation of their internal structure, which we performed for subsamples from our study. *H. gracilis* was rare in the subsamples, so this N species was probably rare overall. In order to process the more than 1000 experimental panels, we were limited to external visual examination to identify species. Thus, we simply identified these two tube worm species as *Hydroides* spp. for the study results. Although it did not settle on our experimental panels, the Asian kelp *Undaria pinnatifida* is also a species of concern in California harbors.[59]

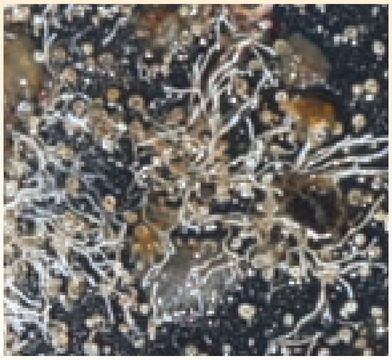
HULL FOULING SPECIES OF CONCERN

PHOTOS: CAROLYNN CULVER, LEIGH JOHNSON, MICHELLE LANDE

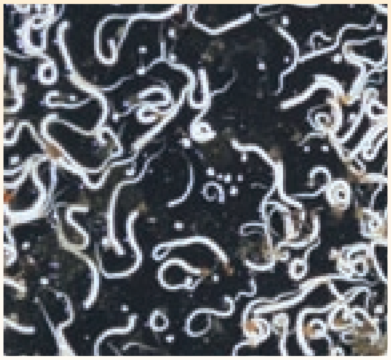
1. *Ciona spp.* (*C. intestinalis*, *C. savignyi*) NN sea squirts (individual tunicates). These two were not identified to the species level. Form large groups of translucent "chimneys." Rapidly filter food from water. Copper tolerant.



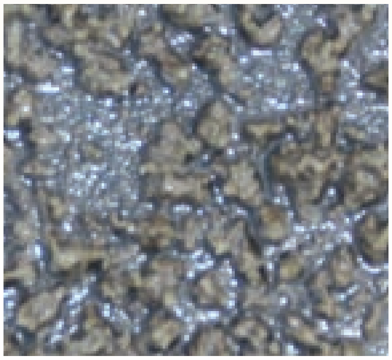
2. *Diplosoma listerianum* NN colonial tunicate. Forms dense, flat, dull-colored, mucous-covered colonies that are difficult to remove. Copper tolerant.



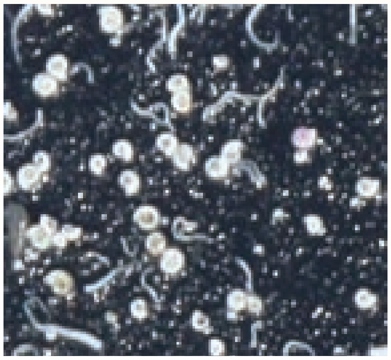
3. *Filograna implexa* NN tube worm. Very thin, long calcareous tubes. Form large aggregations. Copper tolerant.



4. *Hydroides* spp. NN (*H. elegans*) and N (*H. gracilis*) tube worms. Form long calcareous tubes that are difficult to remove. Form large aggregations. Copper tolerant. In southern California they are sometimes called South China Seas coral worm, but they are not related to corals.



5. *Laticorophium baconi* C amphipod. Build and live in dense, irregular, brown mud tubes. Copper tolerant. Provides foundation for less copper tolerant species to attach.



6. *Spirorbid* sp. Unr tube worm. Highly abundant. Forms small, semicircular, calcareous spiral tubes that are difficult to remove. Copper tolerant. Often look like small white dots or curls.

7. *Watersipora subtorquata* NN encrusting bryozoan. Forms large masses of pink, orange or reddish, wavy, brittle "petals." Copper tolerant. Provides a foundation for less copper tolerant fouling species to attach.

APPENDIX 2. FACTORS AFFECTING FOULING GROWTH: TYPE AND AGE OF HULL COATINGS

Developing an effective IPM program for boats requires understanding the factors that influence hull fouling. Some factors are directly associated with boats, such as the type and age of hull coatings (this appendix) and hull cleaning practices (Appendix 3). The geographic location of the harbor, the location of the slip within the harbor and environmental factors that vary within harbors also may play a role (Appendix 4). Fouling on nearby docks also produces spores and larvae that can re-infest boats (Appendix 4).

To develop **IPM for Boats**, we conducted a series of experiments to improve understanding of these factors. This and the next two appendices describe the experiments and findings of our research that were used to formulate our recommendations for an integrated fouling control program.

General Methods

Methods common to all experiments are described in this section. Methods specific to a particular experiment are described in the appropriate section.

Experimental Sites:

Experiments were conducted at two coastal sites in southern California. The northern site, Santa Barbara Harbor (SBH), is a small craft harbor for recreational and commercial boats. Sixteen stations were distributed equally among four locations arranged from the outer to inner sections of SBH (Fig. 3a).

The southern site, Shelter Island Yacht Basin (SIYB) of San Diego Bay, is a recreational boat basin. Twelve stations were distributed equally among three locations in SIYB, ranging from outer [Kona Kai Marina (KKM)] to middle [Southwestern Yacht Club (SWYC)] to inner [Half Moon Anchorage (HMA)] sections of this basin (Fig. 3b).

Experimental Design:

Experimental 15 cm x 15 cm (6 in x 6 in) fiberglass panels were coated by a reputable boat repair yard in San Diego, using standard protocols for boats. Coatings represented one antifouling and three nontoxic brands typically used on recreational boats in southern California.[G] All panels received 1) a base, "gel" coating (Cook Composites polyester gel base coat), which is typically applied to the hull beneath the outer coating. Some panels also received one of three additional coatings: 2) Copper-based antifouling paint or hereafter "copper" coating (Interlux Epoxy Modified Antifouling); 3) nontoxic, ceramic epoxy or "epoxy" coating (CeRamKote Marine); or 4) nontoxic, siliconized epoxy or "slick" coating (Eco-5 Marine). All coatings were black (the only color available for all). Although a variety of toxic coatings are available, we focused on copper as it is the most widely used type.

G Product names do **not** imply endorsement.

