Rock the Boat!

Balancing Invasive Species, Antifouling and Water Quality for Boats Kept in Saltwater

Leigh Taylor Johnson, Marine Advisor and
Jamie Anne Gonzalez, Program Representative
University of California Cooperative
Extension-Sea Grant Extension Program
County of San Diego MS-O18
5555 Overland Avenue, Suite 4101
San Diego, CA 92123

California Sea Grant College Program Report No. T-064

Acknowledgments

Copies of this publication are available from: Leigh Johnson, Marine Advisor, University of California Cooperative Extension – Sea Grant Extension Program; County of San Diego MS O-18; 5555 Overland Avenue, Suite 4101; San Diego, CA 92123 (858) 694-2845 http://seagrant.ucdavis.edu

Also available from: California Sea Grant College Program, University of California, 9500 Gilman Drive Dept 0232, La Jolla, CA 92093-0232 (858) 534-4446

This publication is based on the White Paper *Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater* – California Sea Grant College Program Publication Number T-061 © Regents of the University of California, May 2006

Authors: Leigh Johnson, Jamie Gonzalez, Cesar Alvarez, Miki Takada and Amber Himes, University of California Cooperative Extension – Sea Grant Extension Program, San Diego, CA
Stephanie Showalter and Jason Savarese, National Sea Grant Law Center, University, MS

Photographs taken by and reprinted with permission of photographers acknowledged. Maps reprtined with publishers' permission.
We would like to thank the following people for their review, advice, assistance, and support:
This paper does not necessarily reflect the views of persons acknowledged.

Guillermo Acosta, Fondo Nacional de Fomento al Turismo (FONATUR), Mexico City, Mexico
Verónica Aguilar, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Mexico City, Mexico
Yoal Aguilar-Hernández, Administración Portuaria Integral de Ensenada, Ensenada, Mexico
Luís Ernesto Aguilar-Rosas, Universidad Autónoma de Baja California, Ensenada, Mexico
Raúl Aguilar-Rosas, Universidad Autónoma de Baja California, Ensenada, Mexico
Darlene Alari, University of California Agriculture and Natural Resources, Riverside, CA
Rolando Bastida-Zavala, Universidad Del Mar, Puerto Angel, Mexico
Kim Beaird, University of California Sea Grant Extension Program, Davis, CA
Carol Berman, University of California Agriculture and Natural Resources, Oakland, CA
Mary Bernardy, University of California Agriculture and Natural Resources, Riverside, CA
David Breninger, Recreational Boaters of California, Auburn, CA
Robin Briggs, Bottom Liner, Long Beach, CA
Carrie Campbell, Clean Seas Company, Jacksonville, FL
Kathy Carrington, University of California Agriculture and Natural Resources, Riverside, CA
Jodi Cassell, University of California Sea Grant Extension Program, San Bruno, CA
Guillermina Chi-Barragán, Universidad Autónoma de Baja California, Ensenada, Mexico
Andrew Cohen, San Francisco Estuary Institute, Oakland, CA
Ashley Coutts, Cawthron Institute, Nelson, New Zealand
Carrie Culver, University of California Sea Grant Extension Program, Ventura, CA
Luis Cruz, Environmental Protection Agency, Washington DC
Lynn Deetz, University of California Agriculture and Natural Resources, Oakland, CA
Jeff DeVaney, Global Source Advantage, San Diego, CA
Lesley Dobalian, California Regional Water Quality Control Board-San Diego Region, San Diego, CA
Diane Edwards, California State Water Resources Control Board, Sacramento, CA
Susan Ellis, California Department of Fish and Game, Sacramento, CA
Bert Ewert, Miramar Landfill, San Diego, CA
Maurya Falkner, California State Lands Commission, Sacramento, CA
Kristin Feindel, Oregon State Marine Board, Salem, OR
Linda Fernandez, University of California, Riverside, CA
Tomás Fernández, Baja Naval, Ensenada, Mexico
Sylvain Fillion, Akzo Nobel, International Paint, Houston, TX
Reinhart (Ron) Flick, California Department of Boating and Waterways, La Jolla, CA
Oliver Floerl, National Institute of Water and Atmospheric Research, Riccarton, New Zealand
Joann Furse, California Sea Grant College Program, La Jolla, CA
Kirk Galarno, City of San Diego Environmental Services Department, San Diego, CA
Fernando García-Pamanes, Universidad Autónoma de Baja California, Ensenada, Mexico
Marsha Gear, California Sea Grant College Program, La Jolla, CA
Cassandra Gie, University of California Agriculture and Natural Resources, Riverside, CA
Cheryl Gneckow, University of California Agriculture and Natural Resources, Riverside, CA
Scott Godwin, B.P. Bishop Museum, Department of Natural Science, Honolulu, HI
Refugio (Cuco) Gonzalez, University of California Agriculture and Natural Resources, Riverside, CA
Myriam Grajales-Hall, University of California Agriculture and Natural Resources, Riverside, CA
Juan Guerrero, University of California Cooperative Extension, Holtville, CA
Susan Hackbarth, University of California Agriculture and Natural Resources, Riverside, CA
Alex Halston, San Diego Diving Services, San Diego, CA
Leslie Harris, Natural History Museum of Los Angeles County, Los Angeles, CA
Elizabeth Haslbeck, Naval Surface Warfare Center, West Bethesda, MD
Paul Heimowitz, United States Fish and Wildlife Service, Portland, OR
Marlan Hoffman, California Marine Services, San Diego, CA
Eric Holm, Naval Surface Warfare Center, West Bethesda, MD
Kathryn Avivah Jacob, United States Environmental Agency, Washington, DC
Andrew Jirik, Port of Los Angeles, San Pedro, CA
David Johnson, California Department of Boating and Waterways, Sacramento, CA
Toroshinia Kennedy, County of San Diego Farm and Home Advisor Department, San Diego, CA
Kenneth Kimmel, University of California Sea Grant Extension Program, Davis, CA
Richard Kittar, Aurora Marine Industries Inc., Mississauga, Canada
Janelle Kohl, University of California Sea Grant Extension Program, Davis, CA
Colin Levings, Fisheries and Oceans, Vancouver, Canada
Larry Lovell, Scripps Institution of Oceanography, La Jolla, CA
Laura Martínez-Ríos del Río, Pro Esteros, Ensenada, Mexico
Tamara Mason, University of California Agriculture and Natural Resources, Riverside, CA
Vivian Matuk, California Coastal Commission, San Francisco, CA
Karen McDowell, San Francisco Estuary Project, Oakland, CA
Russ Moll, California Sea Grant College Program, La Jolla, CA
Wayne Morrison, Shelter Island Boatyard, San Diego, CA
Peter Neimanis, Australian Quarantine and Immigration Service, Canberra, Australia
Tom Nielsen, Nielsen Beaumont Marine, San Diego, CA
Filiberto Núñez-Cebrero, Universidad Autónoma de Baja California, Ensenada, Mexico
Paul Olin, University of California Sea Grant Extension Program, Santa Rosa, CA
Deborah Pennell, Shelter Island Marina, San Diego, CA
Stephen Phillips, Pacific States Marine Fisheries Commission, Portland, OR
Carrie Pomeroy, University of California Sea Grant Extension Program, Watsonville, CA
Bettina Proctor, U.S. Fish and Wildlife Service, Denver, CO
Sandy Purdon, California Department of Boating and Waterways Commission, San Diego, CA
Bill Rashick, Alpha One Diving, San Diego, CA
Karen Renne, University of California Agriculture and Natural Resources, Riverside, CA
Bill Roberts, Shelter Island Boatyard, San Diego, CA
Greg Ruiz, Smithsonian Environmental Research Center, Edgewater, MD
Terry Salmon, University of California Cooperative Extension, San Diego, CA
Dragan Samardzic, Matson Navigation, Oakland, CA
Laura Schulte, University of California Agriculture and Natural Resources, Riverside, CA
Don Schulz, Surfrider Foundation - Huntington Beach/Seal Beach Chapter, CA
Stephanie Showalter, National Sea Grant Law Center, University, MS
Bruce Sifton, 21st Century Coatings, Vancouver, Canada
Nan Singhasemanon, California Department of Pesticide Regulation, Sacramento, CA
Tony Snell, Australian Quarantine and Inspection Services, Canberra, Australia
Luis Solorzano, U.S. Food and Drug Administration, Alameda, CA
Joe Starinchack, U.S. Fish and Wildlife Service, Arlington, VA
Lynn Takata, California State Lands Commission, Sacramento, CA
Wendi Tapia, University of California Agriculture and Natural Resources, Riverside, CA
Pat Torrealba, University of California Agriculture and Natural Resources, Riverside, CA
Raynor Tsuneyoshi (Director), California Department of Boating and Waterways, Sacramento, CA
Alana Valencia, University of California Agriculture and Natural Resources, Riverside, CA
M'K Veloz, Northern California Marine Association, Berkeley, CA
Ted Warburton, Brisbane Marina, Brisbane, CA
Steve Watanabe, California Department of Boating and Waterways, Sacramento, CA
Neil Wilson, Driscoll Boat Works, San Diego, CA
Lisa Wood, City of San Diego Environmental Services Department, San Diego, CA

