Environmental Policy Conflicts on the Horizon:

Vessel Antifouling Paints, Coastal Water Quality, and Invasive Species

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Research Serving California

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Primary audiences for this report include the California Legislature, California State Water Resources Control Board, California Regional Water Quality Control Boards, California Department of Pesticide Regulation (CDPR), and California Department of Boating and Waterways (CDBW). Other audiences include organizations for boat owners, port/harbor/marina/yacht club managers, and hull cleaning, coating, and boat repair companies; and other government agencies and environmental organizations.

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We would like to acknowledge the many people who contributed to the white paper (*Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater*), workshop proceedings (*Managing Hull Transport of Aquatic Invasive Species*), and poster (*Stop Aquatic Invaders on Our Coast!/¡Detenga el Transporte de Especies Invasoras Acuáticas en Nuestras Costas!*) that are source documents for this issue paper. The views expressed herein do not necessarily reflect the views of persons acknowledged.

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EXECUTIVE SUMMARY

Aquatic invasive species (AIS) may be transported among fouling growth on hulls of boats and ships. Boats, such as commercial fishing and pleasure craft, are believed to transport AIS on their hulls between ports and smaller harbors within regions, whereas ships are believed to be responsible for most long-distance AIS transport. Once established, AIS become entrenched in the ecosystem, resisting eradication, and compromising human health and economic production that rely on the marine environment and resources. Much AIS policy and research have focused on large commercial ships and trailered boats. The role of recreational, commercial-passenger and commercial fishing boats in transporting AIS along the California coast is poorly understood, and control programs are not tailored to their operational costs and profiles.

Hull fouling control is critical for operational efficiency of vessels, as well as for reducing risks of transporting AIS. A variety of methods are used to control fouling on boats that are kept in saltwater, such as applying heavy-metal antifouling paint to the hull, periodically cleaning the hull while the boat is in the water, and surrounding the boat with a slip liner to which fresh water is added. Although an uncommon practice in California, some boats are stored out of the water on a hoist or in a boat barn when not in use.

Regulatory concerns about heavy metal contamination of coastal waters have led the International Maritime Organization to initiate a phased ban of tributyl tin in antifouling paint. They have also prompted the California Regional Water Quality Control Boards (CRWQCB) and the U.S. Environmental Protection Agency (USEPA) to regulate copper antifouling paint discharges from vessel hulls in southern California small craft harbors. Copper is discharged from hulls primarily via passive leaching, but also by in-water hull cleaning.

Total Maximum Daily Load (TMDL) programs to regulate copper discharged from antifouling paints encourage the use of nontoxic or less toxic coatings for new boats and replacing copper paints with these coatings at the next routine hull-stripping. TMDL assessments have been completed for Shelter Island Yacht Basin in San Diego County and Newport Bay in Orange County. An assessment is under way at Marina Del Rey in Los Angeles County and a regulatory program has begun at Shelter Island Yacht Basin. Dissolved copper levels above the standard of 3.1 µg/l harm marine life, especially mollusks, crustaceans and echinoderms. However, fouling control is necessary to maintain vessel speed, fuel efficiency, and hull integrity.

California agencies are considering a statewide approach to reduce copper pollution from antifouling paints. The California Department of Pesticide Regulation (CDPR) is communicating with the USEPA and the California Department of Boating and Waterways (CDBW) about reevaluating copper-based antifouling paints. The re-registration eligibility decision for these paints will outline risk reduction measures required for continued registration and use. The CSWRCB and CRWQCBs will act on a statewide measure if the CDPR does not do so within two years.

The proposed National Aquatic Invasive Species Act of 2005 encourages the avoidance of in-water hull cleaning, proper use of antifouling coatings, and collection and disposal of fouling growth. Aquatic invasive species (AIS) compromise native habitats, human health and economic production based on marine environments and resources. Millions of dollars in public and private costs have resulted from AIS-related damage to shorelines, structures, human health, ecosystems, fisheries and aquaculture production. Eradication, when possible, can cost millions of dollars for a single harbor. *The analysis in this report also applies to the draft California Aquatic Invasive Species Plan, although it was conducted before that document was released.*

Due to their heavy exposure to international shipping, large ports become breeding grounds for AIS, which recreational boats and commercial and commercial-passenger fishing boats help to spread along the coast. AIS introductions may increase between the U.S. and Mexico, because the Mexican government proposes to expand boat tourism in Baja California during 2004-2029.

In response to such threats, the UC Sea Grant Extension Program (SGEP) has developed a range of projects on nontoxic antifouling strategies and hull-borne invasive species, including:

- a demonstration project on nontoxic strategies for boats;
- an economic study of incentives for boaters to switch to nontoxic strategies;
- three technical reports and a one-half hour documentary on these projects;
- workshop proceedings: *Managing Hull Transport of Aquatic Invasive Species*;
- a white paper: *Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater*; and
- an educational poster: *Stop Aquatic Invaders on Our Coast!/Detanga el Transporte de Especies Invasoras Aquáticas en Nuestras Costas!*

(Copies of these publications [except the poster] can be downloaded from the UC SGEP website Publications Page at http://seagrant.ucdavis.edu/publications.htm and hard copies of all can be requested from ltjohnson@ucdavis.edu or jagonzalez@ucdavis.edu.)

Data were not available on full public and private costs of AIS damages or expected costs for research, education, management and eradication programs. However, the exorbitant costs likely to be prevented by these programs can be expected to exceed the costs of the programs. Evaluative criteria used in this analysis focus on expected effects on fouling control, coastal water quality and ecosystems, AIS, boat owners, port/harbor/marina/yacht club managers, and hull cleaning and boat repair companies. Public costs are mentioned generally.

STATUS QUO POLICIES AND ANALYSES

TMDL Programs for Dissolved Copper from Boats' Antifouling Paints

- *Ability to Control Fouling Growth*: If nontoxic, less toxic and other alternative hull coatings are not properly maintained, fuel efficiency, vessel speed and hull integrity will be compromised.

- *Water Quality, Ecosystems and Structures*: Marine organisms, their habitats and ecosystems in ports and harbors will likely benefit from the TMDL programs.

- *Aquatic Invasive Species*: Restrictions on heavy-metal, antifouling paints could exacerbate invasions as the toxicity of vessel hulls declines and as water quality improves. Alternately, native ecosystems may flourish and become more resistant to invasions as water quality improves.

- *Boat Owners*: The feasibility of using nontoxic coatings diminishes if their cost is too high. Restrictive antifouling policies that target small areas may unfairly burden local boaters, limit the market for alternative coatings and discourage their development, research and availability.

- *Port, Harbor, Marina and Yacht Club Managers*: Water quality improvements would maintain participation in boating and sport fishing and attract tourists. However, monitoring and evaluating hull coatings on tenants' boats poses a significant burden on these small businesses.

- *Underwater Hull Cleaning Companies*: Less-toxic and nontoxic hull coatings foul more quickly. Hull cleaners will need to purchase more costly, powered, hull-cleaning equipment and larger boats to transport it.

- *Boat Repair Yards*: Environmental compliance may discourage participation in boating and/or put California boating businesses at an economic disadvantage as boaters may choose to purchase copper-based antifouling paints or keep their boats in other areas of the U.S. or in Mexico.

California Department of Pesticide Regulation and U.S. Environmental Protection Agency Reevaluation of Copper-Based Paints

Restricting or banning copper-based antifouling paints statewide would expand the scope of most consequences discussed above. However, it would remove the disadvantages posed by limiting restrictions to smaller areas.

National Aquatic Invasive Species Act of 2005

- *Ability to Control Fouling Growth*: Discouraging in-water hull cleaning and encouraging collection and disposal of fouling growth is cost prohibitive for fouling control on larger boats kept in saltwater and removed for maintenance every one to three years. The technology to collect fouling growth while cleaning underwater is not suitable for smaller vessels. Copper-based paints must be cleaned thirteen times per year and nontoxic coatings must be cleaned twenty-six times per year in southern California. Annual, in-water, hull-cleaning costs are $650 for copper-based paints and $1,300 for nontoxic coatings. Annual, haul-out, hull-cleaning costs are $5,980 for copper-based paints and $11,960 for nontoxic coatings.

- *Water Quality, Ecosystems and Structures*: Encouraging proper use of antifouling coatings to eliminate or minimize AIS introductions would continue the discharge of copper from antifouling paints into coastal waters. Some studies indicate that some invasive fouling species are more tolerant of copper and tributyl tin than native species are, giving invasive species a competitive edge over native species. Preventing in-water hull cleaning and encouraging collection of fouling growth could help slow the spread of AIS along the coast. However, because many recreational boats are moored most of the time, such a prohibition may not be necessary unless they have returned with heavy fouling from a long trip or a visit to a major port or event attended by boats from many areas.

- *Aquatic Invasive Species*: Requiring boats to be hauled for cleaning and requiring the collection and disposal of fouling growth, would allow invasive species that may be present to be contained and reduce the risk of introductions. This can be accomplished easily and inexpensively by owners of trailered boats. However, the technology to collect fouling growth from ships while cleaning underwater is not suitable for boats. Boats normally kept in saltwater would have to be hauled out in order to collect and dispose of fouling growth, which would be cost prohibitive and the volume of haul-outs for cleaning may exceed boat repair yard capacity.

- *Boat Owners*: Discouraging or banning in-water hull cleaning could significantly reduce participation in recreational boating as the annual cost to haul and clean a boat’s hull is significantly more than the annual cost for in-water hull cleaning. If boat owners avoided hull cleaning to control costs, vessel speed, fuel efficiency and hull integrity would suffer and petroleum pollution of air and water would increase.

- *Port, Harbor, Marina and Yacht Club Managers*: Effects would be minimal unless they were required to actively discourage in-water hull cleaning.

- *Underwater Hull Cleaning Companies*: Employment of approximately 87 to 174 divers plus the administrative staff of hull-cleaning companies would be lost in San Diego County, if underwater hull cleaning were banned or discouraged. The statewide figure would be larger.

- *Boat Repair Yards*: Boatyards would be responsible for much of the hull cleaning and collection and disposal of fouling growth if underwater hull cleaning was banned or discouraged and if fouling growth collection was encouraged. However, boatyards likely lack capacity to handle this amount of hauling and cleaning and expansion is limited by competing uses for waterfront property.

Water Quality and Invasive Species Policy Conflicts

Despite technological advances aimed at reducing vessel fouling, the movement of fouled hulls still contributes significantly to AIS transport. Toxic antifouling paints simply retard fouling growth; they do not prevent it from becoming established on vessel hulls. Thus, periodic hull cleaning is needed even when antifouling paints are present. Policies restricting in-water hull cleaning would require frequent, cost-prohibitive haul-outs to remove fouling growth, which may discourage participation in boating. Furthermore, water quality degradation from antifouling paints may give hull-borne AIS, which have developed a tolerance of heavy metals, a competitive edge over native species.

ALTERNATIVE POLICY OPTIONS AND ANALYSES

The following measures are proposed to fill gaps and reduce conflicts identified for the status quo policies. We hope that they will stimulate discussions that lead to solutions.

- **Implement a regional approach and global perspective for all boats and ships.**

  This will help to reduce problems created by policy differences and resolve AIS problems that are exacerbated when boats cross state and national boundaries. Economies of scale may be realized through regional coordination.

- **Choose appropriate strategies and periodically evaluate and update them.**

  This will save public funds and avoid unduly burdening boat owners, port/harbor/marina/yacht club managers, and hull cleaning and boat repair companies. Prevention is more ecologically and cost effective than control, mitigation or eradication. Control and containment are most appropriate when the species is established and begins to increase its range. If the population of the AIS has completely colonized and a management technique is not yet implemented, mitigation may be viable.

- **Balance immediate action and research.**

  Immediate, collaborative education programs will raise boater awareness of these issues and provide economical best practices they can readily apply that will increase adoption of the recommended practices. Longer-term benefits can be expected from results of research and research-based education programs.

- **Develop a Hazard Analysis and Critical Control Point (HACCP) strategy.**

  A HACCP strategy identifies "critical control points" at which removing fouling growth from hulls and underwater running gear will be most effective in preventing or controlling AIS transport. Boat owners, port/harbor/marina/yacht club managers, underwater hull cleaning and boat repair companies, government staff, scientists and others can help to develop this information. Focusing efforts on these areas will help to reduce costs and avoid unnecessary procedures.

- **Develop, evaluate and update system for tailoring hull maintenance to boats' situations.**

  Proper use of antifouling strategies will allow selection of coating and companion strategies appropriate to the situation. Boats that do not travel long distances are likely to contribute to elevated copper levels and are less likely to encounter potentially invasive species. The greatest reduction in pollution with a low risk of AIS transport could be achieved if such boats used nontoxic hull coatings with companion strategies. Boats that travel long distances, spending more time at sea, are most likely to acquire and transport AIS. These boats may be better candidates for copper-based or less toxic antifoulants as they would discharge relatively less toxicants into marina waters. Periodic evaluation and updates based on lessons learned will improve such a system.

- **Adopt general hull maintenance practices to control AIS.**

  Hull and underwater running gear should be cleaned before a trip to a new region, an island, or event attended by many boats, before moving to a new location and before returning home. Special diligence is needed if the craft is kept in or visits a major port. This will decrease drag, hull deterioration, and the risk of introducing species to new regions or bringing them home. Hauling and cleaning fouled boats within one week of arrival from outside the region should prevent release of new species to local ecosystems, according to Australian recommendations.

- **Develop certificate programs.**

  A certificate identifying hull coatings and maintenance practices to determine compliance with TMDL regulations and status with respect to hull-borne AIS control should be simple, easy to implement and low cost. Involving boat owners and the boating industry in developing it would produce a system that is more feasible and cost-effective to implement.

- **Consider lessons from "Down Under."**

  Adapting lessons from Australia's experience may reduce public and private costs and avoid mistakes that might be incurred by designing a new system. The Australian Quarantine and Inspection Service asks owners of vessels under 25 meters (82 feet) that are traveling internationally to be sure their boats are clean before leaving their last port and asks those piloting boats arriving from overseas to complete a questionnaire to determine the risk posed by the vessel and appropriate control measures. Administering such a survey for California boats would pose logistical challenges, given the large number of boats and heavy traffic along the North American Pacific coast. Before establishing a survey system, consideration should be given to what data is critically needed, under what circumstances, how it would be used to reduce AIS transport by boats and who would develop and implement it.

- **Conduct research, monitoring and education appropriate for boats kept in saltwater.**

  Research will identify risks and feasible, cost-effective management measures and practices for reducing risks posed by larger boats kept in saltwater. Monitoring will enable managers to evaluate effectiveness of management measures and practices and to suggest means for improvement. Immediate and continuing education programs based on research, on long-term, validated practices, and on monitoring results will enable boat owners, port/harbor/marina/yacht club managers, and hull cleaning, coating and boat repair businesses, government agencies and environmental organizations to make appropriate and sustainable decisions. Research, monitoring and education programs will create public and private costs. However, they are needed to provide a reliable foundation for programs and practices to protect water quality and coastal ecosystems in a feasible and cost-effective manner.

INTRODUCTION*

Aquatic invasive species (AIS) may be transported among fouling growth on hulls of boats and ships. Boats, such as commercial fishing and pleasure craft, are believed to transport AIS on their hulls between ports and smaller harbors within regions, whereas ships are believed to be responsible for most long-distance AIS transport. Once established, AIS become entrenched in the ecosystem, resisting eradication, and compromising human health and economic production that rely on the marine environment and resources. Much AIS policy and research have focused on large commercial ships and trailered boats. The role of recreational, commercial-passenger and commercial fishing boats in transporting AIS along the California coast is poorly understood, and control programs are not tailored to their operational costs and profiles.

Hull fouling control is critical for operational efficiency of vessels, as well as for reducing risks of transporting AIS. A variety of methods are used to control fouling on boats that are kept in saltwater, such as applying heavy-metal antifouling paint to the hull, periodically cleaning the hull while the boat is in the water, and surrounding the boat with a slip liner to which fresh water is added. Although an uncommon practice in California, some boats are stored out of the water on a hoist or in a boat barn when not in use.