GRAPHIC: LORIN LIMA

FIGURE 3A. Santa Barbara Harbor: 16 experimental stations (colored dots) organized in 4 locations (Roman numerals)

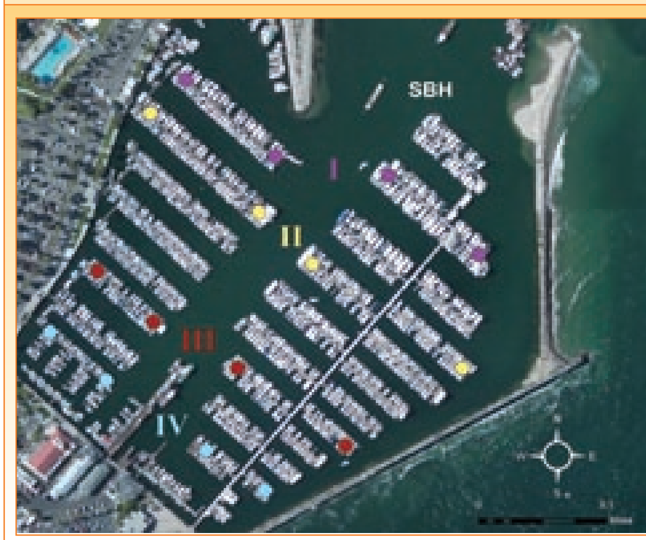


FIGURE 3B. Shelter Island Yacht Basin: 12 experimental stations (colored dots) organized in 3 locations (marina labels)

GRAPHIC: LORIN LIMA

PHOTO: LEIGH JOHNSON

Attaching experimental frame to dock

PHOTO: CESAR ALVAREZ

Identifying *Hydroides* tube worms to species level by dissecting them

For more information on nontoxic hull coatings see *Alternative Antifouling Strategies Sampler*.[60]

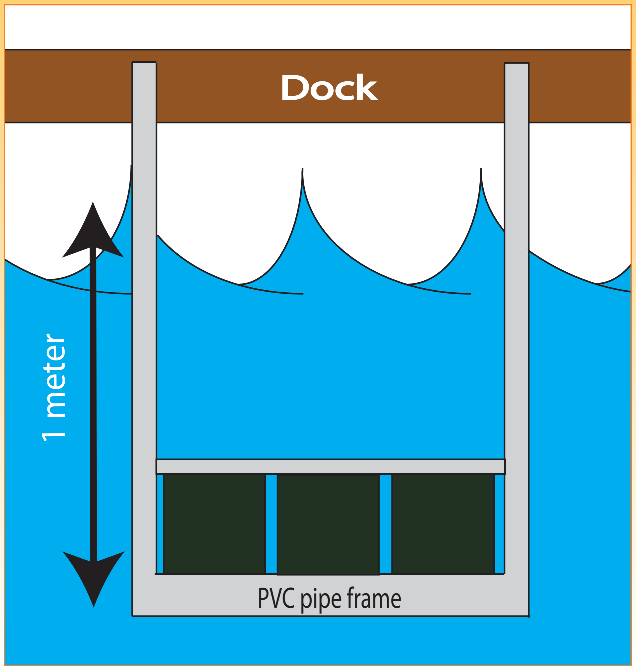
Panels were attached to PVC pipe frames. Frames were bolted to docks at study stations so that panels were submerged 1 m (~ 3 ft) below the water's surface (Fig. 4). The frame size, number of panels per frame, coating types, and the length of time and season left in the water varied according to the aims of each experiment.

Data Collection and Analysis:

Panels were collected at the end of each experimental period. For all but one experiment, fouling (settled or recruited[F] stages) was identified to the lowest taxonomic[H] level possible and quantified by the percentage cover of colonial fouling organisms[I,61] and the density (counts per panel) of individual organisms. Species were identified as native to the area (N), non-native (NN), cryptogenic (unknown origin) (C) or as unresolved (Unr) for organisms whose taxonomy has yet to be clarified.[62,63,64] Table 1 lists the species found on panels in our study, organized in their taxonomic groups. For the one experiment (hull cleaning) where we did not use these methods, we determined the amount of fouling on the panels by scraping off the fouling, drying the resulting material and then weighing it to measure the biomass of fouling organisms.

GRAPHIC:MICHELLE LANDE

FIGURE 4. Experimental frame design



At each station we also measured several environmental parameters that were known to influence where and how abundant a species may be:

- water temperature[65,66,67]
- salinity[68]
- water motion or flow[69]
- shading[70,71]
- nearby members of the same species[72,73]
- proximity to the seafloor (i.e. water depth)[74]

We used submersible data loggers to continuously

H Taxonomy is a system for classifying (organizing) living things into related groups. A phylum is a high taxonomic level, e.g. brown algae (kelp, etc.) or mollusks (mussel, abalone, squid, etc.). The species is the basic unit of taxonomy. Each species belongs to a genus and is called by its genus and species names, which are italicized, e.g. *Filograna implexa*. If the species is uncertain, the genus will be followed by sp. or spp. for one or more species. After the first time a species is mentioned the initial of the genus may be used, followed by the species name (e.g., *F. implexa*).

I A "colonial" invertebrate species lives in a matrix. Coral reefs are well-known examples. Many bryozoans are colonial, such as *Watersipora subtorquata*. In contrast tube worms, such as *Hydroides* spp., are "individuals," although large numbers may live close together.

TABLE 1. Species recruiting to panels. Origin: C = cryptogenic; N = native; NN = non-native; Unr = unresolved; UnID = unidentified. Coating Type: E = nontoxic epoxy; S = nontoxic slick; G = nontoxic gel base; C = toxic copper. X = Species present. Asterisks: * = very rare species found on only one nontoxic panel at one time at a site; ** = rare species found on one to five panels. Diamonds: ◆ = species found on only one copper panel at one time at a single site; ◆◆ = species that did not recruit directly to copper panels. Species with names in **bold** occupied the most space **on copper** over time. Results from two experiments are shown in the table:1) 1-month (at a time) submersions over a year for sets of 4 coatings at all 28 stations and 2) 3-, 6- and 12-month continuous submersions for copper coating at KKM and HMA, only.