We would also like to thank those who participated in the *Workshop on Managing Hull Transport of Aquatic Invasive Species* on May 11, 2005 in San Francisco, CA.

This publication was supported in part by the California Department of Boating and Waterways Project No. 04-106-111 and No. 05-106-116, the California Policy Research Center Project No.EEN03A, the U.S. Department of Agriculture's Renewable Resources Extension Act Projects No. 05-24 and No. 06-04, the Western Regional Panel of the Aquatic Nuisance Species Task Force through the Pacific States Marine Fisheries Commission Project No. 05-73, the California State Lands Commission, National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration under NOAA Grant #NA04OAR4170038, Project number A/E-1 through the California Sea Grant College Program, and in part by the California State Resources Agency, the University of California Sea Grant Extension Program, Regents of University of California, the University of California Agriculture and Natural Resources and Cooperative Extension, and the County of San Diego. The views expressed herein do not necessarily reflect the view of any of those organizations.

Who should care about aquatic invasive species on boat hulls?

Boat owners are working hard to prevent pollution so they can enjoy clean boating. Lurking on the hulls of their boats, aquatic invasive species (AIS) can escape into local waters and multiply, creating problems for years to come. In California, AIS carried on vessel hulls disturb native habitats, affect biodiversity, and alter ecosystems. Boaters in lakes and rivers are already doing a good job removing invasive species, such as zebra mussels, before they trailer their boats to a new location. This report focuses on recreational boats that are kept in saltwater, are removed only for maintenance and travel by sea.

Preventing AIS on hulls of boats kept in saltwater is complicated by growing concerns about pollution from copper-based hull paints. Toxic, antifouling paints are pesticides used to control fouling growth. However, they slow, rather than prevent, fouling. They also create a water quality problem. Further, there is growing evidence that invasive, fouling species are more tolerant of copper than native species.[1,2,3] Thus, antifouling paints, alone, cannot be expected to solve the problem of hull-borne AIS.

Surf Fishing

Photo by: E. Lee Fitzhugh, Wildlife Management Specialist Emeritus, UC Davis

This report is intended to assist the following groups in cooperating to prevent and control AIS introductions from boat hulls, while protecting coastal water quality:

- boat owners;
- boat maintenance, repair and coating businesses;
- port, harbor, marina and yacht club managers;
- scientists;
- policy makers;
- government agencies; and
- environmental organizations.

See page 19 for freshwater AIS control.

Recreational Sail Boat

Photo by: Cesar Alvarez, UC SGEP

When is fouling growth invasive?

Fouling occurs when marine microbes, plants, animals, and/or their spores and larvae attach and grow on a vessel hull. If they survive the trip to a distant harbor, they may escape into local waters by spawning, releasing spores, or during hull cleaning. Some new arrivals become invasive, out-competing local species for food, overgrowing them and altering their habitat. Burrowing species, such as shipworms and isopods, may damage structures and shorelines. Some AIS cause new diseases for humans and marine life. Programs to control or eradicate them are expensive and rarely succeed.[4 5]

Why does it matter if AIS reduce biodiversity?