Regulatory concerns about heavy metal contamination of coastal waters have led the International Maritime Organization to initiate a phased ban of tributyl tin in antifouling paint. They have also prompted the California Regional Water Quality Control Boards (CRWQCB) and the U.S. Environmental Protection Agency (USEPA) to regulate copper antifouling paint discharges from vessel hulls in southern California small craft harbors. Copper is discharged from hulls primarily via passive leaching, but also by in-water hull cleaning.

Antifouling paints typically contain heavy metals that serve as pesticides to deter accumulation of fouling growth on the hulls of boats. The paints are engineered to slowly leach metals, assuring a fresh supply of pesticide at the surface of the paint. The leached

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* The primary audiences for this report are the California Legislature, California State Water Resources Control Board (CSWRCB), California Regional Water Quality Control Boards (CRWQCBs), California Department of Pesticide Regulation (CDPR) and California Department of Boating and Waterways (CDBW). The Legislature, Water Boards and CDPR will need to decide how to control AIS on boat hulls, while protecting coastal water quality. CDBW has expertise and well-developed avenues of communication for assisting boat owners and boating businesses in managing such challenges.

Additional audiences include boat owners (especially those of larger, recreational boats on which this paper focuses, although some information may be adapted for other small craft, such as commercial and commercial-passenger fishing boats); boating, fishing and coating businesses; academic and environmental organizations; and government staff and policymakers who may also be affected by these issues. The success of the Clean Marinas California program demonstrates that organizations of boat owners, boating businesses and waterfront authorities can be capable and effective partners or leaders in developing and implementing measures to protect coastal water quality and control hull-borne, invasive species. California has many long-established marine trade and boat owner associations that already communicate with state and federal agencies.

metals can accumulate in the water of poorly flushed boat basins to levels that have been shown through scientific research to harm marine life, especially mollusks, crustaceans and echinoderms. Newer studies have shown salmon behavior, including predator avoidance, is affected by low copper levels. This suggests that copper might affect other fish species, too. Most effects are sub-lethal; for example, they may hinder metabolic processes, reproduction, development, activity levels and behavior. Thus, the damage is chronic and less noticeable than, for example, fish kills caused by sudden oxygen depletion. Paints containing the highly toxic chemical, tributyl tin, have been banned for recreational boats and will be phased out for all vessels making international voyages by 2008.

A Total Maximum Daily Load (TMDL) program was recently approved by the California Regional Water Quality Control Board (CRWQCB), San Diego Region, for the Shelter Island Yacht Basin in San Diego Bay to regulate copper antifouling paint discharges.[1] The compliance schedule requires copper discharges from recreational boats to be reduced by 76% of current estimated loading over a 17-year period.[2] Regulations to severely reduce copper leaching from small-craft, antifouling paints may also be proposed for Newport Bay and Marina Del Rey in the next few years because TMDL programs for dissolved copper are under way there.[3] In late 2005, the CRWQCB, San Diego Region, recommended that other areas of San Diego Bay be added to the Section 303(d) list of water bodies impaired by dissolved copper.[4] At least one new antifouling paint contains the heavy metal, zinc, which may come to impair water quality, if widely used.

While antifouling policies aim to reduce water quality degradation due to leaching of metals such as tributyl tin and copper, policies on the hull transport of AIS aim to reduce the introduction of AIS by containing fouling growth and/or recommending use of antifouling paints. Virtually all the ports and bays of North America have at least some no indigenous marine species that have arrived from other parts of the globe, primarily via shipping. Ruiz et al. found in 2000 that shipping is the sole vector for approximately half of known invasions on North American coasts: 48% on the Pacific coast, 60% on the Atlantic coast and 64% on the Gulf coast.[5] Hull fouling in particular contributes to AIS transport: the faster speed of modern ships may enhance survival of certain low-salinity species that would not survive as well under longer exposures to seawater;[6] many slower-moving vessels may allow increased survivorship of other AIS.[7] For example, the barnacle (*Chthamalus proteus*) was probably introduced to Hawaii as larvae spawned from adults in a vessel hull-fouling community.[8] Once aquatic invasive species are established, they are difficult to eradicate.

As their abundance and range increase over time, the impact of AIS becomes more severe.[9] Millions of dollars in public funds have been expended to eradicate the invasive seaweed, *Caulerpa taxifolia*, from Agua Hedionda Lagoon in San Diego County and similarly to rid the black-striped mussel (*Dreissena polymorpha*) from Darwin Harbor in Australia. Damage to San Francisco Bay shorelines from the burrowing isopod (*Sphaeroma quoyanum*) and to ships and docks worldwide from burrowing teredo worms ranges much higher. Other species have seriously damaged fisheries and aquaculture operations and threatened human health. Damages and costs are reviewed extensively in our white paper mentioned below. Extensive public and private costs of AIS can be expected to rise as international shipping increases.

The University of California Sea Grant Extension Program (UC SGEP) has prepared a white paper, *Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater*. It examines risks posed by invasive species transported on boat hulls, considers the potential for conflict between policies to reduce pollution from antifouling paints and policies to control hull-borne invasive species, and recommends means for controlling invasive species while protecting coastal water quality. The white paper includes extensive background material, analysis and additional recommendations.

The UC SGEP conducted a workshop, "Managing Hull Transport of Aquatic Invasive Species," with the California State Lands Commission in 2005 that convened 66 boat owners, port/harbor/marina/yacht club managers, ship and boat repair/maintenance and coating business representatives, academics, government agency staff, policymakers, and environmental representatives. They heard expert presentations, deliberated, and recommended management measures, research and education. Material presented in this issue paper draws on information from the workshop proceedings and the white paper.

HISTORY OF THE ISSUE

Coastal Water Quality and Vessel Antifouling Paints

Regulatory concerns about heavy-metal contamination of coastal waters has led the International Maritime Organization to initiate a phased ban of tributyl tin in antifouling paints that will be completed in 2008 for vessels making international voyages.[10] The U.S. banned TBT in 1988 for vessels under 25 meters (82 feet).[11] The California Department of Pesticide Registration and the U.S. Environmental Protection Agency (USEPA) are reevaluating copper-based antifoulants and are expected to announce a decision late in 2006. They will explain their risk-assessment conclusions and outline risk reduction measures that may be required for continued registration and use.[12] USEPA is also considering whether to lower the level of dissolved copper allowed in boat basins.[13] TMDL programs will restrict copper antifoulants in some southern California marinas over the next several years (see below).

Tributyl tin (TBT) is toxic to marine life at low concentrations.[14] Research found that elevated TBT levels in the water column caused imposex (sex changes) in whelks, oyster deformations, and overall effects in the food web by accumulating in lower organisms.[15] Severe imposex causes sterility,[16] and local populations decreased dramatically or became extinct around ports.[17] As early as 1975, significant and repeated disturbances occurred in Arcachon Bay oyster farms on the French Atlantic coast. TBT contamination of local breeding waters caused stunted growth and failure to reproduce.[18] Imposex has been documented in the wild for as many as 150 species of marine snails worldwide.[19] The relationship of imposex to shipping traffic, poor recovery of affected populations in some areas, and widespread accumulation of butyltin residues in marine mammals led to calls to prohibit TBT on all vessels.[20]

TMDL Programs to Reduce Elevated Levels of Copper from Antifouling Paints

Copper-based boat bottom paints are legally registered pesticides[21] that are facing new restrictions. Recently, CRWQCBs and the USEPA identified dissolved copper levels exceeding federal and state standards in southern California small craft harbors.[22] A TMDL program is a written plan that describes how an impaired water body will meet water quality standards that have been established for it.[23] Section 303(d) of the federal Clean Water Act requires each state to maintain a list of impaired water bodies.[24] The California Toxics Rule (CTR) defines levels of pollution that are low enough to protect marine life based on many scientific studies; currently the standard for dissolved copper is 3.1 µg/l (micrograms per liter). In other words, the ratio of dissolved copper to water can be no more than 3.1 parts of copper to 1 billion parts of water.[25]

Elevated copper levels affect growth, development, feeding and other activity levels, reproduction, and survival at various life stages of: mussels, oysters, scallops, crustaceans, and sea urchins. High copper levels also change the types of phytoplankton that thrive in boat basins.[26] Low levels of dissolved copper affect juvenile coho salmon's sense of smell, which is critical for homing, foraging, and predator avoidance.[27] Such effects should be investigated for other fish species.

Total Maximum Daily Load Program – Shelter Island Yacht Basin

A Total Maximum Daily Load program was approved in September 2005 by the California State Water Resources Control Board for the Shelter Island Yacht Basin in San Diego Bay to regulate copper antifouling paint discharges. It calculated that antifouling paints contributed 98% of total copper loading to the basin, primarily via passive leaching.[28] The Southern California Coastal Water Research Project found in 2003 that 95% of dissolved copper from antifouling paints is released through passive leaching and 5% during hull cleaning.[29]

The compliance schedule requires copper discharges from recreational boats to be reduced by 76% of current estimated loading over 17 years.[30] Loading due to passive leaching must be reduced by 81% and loading due to underwater hull cleaning must be reduced by 28% from current loading. Overall, passive-leaching loading must be reduced by 75% and underwater hull-cleaning loading must be reduced by 1% from the combined total loading of all sources to the Yacht Basin.[31]

The compliance schedule includes a two-year orientation period followed by a 15-year reduction period. It assumes that all new boats entering the yacht basin will use nontoxic or less toxic coatings and that existing boats must replace copper coatings with nontoxic or less-toxic coatings at the next routine hull-stripping.[32] These coatings require companion strategies, such as slip liners, boat lifts and frequent hull cleaning to control fouling.

The Office of Administrative Law approved the Shelter Island Yacht Basin TMDL program as of December 2, 2005, beginning the two-year orientation period.[33] Thus, the 15-year reduction period will extend from late 2007 until late 2021. By late 2021, copper discharges must be at least 76% less than in 2005.[34] The TMDL program was granted final approval by the USEPA in February 2006.[35]

Total Maximum Daily Load Programs – Newport Bay and Marina Del Rey

A TMDL assessment has been completed for Newport Bay in Orange County and another is under way at Marina Del Rey in Los Angeles County.[36] Based on calculations from the Shelter Island Yacht Basin TMDL program and local data for Newport Bay, passive leaching from recreational boats and underwater hull cleaning is estimated to comprise over 80% of dissolved copper discharged into Newport Bay.[37] In late 2005, the CRWQCB, San Diego Region, recommended adding other areas of San Diego Bay to the section 303(d) list of water bodies impaired by dissolved copper.[38] Thus, similar restrictions on leaching of copper from antifoulants may be extended to other parts of southern California in coming years.

Dissolved Copper Standards in California and United States

The CTR concentration levels for dissolved copper are the same as those in the USEPA National Recommended Water Quality Criteria.[39] The USEPA has proposed lowering the allowable level of dissolved copper in coastal waters from 3.1 µg/l to 1.9 µg/l.[40] If the standard is lowered, restrictions on copper-based, antifouling paints are likely to spread well beyond southern California. Indeed, in the United States, copper is the most common metal found at toxic concentrations in marina waters.[41]

International Policies for Copper-Based Antifouling Paints

Copper-based antifouling paints have already been banned for use by pleasure craft in the Netherlands[42] and the east coast of Sweden and are restricted on the west coast of Sweden[43] and in Denmark.[44]

Aquatic Invasive Species Policies for Vessel Hulls

Once aquatic invasive species (AIS) enter the local marine environment, they will likely remain. AIS affect existing communities and modify native habitats. This can occur through predation on native species, such as the European green crab (*Carcinus maenas*) in California; modifying habitat, for example smothering by the invasive weed (*Caulerpa taxifolia*) in California and the black striped mussel (*Mytilopsis sallei*) in Australia; or providing new structural habitat, such as the New Zealand screwshell (*Maoricolpus roseus*) in Australia. Environmental changes caused by one species may enhance opportunities for others to invade.[45] This problem is sometimes called “invasional meltdown.”[46] Once established, aquatic invasive species are very expensive (and usually impossible) to eradicate.

The main socioeconomic impacts of AIS are negative impacts on human health and decreases in economic production based on marine environments and resources. These include fisheries, aquaculture, tourism, structures and shorelines. These effects may cause decreased employment in economic activities directly affected by AIS. For example, the invasive European green crab (*Carcinus maenas*) competes with the native Dungeness crab (*Cancer magister*), an important commercial species from San Francisco Bay to Washington State. Quality of life may be affected as AIS alter the natural environment.[47]

National Aquatic Invasive Species Act of 2005

Section 101 (3) (B) (iv), (v) of the United States Senate[48] and House[49] versions of the National Aquatic Invasive Species Act of 2005 suggests guidelines on best management practices to eliminate or minimize AIS transport by vessels. The guidelines include proper use of antifouling coatings and, to the maximum extent practicable, collection and proper disposal of debris from the cleaning of the hull. Section 305 prescribes "an education, outreach and training program directed toward marinas and marina operators regarding … (III) encouraging regular hull cleaning and maintenance; avoiding in-water hull cleaning" for watercraft at marinas. The Act has not been passed but has numerous co-sponsors in both houses.

California Assembly Bill 433

State law requires the California State Lands Commission, in consultation with the U.S. Coast Guard and a technical advisory group, to submit a report to the Legislature and general public analyzing the discharge of nonindigenous species from vessel vectors other than ballast water (i.e., hull fouling, sea chests, suction grids, propellers, chains, anchors, piping, tanks, etc.). The report must evaluate relative risks of those vectors, and recommend actions to reduce discharges of nonindigenous species by those vectors. The Commission has submitted the report to the Legislature and made it available to the public.[50] According to AB 433, "vessel" means a vessel of 300 gross registered tons or more, so the bill is focused on larger, commercial ships.

National Strategies to Prevent AIS Introductions

The 100th Meridian Initiative is a containment strategy in which U.S. and Canadian federal, state, provincial and local agencies are cooperating. The seven-step program is designed to prevent zebra mussels (*Dreissena polymorpha*) from spreading west of the 100th longitudinal meridian that runs through Manitoba, the Dakotas, Nebraska, Kansas, Oklahoma and Texas:

1) Inform and educate the public about zebra mussels, such as how they are transported and their impacts.

2) Conduct voluntary examination of vessels and related equipment as well as questionnaires designed to determine whether the boat is at risk of infestation.

3) Include boats used for commercial purposes, such as fishing boats.

4) Monitor the water so that action can be taken as soon as zebra mussels are detected.

5) If zebra mussels are detected, act immediately to eradicate or control them.

6) Determine other vectors or pathways that may contribute to zebra mussel infiltration and assess the likelihood that these pathways can introduce them.

7) Maintain the efficacy of the 100th Meridian Initiative.[51]

The "Stop Aquatic Hitchhikers!" campaign and web site (http://protectyourwaters.net) were developed to empower boaters to help stop the transport and spread of these harmful "hitchhikers." They recommend:

1) understanding the basic problem and solutions,

2) following the recommended procedures for cleaning items used in the water,

3) avoiding releasing fish/animals/plants into waters,

4) helping to inform others, and

5) getting involved in policy and legislative solutions.

Recommendations for recreational boats in the National Aquatic Invasive Species Act of 2005, the 100th Meridian Initiative, and the Stop Aquatic Hitchhikers! program appear to be aimed at freshwater AIS and trailered boats that owners can easily remove and inexpensively wash at launch ramps. In contrast, larger boats kept in saltwater are removed at most once per year and in southern California once every two to three years for maintenance at a boat repair yard at considerable expense.

Much AIS policy and research has focused on commercial ships and trailered boats. The role of recreational, commercial-passenger and commercial fishing boats in transporting AIS on the California coast is poorly understood and control programs are not tailored to their operational costs and profiles.