			Submersion Time and Coating Type Results						
			1) Occurred at any of 28 stations				2) KKM and/or HMA		
Phyla	**Species**	**Origin**	**1 mo E**	**1 mo S**	**1 mo G**	**1 mo C**	**3 mo C**	**6 mo C**	**12 mo C**
ALGAE									
Chlorophyta	*Cladophora sp.*	Unr	X	X	X	X**			
	Colpomenia sp.	Unr	X	X	X			X◆	
	Ectocarpacea	Unr	X	X	X				
	Enteromorpha sp.	Unr	X	X	X	X**			
	Green monofilament	UnID					X◆		
	Ulva sp.	Unr	X**	X**	X**				
Rhodophyta	***Rhodymenia pacifica***	N			X*			X◆◆	X
	Antithamnion sp.	Unr	X	X	X				
INVERTEBRATES									
Annelida	***Filograna implexa***	NN	X	X	X		X	X	X
	Hydroides spp. complex *H. elegans, H. gracilis*	NN, N	X	X	X	X**	X	X	X
	Myxicola sp. A - Harris	Unr	X*						
	Sabellid (likely *Pseudopotamilla* sp.)	UnID	X*			X**			
	Spirorbid sp.	Unr	X	X	X	X**	X	X	X
Mollusca	*Mytilus* sp.	UnID	X*						
Chordata[A]	***Aplidium californicum***	N	X	X	X				X
	Botrylloides diegensis	N	X	X	X				X◆
	Botrylloides violaceus	NN	X	X	X				X◆
	Botryllus schlosseri	NN	X	X	X				
	Ciona spp. C. intestinalis or C. savignyi	NN/ NN	X	X	X		X◆		X
	Diplosoma listerianum	NN	X	X	X	X**	X◆		X
	Styela clava	NN	X						
	Styela plicata	NN	X	X	X				
	Molgula sp. (most likely *M. ficus* or *M. verrucifera*)	Unr	X**	X**					
	Unidentified tunicates (n=3)	UnID	X	X	X**				
Crustacea[B]	***Laticorophium baconi*** (amphipod with tube mats)	C	X	X	X	X◆	X	X	X
Bryozoa[C]	***Bowerbankia* sp.**	Unr	X	X	X		X	X	X
	Bugula californica	N	X	X	X				X
	Bugula neritina	NN	X	X	X			X	X
	Celleporaria brunnea	N	X	X	X			X◆	
	Crisulipora occidentalis	N	X	X	X				X◆
	Cryptosula pallasiana	NN	X	X	X				X◆
	Membranipora sp.	Unr	X	X	X				
	Thalamoporella californica	N	X	X	X			X◆	
	Tubulipora sp. (Either T. *tuba* or *T. pacifica*)	N	X	X	X				
	Watersipora subtorquata	NN	X	X	X			X	X
Porifera	Unidentified sponges (n=2)	UnID		X**	X*				X◆

[A] All species listed as Chordata belong to a sub-phylum Urochordata, also known as tunicates.
[B] Crustacea is a sub-phylum of the Arthropoda. [C] Bryozoa is also known as Ectoprocta.

record water temperature, a refractometer for salinity, SLODS™ cards[J,75] for water flow, and a tape measure for determining water depth. Presence of nearby members of the same species was determined by taking photographs of three, small panel-sized (15 cm x 15 cm) sections of the dock where the frame was later attached after the fouling organisms were removed. The percentage of cover of fouling organisms on each dock section was quantified from the photographs. Shading was not directly measured. However, all frames were arranged facing northeast in SBH and northwest in SIYB, so that the fronts of all panels received similar angles of light during the day. The backs faced the shaded undersides of the docks.


PHOTO: CAROLYNN CULVER

Counting fouling organisms using grid placed over experimental panel

Does the Type of Hull Coating Matter?

We studied the influence of different types of hull coatings on fouling recruitment over one-month periods. In general some coatings fouled more heavily and certain species were more abundant on specific coatings.

Using methods described above, we placed sets of four panels in the water on experimental frames at all 28 study stations in both harbors. Each set had one panel with the toxic copper coating, one with the nontoxic epoxy coating, one with the nontoxic slick coating; and one with the nontoxic gel base coating. At the end of each month in the water, they were removed and replaced with sets of fresh new panels. This was repeated 12 times over the span of a year (July 2008-June 2009).

Only a few species (Table 1) recruited to the copper panels during the 12, one-month intervals. Two are NN species: the colonial tunicate *Diplosoma listerianum* and the tube worm *Hydroides elegans*. It is possible, but less likely that the N tube worm *Hydroides gracilis* may have been present but was mixed in with the NN *H. elegans*. (Table 1) The amphipod *Laticorophium baconi* is C. The remaining species found on the panels are Unr: a sabellid worm that could not be fully identified; spirorbid tube worms; and two types of algae, *Cladophora* sp. and *Enteromorpha* sp. Recruitment of these species was quite low. They occurred on only 13 of the 672 panels. Generally, colonial species like the tunicate *D. listerianum* covered less than 1%-2% of the panel surface and there were just a few (on average 2-4) individual *Hydroides* spp. tube worms. Apparently, these species tolerate copper, having settled so quickly (within one month) on surfaces with newly applied toxic paint.

In contrast, the nontoxic coatings were readily fouled by many species (Table 1). About 20% of the fouling on the panels at the northern site SBH, and 30% at the southern site SIYB, was comprised of NN species. At both sites the most abundant NN species were the branching and encrusting bryozoans *Bugula neritina, Watersipora subtorquata* and *Cryptosula pallasiana,* the tube worm *H. elegans*, and the colonial tunicates *D. listerianum* and *Botrylloides violaceus*. At SIYB two more NN species also were common: the tube worm *Filograna implexa* and the colonial tunicate *Botrylloides schlosseri*.