Biological diversity is the amount of variety among living things. Genetic variation within a species might provide greater disease resistance to some and greater speed to others; it is the foundation of species' adaptability to shifting environments.[6] If there is more genetic variability among the members of a species, there is a better chance that at least some will survive challenges, such as epidemics or new predators. Biodiversity also refers to the variety of plants, animals and microbes living in a type of habitat, such as a kelp forest or estuary, or living in a geographic region, such as the Southern California coast or San Francisco Bay.[7] Species that we value need a variety of habitats, a variety of other species to provide food, shelter and other ecological needs, some periodic physical disturbance, and some geographic isolation. By carrying fouling species long distances, shipping reduces geographic isolation, which increases risks of successful invasions that can reduce biodiversity.[8]

Coasts with clean water and diverse plants and animals attract people who enjoy boating, fishing, swimming, surfing, viewing wildlife and relaxing in a beautiful setting. Their activities support valuable recreation and tourism industries, such as the California boating industry that was worth $16 billion (1.2% of the State Gross Product) in 2000.[9] By crowding out native species, AIS can thus reduce the social and economic value of coastal ecosystems.[10]

Recreational Power Boat

Photo by: Leigh Johnson, UC SGEP

How do vessels carry AIS?

Marine aquatic invasive species can be carried by recreational, commercial, and military vessels on hulls,

FIGURE 1. Popular California boating and fishing sites[20]

anchors and rudders, or in sea chests and ballast water. Recent studies have found that fouling growth on vessel hulls is an important vector for AIS.[11 12 13 14 15]

The higher speed of modern ships may allow low-salinity species to survive by shortening their exposure to seawater.[16] Slower water flow over hulls of slow-moving vessels may help salt-tolerant AIS to survive trips on exposed, hull surfaces.[17]

Recreational boats that visit major ports, where AIS have been brought by long-distance vessels, may spread them when attending events such as races or fishing tournaments, visiting harbors along the coast and returning home from such trips.[18] Commercial fishing boats that spend months far from home or follow fishing seasons along the coast also transport AIS.[19]

Thus, ships are likely responsible for most long-distance AIS transport and boats likely foster regional AIS transport. As a result, large ports with international shipping serve as sources for species that can become invasive and spread to surrounding regions.

How do invasions proceed?

Fouling organisms can become invasive when they arrive in new regions, which lack parasites, predators and diseases that can control their populations. They may multiply rapidly, displacing native species. Burrowing species, such as shipworms and isopods, may damage structures.

Many factors determine whether AIS will thrive in their new environment. Biodiversity, water temperature, weather, salinity, port or ocean characteristics, vessel characteristics, quality of hull maintenance, changes in source or receiving regions, traits of particular species, and activities associated with military conflicts are examples of factors that may influence survival of a species arriving in a new region.[21 22 23 24 25 26]

Houseboat

Photo by: Jamie Gonzalez, UC SGEP

Recreational Marina Near Cargo Ship Wharf, Port of Los Angeles

Photo by: Cesar Alvarez, UC SGEP

To evaluate the risk of AIS transport by California's recreational boats, it is important to understand the scope of boat movement within and beyond the state. Traffic to and from Baja California is significant, because of its proximity and popularity with California boaters.

Table 1 shows the percentage of boaters in each region who took various numbers of trips over 100 miles from home in 2000. In the South Coast region, nearly one-half of boaters took no trips over 100 miles from home. Elsewhere, the majority of boaters took no trips over 100 miles from home. About one-fourth to nearly one-half of boaters in each region took a few (one to five) trips that year. The last one-seventh to one-fifth of boaters in each region took occasional to very frequent (six to more than 20) long trips in 2000.

TABLE 1. Percentage of boaters by region who traveled more than 100 miles from home in 2000 [27]

# 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%

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

Sport Fishing Boat

Photo by: Jamie Gonzalez, UC SGEP

Heavy California boat traffic for races and fishing beyond local regions suggests a high risk for hull-borne AIS transport. Although many AIS have already reached California, it is important to prevent new (and possibly unknown) arrivals. It is also important to avoid spreading native species and locally established AIS to other areas.

How important is boat traffic between California and Baja California?

According to Fonatur (Mexican Federal Tourism Promotion Fund), in 1998, 80% of the boats entering the Ensenada, Baja California harbor, were from the United States, especially California. About half of the boats that enter Baja California stay in a marina. The rest use natural anchorages near marinas, stay a short time, or simply cruise for most of their trip.[28] There are also annual and biennial races that bring California boaters to Baja California.

A major, Mexican tourism initiative will renovate or build several marinas. La Escalera Náutica (The Nautical Staircase) was proposed in 2001. It was revised and renamed Proyecto Mar de Cortés (The Sea of Cortez Project) in 2004.[29] Increasing Mexican marina capacity would increase boat traffic between California and Baja California and thus AIS transport risk.

A new Mexican policy of 2005 ended domestic clearing in Mexico and will likely bring more California boaters to Baja California. Formerly, boat owners arriving in Mexico from California had to check in at every stop. Now, they will only need to check in with the port captain and immigration authority at the first port of entry and check out when leaving the country. This change may reduce costs to cruise in Mexico by hundreds of dollars each season.[30]

FIGURE 2. Popular Northwestern Mexico boating and fishing sites[31]

What's the human side of problems caused by hull-borne AIS?

Hull-borne AIS can cause severe economic and ecological damage. Burrowing and fouling species can damage shorelines, structures, equipment, and vessels, requiring costly repair or replacement. Most significant and long-lasting are the ecological effects of AIS on the receiving region.[32 33 34 35 36] They may prey on, parasitize, out-compete, cause or carry diseases, or alter habitats of native species.

Primary socio-economic impacts of AIS are negative

Photo by: Leigh Johnson, UC SGEP

Commercial Fishing Boat

Lobster Traps

effects on human health and economic activities that depend on marine environments and resources. Local quality of life may decline as AIS alter the natural environment.[37] For example, European green crab (*Carcinus maenas*) competes with native Dungeness crab (*Cancer magister*), an important commercial species in northern California, Oregon and Washington. An invasive strain of green seaweed (*Caulerpa taxifolia*), (successfully eradicated in Southern California[38]), has spread over much of the Mediterranean Sea floor and smothered habitat for marine life that people enjoy consuming or viewing or that are critical to local ecosystems.[39] [40] Some invasive species cause or carry human diseases or foster other species that do.[41]

Once invasive species enter the local marine environment, they will likely remain forever. New arrivals may change the environment, making it easier for other introduced species to survive and become invasive.[42] This is sometimes called "invasional meltdown."[43]

Effects of ecosystem changes and resulting socio-economic impacts may take longer to appear and be more challenging to understand and remediate than structural damages.