Proyecto Mar de Cortés and Centro Integral de Servicios

Currently, 60% of boats entering Baja California at Cabo San Lucas are from the United States and 80% of boats entering at Ensenada are from the United States, particularly California. The Mexican government proposes to expand boat tourism in Baja California during 2004-2029, renovating or developing 29 nautical stations via the Sea of Cortes project. An earlier project, The Nautical Ladder, was planned to develop 24 stations by 2015, but studies determined the potential market could not support such rapid development.[52] Further, a new, streamlined yacht documentation processing service, the Centro Integral de Servicios in Ensenada, has replaced the old, time-consuming policy that required foreign boaters to check in at every port visited in Baja California and comply with requirements at diverse offices and banks.[53]

UC SEA GRANT EXTENSION PROGRAM PROJECTS ON NONTOXIC ANTIFOULING ALTERNATIVES AND HULL-BORNE INVASIVE SPECIES

The antifouling market is heavily affected by environmental considerations and bans on toxic antifouling paints. The TBT phase-out will be complete by 2008. In the long-term other toxic antifouling paints may be severely restricted or banned due to water quality concerns. If so, new, nontoxic or much less toxic antifouling technologies will be needed. Companies both large and small are developing and testing innovative nontoxic and alternative antifouling products.[54] A few boat bottom coatings with reduced environmental impacts have reached the market and some hold promise. However, most have not been evaluated independently of the manufacturers.

A nontoxic antifouling strategy combines a nontoxic boat bottom coating with a companion strategy. Examples of companion strategies include: frequently cleaning the coating, surrounding the boat with a slip liner and adding freshwater to discourage marine fouling growth, and storing the boat out of water. Because a nontoxic bottom coating will not slow fouling growth, it must be cleaned about twice as often as a copper-based paint, if the boat is stored in water. In addition, some nontoxic bottom coatings are more expensive to apply. Currently available, nontoxic coatings may be applied to the gel coat on new boats or to a similar type of old nontoxic coating, depending on the product. However, they will not adhere to copper-based paints. Thus, old copper-based paint must be stripped from the hull before a nontoxic bottom coating can be applied.

Economics of Switching to Nontoxic Bottom Coatings

The University of California Sea Grant Extension Program (UC SGEP) in San Diego and the University of California, San Diego, Department of Economics studied economic incentives for boaters to switch to nontoxic bottom coatings. The resulting report, *Transitioning to Non-Metal Antifouling Paints on Marine Recreational Boats in San Diego Bay*, was submitted to the Department of Boating and Waterways in 2002 and to the Legislature in 2003. The study found that increased maintenance and application costs for a nontoxic bottom coating may be made up by increased lifespan of durable, nontoxic epoxy and ceramic-epoxy coatings. A random sample of 200 boaters in the San Diego Bay area found that they replace copper antifouling paint every two or three years because the cuprous oxide has been depleted. According to paint and coatings manufacturers, some nontoxic coatings may last up to 12 years because they are durable and do not depend on the leach rate of cuprous oxide. The study found that boat repair yards and hull cleaners estimate boats need to have built-up layers of copper paint stripped every 12 to 20 years (average of 15 years). Economically it is more reasonable to apply a nontoxic coating to new boats without antifouling paint or to boats that are ready to be stripped.[55] Findings included policy alternatives that were incorporated in the timetable for the Shelter Island Yacht Basin TMDL program for copper.

Nontoxic Hull-Coatings Demonstration Project

The UC SGEP examined the performance of three nontoxic bottom coatings on six boats in San Diego Bay. Divers reported on coating condition, fouling growth, diver effort levels, and aggressiveness of tool needed each time they cleaned the hulls. Each factor was rated on a scale, with five being the highest and one the lowest. Overall, water temperature and time since the last cleaning were primary predictors of fouling growth. The Best Management Practices (BMPs) of using a gentler tool and cleaning frequently helped to extend coating life and compensate for higher application and cleaning costs. Cleaning more frequently prevents fouling growth from accumulating to high levels. In turn, this allows divers to use less aggressive cleaning tools, spend less time cleaning, and exert less effort. Frequent cleaning may thus be expected to extend the life of the coating, reduce the cost of each cleaning and reduce wear and tear on hull cleaners. This is especially important when water is warmer and fouling organisms grow faster. Power cleaning tools enabled divers to use a less aggressive tool and exert less effort.[56]

At the end of the demonstration project in fall 2003, the over-one-year-old epoxy and ceramic-epoxy coatings were in nearly new condition and the five-year-old epoxy coating was in good condition. In summer 2005, all four of the demonstration boats with epoxy or ceramic-epoxy coatings were in good condition: one sailboat's coating had lasted about seven years, while the other three had lasted over three years. Unfortunately, the silicone-rubber coating used on two boats only lasted one year. It was preferred by boaters who liked to race and were willing to invest in frequent cleaning and annual replacement.[57] The epoxy and ceramic-epoxy coatings have already exceeded the typical useful life of copper-based coatings and can be expected to last for several more years. Thus, they are likely to make up for higher application and hull-cleaning costs by avoiding frequent replacement if the boat does not need to be hauled for other maintenance purposes. This confirms predictions of the economic study report.

UC SGEP Publications and Presentations

The UC SGEP has published three technical reports and a one-half hour documentary and has presented numerous seminars on the above projects. (The publications can be downloaded from the UC SGEP website Publications Page at http://seagrant.ucdavis.edu/publications.htm, and hard copies can be requested from ltjohnson@ucdavis.edu or jagonzalez@ucdavis.edu.)

- *What You Need to Know About Nontoxic Antifouling Strategies for Boats* summarizes technical information on nontoxic antifouling strategies for recreational boats, copper antifouling paint policies in the U.S. and Europe, and toxic effects of copper on marine life.

- *Making Dollars and Sense of Nontoxic Antifouling Strategies for Boats* is written for a general audience and based on the economic research discussed above and also includes a worksheet to calculate costs of using copper and nontoxic coatings.

- *Staying Afloat with Nontoxic Antifouling Strategies for Boats* summarizes results and conclusions of the nontoxic hull-coatings demonstration and provides updated antifouling policies and strategies, including a "Nontoxic Antifouling Strategies Sampler."

- *Time for a Change: Alternatives to Copper-Based Boat Bottom Paint/Es hora de cambiar: Alternativas a la pintura a base de cobre para cascos de botes* is a one-half hour documentary available on DVD, based on UC SGEP research and interviews with numerous stakeholders.

The UC SGEP presented nontoxic antifouling strategies research results at 80 seminars, conferences, committee meetings, hearings, field days, public exhibits, workshops and television broadcasts during 2002-2005 to hundreds of boat owners, boating and coating business representatives; government staff and policymakers; scientists; environmental representatives; and an unknown number of the general public.

UC SGEP Projects Addressing Invasive Species and Coastal Water Quality

The UC SGEP has conducted the following projects to examine the issues of water quality protection and invasive species prevention. (The first two publications may be downloaded from the UC SGEP website Publication Page at http://seagrant.ucdavis.edu/publications.htm, and hard copies of the poster and other publications can be requested from ltjohnson@ucdavis.edu or jagonzalez@ucdavis.edu.)

1. Workshop proceedings (published December 2005): *Managing Hull Transport of Aquatic Invasive Species.* The University of California Sea Grant Extension Program and California State Lands Commission convened a workshop on May 11, 2005, in San Francisco. Sixty-six representatives of shipping, boating and coating businesses; vessel owners; and government, environmental and academic organizations attended. They listened to expert presentations on ecological, legal and technical aspects of hull-borne AIS and fouling control, deliberated and made recommendations for technologies, management measures and policies to prevent and control AIS hull transport in California.

2. White paper: *Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater*. Potential conflicts exist between policies to reduce pollution from antifouling paints and policies to control hull-borne invasive species. The white paper is an in-depth review of coastal, marine AIS carried on boat bottoms in California; their structural, socioeconomic, and ecological impacts; California and Baja California coastal, boat traffic patterns; interplay of laws, regulations,

and agencies for hull fouling and AIS control; hull-fouling control techniques; and research, education and management measures that may reduce AIS introductions, while protecting coastal water quality.

3. Educational poster (to be published early in 2006): *Stop Aquatic Invaders on Our Coast!/Detanga el Transporte de Especies Invasoras Aquáticas en Nuestras Costas!* Most of the boats entering Baja California at Cabo San Lucas and Ensenada are from the U.S., particularly California. Recent Mexican policy changes will likely increase Baja California boat tourism and the risk posed to both regions by hull-borne AIS. The poster explains problems caused by hull-borne AIS and how to reduce the risk of transporting them on boat hulls.

EVALUATIVE CRITERIA FOR POLICIES AND OPTIONS

Data on full public costs that may be incurred to prevent and control AIS and on benefits of avoiding costs and damages they may cause were beyond the scope of this paper. However, some public and private costs would be incurred to develop and implement research, education and management programs. Given the extremely high costs and persistence of damages caused by AIS and of eradication/control programs, savings created by effective prevention programs will likely exceed the costs of implementing them. Beyond these general considerations of expected public expenditures and avoided costs, the following criteria were used to evaluate status quo options and proposed alternative policy options.

1. Effects on ability to control fouling growth in order to reduce its effects on vessel speed, fuel efficiency and hull integrity

2. Effects on water quality and viability of marine organisms, habitats and ecosystems, as well as coastal structures

3. Effects on aquatic invasive species

4. Socioeconomic effects on:

    A. Boat owners

        1) Operational costs (nontoxic coatings, frequent haul outs for cleaning, use of slip liner or boat lift, reporting on hull coating used and its age, voyages and cleaning history, etc.)
        2) Desire to continue or begin participating in boating

    B. Port, harbor, marina and yacht club managers

        1) Operational costs (extra staff, reporting requirements, etc.)
        2) Capacity to evaluate and determine antifouling methods, level of fouling on resident and arriving vessels

C. Underwater hull cleaning (UWHC) companies

1) Ability to stay in business
2) Operational costs and capacity to clean nontoxic and less toxic coatings (powered equipment, larger boat)

D. Boat repair yards

1) Capacity to apply nontoxic and other alternative paints
2) Capacity to haul and clean yachts and commercial/commercial-passenger fishing boats as frequently as needed to control fouling (and AIS) with copper-based, nontoxic, and less-toxic coatings

POLICY OPTIONS AND ANALYSES

Status Quo Policies and Analyses

Policy: TMDL Programs for Dissolved Copper from Boats' Antifouling Paints

A Total Maximum Daily Load program was recently approved by the California State Water Resources Control Board for the Shelter Island Yacht Basin in San Diego Bay to regulate copper antifouling paint discharges.[58] A TMDL assessment has been completed for Newport Bay in Orange County and another is under way at Marina Del Rey in Los Angeles County.[59] In late 2005, the California Regional Water Quality Control Board, San Diego Region, has recommended that other areas of San Diego Bay be placed on the section 303(d) list of impaired water bodies due to elevated levels of dissolved copper.[60] These policies will require reductions of dissolved copper levels in the yacht basin by reducing use of antifouling paints that contain copper.

Policy Analysis

1. Effects on Ability to Control Fouling Growth

Fouling growth on boat hulls affects boat owners and boating businesses by creating drag, slowing sailboats and increasing power boat fuel consumption. Antifouling paints with heavy metals, such as tin and copper, have been used widely to slow fouling growth. The primary goal of antifouling paints is to prevent hull roughness, because fouling can increase vessels' resistance to movement through the water by 7% to 10%,[61] increasing fuel consumption in some cases by 30%.[62] Nontoxic hull coatings require companion strategies, such as frequent cleaning, storing the boat out of water, or using a slip liner to which freshwater is added. Hull coatings with less copper need to be replaced more often, providing no net reduction in copper discharges. New nontoxic and other alternative hull coatings are in development and need to be tested for performance and durability. If nontoxic, less toxic and other alternative hull coatings are not properly maintained, fuel efficiency, vessel speed and hull integrity will be compromised.

2. *Effects on Water Quality, Ecosystems and Structures*

Marine organisms, their habitats and ecosystems in ports and harbors will likely benefit from the TMDL programs; copper discharges in the Shelter Island Yacht Basin are required to be at least 76% less by late 2021 than in 2005. Improved water quality may help to moderate the effects of coastal development on biodiversity. More than half of the United States' population lives and works within 50 miles of the coastline, but coastal areas account for only 11% of the nation's land area. In recent years, 40% of new commercial development and 46% of new residential development have occurred near the coast, which has increased polluted runoff and destroyed coastal habitats.[63] The coastal zone contains most of the infrastructure for marine recreation and tourism, the ports and harbors, and the urban, resort and industrial development in the U.S. Because biodiversity provides ecological, economic and aesthetic values, it is essential to coastal economies and quality of life. However, if alternative hull coatings are not properly maintained, increased fuel consumption may increase air and water pollution by spills and combustion of petroleum products.

3. *Effects on Aquatic Invasive Species*

Restrictions on heavy-metal antifouling paints could exacerbate invasions as the toxicity of vessel hulls declines and as water quality improves in coastal ports and harbors. On the other hand, native ecosystems may flourish and become more resistant to invasions as water quality improves. Water quality improvements may foster more abundant and diverse fouling communities that could colonize the hulls of visiting ships.[64] The recent decline in use of certain antifouling compounds, such as tributyl tin, may increase hull fouling on certain vessels.[65]

Initial results from studies at the University of New South Wales in Australia suggest that certain invasive species benefit from highly polluted environments and they would be less successful if pollution, in particular from antifouling paints, were reduced. Although not yet published, their clearest results are from the bryozoan, *Bugula neritina*. Populations of this organism thrive in a highly polluted environment but are out-competed where water quality is good. They occur in areas of good water quality but are less dominant.

Initial results with *Bugula* also suggest these findings will likely apply to three other invasive bryozoans, *Watersipora subtorquata*, *Tricellaria porterii* and *Schizoporella errata*, all of which are highly tolerant of copper. Research is needed to determine whether this also applies to other AIS that generally compete better for space, such as sponges and colonial or solitary ascidians.[66]

In a study of experimentally assembled communities, decreasing native diversity increased the survival of invaders. Increasing native diversity also decreased the availability of open space.[67]

Jeff Crooks of the Tijuana River National Estuarine Research Reserve compared the diversity of AIS and native fouling organisms in the San Francisco Bay Area (Tiburon) when exposed to varying concentrations of copper contamination. The diversity of natives declined with increasing contamination, while the diversity of AIS did not. This suggests that contamination may affect an ecosystem's vulnerability to invasion.[68]

4A. Effects on Boat Owners

Improved water quality and biodiversity will help to maintain recreational and aesthetic values that attract and retain participants in recreational boating and sport fishing. However, restrictive antifouling policies that target small areas, such as Shelter Island Yacht Basin, may unfairly burden local boaters and discourage them from renting slips at targeted marinas and ports. Furthermore, limiting restrictions on copper-based paints to a small geographic area will limit the market for alternative coatings and discourage their development, research and availability. However, if restrictions are established over a wide geographic area, the demand for alternatives will be high, as long as costs are not prohibitive and boaters wish to continue boating.

Although nontoxic coatings provide environmental benefits, the feasibility of using them diminishes if their cost is too high. Reporting on the hull coating used, its age, and maintenance history may be time-consuming for boat owners. Costs to switch to nontoxic or other alternative coatings and use companion strategies, such as frequent cleaning, are an important consideration. In-water hull cleaning costs $1.10-$1.25 per foot of boat length, according to San Diego area hull cleaners. Copper-based bottom paints are typically cleaned 13 times/year and nontoxic hull coatings are typically cleaned 26 times/year.[69] For a typical 40-foot boat in the San Diego area and $1.25/foot hull cleaning cost, it would cost $650/year to keep a copper-based bottom paint smooth and $1300/year to keep a nontoxic hull coating smooth. Nontoxic hull coatings that are currently available will not adhere to copper-based antifouling paints, which must be stripped before the nontoxic coatings can be applied. In the San Diego area, stripping a copper-based bottom paint costs $120 per foot of boat length, or $4800 for a typical, 40-foot boat. On average, boats in southern California are stripped every 15 years.[70] Some boaters may need to strip their hulls before it would otherwise be needed in order to comply with restrictions on copper-based antifouling paints.