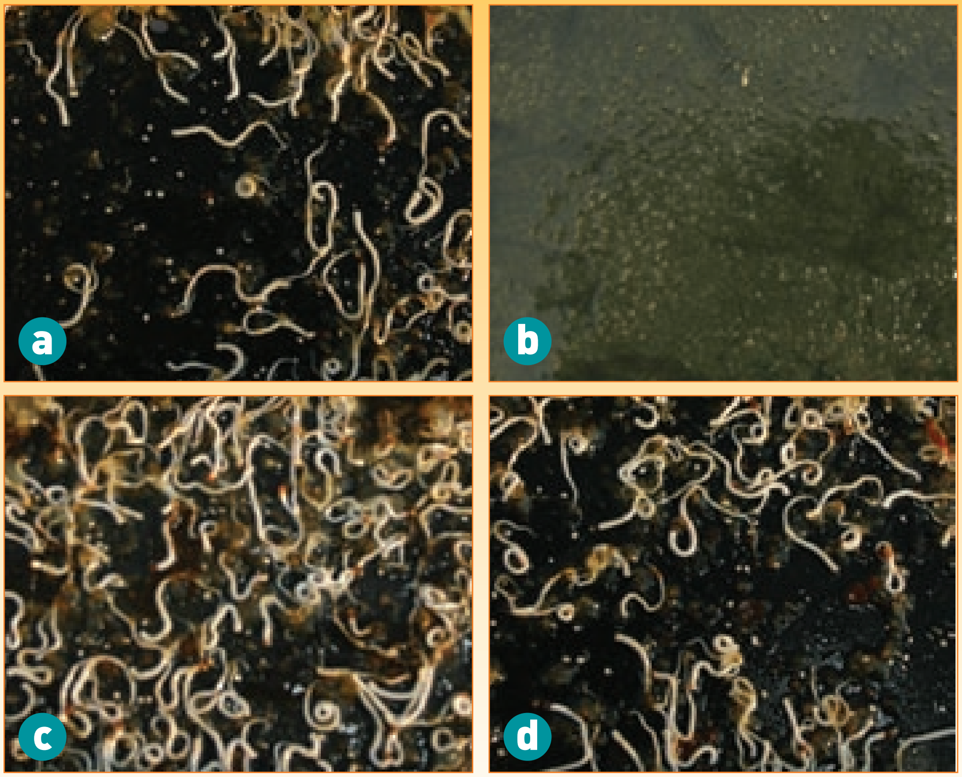
Although only a few tube worms occurred on the panels with toxic copper coatings, many occurred on the panels with nontoxic coatings. At both sites spirorbid worms were the most abundant, averaging hundreds per panel. *Hydroides* spp. tube worms were also common, averaging 10-30 per panel. At SIYB there were also many NN *Filograna implexa* tube worms, averaging 16 per panel.

At both harbors, fouling was generally similar on the panels with the various nontoxic coatings. At SIYB there were two exceptions: 1. recruitment of the NN encrusting bryozoan *Watersipora subtorquata* was higher on the slick and epoxy coatings than on the gel coating; and 2. recruitment of the *Hydroides* spp. tube worms was also higher on the panels with the epoxy coating than on the slick or gel-coated panels. These exceptions occurred in SIYB only, and not in SBH, possibly due to lower abundance of these fouling species there.

These findings illustrate how the amount and type of

J A SLODS™ card is composed of molded plaster affixed to a hard plastic "card" that can be attached to an experimental frame. Plaster is lost from the card at a rate that is proportional to the speed of water flowing over it.

PHOTOS: CAROLYNN CULVER, LEIGH JOHNSON, MICHELLE LANDE



Panels with (a) gel, (b) copper, (c) epoxy and (d) slick coatings allowed to foul for one month. Note more recruitment of *Hydroides* spp. to epoxy

fouling can be affected by the type of hull coating. The toxic copper coating clearly had less fouling than the nontoxic coatings, although some fouling still occurred and included NN organisms. The three nontoxic coatings (epoxy, slick and gel) were not effective at decreasing fouling. Further, recruitment of two species of concern was higher on the epoxy and/or slick coatings than the gel base coating. This suggests that some fouling organisms preferred the surface characteristics of these coatings. Thus, both toxic and nontoxic coatings represent a risk for spreading invasive species. While this risk is higher for the nontoxic coatings, they are not considered pesticides in California.[76] Thus, they likely have less impact on water quality than toxic coatings.

How Important Is the Age of a Hull Coating?

As shown above, fouling was greatly reduced on panels with newly applied, toxic copper coatings submerged for a short (1 month) time. Given that copper coatings are designed to leach (lose) copper, we wanted to determine whether more fouling would occur as it aged. And, as some non-native species are known to be copper-tolerant,[77] we wanted to know whether NN species would appear first and cover more of the panels over time than N species. Further, we wanted to test reports that a copper coating could control fouling effectively without periodic hull cleaning.

To answer these questions we deployed another set of panels in SIYB at 4 stations in the inner location (HMA) and 4 stations in the outer location (KKM). All panels were coated with the copper coating (over a gel-coat base) and allowed to foul for 3, 6 or 12 months. Using the methods described above, we compared fouling on these panels over time.

After twelve months, two species that were common to both SIYB locations occupied the most space on the copper panels: the C amphipod *Laticorophium baconi*, as evident from tube mats it made, and the NN colonial tunicate *Diplosoma listerianum*. Eight more fouling species were common on the panels, but they did not all occur at both locations.

The amount of space that the commonly occurring species covered increased substantially over time. Particularly striking was the increase in space covered by the amphipod *L. baconi* tube mats from 3 months to 6 months and that remained high after 12 months. An increase in cover from 6 months to 12 months was also evident for the the NN encrusting bryozoan *Watersipora subtorquata* at KKM and the Unr encrusting bryozoan *Bowerbankia* sp. and the NN tube worm *Filograna implexa* at HMA.

Five more species were detected only after 12 months of submersion at one or both locations: NN *Diplosoma listerianum* (HMA), N *Aplidium californicum* (both sites), NN *Filograna implexa* (KKM), NN *Bugula neritina* (KKM) and N *Bugula californica* (KKM). These species may have settled so late due to a lack of larvae in the area or a sensitivity to copper. For NN *D. listerianum* at HMA, and for NN *B. neritina* and NN *Filograna implexa* at KKM, it was likely that a lack of larvae at the particular location delayed recruitment, as each had settled earlier on the copper panels at the other location.

However, at HMA, only a few NN *F. implexa* tube worms occurred on the copper panels after three months of exposure. This was surprising, as many of these worms

Accumulation of fouling as copper panels age (a) 3, (b) 6 and (c) 12 months

PHOTOS: CAROLYNN CULVER, LEIGH JOHNSON, MICHELLE LANDE

settled on the nontoxic coatings during the same time. Further, one year later during the same time of year and after 12 months of exposure, hundreds of these tube worms settled on the aged copper panels. This finding suggests that the worms may have been more sensitive to the younger copper coating, but that they were able to tolerate the more aged copper coating. N *Bugula californica* also may be more sensitive to copper as this species did not occur at either site until panels were submerged for 12 months.

Interestingly, recruitment of the N red algal species *Rhodymenia californica* was aided by the presence of the NN bryozoan *Watersipora subtorquata*. The N alga was found on top of the NN bryozoan on copper panels after being submerged for only 6 months at KKM. It wasn't until after 12 months of submersion at KKM that this alga recruited directly onto the copper panels. Also at KKM the N bryozoan *Bugula californica* recruited on top of NN *W. subtorquata* but not until the copper panels had been submerged for 12 months. The N bryozoan *B. californica* also recruited directly onto some copper panels submerged for 12 months. These findings illustrate how one copper tolerant species may provide a foundation to which less tolerant species may attach.