Photos by: Leigh Johnson, UC SGEP

Commercial Fishing Boats, Port of San Diego

What's the story of hull-borne invasions in California?

The California Department of Fish and Game (CDFG) conducted a study to determine the location and range of invasive species populations along the California coast in 2000 and 2001. Based on their study, they prepared a list of non-indigenous species occurring in marine and estuarine waters of California. Overall, they found 360 species that were characterized as introduced to California's coastal ecosystems.

They found that hull fouling was the most common vector in Humboldt Bay, Port Hueneme, Ports of Los Angeles and Long Beach, and San Diego Bay. It was also the most important AIS vector in eight of the twelve smaller harbors and bays that were studied. This suggests that hull fouling plays a more important role in AIS transport to smaller ports than to larger ones.[44]

San Francisco Bay is one of the most invaded ecosystems in California[45] and the world.[46] Over 175 exotic species inhabit its salt and brackish tidal waters and over 75 other species live in the Sacramento-San Joaquin Delta. Perhaps another 100-200 species are considered "cryptogenic" in San Francisco Bay, i.e. their origin is unknown.[47] Hull fouling introduced 26% of AIS in San Francisco Bay.[48]

Fishing boats and pleasure craft capable of ocean voyages may transport AIS via hull fouling. For example, Humboldt Bay has 95 possible invasive species and 65 species that are clearly invasive. Some ships arrive there from West Coast ports and fishing boats regularly visit ports in Oregon, Washington, and Alaska.[49]

Elkhorn Slough estuary in Central California has about ten times as many exotic species as the open coast. Fieldwork and a literature review found that 56 AIS were known, of which 70% were associated with hull fouling. They may have been carried from San Francisco or other regional ports by currents or on hulls of boats that anchored in areas with abundant, established populations of invaders. The effect of international shipping on AIS introductions thus extends to both commercial ports and isolated bays, such as Elkhorn Slough.[50]

In Southern California, most AIS collected in 2000 during a survey of sheltered waters between San Diego and Oxnard were native to the northwestern Pacific, primarily Japan, Korea, and northern China. Hull transport may be the vector for two-thirds of reported AIS.[51]

What are some hull-borne AIS and the problems they cause in California?

Hull-borne AIS have characteristics and life histories that enable them to attach to vessels and to colonize new areas upon arrival. For example some species reach new homes via mobile larvae or spores. Some can attach firmly on or burrow into hard surfaces. Others nestle among or cling to other fouling growth, so that they are not swept away by currents or hull motion.

The following examples describe AIS that have already arrived. They illustrate why it is critical to prevent future and control existing invasions.

Molluscs

Some of the most damaging aquatic pests are bivalve (two-shelled) molluscs, such as the Pacific shipworm (*Bankia setacea*), Atlantic shipworm (*Teredo navalis*), and zebra mussels (*Dreissena polymorpha*).

Zebra Mussels (*Dreissena polymorpha*)

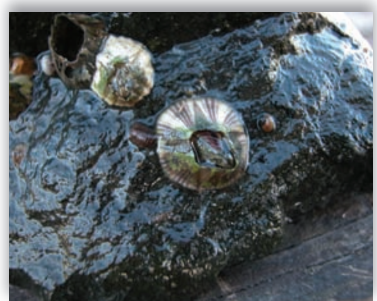
Photo by: U.S. Army Corps of Engineers

Shipworms bore into and damage wooden structures and vessels. In current dollars, *Teredo navalis* caused between $2 billion and $20 billion in damages to maritime facilities in San Francisco Bay in the early 20th century.[52] Today, they primarily affect smaller vessels made partly or entirely of wood.[53]

One of the most widely known freshwater AIS carried by recreational boats is the Eurasian zebra mussel. They compete with native species for food, disrupt food cycles, create drag on boat hulls, and clog water intake pipes, sluices and irrigation ditches.[54] Currently limited in North America to areas east of the 100th longitudinal meridian,[55] zebra mussels potentially threaten California's lakes and streams.

Crustaceans

The striped barnacle (*Balanus amphitrite*) from the Southwestern Pacific and Indian Oceans has been found in San Francisco Bay and parts of Southern California. Introduced by ship fouling, it can cause serious biofouling problems, reducing a ship's speed by up to 40% and increasing fuel consumption. Dense accumulations of barnacles can also serve as refuges for other AIS such as the Harris mud crab (*Rhithropanopeus harrisii*).[56]



Striped Barnacle (*Balanus amphitrite*)

Photo by: Andrew N. Cohen, SFEI

Thought to have been introduced to the U.S. on ship hulls or among rocks and mud loaded as solid ballast,[57] [58] the European green crab (*Carcinus maenas*) was first reported in California in the 1980s and now extends from San Francisco Bay into Washington state. The green crab can change entire ecosystems[59] by exhausting food supplies of native crabs, threatening their survival and that of species that feed on them. It can thus affect local economies where native species, such as the Dungeness crab (*Cancer magister*), are important. Some scientists believe the green crab may harm Dungeness crab fisheries by preying on juveniles.[60] The green crab also feeds upon cultured oysters, mussels, and native clams, such as *Nutricola tantilla* and *N. confusa*.[61]

European Green Crab (*Carcinus maenas*)

Photo by: Luis A. Solorzano, Californiabiota.com

The burrowing Australasian isopod (*Sphaeroma quoyanum*) was introduced to San Francisco Bay among ship fouling from Australia and New Zealand in 1893 and quickly spread to other California bays and

Burrowing Isopod (*Sphaeroma quoyanum*)

Photo by: Tim Davidson, Oregon Institute of Marine Biology harbors in the same manner.[62] It riddles soft bay shores with quarter-inch wide holes and has caused shorelines in some regions to retreat by several yards.[63]

Ascidians

Botryllus schlosseri, commonly known as the star sea squirt or the golden star tunicate, is believed to be native to Europe and "has probably been spread by ship fouling since ancient times." It was first documented in San Francisco Bay in the 1940s and had become common on marina floats in San Diego by the 1960s.[64] The star sea squirt fouls vessel hulls, aquaculture structures and other submerged structures.[65] It can overgrow and compete with cultured oysters and mussels and increase processing costs for these shellfish.[66]