Longevity is an important factor in the economic value of a nontoxic coating. Copper-based paints are typically replaced every two to three years in the San Diego area; in many parts of the United States they are replaced annually. Durable epoxy and ceramic-epoxy coatings may last 6-10 years and so may produce cost savings by avoiding the need for frequent replacement.

4B. Effects on Port, Harbor, Marina and Yacht Club Managers

Port and harbor authorities and marina and yacht club managers would derive economic benefits from water quality improvements that maintain participation in boating and sport fishing and attract tourists. However, they have been given responsibility to monitor and evaluate hull coatings on tenants' boats, posing a significant burden on these small businesses. Shelter Island Marina Manager Deborah Pennell commented that she will need to hire additional staff to comply with the Shelter Island Yacht Basin TMDL program. She also noted that it is difficult to determine from paperwork provided by boat repair yards whether the type and copper content of bottom paint on each boat in her marina is in compliance.[71] Historically, boat repair yards likely have not needed to provide this level of detail to boat owners. It could be even more difficult for marina managers to determine whether hull coatings that were applied to tenants' boats beyond the local area or in Mexico are in compliance.

4C. Effects on Underwater Hull Cleaning Companies

Less-toxic and nontoxic hull coatings foul more quickly. During our nontoxic bottom coatings demonstration, two experienced and respected hull cleaners noted that it was difficult to clean them with hand tools, because fouling accumulated rapidly.[72] Thus, hull cleaners will need to purchase more costly, powered, hull-cleaning equipment and larger boats necessary to transport it. Larger San Diego area hull cleaners have already made this investment but smaller companies have indicated that the expense is prohibitive. To comply with the TMDL program, many boats will need to acquire nontoxic or less toxic hull coatings. This may provide sufficient return on the investment in more expensive equipment and boats to make it feasible for smaller, hull-cleaning companies. Training on best management practices for maintaining hulls with alternative coatings may be necessary to ensure their longevity. The California Professional Divers Association offers training and certification on environmentally friendly hull cleaning practices for copper-based and nontoxic coatings.

4D. Effects on Boat Repair Yards

Environmental compliance may discourage participation in boating and/or put California boating businesses at an economic disadvantage as boaters may choose to purchase copper-based antifouling paints or keep their boats in other areas of the U.S. or in Mexico.

The Shelter Island TMDL schedule to reduce copper discharges from antifouling paints considered boat repair yard capacity as well as boat maintenance schedules. Currently available nontoxic coatings will not adhere to old copper-based antifouling paint, which must thus be stripped before a nontoxic coating is applied. Based on a 2002 study by the University of California Sea Grant Extension Program and University of California-San Diego Department of Economics, phasing out copper paint for the 7,342 recreational boats that were kept in San Diego Bay in summer 2002 would cost $20 million above and beyond usual maintenance costs if it occurred over seven years, which is the shortest possible time given San Diego boat repair yard capacity. If it occurred over 15 years, it would cost only $1 million extra as it would allow boats to be converted to nontoxic coatings when they are 15 years old and are typically ready to be stripped.[73] These factors should be considered if policies are developed to restrict copper-based antifouling paints elsewhere in California.

A San Diego boatyard offers low-copper paint with a two-year, hull-maintenance program: inspect at 3 months, haul and clean at 6 months, inspect at 9 months, haul and clean at 12 months, etc. Since low-copper paint is applied similarly to high-copper paint, no staff training would be required. Boaters would not have to pay for in-water hull cleaning. However, paint company representatives have indicated that, compared to high-copper paints, low-copper paints must be replaced more often, or more coats must be applied, to maintain pesticidal efficacy. [74] Because 95% of copper discharges from paints occur through passive leaching, [75] this system is not likely to reduce copper discharges significantly.

Policy: California Department of Pesticide Regulation and U.S. Environmental Protection Agency Reevaluation of Copper-Based Paints

California agencies are considering a statewide approach to reduce copper pollution from antifouling paints. The San Diego Unified Port District has requested the California Department of Pesticide Regulation (CDPR) to reevaluate copper-based antifouling paints and to consider taking a statewide approach to reduce elevated copper levels in marinas.[76] If impacts of copper-based antifouling paints on water quality are not adequately addressed by CDPR after two years, the San Diego Regional Water Quality Control Board, in conjunction with the California State Water Resource Control Board, will work with all coastal Regional Water Quality Control Boards to develop a state policy to address water quality impairments in marinas from copper-based antifouling paints.[77]

To assist in coordinating efforts, CDPR convenes a Copper Antifouling Paint Sub-Workgroup as a forum for communication among state agencies and other interested parties involved in this issue. The Copper Antifouling Paint Sub-Workgroup and CDPR are communicating with the U.S. Environmental Protection Agency (USEPA) on the reevaluation of copper-based antifouling paints.[78] The agency is conducting an environmental risk assessment for the antimicrobial use of coppers (i.e., wood preservation, antifoulants, etc.),[79] the conclusions from which will be issued in the near future, along with any risk reduction measures required for continued registration and use.

Policy Analysis

Restricting or banning copper-based antifouling paints statewide would expand the scope of most consequences discussed above for the Shelter Island Yacht Basin TMDL program and other TMDL programs for dissolved copper due to antifouling paints. However, it would remove the disadvantages posed by limiting restrictions to one or a few small areas.

Policy: California Assembly Bill 433

Current state legislation requires the California State Lands Commission, in consultation with the U.S. Coast Guard and a technical advisory group, to analyze and report on AIS introductions due to hull fouling.

Policy Analysis

California Assembly Bill 433 is tailored to commercial ships of 300 gross registered tons or more; there are no provisions for measures appropriate to small craft, such as recreational boats and commercial and commercial-passenger fishing boats.

Policy: National Aquatic Invasive Species Act of 2005

Given the many sponsors to the Senate and the House versions of this bill, it will very likely pass. Section 101 (3) (B) (iv), (v) of the United States Senate[80] and House[81] versions suggests guidelines on best management practices to eliminate or minimize AIS transport by vessels. The guidelines include proper use of antifouling coatings and, to the maximum extent practicable, collection and proper disposal of debris from hull cleaning. Section 305 prescribes "an education, outreach and training program directed toward marinas and marina operators regarding … (III) encouraging regular hull cleaning and maintenance; avoiding in-water hull cleaning" for watercraft at marinas.

Policy Analysis

1. Effects on Ability to Control Fouling Growth

By encouraging hull cleaning, maintenance, and collection and disposal of fouling growth, this policy supports fouling control. However, discouraging in-water hull cleaning and encouraging the collection of fouling growth would create cost barriers discussed above and elaborated below. It would be cost-prohibitive for fouling control on larger boats kept in saltwater and removed for maintenance once in one to three years.

2. Effects on Water Quality, Ecosystems and Structures

This policy encourages proper use of antifouling coatings to eliminate or minimize AIS introductions. This would continue the discharge of copper from antifouling paints into coastal waters. Some studies indicate that some invasive fouling species are more tolerant of copper and tributyl tin than native species are, giving AIS a competitive edge over native species.[82]

The policy also encourages hull cleaning and collection and disposal of fouling growth. Avoiding in-water hull cleaning and encouraging collection of fouling growth would foster healthier ecosystems by reducing copper discharges somewhat and AIS releases. Reduced AIS releases would decrease the risk of introducing species that could damage coastal structures. See the discussion below of other potential effects on water and air quality, at the end of section 4A.

AIS carried on vessel hulls can cause severe economic and ecological damage. Invasive species are second only to habitat loss as a threat to biological diversity and ecological integrity. Some scientists believe that problems posed by invasive species may soon surpass those caused by habitat loss.[83]

Due to their heavy exposure to international shipping, large ports become sources for intraregional spread. Small craft play a role in transporting AIS along the coast from the larger ports.[84] In other words, larger ships probably accomplish most of the long-distance transport, while recreational boats and commercial and commercial-passenger fishing boats have been implicated in spreading invasive species along the coast. For example, the burrowing isopod (*Sphaeroma quoyanum*) which fosters shoreline erosion, originated in Australia and New Zealand and is now found in Elkhorn Slough.[85] It was first reported in San Francisco Bay in 1893 and rapidly spread throughout California bays and harbors, almost certainly via hull fouling.[86]

The entire California coast has experienced some level of invasion by species not native to the state or not native to the area of the coast where they have been discovered. In many cases, the introduction of AIS from hull fouling causes both ecological damage and millions of dollars worth of structural damage. In California, invasive species transported via ship hulls disturb native habitats, affect biodiversity, and alter ecosystems. Indeed, the area is considered the most invaded marine region in the world, and in 1998, had an average of one intruder every 14 weeks.[87]

Thus, reducing the release of hull fouling species by preventing in-water hull cleaning of boats could help to slow the spread of invasive species along the coast. However, many recreational boats spend most of their time at the dock, so such a prohibition may not be necessary unless they have returned with heavy fouling from a long trip, a visit to a major port, or an event attended by boats from many areas. This will be discussed in more depth in the section on policy alternatives.

3. Effects on Aquatic Invasive Species

Requiring boats to be hauled for cleaning and requiring the collection and disposal of fouling growth would allow invasive species that may be present to be contained and reduce the risk of introductions. This can be accomplished easily and inexpensively by owners of trailered boats. Costs for larger boats would be prohibitive and the volume of haul-outs for cleaning may exceed boat repair yard capacity. (See sections 4A and 4D below. According to hull cleaners in the San Diego area, the technology to collect fouling growth while cleaning under water is not suitable for boats normally kept in saltwater; they would have to be hauled in order to collect and dispose of fouling growth, which would be cost prohibitive. (See the analysis of Policy: General Hull Maintenance Practices to Control Invasive Species below about the development of devices to collect and contain fouling removed during in-water hull cleaning.)

4A. Effects on Boat Owners

In the San Diego area, for boats kept in saltwater, boaters generally pay $1.10 to $1.25 per foot of boat length for in-water hull cleaning.[88] They pay approximately $8.00 to $10.00 per foot to have the boat hauled and an additional $40.00-$60.00 to have it hydro-washed and inspected for maintenance needs.[89] Boats with copper-based antifouling paints are generally cleaned in the water 13 times per year, while boats with nontoxic coatings are generally cleaned in the water 26 times per year in San Diego Bay. The importance of regular hull cleaning is apparent in the photographs in Appendix A; dense fouling approximately three inches deep accumulated in three months on a nontoxic hull coating of a dinghy that remained at the dock in San Diego Bay. Note that fouling was easily removed from this particular, slick, nontoxic coating. Tables 1 and 2 show in-water and haul-out hull-cleaning costs for a typical 40-foot boat kept in saltwater in San Diego Bay.

Table 1. Annual In-Water Hull-Cleaning Costs for Copper Paints and Nontoxic Coatings

	In-Water Hull Cleaning Service	In-Water Hull Cleaning per year
Copper Paint	$1.25/foot X 40 feet = $50	$50 X 13 cleanings = $650
Nontoxic Coating	$1.25/foot X 40 feet = $50	$50 X 26 cleanings = $1300

Table 2. Annual Haul-Out Hull-Cleaning Costs for Copper Paints and Nontoxic Coatings

	Haul-Out/Hull Cleaning Service	Haul-Out/Hull Cleaning per year
Copper Paint	$10/foot X 40 feet + $60 = $460	$460 X 13 cleanings = $5,980
Nontoxic Coating	$10/foot X 40 feet + $60 = $460	$460 X 26 cleanings = $11,960

Thus, the annual cost to haul out and clean a boat's hull is more than nine times the annual cost for in-water hull cleaning, whether the boat has a copper-based antifouling paint or nontoxic hull coating. Fees to collect and dispose of removed fouling organisms would be in addition to haul-out and hydro-washing costs. Unless boat repair yards significantly lower prices for hauling and cleaning, these costs would be prohibitive for maintaining smooth hulls, especially for boats with nontoxic hull coatings.

Thus, policies to discourage or ban in-water hull cleaning could significantly reduce participation in recreational boating. If boat owners avoided hull cleaning to control costs, vessel speed, fuel efficiency and hull integrity would suffer, creating other costs and increasing water and air pollution from discharges of petroleum and its combustion products.

4B. Effects on Port, Harbor, Marina and Yacht Club Managers

Effects on port/harbor authorities and marina/yacht club managers would be minimal, unless they were required to actively discourage in-water hull cleaning.

4C. Effects on Underwater Hull-Cleaning Companies

Employment statistics are not available for this industry but they can be estimated. Approximately 10,000 recreational boats are kept in San Diego County harbors. Copper-based bottom paints are typically cleaned 13 times per year, requiring 130,000 cleanings for the local fleet. Hull cleaning often includes additional services, such as inspecting and reporting condition of the coating, underwater running gear and through-hull fittings and replacing sacrificial zinc anodes. Travel and set-up require additional time. Assuming one diver can clean six boats per day, working five days per week, 50 weeks per year, then he could perform 1,500 cleanings per year and 87 divers would be needed to clean the local fleet, if all had copper-based bottom paints. Nontoxic coatings must be cleaned twice as often, so 174 divers would be needed to clean the local fleet if all had nontoxic coatings. Thus, employment of 87 to 174 divers plus the administrative staff of hull-cleaning companies would be lost in San Diego County if underwater hull cleaning were banned or discouraged. The statewide figure would be larger.

4D. Effects on Boat Repair Yards

Boatyards would be responsible for much of the hull cleaning and collection and disposal of fouling growth if underwater hull cleaning was banned or discouraged and fouling growth collection was encouraged. However, the capacity of boatyards to handle this amount of hauling and cleaning must be considered. Recreational boats with copper-based bottom paints would need to be hauled and cleaned 13 times per year, and those with nontoxic coatings would need to be hauled and cleaned 26 times per year. Again, the importance of regular hull cleaning for recreational boats can be seen in the photographs in Appendix A, which show dense fouling approximately three inches deep that accumulated in three months on a nontoxic hull coating of a dinghy moored in Shelter Island Yacht Basin of San Diego Bay. Commercial and commercial-passenger fishing boats would also need to be hauled and cleaned to control fouling growth, but less often because more frequent use discourages fouling from accumulating.

At first glance this would seem to represent a financial bonanza for boat repair yards. However, constraints on the capacity of San Diego County boat repair yards to convert boats to nontoxic coatings reported in our 2002 economic research[90] suggest that they do not have the capacity to perform the 130,000 – 260,000 haul-outs and hydro-washes that would be needed annually to maintain hull smoothness on the 10,000 recreational boats kept in local harbors, not to mention commercial boats. Availability of property to expand boat repair yard capacity is limited by competing uses for waterfront real estate. This capacity constraint likely pertains in other urban areas with many recreational boats and crowded waterfronts.

Policy Analysis of Water Quality and Aquatic Invasive Species Policy Conflicts

There is an assumption that hull fouling has been significantly reduced, if not eliminated, by significant improvements in antifouling paint technology, combined with an increase in vessel speeds and cargo loading times.[91] The concurrent assumption has been that antifouling paints could also prevent AIS introductions. However, as recent studies indicate, despite technological advances aimed at reducing vessel fouling, the movement of fouled hulls is still an important factor in the transfer of AIS.[92] The reason is that toxic antifouling paints simply retard fouling growth; they do not prevent it from becoming established on vessel hulls. Thus, periodic mechanical hull cleaning is needed even when antifouling paints are present.[93] Indeed, significant settlements of biota can attach to hulls over some days and can be rapidly transported worldwide.[94] Thus, policies restricting in-water hull cleaning would require frequent, cost-prohibitive haul-outs for removing fouling growth, discussed above. This may discourage boaters from continuing with boating and new boaters from beginning participation. This would jeopardize economic contributions of the California boating industry to the state's economy; it was worth $16 billion, or 1.2% of the State Gross Product, in 2000.[95]

Moreover, some species or strains have evolved resistance to copper-based antifouling paints.[96] Russell and Morris[97] call this adaptation "ship fouling as an evolutionary process." The recent decreased use of certain antifouling compounds, such as paints containing tributyl tin, may foster increased fouling communities on certain vessels.[98] Thus, policies requiring frequent re-application of strong antifouling compounds may degrade water in harbors and boat basins. Such water quality degradation may also give hull-borne AIS, which have developed a tolerance of heavy metals, a competitive edge over native species.