These data also suggest that the copper coating was less toxic after being submerged for 12 months, presumably due to decrease in the toxin by leaching over time. This conclusion is supported by the fact that some species did not attach directly to the panel until the panel was submerged for more than 6 months.

In general, NN species appeared sooner than N species on copper panels, albeit at very low levels. At KKM after 3 months of submersion the NN colonial tunicate *Diplosoma listerianum*, but no N species, had fouled the panels. At HMA three NN species and possibly one N species fouled the panels within three months: NN *Ciona* spp., NN *Filograna implexa,* NN *Hydroides elegans* and possibly N *Hydroides gracilis*.

Overall, more NN than N species occupied space on copper panels submerged for 12 months. At HMA five NN species (*Diplosoma listeranium*, *Filograna implexa*, *Watersipora subtorquata*, *Bugula neritina* and *Hydroides elegans*), but only one N species (*Aplidium californicum*), recruited to the 12-month panels. At KKM five NN species (*D. listeranium*, *F. implexa, W. subtorquata*, *B. neritina*, and *Ciona* spp.) and three N species (*Rhodymenia californica*, *Bugula californica*, *A. californicum*) recruited to the 12-month copper panels. Four of the five NN species were the same for both locations.

At KKM after 12 months NN species covered significantly more space than N species on copper panels. At HMA a similar trend for higher recruitment of NN than N was also evident. Results at HMA were not statistically significant, likely because there was greater variation in recruitment among panels at those four experimental stations.

These results clearly show that as a copper coating ages, its ability to control fouling is reduced; increased fouling levels occurred as soon as six months. Further, NN species that can tolerate copper are first to settle on the surfaces and they become more abundant over time. Thus, NNs may be more readily spread on boats with a copper hull coating if the fouling is not removed within six months after the paint was applied.

APPENDIX 3. FACTORS AFFECTING FOULING GROWTH: HULL CLEANING

As we have shown (Appendix 2), hull coatings, no matter the type, do not entirely prevent fouling. Additional tactics are therefore needed to help control fouling. In-water hull cleaning is commonly practiced in California to help control fouling and maintain boat performance. However, scientists in Australia published studies that concluded hull cleaning practices promoted the next generation of fouling organisms. That is, experimental panels that were cleaned by Australian methods had more new fouling than uncleaned panels.[78] Different hull cleaning practices are used in California, but their effectiveness had not been assessed scientifically.

Are California hull cleaning practices effective?

We designed a hull cleaning experiment to quantify the effects of California hull cleaning practices on fouling growth. We used the California Professional Divers Association's (CPDA's) best management practices (BMPs).[79] They call for cleaning hulls as often as necessary in order to use the most gentle cleaning tool possible. In contrast, the Australian scientists allowed fouling to grow for seven months and then removed it with a scraper, which is an abrasive tool, and left behind traces of organisms.

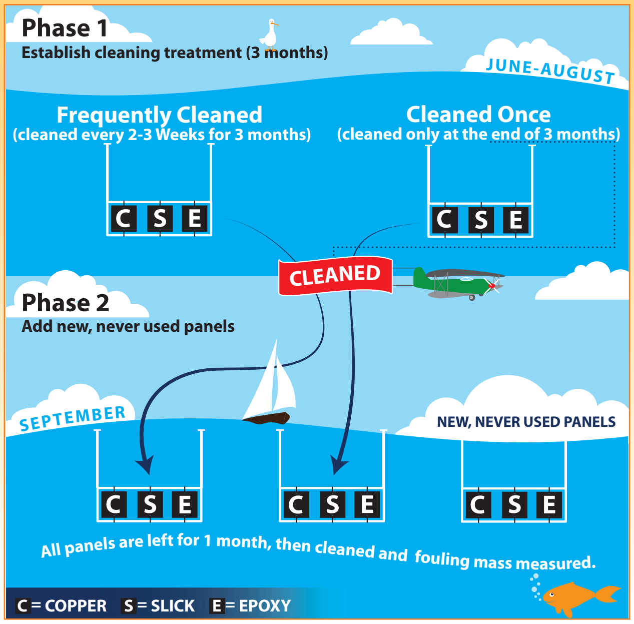
This experiment was conducted at one location in SBH and two locations in SIYB, for four warm-water months, when fouling rates are high. Sets of nine panels were used at four stations at each location. The nine panels included 3 coating types (copper, epoxy and slick) and 3 cleaning treatments, described below. Each time we cleaned any of the panels, we used the 5-point scale of the CPDA's BMPs (Table 2) to assess the level of

TABLE 2. Five-point Scale of the California Hull Cleaning Best Management Practices[81,82]

*	Coating Condition	Fouling Growth	Cleaning Tool***,****	Diver Effort
1	New, slick finish, still shiny if appropriate to type of coating	Light silting (looks like dust) that can be brushed off with a piece of carpet. Some plumes of discoloration.	Use for Level 1 Fouling Growth: a. Carpet, soft, medium to long shag b. White pad, soft c. Soft nylon bristle brush, bristle thickness .028-.032 d. Soft polypropylene brush, bristle thickness .022-.032	Light pressure: very easy to remove growth with one wipe
2	Shine is gone or surface is lightly etched on all of coating, no physical blemishes or defects	Moderate silting (a solid, discernible, physical layer) that must be removed with a soft brush or green 3M® pad.	Use for Level 2 Fouling Growth: a. Green pad, medium b. Nylon bristle brush, medium, bristle thickness .040	Light to medium pressure: still easy to remove growth but may require two or more passes in some areas to remove growth
3	Some blemishes or defects in coating on up to 20% of boat bottom	Dark algae impregnation. Algae must be scrubbed off; can't just wipe it off.	Use for Level 3 Fouling Growth: a. Purple pad, medium b. Nylon bristle brush, medium, bristle thickness .050	Light scrub, firm effort: firm wipe and/or multiple wipes or passes with brush to remove growth
4	Some blemishes or defects in coating on 20%-50% of boat bottom	Hard growth. Need heavier tools, such as steel wool, plastic and metal scrapers.	Use for Level 4 Fouling Growth: a. Brown pad, coarse b. Black pad, coarse c. Stainless steel row bristle brush	Firm scrub, hard effort: firm scrub and continuous passes required to remove fouling growth
5	Blemishes or defects on over 50% of boat bottom	Lengthy, soft algae and hard, tube worms and possibly barnacles impregnating the coatings. Coral** growth can be seen to extend out from the hull. Clean with metal scrapers and stainless steel brushes.	Use for Level 5 Fouling Growth a. Steel pad, abrasive b. Flat wire bristle brush, very coarse c. Whirlaway® tool, very abrasive	Hard scrub, very hard effort: even with hard physical effort, growth presented a challenge to remove with pad or brush

* 1 is best condition; 5 is worst condition
** Coral is a common name used in San Diego for tube worms, e.g. *Hydroides* spp.
*** Carpet and pads are hand operated tools; brushes and Whirlaway® are powered tools.
**** In practice, choice of tool did not always correspond to fouling growth level.