The sea vase (*Ciona intestinalis*) is believed native to northern Europe and was recorded in Newport Bay, California in 1949. "Huge populations occur during the spring and summer in the more sheltered regions of harbors from Los Angeles to San Diego."[67] It was spread worldwide among ship fouling.[68] *Ciona intestinalis* significantly affects hanging shellfish aquaculture operations. Its heavily concentrated bundles compete with the shellfish for food and add immense weight, often pulling cultured mussels off their lines. Sea vases can overgrow mussels to the point where they can no longer open their shells to feed.[69]

Photo by: Tim Davidson, Oregon Institute of Marine Biology

Club Sea Squirt (*Styela clava*)

Styela clava, commonly known as the club tunicate or club sea squirt, originated in Korea and was first documented in Newport Harbor, California in 1933. It "probably arrived during the late 1920s on ship hulls or in ballast water or inadvertently with the import of Japanese oysters to Elkhorn Slough, with subsequent ship transport along the California coast."[70] *Styela clava* can reach high densities and significantly increase drag on vessels' hulls.[71] It can be a major problem for shellfish aquaculture by competing for space and food, or by consuming their planktonic larvae and thus reducing their rates of settlement. It causes an asthmatic condition in oyster shuckers if they hammer open fouled oysters in poorly ventilated areas.[72]

Annelids

Two invasive, serpulid tubeworms that have been distributed worldwide on ships' hulls are *Hydroides diramphus* and *H. elegans*.[73] *H. elegans* tends to occur in polluted harbors.[74] In San Diego, they are often called tube coral or South China Seas coral worm, because they live in a white, crusty shell resembling a small coral.

Photo by: Cesar Alvarez, UC SGEP

Tubeworms (*Hydroides spp.*) and Sea Vases (*Ciona spp.*)

The origin of these two species is difficult to document because they occur in many places, such as Northern Europe, Australia, the Gulf of Mexico, the Caribbean Sea, the U.S. Atlantic coast, and Hawaii.[75] [76] [77] Currently, they are found on boat hulls in San Diego Bay and are being introduced to Baja California. Copious quantities of their calcareous tubes can foul submerged structures, including vessels, wharves, pontoons, and aquaculture equipment. Primary economic impacts of these tubeworms include the cost of cleaning fouled surfaces, increased drag on fouled vessels, damage to antifouling paints, and blockages or inefficiencies in seawater cooling systems. They may compete with other species for food and space.[78] These subtropical species pose a risk in Southern California and Baja California, where warm waters allow them to thrive.[79]

Cnidarians

The invasive, spotted jellyfish (*Phyllorhiza punctata*), has been found in California. It preys on larval fish, competes with shrimp and fish for food and is a nuisance to fisheries because it can get caught in fishing nets. The attached polyp stage of this species, which buds off juvenile jellyfish, could be transported on vessel hulls.[80]

Bryozoans

The invasive, spaghetti bryozoan (*Zoobotryon verticillatum*) causes ecological and structural damage in California. Large masses of this species were reported in San Diego in 1902 and it had reached San Francisco Bay by 1992.[81] It is introduced among ship fouling and affects fisheries by fouling fishing gear.[82]

The encrusting bryozoan (*Watersipora subtorquata*)

Photo by: Luis A. Solorzano, Californiabiota.com

Encrusting bryozoan (*Watersipora subtorquata*)

was first collected in Ventura County, California in 1963. It probably reached the West Coast of North America as fouling on ship hulls. *Watersipora subtorquata* is less sensitive to copper than many fouling organisms. Therefore, once it colonizes a hull, it provides a surface on which other species that are more sensitive to copper can settle. Because members of this species can self-fertilize they can more easily colonize when carried to a distant location.[83]

Photo by: Kathy Ann Miller, UC Berkeley

Asian kelp (*Undaria pinnatifida*)

Seaweeds

The invasive brown alga known as Asian kelp (*Undaria pinnatifida*) is believed to be native to Japan, Korea, and China. It was first discovered in California in spring 2000 and by summer 2001 had colonized from Monterey Bay to Santa Catalina Island. It was reported in Baja California in 2003, likely introduced as young stages attached to ship hulls or as spores discharged from ship ballast water. The Port of Ensenada experiences intense traffic by commercial vessels and cruise ships,[84] as well as recreational boats. This kelp grows quickly and can crowd out native algae and other aquatic species, harming the local ecosystem and threatening shellfish industries.[85] [86] *Undaria* also fouls boats, decreasing their efficiency.[87]

Port of Ensenada

Photo by: Cesar Alvarez, UC SGEP

How can we manage risks posed by AIS?

Management strategies may combine prevention, eradication, containment, control, mitigation, quarantine and education and outreach to control risks posed by AIS. We will describe each technique and provide examples of how they are being used to control AIS.

Prevention

Prevention is the easiest way to combat bioinvasions. Costs created by a single, successful invasion, such as the loss of an entire fishery on the United States' Atlantic Coast or the exorbitant costs associated with zebra mussels in the Great Lakes, far outweigh expenses necessary to prevent the establishment of invasive species.[88] Southern California boaters are plagued by invasive tubeworms that quickly foul hulls and underwater structures.

New Zealand and Australia have acted aggressively to discourage AIS introductions. Biosecurity New Zealand recommends cleaning vessels in a facility where waste material, which could contain AIS, is collected and disposed away from coastal waters.[89]

The Australian Quarantine and Inspection Service (AQIS) inspects all vessels upon arrival to assess fouling[90] and requires all vessels to notify them before entering Australian waters.[91] They have implemented a mandatory biofouling protocol for vessels less than 25 meters in length as of July 2007. The protocol is based on identifying acceptable and unacceptable forms and levels of biofouling. Vessels assessed as presenting a low biofouling risk will be cleared. Vessels will not pass the biofouling assessment if:

- Secondary fouling is clearly visible (advanced state of fouling represented by a substantial, well developed community); or
- A high risk invasive species is observed; or
- The vessel is unable to produce sufficient documentary evidence regarding maintenance and cleaning of the vessel.