Policies: Proyecto Mar de Cortés and Centro Integral de Servicios

The Mexican government's Sea of Cortes project proposes to expand boat tourism in Baja California during 2004-2029 by renovating or developing 29 nautical stations. The project also includes plans to expand and improve an east-west highway to facilitate transportation of trailered boats across the peninsula. Currently, 60% of boats entering Baja California at Cabo San Lucas are from the United States and 80% of boats entering at Ensenada are from the United States, particularly California.[99] A new, streamlined yacht documentation processing service, the Centro Integral de Servicios in Ensenada, will make it much easier for American boaters to visit Baja California.[100]

Policy Analysis

Increased marina development and cross-border traffic of both trailered and larger boats can be expected to affect water quality, habitats and ecosystems in Baja California ports, harbors, marinas and estuaries. Further, it will increase the already significant risk of hull-borne transport of aquatic invasive species in both directions. Boat owners will have more recreational opportunities. California boat repair yards may lose some business to Mexican facilities as Mexican marinas are modernized and become more numerous and because yacht processing procedures have been streamlined.

Alternative Policy Options and Analyses

The following measures are proposed to fill gaps and reduce conflicts and consequences identified in our analyses of the status quo policies above. The objective of these alternatives is to complement those policies in order to control invasive species while reducing water quality impacts of antifouling paints on boats kept in saltwater and typically removed once every one to three years for maintenance. The alternatives include management strategies and techniques, considerations for future research and education, and vessel hull husbandry practices. We hope they will stimulate discussion and be useful to policymakers and others in establishing policies, management measures and practices that are cost effective, feasible, and sustainable in terms of both the environment and human capacity.

Policy: Implement a Regional Approach and Global Perspective for All Boats and Ships

Policymakers and stakeholders should develop a coordinated approach with states and provinces on the North American Pacific coast. It should consider recreational, commercial and commercial-passenger fishing boats kept in saltwater, as well as ships and trailered boats. Inter-agency communication and regional sharing of research data would improve effectiveness of management programs. Particular attention should be paid to communicating and coordinating with agencies, scientists, boating businesses and port/harbor authorities in Baja California, Mexico. Lessons learned in Hawaii, the midwestern United States, Australia and New Zealand may provide useful insights. A global perspective in which experiences are shared and compatible policies are developed would improve the effectiveness of programs to control longer-distance transportation of invasive species by all types of boats.

Policy Analysis

A regional approach and global perspective will help to reduce problems created by policy differences and are critical for resolving invasive species problems that are exacerbated when boats cross state and national boundaries. It will help to alleviate problems of documenting hull coatings on boats that are kept in marinas subject to TMDL regulatory programs for copper-based antifouling paints. Economies of scale may be realized through regional coordination. Evaluating policies and outcomes from Australia and New Zealand will reduce costs and inconveniences that could result from developing policies without the benefit of such experiences. However, it will be important to adapt them to vessel traffic patterns and ecological and socio-economic factors of the North American Pacific coast, including California.

Policy: Choose Appropriate Strategies and Periodically Evaluate and Update Them

Management measures and practices should be focused on situations most likely to achieve results, and strategies arrived at need to be periodically evaluated and updated. Prevention is more ecologically and cost effective than control, mitigation or eradication. Reducing the number of organisms associated with boat hulls can help to prevent introductions. The Australian government quarantines arriving vessels, if they are suspected of carrying invasive species. Costs, the heavy vessel traffic on the North American Pacific coast, and other aspects of feasibility must also be considered in devising strategies.

Although control does not eliminate entire communities of nonindigenous species, it may be more economically feasible than eradication. Control and containment are most appropriate when a species has become established and has begun to increase its range.[101] If the population of the invasive species has completely colonized and a management technique is not yet implemented, mitigation may be viable.[102]

Policy Analysis

The multi-billion-dollar boating and sport fishing industries depend on their ability to provide intangible recreational values. Commercial and commercial-passenger fishing industries are already challenged by declining fish stocks and increased fuel costs. Choosing appropriate and effective management measures and practices will save public funds, avoid unduly burdening boat owners, hull cleaning and boat repair businesses, and port/harbor/marina/yacht club managers, while protecting water quality and controlling invasive species. Periodic evaluation will enable managers to assess success and update management measures and recommended practices for further cost savings and efficacy.

Policy: Balance Immediate Action and Research

Boat owners can take some actions immediately (see the section on hull husbandry below). Most are enhancements of actions commonly taken by recreational boat owners before a cruise or before participating in an event. Some are adapted from Australian practices. Boat owners need to be educated on the importance of controlling invasive species and practices for doing so. Education recommendations are detailed in Appendix B. Scientific research is needed to understand the scope and nature of the invasive species risk posed by boats on the California coast and to develop an effective long-term strategy to prevent and control introductions. Research considerations are also outlined in Appendix B. Involve boat owner and boating business organizations as collaborators in research and education programs.

Policy Analysis

Representatives of boat owners and boating businesses have emphasized the importance of education and outreach in encouraging boaters to improve their environmental practices. We have found in 12 years of experience that research and education programs are most effective when developed and delivered in collaboration with boat owner and boating industry associations. The Clean Marinas California program is an excellent example of what an industry group can achieve if it is convinced that good environmental practices are important. Immediate, collaborative education programs will raise boater awareness of the related water quality and invasive species problems posed by hull fouling and provide readily applicable and economical best practices that will promote adoption of the recommended practices. This will begin the control process, rapidly reduce risks from invasive species and help to protect water quality from antifouling paint pollution. Fostering boater compliance will reduce public costs as well as compliance burdens of port/harbor/marina/yacht club managers and hull cleaning and boat repair businesses. Longer-term benefits can be expected from results of research and research-based education programs. Public costs will be incurred to support research, education and outreach.

Policy: Develop a Hazard Analysis and Critical Control Point (HACCP) Strategy

A HACCP strategy identifies "critical control points" (CCPs) at which removing fouling growth from hulls and underwater running gear will be most effective in preventing or controlling invasive species transport. This approach begins by identifying vessels and situations that pose a higher risk of transporting and introducing hull-borne invasive species. Boat owners, port/harbor/marina/yacht club managers, hull cleaning companies, boat repair yards, resource managers, scientists and others can help to develop this information. They can use it to decide how and when to deploy antifoulants, hull cleaning and other practices, to design research to improve practices, and to design long-term solutions. See Appendix B for research needs and considerations regarding critical control points and associated practices to control invasive species.

Policy Analysis

Focusing efforts on critical control points will help to reduce costs and avoid unnecessary inconvenience. HACCP has been widely adopted and shown to be effective in the seafood processing industry for maintaining seafood quality in a cost-effective manner. It is being taught nationally by U.S. Fish and Wildlife as an effective program for AIS control. If expanded to address water quality, it will help to control costs for all parties and improve results in managing antifouling paint pollution and invasive species associated with boat hulls.

Policy: Develop, Evaluate and Update System Tailoring Hull Maintenance to Boats' Situations

Tailoring hull maintenance to the boat and its situation utilizes a HACCP approach to resolve challenges of managing invasive species and water quality issues for boat hulls. Proper use of antifouling strategies will allow selection of coating and companion strategies appropriate to the situation. The system should be developed in collaboration with associations of boat owners, of port/harbor/marina/yacht club managers, and of hull cleaning and boat repair businesses. It should be periodically evaluated and updated.

Policy Analysis

As noted above, antifouling paints with persistent toxicants, such as tributyl tin and cuprous oxide, pose water quality problems in many boat basins. Tributyl tin antifoulants are already widely banned. Restrictions on copper-based paints have begun in San Diego Bay, and may spread to other parts of California and perhaps the United States. Recent research has identified copper-tolerant, invasive, hull-fouling species.[103] This suggests that boat basins polluted by copper may provide a competitive edge to copper-tolerant species brought in on boat hulls.

Participants in the May 11, 2005 workshop, "Managing Hull Transport of Aquatic Invasive Species," suggested *that the operational dynamic is more important than the total area of a hull surface and that it is especially important to evaluate hulls of vessels that remain in port for long periods of time before traveling long distances to other regions.* Participants noted that studies in Hawaii found that such trips may expose a single destination to repeated inoculations of aquatic invasive species.[104]

Boats that do not travel long distances are less likely to encounter potentially invasive species. We have observed that many recreational boats spend most of their time in the home slip. Table 3 shows that about one-half of all boaters in California's coastal counties take no trips over 100 miles from home. Because their number is large and they spend much time in the home marina, they likely contribute the lion's share to elevated copper levels. Thus, the greatest reduction in pollution with a low risk of invasive species transport could be achieved if such boats used nontoxic hull coatings with companion strategies such as slip liners or frequent, in-water hull cleaning. (See "Policy: General Hull Maintenance Practices to Control Invasive Species" below for recommendations on preparing for a trip.) Photographs in Appendix A illustrate the ease of removing fouling from slick, nontoxic hull coatings.

Boats that travel long distances are most likely to acquire and transport invasive species. Table 3 shows that from 2% to 7% of boats in California's coastal counties make frequent trips over 100 miles from home. These boats may be better candidates for copper-based or less toxic antifoulants, as opposed to nontoxic hull coatings. Because they are relatively few in number and spend more time at sea, they would discharge relatively less toxicant to confined, marina waters.

Table 3. Percentage of Boaters by Region Who Traveled More Than 100 miles from Home in 2000[105]

# Trips > 100 mi.	North Coast	SF Bay	Central Coast	South Coast	San Diego
None	54.0%	52.3%	55.3%	42.7%	55.4%
1-5	33.1%	27.1%	27.2%	44.8%	31.2%
6-20	9.2%	13.3%	13.9%	7.6%	11.3%
> 20	2.9%	6.9%	3.8%	4.9%	2.1%

Data in two columns do not sum to 100% as per published source.

A management system that tailors hull maintenance to the boat and its situation will foster antifouling paint pollution and invasive species control while maintaining boat speed, fuel efficiency and petroleum pollution control. This will help to protect water quality and native ecosystems. Such a system will require some initial investment of public and private funds, but in the long-term it can be expected to save costs for and assist boat owners, port/harbor/marina/yacht club managers and hull cleaning and boat repair businesses in complying with regulations on antifouling paints and invasive species.

Policy: General Hull Maintenance Practices to Control Invasive Species

The following practices are proposed to control invasive species on boats kept in saltwater and removed once every one to three years to reapply paint and inspect underwater running gear and through-hull fittings. Owners of trailered boats may visit the excellent Stop Aquatic Hitchhikers! website (see the bullet point below). These recommendations are incorporated in our bilingual poster, “Stop Aquatic Invaders on Our Coast!/¡Detenga el transporte de especies invasoras acuáticas en nuestras costas!”

- If you use copper-based antifouling paint, replace it when copper is depleted.
- Nontoxic boat bottom coatings are safer for aquatic life, but frequent cleaning is needed. Please visit http://seagrant.ucdavis.edu for more information.
- Clean the hull of your boat, underwater running gear, and internal seawater systems before traveling beyond your home region, especially if you will visit major ports, international waters, islands, or events with boats from many places.
- Clean them all again before moving to another region or returning home.
- If your boat is heavily fouled after such trips, haul it for cleaning within one week after arrival and contain the fouling growth.
- Drain livewells, bait tanks, and bilge water before traveling and before returning.

- If you trailer your boat, please follow the guidelines at the excellent Stop Aquatic Hitchhikers! website http://www.protectyourwaters.net.

- In California, report aquatic invasive species found on your boat or in your marina to The National ANS Hotline 1-877-STOP-ANS (1-877-786-7267).

- In Baja California, report aquatic invasive species found on your boat or in your marina to Comisión nacional para el conocimiento y uso de la biodiversidad (CONABIO) 01 (55) 5528-9142

Policy Analysis

Costs and benefits are generally similar to those discussed for policies on immediate action, HACCP and tailoring hull maintenance to the boat and its situation. Cleaning the hull and underwater running gear before a trip will benefit boat owners. Fouling growth increases hull roughness and drag, increasing fuel consumption by 0.3% to 1% or more, and reducing maneuverability. Fouling growth eventually penetrates the coating, requiring more aggressive cleaning and leading to paint loss and hull deterioration.[106] If fouling was accumulated while the boat was in local waters, then in-water cleaning will not release any new species to the local ecosystem. Because only 5% of copper discharged from antifouling paints is due to in-water hull cleaning, effects on water quality are expected to be negligible for copper-based paints and nil for nontoxic coatings. Hull cleaning companies will receive additional revenues from in-water cleaning. New, nontoxic coatings will need to be evaluated independently of the manufacturers, in regions with different climates and fouling communities, and on boats with different operating profiles.

For fouled boats arriving from outside the region, hauling and cleaning within one week of arrival should prevent release of new species to local ecosystems, according to Australian authorities.[107] Boat repair yards will receive additional revenues. Boat owners will incur additional costs. Port/harbor/marina/yacht club managers may incur costs for determining whether newly arrived boats should be hauled for cleaning. Asking arriving boat owners to report their travel history may help to manage this cost (see “Policy: Consider Lessons from ‘Down Under’” below).

The U.S. Navy is developing devices to collect and contain fouling removed during in-water hull cleaning, for example, the Submerged Cleaning and Maintenance Platform (SCAMP™) or the SeaKlean™ multi-brush and vacuum systems.[108] They are reported to be effective at cleaning vessel hulls, but their efficiency in capturing and containing all biological material is reported to vary, depending on the extent of fouling, water conditions and operators’ skills.[109] The New Zealand Diving and Salvage Ltd. is developing in-water hull-cleaning and vacuuming equipment that can gather marine organisms and filter the resulting effluent down to 50 µm with minimal chance of release to the environment. However, technical challenges remain.[110] This type of hull cleaning equipment has been developed for larger ships. It may not be feasible for recreational boats. Suitable technology needs to be developed for collecting fouling that is removed during in-water hull cleaning.

Policy: Certificate Programs

A certificate program is needed to identify the hull coating on each boat and document its characteristics clearly, consistently and completely to assist marina managers, for example, in determining whether tenants' boats are in compliance with TMDL regulations on copper-based antifouling paints. To assist port/harbor/marina/yacht club managers, for example, in determining each boat's status with respect to hull-borne invasive species control, it may be effective to implement a program for documenting antifouling strategies used for each boat, including coatings and necessary companion strategies/maintenance. It should take into account local conditions and policies. It should be simple, easy to implement and low cost. The success of the Clean Marinas California program suggests that boating business organizations can be effective in developing and implementing such programs in a manner that is cost effective and feasible for protecting water quality and controlling invasive species.

Policy Analysis

Developing and implementing a certificate program would incur public or private costs. Involving boat owner, port/harbor/marina/yacht club, hull cleaning and boat repair business representatives in developing it would produce a system that is more feasible and cost-effective to implement. It can be expected to enhance other measures to protect water quality and ecosystems and reduce costs for responsible parties who must identify boat owners who are implementing appropriate practices and educate those who are not.

Policy: Consider Lessons from "Down Under"

Control measures developed in Australia should be evaluated and adapted for use on the North American Pacific coast.

Policy Analysis

Dr. Oliver Floerl of the National Institute of Water and Atmospheric Research in New Zealand has found that 80% of New Zealand's boats don't travel much or only very locally, 10% are used for wider-reaching domestic trips and another 10% are used for international travel.[111] He suggests that caution should be taken before applying blanket regulations, which may unfairly target boats that do not pose a risk. His observations and recommendation are similar to those made for recreational boats in California.