FIGURE 5. Procedure for hull cleaning experiment



GRAPHIC: RYAN KRASON

fouling, the harshness of the tool and the level of effort required to remove fouling on each panel.

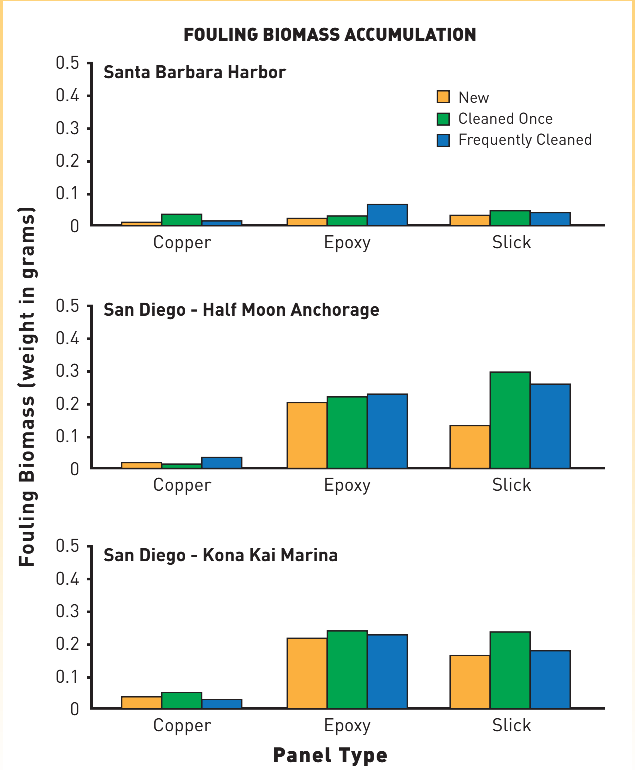
We began by submerging two sets of panels at each station for three months (June-August). During this time, one set of panels with the 3 coatings was cleaned according to the CPDA's BMPs for summer in southern California: every two weeks for nontoxic coatings and every three weeks for the toxic copper coating.[80] These panels represented the "frequently cleaned" experimental treatment. The second set of panels was cleaned only once at the end of the three-month period, representing the "cleaned once" treatment. The "cleaned once" treatment simulated methods used in the Australian study, albeit not as extreme.

After three months, these two sets of panels were cleaned and placed back into the water for a fourth month (September) and another set of new panels that had never been used was added to each frame. The new panels represented the new, "never cleaned" treatment for each of the three coating types.

After the fourth month, the accumulated fouling was removed from all panels. The resulting material was dried and weighed to determine whether the amount of fouling that accumulated in month four was different for the three cleaning treatments. Figure 5 illustrates the procedure for the hull cleaning experiment.

Statistical analyses showed that the coating type had a significant influence on the type of fouling organisms that settled on the panels. Copper panels were mostly fouled by a biofilm. Epoxy and slick panels were dominated by dark green algae and organisms with a calcareous (calcium carbonate) shell or tube, e.g. *Hydroides* spp. tube worms and spirorbid worms. Similar types of fouling were found in both SBH and SIYB as well as among all three cleaning treatments.

FIGURE 6. Amount of fouling growth accumulating on panels of differing coatings and cleaning treatments



GRAPHIC: CAROLYNN CULVER

In contrast, statistics showed that during the fourth month, panels that had been frequently cleaned had accumulated the same amount of fouling as the panels that had been cleaned once and as those that had never been cleaned (new panels). In other words, panels that underwent the three cleaning treatments did not accumulate different amounts of fouling during the fourth month. (Fig. 6) Unlike the Australian study, our results showed that frequent, gentle cleaning did not stimulate new fouling growth.

A slightly more abrasive tool and more effort were needed to clean the epoxy and slick coatings than the copper coating. Further, panels that were cleaned frequently and panels that were cleaned once required a slightly more abrasive tool and effort than the new panels that were not fouled or cleaned until the fourth month. Tools ranged from

PHOTO: CAROLYNN CULVER

Examples of common hull cleaning tools: (a) carpet, (b) white pad, and (c) green pad

level 1 to level 2, i.e. from a piece of shag carpet or a white 3M™ pad to a green 3M™ pad. No scrapers or wire brushes were used.

The difference between our conclusions and those of the Australian scientists is most likely due to the difference in hull cleaning practices. Our panels were cleaned frequently and gently, according to the BMPs of the CPDA. In contrast, the other scientists allowed fouling growth to accumulate and mature for seven months. It then had to be cleaned with a scraper, which is abrasive, and left remnants of fouling organisms. The scraper may have scratched the coating on their experimental panels, which may have helped new fouling spores and larvae gain a "foothold." Further, the Australian scientists suggested that scraping or scrubbing fouling organisms may release chemical signals, which attract species that prefer to live in groups (such as hull fouling species).[83,84]

PHOTO: LEIGH JOHNSON

Capturing accumulated fouling at end of experiment

Our results support the use of the CPDA's BMPs for hull cleaning. These practices not only help control fouling without stimulating it, but the frequent gentle cleaning also has the added benefits of:

- extending the life of a hull coating,[85] as a less aggressive tool is needed, leading to fewer deep scratches/chipping and fewer remnant parts of fouling organisms;
- decreasing time available for development of NN and other fouling organisms, thereby reducing the likelihood that they will reach maturity and reproduce in the home port or elsewhere; and
- increasing the likelihood that organisms will be damaged and removed while they are smaller and less developed, thereby not surviving in the harbor.

APPENDIX 4. FACTORS AFFECTING FOULING GROWTH: LOCATION AND ENVIRONMENTAL FACTORS

We also investigated the biology of hull fouling species and how they respond in different locations to the environment and nearby sources of pest populations.

Is Fouling a Greater Problem in Some Harbors?