Those vessels that do not pass will likely be directed to a quarantine berth and given the option of leaving Australian waters or undertaking a more detailed inspection and/or cleaning or treatment of internal seawater systems, as determined by the risk.[92]

Once AIS have been introduced, eradication, containment, control, mitigation and quarantine may be needed.[93 94] Education is necessary to obtain the public cooperation that is vital to success in preventing and controlling AIS.

Eradication

Eradication completely removes AIS; cases of successful marine AIS eradication are rare. Chances of success are highest when few members of an invasive species have become established and the possibility that they will spread is slight.[95]

The black-striped mussel (*Mytilopsis sallei*), arrived in the harbor at Darwin, Australia on boat hulls or in the seawater piping of a recreational vessel from overseas. It is closely related to the zebra mussel (*Dreissena polymorpha*) that clogs channels and pipes and competes with native species in the United States. The black-striped mussel is considered a substantial threat to Australia's marine biodiversity, ports, shipping, aquaculture, recreational and commercial fishing, and tourism industries.

Risk assessment and analysis determined that eradication was economically and environmentally feasible.[96 97] At a cost of AUS$2.2 million, the infested marinas were quarantined and treated with chemicals. Twelve months after treatment, the area was examined and no black-striped mussels were found.[98] Vessels that had left the site before the eradication were tracked and treated.[99 100]

All vessels entering Darwin harbor are now subject to a rigorous risk management process to prevent future bioinvasions. The process includes risk assessment, visual inspection of high risk vessels, and quarantine of vessels carrying potential marine pest species on their hulls.[101] By 2003, 20 marine pest species had been excluded from Darwin's marinas, saving AUS$44 million by avoiding eradication costs.[102]

In Central California, the South African sabellid tubeworm (*Terebrasabella heterouncinata*) infested abalone farms and the intertidal zone of at least one cove. This invasive, shell parasite can deform and stop the growth of all West Coast abalone species and other marine snails. Its effects on native snails could change seaweed communities, affecting many other species that depend on them.[103] Approximately 1.6 million snails were removed from the affected cove, reducing the host population to a level that was too low to sustain the parasite.[104]

The invasive seaweed *Caulerpa taxifolia* was eradicated from two Southern California lagoons.[105] (As noted above, this seaweed has overgrown vast tracts of Mediterranean seafloor.) US$1.1 million was spent in the first year, alone, on a labor-intensive eradication strategy. Survey teams located and treated *C. taxifolia* infestations.[106] Overall, more than US$4.5 million in federal, state, and private funds has been spent to eradicate *Caulerpa taxifolia* at Huntington Harbor and Agua Hedionda Lagoon.[107 108]

FIGURE 3. Invasive Species Control Points

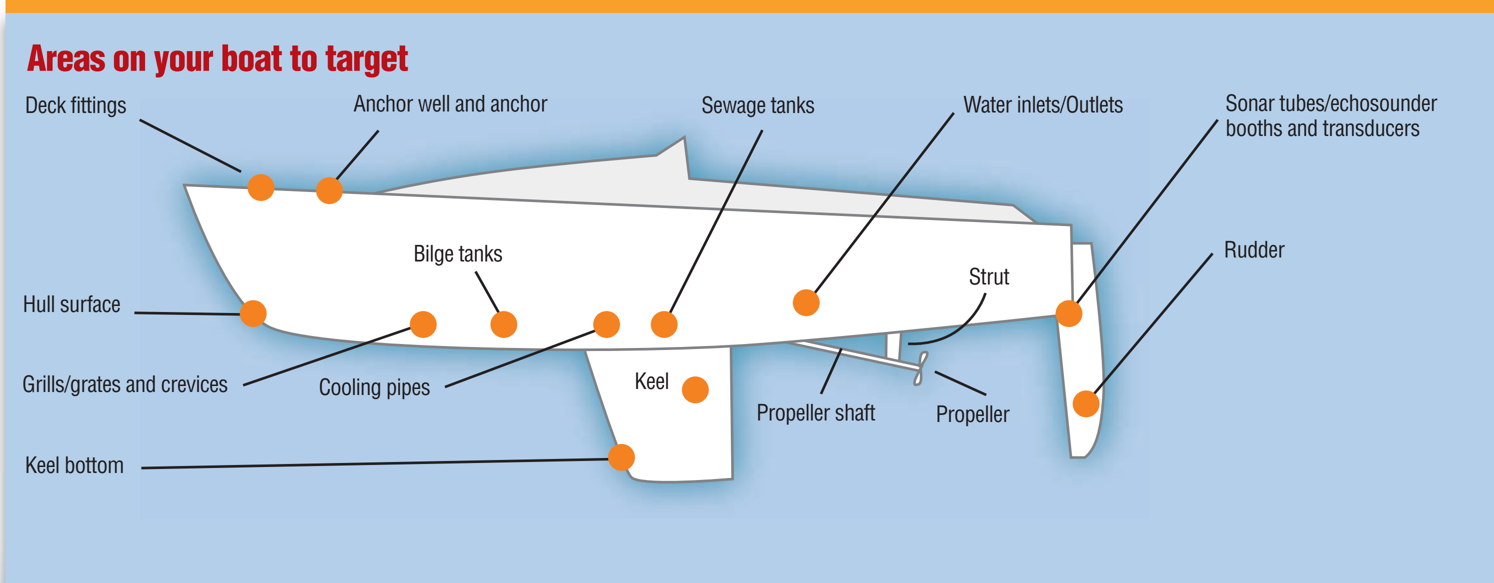


Diagram courtesy of: AQIS Seaports Program, Australia

Containment

Containing invasive species involves confining them within a defined area and stabilizing their populations.[109] Circumstances should be evaluated to determine whether fouling growth removed from hulls should be contained. If potential invaders are released into the water, they may reattach to boat bottoms or become established in the environment. The zebra mussel (*Dresseina polymorpha*) probably became widespread in Ireland in this manner.[110]

In Australian ports, in-water hull cleaning is prohibited for vessels arriving from international waters because it could release invasive species into the local environment. Boats that travel locally are not subject to this restriction.[111]

San Diego, California hull cleaners recommend avoiding cleaning the hulls of vessels arriving from long-distance voyages inside harbors.[112] [113]

As seen in Table 1, the majority of California boaters do not travel more than 100 miles from home.[114] Dr. Oliver Floerl of the National Institute of Water and Atmospheric Research in New Zealand found that 80% of New Zealand boats do not travel much or only short distances; 10% are used for wider-reaching domestic trips and another 10% are used for international travel.[115] Hence, caution should be taken before applying blanket regulations that may unduly burden owners of boats that do not pose a risk.