The Australian Quarantine and Inspection Service (AQIS) asks owners of vessels under 25 meters (82 feet) that are traveling internationally to be sure their boats are clean before leaving their last port: "Keep all ancillary gear and internal seawater systems clean of marine pests and growth; and clean your vessel's hull within one month before arrival; or apply antifouling paint within one year before arrival; or book your vessel in to be slipped and cleaned within one week of arrival." It is noteworthy that the emphasis on antifouling paint does not consider its water quality impacts.

AQIS asks boat owners to pay special attention to the high risk areas: "hull, keel and rudder; propellers and shafts; anchor wells (including anchor chain and rope); water intakes and outlets; tenders and outboard motors; and sea strainers and internal water systems." This (currently voluntary) program is expected to become mandatory on October 1, 2006.[112]

AQIS also asks boats arriving from overseas to complete a questionnaire that will help them to determine the risk posed by the vessel and appropriate control measures. However, administering such a survey for some or all California boat traffic would pose logistical challenges due to heavy boat traffic on the North American Pacific Coast. Before establishing a survey system, consideration should be given to what data is critically needed, under what circumstances, how it would be used to reduce invasive species transport by boats and who would develop and implement it.

Adapting lessons from Australia's experience will reduce public and private costs and avoid mistakes that might be incurred by designing a system *de novo*. It will enhance the speed at which water quality and ecosystem benefits are realized.

Policy: Conduct Research, Monitoring and Education Appropriate for Boats Kept in Saltwater

The recommendations presented above should enable boat owners to take immediate action that will reduce the risks of transporting invasive species on boat bottoms. Research and continuing education are needed for long-term success. Research, monitoring and education programs should be prioritized, developed and, where appropriate, conducted in collaboration with representatives of boat owners, port/harbor/marina/yacht club managers, boat repair and maintenance businesses, responsible agencies, educational and environmental organizations. Considerations for future research and education are detailed in Appendix B.

Policy Analysis

Most existing research and education on invasive species transported by vessels has focused on ships engaged in international commerce and on smaller boats that are trailered, especially among freshwater lakes and rivers. The nature and scope of risks posed by larger boats kept in saltwater are less well understood. Research will identify risks as well as feasible and cost-effective management measures and practices for reducing those risks. Monitoring will enable managers to evaluate effectiveness of management measures and practices and to suggest means for improvement. Immediate and continuing education programs based on research, on long-term, validated practices, and on monitoring results will enable boat owners, port/harbor/marina/yacht club managers, hull cleaning, coating and boat repair businesses, government agencies and environmental organizations to make appropriate and sustainable decisions. Research, monitoring and education programs will create public and private costs. However, they are needed to provide a reliable foundation for programs and practices to protect water quality and coastal ecosystems in a feasible and cost-effective manner.

CONCLUSIONS

Risks posed by aquatic invasive species can be expected to increase as international shipping commerce continues to grow. Ships are responsible for most of the long-distance transport of aquatic invasive species—in ballast water, on hulls and on underwater structures. However, there is increasing evidence that boats transport them along the coast within a region. Hull husbandry practices to prevent and control invasive species transport will need to consider water quality, tolerances of invasive and native species to antifouling toxicants, changes in antifouling paint regulations, and costs of new products, practices and reporting requirements.

Although this report focuses on California and Baja California, invasive species management systems will need to be coordinated throughout the west coast of North America, if they are to succeed. Lessons learned in Australia, New Zealand, Hawaii and the midwestern United States can provide valuable insights. However, management systems and policies to support them must address the unique situation and characteristics of boats that are kept in saltwater and removed every one to three years for maintenance. Managers will need to communicate among each other and with policymakers, boat owners, boating, fishing and hull-coating businesses, scientists and educators to develop effective and sustainable policies.

Boat owners and boating businesses can take immediate steps to prevent and control invasive species transport on hulls and underwater running gear. A first step would be to clean the hull before leaving the home harbor to visit a distant region, island or event with boats from many regions. Boats kept in major ports are at a higher risk of acquiring invasive species from international shipping. Their owners should be especially diligent in cleaning the hull before leaving for another harbor. Boat owners who have left their home region or visited a major port should clean hulls before traveling to a new destination or returning home. Within one week of arrival from a distant region or major port, heavily fouled boats should be hauled out, their hulls cleaned and removed material contained. These practices are adapted from existing hull husbandry practices and thus should be straightforward and simple to use.

Research is needed to more clearly define the types of invasive species that are likely to be transported on boat hulls and their expected ecological and socioeconomic impacts on recipient regions. Research is also needed to develop appropriate management systems and to evaluate new hull husbandry products and practices.

Education has a strong track record in encouraging boat owners and boating businesses to prevent pollution. It has also been demonstrated to be effective in encouraging boat owners to prevent transport of invasive species in the midwestern United States. Boat owner and boating business representatives have recommended education as the most effective tool for changing practices to prevent transport of invasive species by boats in California. Involving boat owner, boating and fishing business organizations, as well as groups such as Clean Marina, BoatUS Foundation, Coast Guard Sea Partners and Sea Grant Colleges, in developing and conducting education and outreach are effective approaches. Education programs should be based on research, or on long-term and validated practices, in order to provide accurate information.

Appendix A: Photographs

Photo Credits: Cesar J. Alvarez, Program Representative, University of California Cooperative Extension- Sea Grant Extension Program

Twelve weeks' undisturbed fouling by invasive tubeworms (*Hydroides* sp.) and sea squirts/tunicates (*Ciona* sp.) on nontoxic, siloxane hull coating in San Diego Bay, October 20, 2005. Growth extends approximately 3 inches from hull surface.

Tubeworms and sea squirts/tunicates were easily peeled off same nontoxic hull coating in San Diego Bay, October 20, 2005.

Hydro-washing easily removed tubeworms and sea squirts/tunicates from the same boat hull at a San Diego Bay boatyard, November 30, 2005.

Close-up view of boat hull after hydro-washing removed tubeworms and sea squirts/tunicates at a San Diego Bay boatyard, November 30, 2005.

Appendix B: Considerations for Future Research and Education

Research to Determine Ecological Risk and How to Address It

- Determine the effect of increased levels of pollution found in ports, harbors and marinas, for example antifouling paint toxicants, other vessel pollution and polluted runoff, on:
    - native species and their ability to compete with introduced species;
    - nonnative species introduced on boat hulls and underwater running gear.
- Determine identity and characteristics of nonnative species occurring on hulls of pleasure craft, commercial fishing boats and commercial-passenger fishing boats in California and Baja California:
    - identification;
    - environmental conditions in regions of origin and destination;
    - abundance on hulls;
    - abundance in recipient regions;
    - ecological (and related socio-economic) effects in areas where they have been introduced;
    - occurrence at major ports and at smaller harbors.

Research to Refine a HACCP Approach

Risk and critical control points (CCPs) assessments for a Hazard Analysis Critical Control Points (HACCP) system should consider at least:

- How often a boat is used or how long it has been kept at mooring since last use;
- Vessel type, speed and typical lifespan;
- Where it is kept, such as:
    - marina in a major, shipping port;
    - marina in a smaller harbor without ship traffic;
    - antifouling water quality regulations in harbor where it is kept;
    - geographic region and climate;
- Types of uses, locations, route, distance traveled, such as:

  - participation in events that attract many boats from different regions;
  - cruising to distant locations;
  - participation in local events with local boats;
  - cruising to locations in the region;
  - travel among smaller harbors;
  - travel between a major port and a smaller harbor;

- Season of the year;
- Hull husbandry practices;
- Age and type of bottom coating;
- Companion, antifouling strategies used, for example, hull-cleaning frequency, slip liner, hoist;
- Level of risk associated with each CCP;
- Management practices for each CCP.

A management system for implementing a HACCP approach should consider at least:

- Lead organization and partners;
- Geographic scope and collaboration with other regions;
- Roles of research, education and regulation;
- Roles of community groups and government;
- Monitoring implementation and effectiveness of practices; and
- How responsibility and costs for implementing system are distributed among boat owners, boating and hull-coating businesses, and government/tax payers.

Research to Assess Socioeconomic Factors and How to Address Them

Research is needed to determine costs and burdens and how they should be distributed for reducing hull-borne invasive species transport by boats. Consider the following:

- Improve understanding of social and economic risks posed by invasive species transported on boat hulls.

- Determine social and economic benefits to be derived from controlling transport of invasive species on boat hulls.

- Determine social, economic and environmental values and how they may affect public and commercial response to risks posed by invasive species carried on boat hulls.

- Determine costs to implement proposed management systems and practices.

- Determine costs to be carried by boat owners, marinas, government/taxpayers, companies that manufacture boats and hull coatings, etc. for proposed management systems and practices, according to vessel types, uses, etc., for example:

    - Eradication, control, mitigation and monitoring costs will likely be paid by government via tax funds. They may be very high and concentrated.

    - Prevention costs will likely fall more heavily on boat owners and boating businesses. They may be lower overall and more widely distributed.

    - Incentives may be effective in encouraging boat owners and boating business to participate in prevention.

- Determine costs of fouling control strategies with respect to:

    - anticipated uses;
    - trip lengths and frequencies for different types of boats;
    - typical cruising speeds for different types of boats;
    - how long boat owners typically keep a given type of boat;
    - typical useful life for a given type of boat;
    - regulatory programs in harbors where boats are kept or that they may visit.

- Determine expected effects of proposed management systems and practices on boat owner participation in boating and on boating business operations.

- Determine ways to adjust management systems and management practices to achieve effective control at lower cost to boat owners, boating business and government/taxpayers.

Research to Develop Cost and Environmentally Effective Management Systems

- Evaluate systems used in other countries and other parts of the United States to control transport of invasive species on boat hulls.

- Determine how best to adapt them to boats kept in saltwater and traveling in California and Baja California.

- Involve the boating community in research to develop effective systems that are easy for them to adopt.

- Determine how to monitor vessels for risk in a way that controls costs and reduces time/inconvenience for government, boat owners, and boating and fishing businesses.

- Determine whether and how to develop a certification system for boat owners and boating businesses using best management practices.

- Determine how to develop a North American west coast regional approach that considers:

    - traffic patterns for recreational and fishing boats;

    - variations in climate, culture and legal/regulatory systems among states, provinces and nations;

    - risks posed by invasive species that have arrived and those that may arrive in future;

    - opportunities for early detection;

    - environmentally and cost-effective regional control measures and practices

    - opportunities for agencies to share data, experiences, and resources;

    - boating and fishing community insights and resources;

    - existing hull husbandry practices in local areas, as well as wider regions;

    - opportunities to control via harvest for sale or personal consumption;

    - a stepwise approach, for example, education, warning, regulation.

Research to Assess and Improve Hull Husbandry Practices

- Determine existing hull husbandry practices with respect to local climate, fouling communities and infrastructure.

- Determine how to adapt them for controlling invasive species transport on boat hulls and underwater running gear.

- Determine strategies that combine boat bottom coatings and companion practices such as in-water hull cleaning, slip liners, and hoists, to:

- prevent water penetration;
- control invasive species and other fouling growth;
- protect coastal water quality by meeting federal and state standards.

- Test the effectiveness of these strategies in regions with different climates, fouling communities and on different types of boats with different operational profiles.

- Evaluate new products and practices before recommending them to boat owners and boating businesses for:

    - regulatory status;
    - effect on water quality;
    - effectiveness in controlling fouling and whether they need to be combined with another product or practice;
    - costs to acquire, apply and maintain;
    - special application and maintenance procedures;
    - durability/life span;
    - effect on vessel performance, such as racing and cruising speeds and fuel consumption.

- Determine costs of fouling control strategies with respect to:

    - anticipated uses,
    - trip lengths and frequencies for different types of boats,
    - how long boat owners typically keep a given type of boat,
    - typical useful life for a given type of boat; and
    - regulatory programs in harbors where boats are kept or that they may visit.

- Determine the relationship between efforts to protect water quality from impacts of copper antifoulants and efforts to control invasive species among hull-fouling growth.

- Determine management practices of high-risk boats.

- Develop hull-husbandry, best-management practices based on research results and incorporate in education and outreach programs.

Education and Outreach

We strongly recommend educating boat owners and boating businesses about problems posed by introducing invasive species and simple, cost-effective practices for controlling them. The reasons include:

- At our May 11, 2005 workshop, "Managing Hull Transport of Aquatic Invasive Species," boating community representatives strongly recommended using education and outreach to encourage boat owners and boating businesses to control invasive species carried on boat hulls and underwater running gear.

- The national Clean Marina movement has demonstrated success using education to increase marina managers' and boat owners' awareness of and willingness to help prevent pollution.

- A survey conducted in the midwestern United States found that when boaters were told about the effects of specific invasive species, they commented that they wanted to keep the species out of "my lake" and that "it is my personal responsibility." [113]

- During our 12 years of experience conducting research and education to assist the boating community in pollution prevention, we have observed that clean water and abundant marine life are significant incentives to attract people to participate in boating and encourage them to prevent pollution. Further, we have observed that peer pressure and marketing advantages are significant incentives attracting marina managers to participate in Clean Marina programs.

- We have observed that boater and boating business organizations, such as BoatUS Foundation, Association of Marina Industries and Clean Marinas California, are successful in educating and encouraging boat owners and marina managers to prevent pollution. Associations of sport, commercial and commercial-passenger fishing boat owners provide educational assistance to their members.

Criteria and means for education and outreach programs to prevent hull transport of invasive species may include the following:

- Base education on scientific research.

- Increase communication among scientists, managers, policymakers, and members of the boating and fishing communities.

- Involve boat owner, boating and fishing business organizations in developing and conducting research and outreach.

- Utilize organizations with a successful record of environmental education for boat owners and boating business, for example Clean Marina programs, BoatUS Foundation, US Coast Guard Sea Partners program, Sea Grant Extension programs, and US Fish and Wildlife Service's Stop Aquatic Hitchhikers! program.

- Disseminate information via boating and fishing organizations, the Internet, and supply and service businesses patronized frequently by boat owners, such as marinas, supply stores, boat brokers, and boating and fishing magazines, newspapers and radio or television programs.

- Develop cross-border partnerships to ensure that boat owners are educated beyond their home harbors.

- Educate on specific invasive species that may be carried on boats, the problems they create for native species and for people, and means for controlling them.

- Educate boat owners to identify and report aquatic invasive species.

- Clearly explain the importance of monitoring and prevention, especially for high-risk species. If it is too late for prevention, clearly explain importance of eradication, control or mitigation.

- Clearly explain how recommended practices help to control hull-borne invasive species, while protecting water quality and native marine life.

- Educate on practices adapted from existing fouling growth management practices to make it easy for boat owners and boating businesses to use them.

- Utilize a diversity of media and languages to reach all boat owners and boating businesses.

- Evaluate the effectiveness of educational programs. Share findings, such as research needs and opportunities to improve management and education. Incorporate feedback in updates.

NOTES

[1] California Regional Water Quality Control Board, San Diego Region. 2004. "Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay," Revised Public Review Draft. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 28, 2005.

[2] California Regional Water Quality Control Board, San Diego Region. 2004. "Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay," Public Review Draft revised October 14, 2004. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf. Accessed October 17, 2005.

State Water Board Resolution No. 2005-0071. 2005. "Approving an Amendment to the Water Quality Control Plan for the San Diego Region to Establish a Total Maximum Daily Load (TMDL) for Dissolved Copper in Shelter Island Yacht Basin." http://www.waterboards.ca.gov/resdec/resltn/2005/rs2005-0071.pdf Accessed October 18, 2005.

[3] U.S. Environmental Protection Agency. 2002. Total Maximum Daily Loads for Toxic Pollutants: San Diego Creek and Newport Bay, CA. U.S. EPA Region 9, San Francisco, CA. http://www.epa.gov/Region9/water/tmdl/nbay/summary0602.pdf Accessed October 17, 2005.