Our two study sites are characterized by different oceanographic conditions. SBH is within the "California Transition Zone" where warm and cold water masses mix, whereas the San Diego region is influenced by a single warmer water mass.[86] Fouling rates are believed to be higher in southern California harbors than in central and northern California harbors. Because we gathered data at the same time and used the same experimental methods at these locations, we were able to compare fouling at the two sites.

For the hull cleaning experiment (Appendix 3),

Panels from (a) SBH, (b) HMA and (c) KKM show location, not cleaning treatment, influenced fouling

PHOTOS: CAROLYNN CULVER, LEIGH JOHNSON, MICHELLE LANDE

statistical analysis showed that geographic location influenced the amount of fouling, with much less fouling at SBH than at SIYB. Further, the experiment that evaluated fouling on different hull coatings over one-month time periods (Appendix 2) illustrated that there was far less fouling on the gel-coated panels in SBH than in SIYB. Differences in fouling at the two sites may be explained by different water temperatures. Fouling rates may have been greater in SIYB because average water temperature was 2°-3° C (~ 5° F) warmer than in SBH. Marine organisms tend to mature earlier and reproduce more often in warmer waters.[87,88]

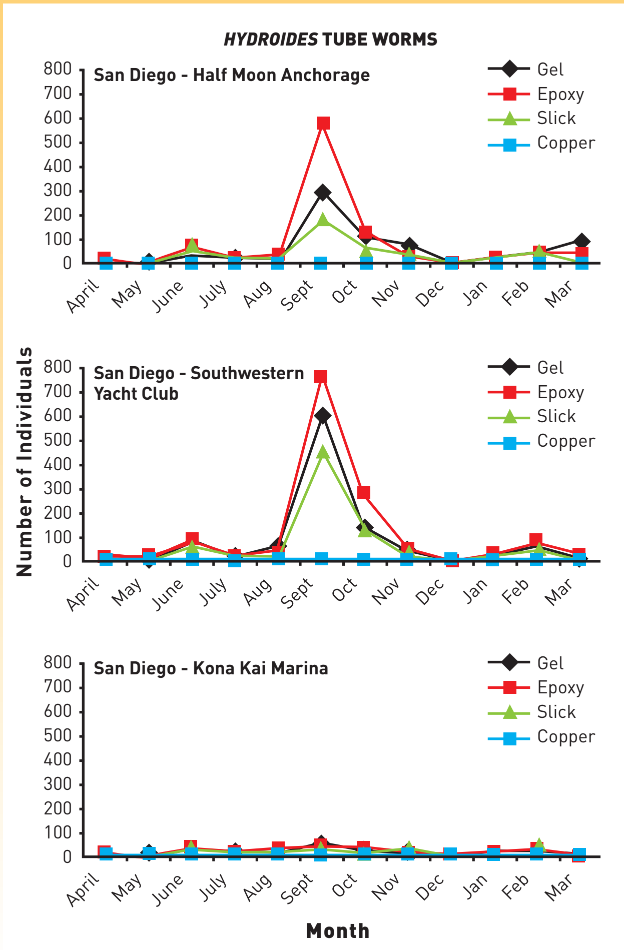
These findings support the idea that fouling may be a greater challenge for boats kept in California's warmer, more southern harbors. Additional studies are needed to validate this claim and factors that may explain it. For example, food availability or larval supply may also play a role.

Is Fouling a Greater Problem in Certain Slips?

To determine whether slip location influenced fouling, we compared fouling on our gel-coated panels that were exposed for one-month intervals at the various stations within each study site. (The same gel-coated panels were part of the study on influence of hull coating type on fouling described in Appendix 2.)

For both sites, location within the harbor significantly influenced recruitment of certain fouling organisms. From outer (I) to inner (IV) locations within SBH, recruitment increased for the NN individual tunicate (sea squirt) *Ciona* spp. and decreased for the NN encrusting bryozoan *Watersipora subtorquata* and C spirorbid worms. From outer (KKM) to inner (HMA) locations within SIYB, recruitment increased for the NN tube worm *Filograna implexa* and decreased for the colonial tunicate *Diplosoma listerianum* and spirorbid worms. However, at the middle location (SWYC) recruitment was highest for the NN encrusting bryozoan *Watersipora subtorquata*, *Hydroides* spp. tube worms and NN branching bryozoan *Bugula neritina* (Fig. 7.).

FIGURE 7. Recruitment of *Hydroides* tube worms to panels with differing coatings at three locations in Shelter Island Yacht Basin, San Diego Bay.



GRAPHIC: CAROLYNN CULVER

What is the Role of Environmental Factors?

Based on these findings, we further explored environmental factors that might explain why recruitment of these particular species was influenced by the location within each harbor. Only three of the measured factors were found to be important: presence of members of the same species (sources of pests) on dock floats, water flow and shading.

Sources of Fouling Species (Pests)

We wanted to determine whether the fouling on our panels may have been influenced by nearby "parent populations" (adult members of the same species). First, we examined photographs that showed the amount of various fouling species on nearby dock floats. We compared findings from the photographs to the amount of fouling on our panels using the experimental methods described above.

Duration of the free-swimming larval phase affects how far they can travel from the source (parent) population. Depending on the species, the larval phase can last a few minutes or many months. The longer that larvae remain in the water, the more likely they will move and be dispersed over longer distances. The shorter the larval phase, the more likely they are to settle near the parent population.

Recruitment of only the NN encrusting bryozoan *W. subtorquata* was associated with greater numbers of its species on nearby dock floats. Its larvae have a very short, free-swimming phase (on the order of hours or less) and thus have limited dispersal ability.