Control

In controlling an invasive species, efforts are aimed at keeping the population low enough to have minimal economic or environmental consequences. Controlling an AIS population may enable native species to regain the upper hand and restore the ecosystem. Methods may include chemical, mechanical, biological and habitat management.[116]

AIS introductions may be prevented by controlling fouling growth on vessels traveling long distances and internationally. Examples of hull-borne AIS control measures include:

1. hauling the vessels and collecting and disposing the growth;
2. allowing fouled vessels to sit out of water for two weeks until fouling growth dies;
3. cleaning hulls outside harbors in deeper water, where fouling growth would be less likely to survive and reattach to other boats or structures; and/or
4. cleaning hulls before leaving and before returning from a trip outside the region or to an island.

Although control does not eliminate entire communities of invasive species, it may be more economically feasible than eradication. Control and containment are most appropriate when the species has settled into the new region and has begun to increase its range.[117]

Mitigation

Mitigation attempts to alleviate impacts of AIS by targeting native species or their environment. [118] It can be labor intensive and costly and may be a first step toward eradication, containment or control.[119] Mitigation should be used in the earliest possible stage of invasion. Hence, early detection of potential AIS is important.[120] However, if eradication, containment, and control are not feasible or have failed, the last resort is to "live with" this species and to mitigate impacts on biodiversity and endangered species.[121] Mitigation protected the endangered Black Parrot in Seychelles, but successful marine examples are rare.[122]

Quarantine

As discussed above, quarantine was part of the strategy for eradicating the black-striped mussel from marinas in Darwin, Australia. The affected marinas were quarantined and treated with chemicals. Boats and ships quarantined at the harbors and marinas were removed from the water and thoroughly cleaned. Policies to prevent future invasions allow arriving vessels to be quarantined if they are suspected of carrying AIS.

Crowded Marina

Photo by: Cesar Alvarez, UC SGEP

Educational Field Day

Photo by: Jamie Gonzalez, UC SGEP

California attempts to exclude infested boats at border crossings. The California Department of Food and Agriculture inspects boats transported by commercial haulers.[123] Trailered boats are also inspected at border inspection stations where they arrive from infested states.[124] If zebra mussels are detected, the boats are quarantined, cleaned and inspected before release by the Department of Fish and Game.[125] Once finalized the California AIS Management Plan will provide a framework to respond to AIS in California.[126]

Education and Outreach

Public education is an important invasive species management tool. Educating boat owners about AIS impacts may motivate them to help prevent introductions. Examples of education and outreach programs include:

The Sea Grant Non-indigenous Species Site (SGNIS) is a national information center that contains a comprehensive collection of research publications and education materials produced by Sea Grant programs and other research institutions across the country on invasive species.[127] See http://www.sgnis.org/

The Aquatic Nuisance Species (ANS) Task Force coordinates governmental efforts dealing with ANS in the U.S. with those of the private sector and other North American interests via regional panels, committees and working groups. Their excellent education programs include workshops, traveling displays, pamphlets, fact sheet, videos, Stop Aquatic Hitchhikers! http://www.protectyourwaters.net/, Habitattitude™ http://www.habitattitude.net/ and other activities.[128]

The 100th Meridian Initiative is a containment strategy in which U.S. and Canadian federal, state, provincial and local agencies are cooperating to prevent zebra mussels from spreading no further west than the 100th longitudinal meridian. For information see http://100thmeridian.org/

Where are antifouling paint regulations headed and what alternatives are effective?

Fouling growth on boat hulls creates drag, slowing sailboats and increasing powerboat fuel consumption. Although antifouling paints contribute to fouling control, recent studies indicate that hull fouling is still an important vector for invasive species.[129 130 131 132] In part this is because toxic antifouling paints slow, but do not prevent fouling growth. Their effectiveness may be influenced by the presence of copper tolerant AIS (see below). Significant fouling can attach to hulls in a matter of days and can potentially be transported worldwide.[133] Thus, periodic, mechanical, hull cleaning is needed even when antifouling paints are present.[134] The next sections will discuss the status of antifouling paints, developing regulations and alternatives.

How do heavy metals from antifouling paints affect the environment?

Metals that leach from antifouling paints can accumulate in the water of poorly flushed boat basins to levels that scientific research has shown will harm marine life. However, some invasive species have evolved resistance to copper-based antifouling paints.[135] Such resistance may facilitate invasions where waters are contaminated, for example by metals leached from antifouling paint.[136] For example, the invasive bryozoans *Bugula neritina* and *Watersipora subtorquata* are able to successfully settle, survive and grow in elevated concentrations of copper.[137 138]

In addition, research shows that decreasing native diversity increases survival of invaders both in the field and in experimentally assembled communities.[139] Unpublished research in San Francisco Bay suggests that invasive species are more tolerant of copper than native species. (Since the study is not yet published, the authors do not wish to disclose with which species they were working.) The study compared the diversity of invasive and native fouling organisms when exposed to varying concentrations of copper contamination. The diversity of

Egret and Kelp in Marina

Photo by: Leigh Johnson, UC SGEP

natives declined with increasing contamination while the diversity of invasive species did not.[140] These results suggest that improving coastal water quality by reducing pollution from antifouling paints and other sources could help native species that are less tolerant of heavy metal and other polluants to resist invasions.

Tributyl tin (TBT) is toxic to marine life at low concentrations.[141] Elevated TBT levels in the water column cause imposex (sex changes) in whelks, deform oysters, and affect the food web by accumulating in lower organisms.[142 143 144 145] Severe imposex causes sterility[146] and local populations decrease dramatically or become extinct around ports where TBT from antifouling paints has accumulated.[147 148 149]

Elevated copper levels affect growth, development, feeding, 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. [150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166] Many of these species support food chains for birds, fish and wildlife that boat owners enjoy.

Some of the newer antifouling paints contain zinc. Such products may cause its concentration in marina waters to rise.[167] Elevated zinc levels may affect early stages of invertebrate growth and maturation and may be lethal.[168]

How are antifouling paints regulated and what might the future hold?