California Regional Water Quality Control Board, Los Angeles Region. 2005. "Total Maximum Daily Load for Toxic Pollutants in Marina Del Rey Harbor." http://www.waterboards.ca.gov/losangeles/html/meetings/tmdl/marina_del_rey/toxics/05_0803/MdR%20Toxics%20Staff%20Report.pdf Accessed October 17, 2005.

[4] Draft Staff Report Supporting the Recommended Revisions to the Clean Water Act Section 303(d) List. September 2005. California Regional Water Quality Control Board Region 9. Fact Sheets Supporting Revision of the Section 303(d) List. (Volume III San Diego Region) http://www.swrcb.ca.gov/tmdl/docs/303d_update/r9_v3.pdf Accessed October 17, 2005.

[5] Ruiz, G.M., P.W. Fofonoff, J.T. Carlton, M.J. Wonham and A.H. Hines. 2000. "Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases." *Annual Review of Ecology and Systematics* 31: 481-531.

[6] Roos, P.J. 1979. "Two-stage life cycle of a Cordylophora population in the Netherlands." *Hydrobiologia* 62: 231-239.

[7] Fofonoff, P.W., G.W. Ruiz, B. Steves, and J.T. Carlton. 2003. In ships or on ships? Mechanisms of transfer and invasion for nonnative species to the coasts of North America. Pages 152-182 in Ruiz, G.M. and J.T. Carlton (eds). *Invasive species: vectors and management strategies.* Island Press, Washington.

[8] Apte, S., B.S. Holland, L.S. Godwin, and J.P.S. Gardner. 2000. "Jumping Ship: A Stepping Stone Event Mediating Transfer of a Non-indigenous Species via a Potentially Unsuitable Environment." *Biological Invasions* 2: 75-79.

[9] Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. "Marine Invasive Alien Species: A Threat to Global Biodiversity." *Marine Policy* 27(4): 313-323.

[10] International Maritime Organization. 2004. Marine Environment: Antifouling Systems. http://www.imo.org/ Accessed October 17, 2005.

[11] 52 Federal Register 37,518 (Oct. 7, 1987).

[12] Singhasemanon, N. 2005. Minutes of Copper Antifouling Paint Sub-Workgroup Meeting of July 14, 2005. Minutes dated August 10, 2005. 5 p.

[13] United States Environmental Protection Agency. 2004. Draft Updated Water Quality Criteria for Copper Fact Sheet. http://www.epa.gov/waterscience/criteria/copper/draftupdatefs.htm Accessed December 28, 2005.

[14] Alzieu, C. 1996. "Biological effects of tributyltin on marine organisms." In *Tributyltin: Case Study of an Environmental Contaminant,* ed. S.J. de Mora, pp. 139-166. Cambridge University Press, Cambridge.

[15] de Mora, S.J. (ed.) 1996. *Tributyltin: Case Study of an Environmental Contaminant*. Cambridge University Press, Cambridge, UK.

Son, M.H. and R.N. Hughes. 2000. "Relationship between imposex and morphological variation of the shell in *Nucella lapillus* (Gastropoda: Thaidadae)." *Estuarine, Coastal and Shelf Science* 50: 599-606.

Bryan, G.W., P.E. Gibbs, L.G. Hummerstone, G.R. Burt. 1986. “The decline of the gastropod *Nucella lapillus* around South-West England: evidence for the effect of tributyltin from antifouling paints.” *Journal of Marine Biology Association of the United Kingdom* 66:611-640.

Bryan, G.W., P.E. Gibbs, G.R. Burt, and L.G. Hummerstone. 1987. “The effects of tributyltin (TBT) accumulation on adult dog whelks, *Nucella lapillus*: long term field and laboratory experiments.” *Journal of the Marine Biology Association of the United Kingdom* 67: 525-544.

[16] Gibbs, P.E., and G.W. Bryan. 1986. Reproductive failure in populations of the dogwhelk, *Nucella lapillus*, caused by imposex induced by tributyltin from antifouling paints. *Journal of the Marine Biology Association of the UK* 66:767-777.

[17] Evans, S.M., S.T. Hawkins, J. Porter, A.M. Samosir. 1994. “Recovery of dogwhelk populations on the Isle of Cumbrae, Scotland following legislation limiting the use of TBT as an antifoulant.” *Marine Pollution Bulletin* 28:15-17.

Harding, M.J.C., Rodger, G.K., I.M. Davies, and J.J. Moore. 1997. “Partial recovery of the dogwhelk (Nucella lapillus) in Sullom Voe, Shetland from tributyltin contamination.” *Marine Environmental Research* 44:285-304.

Crothers, J.H. 1998. “The size and shape of dogwhelks, *Nucella lapillus* (L.) recolonising a site formerly polluted by tributyltin (TBT) in antifouling paint.” *Journal of Molluscan Studies* 64:127-129.

[18] Alzieu, C. 1998. “Tributyl tin: case study of a chronic contaminant in the coastal environment.” *Ocean and Coastal Management* 40:23-36.

[19] Vos, J.G., E. Dybing, H.A. Greim, O. Landefoged, C. Lambre, and J.V. Tarazona, I. Brandt, and A.D. Vethaak. 2000. “Health effects of endocrine-disrupting chemicals on wildlife, with special reference to the European situation.” *Critical Reviews in Toxicology* 30(1): 71-133.

[20] Santillo, D., P. Johnston, and W.J. Langston. 2001. “Tributylyin (TBT) antifoulants: a tale of ships, snails and imposex. Late lessons from early warnings: the precautionary principle 1896-2000.” http://reports.eea.eu.int/ Accessed July 5, 2005.

[21] California Department of Pesticide Regulation. 2004. California Code of Regulations (Title 3. Food and Agriculture) Division 6. Pesticides and Pest Control. http://www.cdpr.ca.gov/docs/inhouse/calcode/020101.html Accessed October 17, 2005.

[22] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Revised Public Review Draft. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf

United States Environmental Protection Agency. 2002. Total Maximum Daily Loads for Toxic Pollutants: San Diego Creek and Newport Bay, CA. U.S. EPA Region 9, San Francisco, CA. http://www.epa.gov/Region9/water/tmdl/nbay/summary0602.pdf

[23] State Water Resources Control Board. 2001. Total Maximum Daily Loads (TMDL) Questions and Answers Fact Sheet. http://www.waterboards.ca.gov/tmdl/docs/tmdl_factsheet.pdf Accessed October 17, 2005.

[24] Clean Water Act Title III – Standards and Enforcement (Sections 301-320) <http://www.epa.gov/region5/water/cwa.htm> Accessed October 17, 2005.

[25] U.S. Environmental Protection Agency. 2000. Establishment of Numeric Criteria for Priority Pollutants for the State of California; California Toxics Rule. http://www.epa.gov/OST/standards/ctrindex.html Accessed October 17, 2005.

[26] Calabrese, A., MacInnes, J. R., Nelson, D. A., Greig, R. A., and P. P. Yevich. 1984. “Effects of Long-term Exposure to Silver or Copper on Growth, Bioaccumulation and Histopathology in the Blue Mussel *Mytilus edulis*.” *Marine Environmental Research*, 11: 253-274.

Coglianese, M. P. and M. Martin. 1981. “Individual and Interactive Effects of Environmental Stress on the Embryonic Development of the Pacific Oyster, *Crassostrea gigas*. I. The Toxicity of Copper and Silver.” *Marine Environmental Research*, 5:13-27.

Gould, E., Thompson, R. J., Buckley, L. J., Rusanowsky, D., and G. R. Sennefelder. 1988. “Uptake and Effect of Copper and Cadmiumon the Gonad of the Scallop *Placopecten magellanicus*: Concurrent Metal Exposure.” *Marine Biology* 97: 217-223.

Johns, D.M. and D.C. Miller. 1982. The use of bioenergetics to investigate the mechanisms of pollutant toxicity in crustacean larvae. In: Vernberg, W.B., A. Calabrese, F.B. Thurberg, and F.J. Vernberg (Eds.). *Physiological Mechanisms of Marine Pollutant Toxicity*, Academic Press, New York, pp. 261-288.

Katz, C. 1998. Seawater Polynuclear Aromatic Hydrocarbons and Copper in San Diego Bay. Technical Report 1768. Space and Naval Systems Center (SPAWAR). San Diego, CA.

Kime, D.E. 1995. The effects of pollution on reproduction in fish. *Reviews in Fish Biology and Fisheries* 5:52-96.

Krett Lane, S. M. 1980. Productivity and Diversity of Phytoplankton in Relation to Copper in San Diego Bay. Technical Report 533. Naval Oceans Systems Center.

Krishnakumar, P. K., Asokan, P. K., and V. K. Pillai. 1990. "(Abstract) Physiological and Cellular-Responses to Copper and Mercury in the Green Mussel *Perna-Viridis* (Linnaeus)." *Aquatic Toxicology*, 18(3):163-173.

La Breche, T.M.C., A.M. Dietrich, D.L. Gallagher, and M. Shepherd. "Copper toxicity to larvel *Mercenaria mercenaria* (hard clam)." *Environmental Toxicology and Chemistry* 21(4): 760-766.

Lee, H. H. and C. H. Xu. 1984. "Effects of Metals on Sea Urchin Development: A Rapid Bioassay." *Marine Pollution Bulletin* 15:18-21.

Lussier, S. M., J. H. Gentile, and J. Walker. 1985. "Acute and Chronic Effects of Heavy Metals and Cyanide on *Mysidopsis bahia* (Crustacea: Mysidacea)." *Aquatic Toxicology* 7:25-35.

MacDonald J.M., Shields J.D., and R. K. Zimmer-Faust. 1988. "Acute toxicities of eleven metals to early life-history stages of the yellow crab *Cancer anthonyi.*" *Marine Biology* 98:201-207.

Martin, M., K.E. Osborn, P. Billig, and N. Glickstein. 1981. "Toxicities of Ten Metals to *Crassostrea gigas* and *Mytilus edulis* Embryos and *Cancer magister* Larvae." *Marine Pollution Bulletin* 12:305-308.

Redpath, K. J. and J. Davenport. 1988. The Effect of Copper, Zinc, and Cadmium in the Pumping Rate of *Mytilus edulis* L. *Aquatic Toxicology* 13:217-226.

Redpath, K. J. 1985. Growth Inhibition and Recovery in Mussels (*Mytilus edulis*) Exposed to Low Copper Concentrations. *Journal of the Marine Biological Association of the United Kingdom* 65(2):421-31.

Stromgren, T. and V. Nielsen. 1991. "Spawning Frequency, Growth, and Mortality of *Mytilus edulis* Larvae, Exposed to Copper and Diesel Oil," *Aquatic Toxicology*, 21:171-180.

VanderWeele, D.A. 1996. The Effects of Copper Pollution on the Bivalve, *Mytilus edulis* and the Amphipod, *Grandidierella japonica* in the Shelter Island Yacht Basin, San Diego Bay, California. M.S. Thesis. San Diego State University, San Diego, CA.

[27] Baldwin, D., J. Labenia, B, French, and N. Scholz. 2004. The impacts of dissolved copper on olfactory function in juvenile coho salmon. NOAA Northwest Fisheries Science Center. http://www.nwfsc.noaa.gov/research/divisions/ec/ecotox/fishneurobiology/copperimpacts.cfm Accessed August 19, 2005.

[28] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Revised Public Review Draft. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 28, 2005.

[29] Schiff, K., D. Diehl, and A. Valkirs. 2003. *Copper emissions from antifouling paint on recreational vessels.* SCCWRP Technical Report #405. Southern California Coastal Water Research Project, Westminster, CA.

[30] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Public Review Draft revised October 14, 2004.
http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 17, 2005.

State Water Board Resolution No. 2005-0071. 2005. Approving an Amendment to the Water Quality Control Plan for the San Diego Region to Establish a Total Maximum Daily Load (TMDL) for Dissolved Copper in Shelter Island Yacht Basin. http://www.waterboards.ca.gov/resdec/resltn/2005/rs2005-0071.pdf Accessed October 18, 2005.

[31] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Revised Public Review Draft. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 28, 2005.

[32] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Public Review Draft revised October 14, 2004.

http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 17, 2005.
[33] California Regional Water Quality Control Board, San Diego Region. 2006. Shelter Island Yacht Basin TMDL for Dissolved Copper. http://www.waterboards.ca.gov/sandiego/tmdls/shelter%20island.html. Accessed August 29, 2006.
[34] Dobalian, L. 2005. California Regional Water Quality Control Board, San Diego Region. Personal communication.
[35] California Regional Water Quality Control Board, San Diego Region. 2006. Shelter Island Yacht Basin TMDL for Dissolved Copper. http://www.waterboards.ca.gov/sandiego/tmdls/shelter%20island.html. Accessed August 29, 2006.
[36] U.S. Environmental Protection Agency. 2002. Total Maximum Daily Loads for Toxic Pollutants: San Diego Creek and Newport Bay, CA. U.S. EPA Region 9, San Francisco, CA. http://www.epa.gov/Region9/water/tmdl/nbay/summary0602.pdf Accessed October 17, 2005.
California Regional Water Quality Control Board, Los Angeles Region. 2005. Total Maximum Daily Load for Toxic Pollutants in Marina Del Rey Harbor.
[37] U.S. Environmental Protection Agency. 2002. Total Maximum Daily Loads for Toxic Pollutants: San Diego Creek and Newport Bay, CA. U.S. EPA Region 9, San Francisco, CA. http://www.epa.gov/Region9/water/tmdl/nbay/summary0602.pdf Accessed October 17, 2005.
[38] Draft Staff Report Supporting the Recommended Revisions to the Clean Water Act Section 303(d) List. September 2005. California Regional Water Quality Control Board Region 9. Fact Sheets Supporting Revision of the Section 303(d) List. (Volume III San Diego Region) http://www.swrcb.ca.gov/tmdl/docs/303d_update/r9_v3.pdf Accessed October 17, 2005.
[39] U.S. Environmental Protection Agency. 1999. Draft Updated Aquatic Life Criteria. EPA-822-R-03-026 http://www.epa.gov/waterscience/criteria/copper/index.htm Accessed October 17, 2005.
[40] United States Environmental Protection Agency. 2004. Draft Updated Water Quality Criteria for Copper Fact Sheet. http://www.epa.gov/waterscience/criteria/copper/draftupdatefs.htm Accessed October 28, 2005.
[41] NCDEM. 1990. North Carolina Coastal Marinas: Water Quality Assessment. North Carolina Division of Environmental Management, Raleigh, NC. Report No. 90-01.
NCDEM. 1991. Coastal Marinas: Field Survey of Contaminants and Literature Review. North Carolina Division of Environmental Management, Raleigh, NC. Report No. 91-03.
[42] The Netherlands Ministry of Housing, Spatial Planning and the Environment. Environmental Inspectorate. 2004. http://www2.vrom.nl/pagina.html?id=8701 Accessed October 31, 2005.
College Toelating Bestrijdingsmiddelen. Pesticides Database Online. 2004. http://www.ctb-wageningen.nl/
[43] Swedish Chemicals Inspectorate. For a Non-Toxic Environment. 2004. http://www.kemi.se/templates/Page____498.aspx Accessed October 31, 2005.
[44] Ministry of the Environment Danish Environmental Protection Agency. Statutory Order on Biocidal Antifouling Paint. 2003. http://www.mst.dk/homepage/default.asp?Sub=http://www.mst.dk/rules/ Accessed October 31, 2005.
[45] Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. "Marine invasive alien species: a threat to global biodiversity." *Marine Policy* 27(4): 313-323.
[46] Simberloff, D. and B. von Holle. 1999. "Positive interactions of nonindigenous species: invasional meltdown." *Biological Invasions* 1:21-32.
[47] Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien secies: a threat to global biodiversity. *Marine Policy* 27(4): 313-323.
[48] United States Senate. 2005. S. 770. National Aquatic Invasive Species Act of 2005. Sec. 305 (2) (B) (ii) (III). http://thomas.loc.gov/cgi-bin/query/F?c109:2:./temp/~c109kcz7JG:e91031 Accessed October 18, 2005.
[49] United States House of Representatives. 2005. H.R. 1591. Sec. 305 (2) (B) (ii) (III). http://thomas.loc.gov/cgi-bin/query/F?c109:1:./temp/~c109kcz7JG:e86012 Accessed October 18, 2005.
[50] Assembly Bill 433. 2003. Vessels: release of nonindigenous species. Section 71210.5.
[51] 100th Meridian Initiative. http://www.100thmeridian.org/about100mi.htm Accessed August 3, 2005.
[52] Conlon, M. 2002. Northwest Mexico Marina Market Analysis. Prepared for the Packard Foundation, EDAW, i-1 – i-2.
Escalera Nautica, "Escalera Nautica of the Sea of Cortes: The Tourism Megaproject of the XXI Century Official Basic Document," http://escaleranautica.com/general12.html Accessed July 2005.