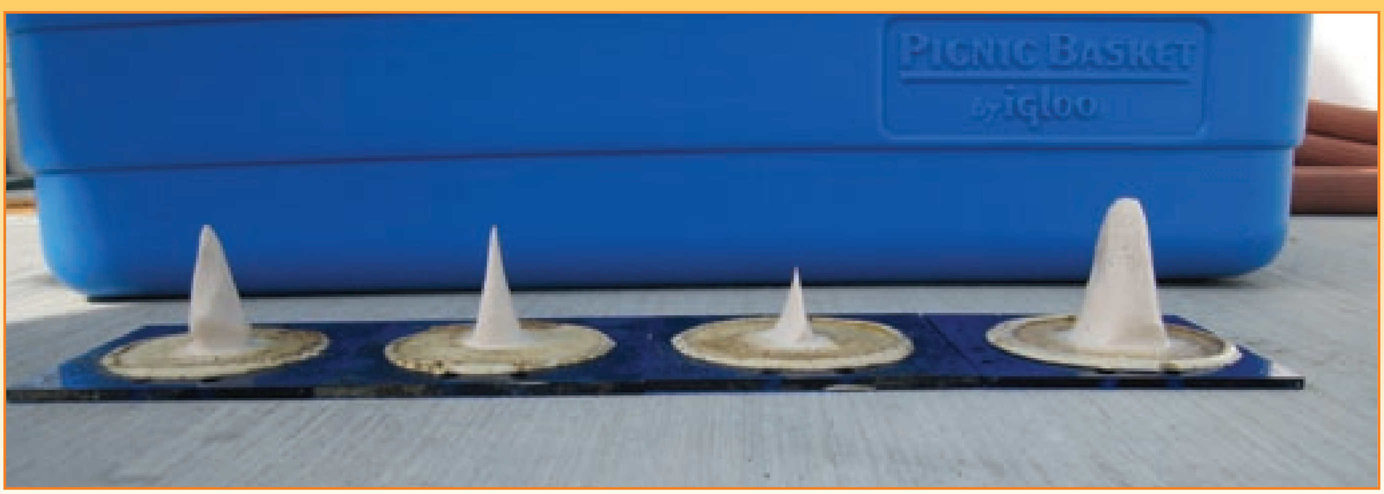
Although the presence of a nearby parent population on the faces of docks only mattered for one species in our study, more were likely present on other surfaces of the docks. Fouling organisms on the dock continually reproduce. Thus, cleaning "hot spots" (areas with abundant fouling and/or sources of species of concern) on docks should be considered as part of a control effort within the harbor or boat basin.

Water Flow in the Harbor

Water flow within a harbor is typically influenced by the tide. Generally, it is greater in slips that are near the harbor's mouth and center channel. Understanding how water flow influences the type and amount of fouling is useful for determining which hot spots, if any, are more likely to become fouled by species that prefer high or low water flow.

We evaluated the influence of ambient and experimentally manipulated water flow on fouling. We measured ambient water flow in both harbors with SLODS™ cards (see General Methods) that were attached to the experimental frame at each station. We compared the amount of material that was lost from each SLODS™ card to the type and amount of fouling on panels at each station over 12 one-month intervals. We manipulated water flow at SBH by attaching a small underwater pump to one end of an experimental frame. There were two panels at either end of the frame, and three frames with pumps for this particular experiment. We compared fouling on panels from the end of the frame with the enhanced flow (with the pump) to panels at the other end

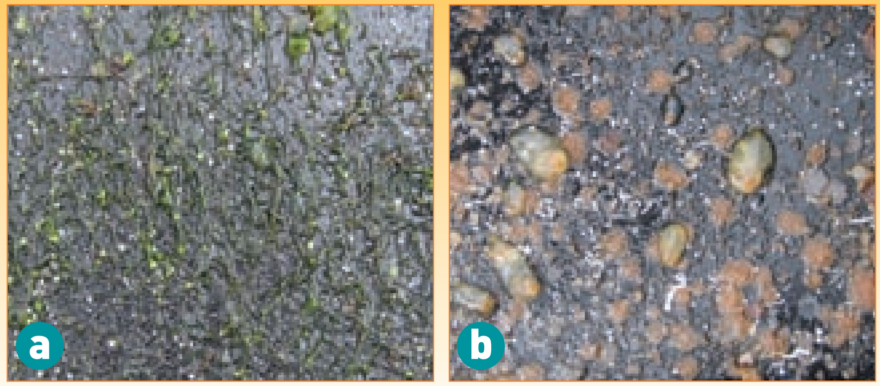
PHOTO: CAROLYNN CULVER



SLODS™ cards measure water flow

of the frame with ambient flow (no pump).

Water flow influenced fouling of only two species, the NN bryozoan *W. subtorquata* and the NN individual tunicate (sea squirt) *Ciona* spp., and it affected them differently. Greater ambient water flow resulted in more recruitment for the bryozoan *W. subtorquata*. In contrast, lower ambient and manipulated water flow resulted in more recruitment for *Ciona* spp. Results suggest that these species will be more abundant in areas where water flow rates favor them. Inspecting boats and docks in high and low flow areas of the harbor could determine hot spots where these NN species are abundant and assist in planning control efforts.



Examples from SBH (a) algae fouling on front versus (b) invertebrates on back

Sunny versus Shady Slips

In both SBH and SIYB we compared fouling rates and species on the fronts versus the backs of our one-month panels at each station throughout the year. As they were secured to frames extending down from the docks, the fronts of the panels faced out toward the sunlight and the backs of the panels faced in toward the shaded undersides of the docks. Algae are plants and therefore need sunlight to grow. Thus, algae primarily occurred on the fronts of the panels, with very little algae on the backs, especially during the summer. In sharp contrast, both the fronts and backs of the panels were fouled by invertebrates, including sea squirts, bryozoans, amphipods and tube worms. When algae was present on the front, fouling by invertebrates was typically much higher on the back than the front.

These results suggest that the amount of sunlight that reaches a hull should be considered when developing strategies for managing fouling, particularly in harbors where algae is abundant. (Algae were much more common on our panels in SBH than in SIYB.) If the hull is in a well-lighted area, be alert for the presence of NN algal species, such as the Asian kelp *Undaria pinnatifida*. Frequent cleaning may help to minimize spread of NN species and reduce staining of hull coatings by algae.

Time of the Year (Season)

Understanding the influence of season is critical for determining when to apply fouling control strategies. Thus, we analyzed monthly recruitment of fouling organisms on gel-coated panels submerged for 12, one-month intervals (described in the section on hull coatings) at both harbors.

Fouling was not limited to a single month or season, but it varied throughout the year. In general, recruitment of NN and other species of concern was greatest from the late spring to early fall (May-October), being quite limited in the winter (January-March). In contrast, recruitment of a few fouling species peaked in the winter, such as the NN bryozoan *Watersipora subtorquata*.

Some species recruited more intensely at certain locations within the harbor during their peak recruitment times. For example in SIYB the NN tube worm *Hydroides spp.* recruited more heavily at the inner (HMA) and middle (SWYC) locations than at the outer location (KKM), and specifically during the late summer/early fall (Fig. 7).

More frequent application of control strategies will be needed during spring and summer when more larvae of most species are in the water. However, fouling control strategies may be required throughout the year, particularly in areas where *W. subtorquata* is abundant.

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