[53] Puerto de Ensenada, "Centro Integral de Servicios," http://www.puertoensenada.com.mx/cis.htm Accessed October 2005.
[54] Keystones, Inc. 2001. Anti-Fouling Paint Desk Market Research Report. http://www.keystones.dk/
[55] Carson, R., M. Damon, L. Johnson and J. Miller. 2002. Transitioning to Non-Metal Antifouling Paints on Marine Recreational Boats in San Diego Bay. Pursuant to Senate Bill 315 passed in 2001; submitted to California Department of Boating and Waterways in 2002.
[56] Johnson, L and J. Gonzalez. 2004. *Staying Afloat with Nontoxic Antifouling Strategies for Boats. California Sea Grant College Program Technical Report No. T-054.*
[57] Ibid.
[58] California Regional Water Quality Control Board, San Diego Region. 2004. Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay, Revised Public Review Draft. http://www.waterboards.ca.gov/sandiego/tmdls/tmdl_files/shelter%20island/SIYB%20TMDL%20Tech%20Rept%2010-14-04%20rev1.pdf Accessed October 28, 2005.
[59] U.S. Environmental Protection Agency. 2002. Total Maximum Daily Loads for Toxic Pollutants: San Diego Creek and Newport Bay, CA. U.S. EPA Region 9, San Francisco, CA. http://www.epa.gov/Region9/water/tmdl/nbay/summary0602.pdf Accessed October 17, 2005.
California Regional Water Quality Control Board, Los Angeles Region. 2005. Total Maximum Daily Load for Toxic Pollutants in Marina Del Rey Harbor. http://www.waterboards.ca.gov/losangeles/html/meetings/tmdl/marina_del_rey/toxics/05_0803/MdR%20Toxics%20Staff%20Report.pdf Accessed October 17, 2005.
[60] Draft Staff Report Supporting the Recommended Revisions to the Clean Water Act Section 303(d) List. September 2005. California Regional Water Quality Control Board Region 9. Fact Sheets Supporting Revision of the Section 303(d) List. (Volume III San Diego Region) http://www.swrcb.ca.gov/tmdl/docs/303d_update/r9_v3.pdf Accessed October 17, 2005.
[61] Lamb, T. 1981. "Measuring fishing vessel energy performance and ways to improve it." SNAME/NOAA Fishing Industry Energy Conservation Conference, Seattle, WA.
[62] Younqlood, J.P., L. Andruzzi, W. Senaratne, C.K. Ober, J.A. Callow, J.A. Finlay, M.E. Callow. 2003. New materials for marine biofouling resistance and release: semi-fluorinated and pegylated block copolymer bilayer coatings. *Polymeric Materials Science and Engineering* 88:608-609
[63] NOAA. 2005. The International Year of the Ocean: Coastal Development Fact Sheet. http://www.yoto98.noaa.gov/facts/cdevel.htm Accessed August 24, 2005.
[64] Carlton, J.T. 1996. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78: 97-106.
[65] Nehring, S. 2001. After the TBT era: alternative antifouling paints and their ecological risks. *Senckenbergiana Maritima* 31: 341-351.
[66] Johnston, E.L. 2005. Pollution and invasive species. Personal Communication, August 18, 2005.
[67] Stachowicz, J.J., H. Fried, R.W. Osman, and R.B. Whitlatch. 2001. "Biodiversity, invasion resistance, and marine ecosystem function: Reconciling pattern and process." *Ecology* 83(9): 2575-2590.
[68] California State Lands Commission. 2005. Vessel Fouling Technical Advisory Group. October 13, 2005 Meeting Minutes.
[69] Hoffman, M. 2005. California Marine Services, personal communication.
Rocco, W. 2005. Aquarius Yacht Maintenance, personal communication.
[70] Carson, R., M. Damon, L. Johnson and J. Miller. 2002. Transitioning to Non-Metal Antifouling Paints on Marine Recreational Boats in San Diego Bay. Pursuant to Senate Bill 315 passed in 2001; submitted to California Department of Boating and Waterways in 2002.
[71] Pennell, D. 2005. Shelter Island Marina, personal communication. October 20, 2005.
[72] McLeod, B. 2005. Omni Precision Diving Services, San Diego, California, personal communication.
Presley R. 2005. Presley Precision Diving Service, Inc., San Diego, California, personal communication.
[73] Carson, R., M. Damon, L. Johnson, and J. Miller. 2002. Transitioning to non-metal antifouling paints on marine recreational boats in San Diego Bay. Pursuant to Senate Bill 315 passed in 2001; submitted to California Department of Boating and Waterways in 2002.
[74] Carson, R., M. Damon, L. Johnson, and J. Miller. 2002. Transitioning to non-metal antifouling paints on marine recreational boats in San Diego Bay. Pursuant to Senate Bill 315 passed in 2001; submitted to California Department of Boating and Waterways in 2002.

[75] Schiff, K., D. Diehl, and A. Valkirs. 2003. Copper emissions from antifouling paint on recreational vessels. SCCWRP Technical Report #405. Southern California Coastal Water Research Project, Westminster, CA.
[76] San Diego Unified Port District Board of Commissioners. April 26, 2005. Agenda Item 14: Recommendation to pursue a statewide and national approach to regulating copper discharges from marine antifoulant paint and approve a concept plan for reducing copper antifoulant discharges in Shelter Island Yacht Basin.
Singhasemanon, N. 2005. Copper Antifouling Paint Sub-Workgroup 5/26/05 Meeting Minutes June 13, 2005. 6 p.
[77] State Water Board Resolution No. 2005-0071. 2005. Approving an Amendment to the Water Quality Control Plan for the San Diego Region to Establish a Total Maximum Daily Load (TMDL) for Dissolved Copper in Shelter Island Yacht Basin. http://www.waterboards.ca.gov/resdec/resltn/2005/rs2005-0071.pdf Accessed October 18, 2005.
[78] Singhasemanon, N. 2005. Copper Antifouling Paint Sub-Workgroup 5/26/05 Meeting Minutes June 13, 2005. 6 p.
[79] Jakob, Kathryn. USEPA. Chemical Review Manager, Regulatory Management Branch II. Antimicrobials Division/Office of Pesticide Programs. Personal communication, August 29, 2006.
[80] United States Senate. 2005. S. 770. National Aquatic Invasive Species Act of 2005. Sec. 305 (2) (B) (ii) (III). http://thomas.loc.gov/cgi-bin/query/F?c109:2:./temp/~c109kcz7JG:e91031 Accessed October 18, 2005.
[81] United States House of Representatives. 2005. H.R. 1591. Sec. 305 (2) (B) (ii) (III). http://thomas.loc.gov/cgi-bin/query/F?c109:1:./temp/~c109kcz7JG:e86012 Accessed October 18, 2005.
[82] Hall, A. 1981. "Copper accumulation in copper tolerant and non-tolerant populations of the marine fouling alga, *Ectocarpus siliculosus* (Dillwyn) Lyngbye," *Botanic Marina* 24 (1981): 223-228.
See also G. Russell and O.P. Morris, "Ship Fouling as an Evolutionary Process," *Proceedings of the 3rd International Congress of Marine Corrosion and Fouling* (Washington, D.C., 1972), 719-730.
J. Crooks, oral commentary, Vessel Fouling Technical Advisory Group, Meeting Summary, California State Lands Commission, Sacramento, CA, October 13, 2005.
[83] Veitch, C. R. and M. N. Clout. 2004. "Turning the Tide: The Eradication of Invasive Species." *Proceedings of the International Conference on Eradication of Island Invasives.*
[84] Wasson, K., C.J. Zabin, L. Bedinger, M.C. Diaz, and J.S. Pearse. 2001."Biological invasions of estuaries without international shipping: the importance of intraregional transport." *Biological Conservation* 102: 143-153.
[85] Ibid.
[86] Cohen, A.N. and J.T. Carlton. 1995. *Nonindigenous species in a United States Estuary: A case study of the biological invasions of the San Francisco Bay and Delta. Report of the United States Fish and Wildlife Service, Washington DC and the National Sea Grant College Program Connecticut Sea Grant. CONN-T-95-002.*
[87] Cohen, A. N. and J. T. Carlton. 1998. "Accelerating Invasion Rate in a Highly Invaded Estuary." *Science* 279:555-558.
[88] Hoffman, M. 2005. California Marine Services, personal communication.
Rocco, B. 2005. Aquarius Yacht Maintenance, personal communication.
[89] Roberts, B. 2005. Shelter Island Boatyard, personal communication.
Miller, B. 2005. South Bay Boatyard, personal communication.
[90] Carson, R., M. Damon, L. Johnson, and J. Miller. 2002. Transitioning to non-metal antifouling paints on marine recreational boats in San Diego Bay. Pursuant to Senate Bill 315 passed in 2001; submitted to California Department of Boating and Waterways in 2002.
[91] Coutts, A.D.M. and M.D. Taylor, 2001. "An Investigation of High Risk Areas on The Hulls of Merchant Vessels for the Translocation of Exotic Fouling Organisms, Cawthron Institute." *Proceedings of the Second International Conference on Marine Bioinvasions*, New Orleans, LA, April 9-11, 2001, pp. 25-27.
[92] Rainer, S.F. 1995. Potential for the introduction and translocation of exotic species by hull fouling: A preliminary assessment. Commonwealth Scientific and Industrial Research Organization (CSIRO) Centre for Research on Introduced Marine Pests. Technical Report 1. Hobart, Australia.
Coutts, A.D.M. 1999. "Hull fouling as a modern vector for marine biological invasions: investigation of merchant vessels visiting northern Tasmania." Unpublished Masters Thesis, Australian Maritime College, Launceston, Tasmania, Australia. 283 pp.

Hewitt, C.L., M.L. Campbell, R.E. Thresher, and R.B. Martin, (Eds.) 1999. Marine biological invasions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests, Technical Report 20, 344pp. Commonwealth Scientific and Industrial Research Organization (CSIRO). Hobart, Australia.

[93] Johnson, L.T. and J.A. Miller. 2002. *What you need to know about nontoxic antifouling strategies for boats. California Sea Grant College Program Report No. T-049.*

[94] Minchin, D. and S. Gollasch. 2003. "Fouling and ship's hulls: how changing circumstances and spawning events may result in the spread of exotic species." *Biofouling* 19:111-122.

[95] California State University, Sacramento Foundation. 2002. California Boating Facilities Needs Assessment. Volume V: Boating Economic Assessment and Demand Projections. California Department of Boating and Waterways, Sacramento, CA.

[96] Hall, A. 1981. Copper accumulation in copper-tolerant and non-tolerant populations of the marine fouling alga, *Ectocarpus siliculosus* (Dillwyn) Lyngbye. *Botanica Marina* 24:223–228.

Johnston, E.L. 2005. Pollution and invasive species. Personal Communication, August 18, 2005.

Stachowicz, J.J., H. Fried, R.W. Osman, and R.B. Whitlatch. 2001. Biodiversity, invasion resistance, and marine ecosystem function: Reconciling pattern and process. *Ecology* 83(9): 2575-2590.

California State Lands Commission. 2005. Vessel Fouling Technical Advisory Group. October 13, 2005 Meeting Minutes.

[97] Russell, G. and O.P. Morris. 1973. Ship fouling as an evolutionary process, p.719-730. *Proceedings of the 3rd International Congress of Marine Corrosion and Fouling*, Washington, D.C., 1972.

[98] Nehring, S. 2001. After the TBT era: alternative antifouling paints and their ecological risks. *Senckenbergiana Maritima* 31:341-351.

[99] Conlon, M. 2002. Northwest Mexico Marina Market Analysis. Prepared for the Packard Foundation, EDAW, i-1 – i-2.

Escalera Nautica, "Escalera Nautica of the Sea of Cortes: The Tourism Megaproject of the XXI Century Official Basic Document," http://escaleranautica.com/general12.html Accessed July 2005.

[100] Puerto de Ensenada, "Centro Integral de Servicios," http://www.puertoensenada.com.mx/cis.htm Accessed October 2005.

[101] Grosholz, Edwin and Gregory Ruiz (eds). 2002. Management Plan for the European Green Crab. Submitted to the Aquatic Nuisance Species Task Force.

[102] Ibid.

[103] A. Hall, "Copper accumulation;" Russell and Morris, "Ship fouling as an evolutionary process;" J. Crooks, oral commentary.

[104] Gonzalez, J. and L. Johnson, eds. 2005. *Managing Hull Transport of Aquatic Invasive Species. Proceedings of May 11, 2005 Workshop in San Francisco, California.* California Sea Grant College Program Report T-059.

[105] California Department of Boating and Waterways. 2002. California Boating Facilities Needs Assessment. Volume 2: Regional Boaters and Boating Facilities.

[106] Milne, A. 1990. Roughness and drag from the marine chemist's viewpoint. *Proceedings of the International Workshop on Marine Roughness and Drag*. London: Royal Institution of Naval Architects.

Rolland, J.P. and J.M. DeSimone. 2003. Synthesis and characterization of perfluoropolyether graft terpolymers for biofouling applications. *Polymeric Materials Science and Engineering* 88:606-607.

California Professional Divers Association. 2003. *Hull Cleaning Best Management Practices Certification Manual*, Version 1.3/Revision 3. Document provided by partnership between Santa Monica Bay Restoration Foundation and California Professional Divers Association.

[107] Australian Quarantine and Inspection Service. 2005. Arriving in Australia with a clean hull: New rules for vessels entering Australia. http://www.daff.gov.au/content/output.cfm?ObjectID=7FBA840F-4324-49E3-B22BCB2C4A3B28E8 Accessed November 8, 2005.

[108] Floerl, O., N. Norton, G. Inglis, B. Hayden, C. Middleton, M. Smith, N. Alcock, and I. Fitridge. 2004. An investigation of hull cleaning and associated waste treatment options for preventing the spread of non-indigenous marine species. Final Research Report for Ministry of Fisheries Project ZBS2002-04 Objectives 1 & 2. National Institute of Water and Atmospheric Research.

[109] U.S. Navy Uniform National Discharge Standards. *Underwater Ship Husbandry Nature of Discharge Report*. http://unds.bah.com/Nod/uwshphub.pdf Accessed October 27, 2005.

[110] Coutts, A.D.M. 2002. The development of incursion response tools-underwater vacuum and filtering system trials. Report prepared for NZ Diving and Salvage Ltd. Cawthron Report No. 755. Cawthron Institute, Nelson.

[111] Floerl, O. 2005. National Institute of Water and Atmospheric Research (NIWA), National Centre for Aquatic Biodiversity and Biosecurity, personal communication, September 27, 2005.
[112] Australian Quarantine and Inspection Service. 2005. Arriving in Australia with a clean hull: New rules for vessels entering Australia. http://www.daff.gov.au/content/output.cfm?ObjectID=7FBA840F-4324-49E3-B22BCB2C4A3B28E8 Accessed November 8, 2005.
[113] Jensen, Douglas A. and Jeffrey L. Gunderson. 2004. Effective Strategies that Work to Prevent the Spread of Aquatic Invasive Species by Recreational Boaters. From the *Abstract Proceedings of the 13th International Conference on Aquatic Invasive Species, September 20 to 24, 2004*.