Environmental concerns led the International Maritime Organization to initiate a phased ban of TBT in antifouling paints that will be fully enforced in 2008.[169] The United States banned TBT in 1988.[170] With the international ban of TBT antifoulants, copper-based antifouling paints have become the standard and zinc-based products have also reached the market.

Copper-based boat bottom paints are legally registered pesticides[171] that are facing new restrictions. Recently, California Regional Water Quality Control Boards (CRWQCB) and the United States Environmental Protection Agency (USEPA) found that dissolved copper levels exceed federal and state standards of 3.1 µg/l (micrograms per liter or parts per billion) in several, Southern California small craft harbors.[172 173]

In 2003 the Southern California Coastal Water Research Project determined that 95% of dissolved copper released by antifouling paints occurs by passive leaching and 5% occurs during in-water hull cleaning.[174] Following a Total Maximum Daily Load (TMDL) assessment, new regulations were approved in 2005 for Shelter Island Yacht Basin in northern San Diego Bay. They require boat owners to reduce copper leached from antifouling paints by 76% over 17 years.[175 176]

In late 2005, the CRWQCB, San Diego Region recommended other areas of San Diego Bay for the section 303(d) list of water bodies impaired by elevated levels of dissolved copper.[177] 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.[178 179]

In the United States, copper is the most common metal found at toxic concentrations in marina waters.[180 181] California agencies are considering a statewide approach to reduce copper pollution from antifouling paints.[182] A California interagency workgroup and the USEPA are reevaluating registration of copper-based antifoulants.[183 184] The USEPA has proposed lowering the allowable level of dissolved copper in coastal waters from 3.1 µg/l to 1.9 µg/l.[185 186] If the agencies move forward with these actions, increased restrictions on copper-based, antifouling paints may spread beyond Southern California.

Copper-based antifouling paints have been banned for use by pleasure craft in the Netherlands.[187 188] They are banned for pleasure craft on the east coast of Sweden and are restricted on the west coast of Sweden[189] and in Denmark.[190]

How else can boaters control hull fouling?

Current and developing regulations on TBT and copper antifoulants are stimulating major coating companies and new, smaller companies to develop innovative, nontoxic and other, alternative antifouling products.[191] If copper-based antifouling paints are banned or restricted, the demand for nontoxic and other, alternative coatings will increase.

How can nontoxic hull coatings possibly be effective?

A nontoxic antifouling strategy combines a nontoxic boat bottom coating with a companion strategy. Examples of companion strategies include: frequently cleaning the coating; storing the boat out of water; or surrounding the boat with a slip liner and adding freshwater to discourage marine fouling growth. Because a nontoxic hull coating will not slow fouling growth, it must be cleaned more often than a copper-based paint if the boat is stored in seawater. This is a new approach for managing fouling growth.

See the UC Sea Grant Extension Program's product Sampler in *Staying Afloat with Nontoxic Antifouling Strategies for Boats* (available at http://seagrant.ucdavis.edu) for a list of several, nontoxic coatings. Before trying them, boat owners should consult local boat repair yards and hull cleaning companies that are familiar with local performance of specific products. An updated Sampler will be published in 2007.

What are some other types of alternative fouling control products?

Some alternative antifouling products are on the market and more are under development. For example a zinc and peroxide based product is on the market; note that zinc is a heavy metal, as are copper and tin. Others include "booster" biocides that are organic and have a relatively short half-life[192] and some incorporate products derived from marine organisms.[193] Phytochemicals (chemicals derived from plants) are also used to prevent fouling.[194][195]

Nontoxic Coating Application

Photo by: Jamie Gonzalez, UC SGEP

What type of independent testing is needed for these new products?

Testing that is independent of the manufacturers is needed to confirm the efficacy, durability, and cost-effectiveness of new coatings under different climatic and operating conditions. No single, antifouling strategy will suit every vessel or location. Water quality and temperature, needs for fouling and invasive species control, cost and technical feasibility must be considered in selecting an antifouling strategy. Although some alternatives show promise for managing fouling growth, their effectiveness and special requirements must be determined over several years and for a wide variety of conditions.

What are the costs and benefits of switching to nontoxic hull coatings?

In 2002 the UC Sea Grant Extension Program in San Diego and the University of California, San Diego Department of Economics studied economic incentives for boaters to switch to nontoxic hull coatings. They found that the longer, service life of durable, nontoxic epoxy coatings could compensate for increased maintenance and application costs for these coatings.[196]

During 2002-2003 the UC Sea Grant Extension Program in San Diego conducted a field demonstration of nontoxic epoxy and ceramic-epoxy hull coatings on four boats in San Diego Bay. One boat had received a nontoxic coating four years earlier. As of Fall 2006, three boats had retained their new coatings for 4.5 years. After 8 years the fourth boat had replaced its coating in 2006 with a newer and smoother, nontoxic product.[197] In contrast copper antifouling paints are replaced on average after 2.5 years in San Diego Bay.[198]

Costs to purchase and apply nontoxic and other alternative coatings may fall as the demand increases, as more applicators are trained in technical considerations, and as more products enter the market. Greater demand will further stimulate research, development and marketing of more effective, nontoxic and other alternative coatings. Costs to convert from copper antifouling paints should also fall as new products are developed that can be applied directly to them. (Old, copper antifouling paints had to be stripped before nontoxic coatings could be applied in the UC demonstration.)

How could policies to reduce antifoulant pollution and to control hull-borne invasive species come into conflict?

Increased regulation or possible bans of copper-based antifouling paints may exacerbate invasions as the toxicity of vessel hulls declines and water quality improves in coastal ports and harbors. On the other hand, native species may be more resistant to invasions if water quality improves and copper-tolerant AIS lose their competitive edge. Policy coordination is needed to resolve conflicts between those that seek to control hull-borne, AIS in hull fouling and those that aim to reduce antifouling paint pollution.

For example Section 101 (3) (B) (ii) (III) of the United States Senate Bill 725, National Aquatic Invasive Species Act of 2007 recommends best management practices to eliminate or minimize AIS transport by vessels. 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.[199]

Under the proposed Act, boats with nontoxic coatings would have to be hauled in order to collect and dispose of fouling growth. Nontoxic coatings do not retard fouling growth, so they need to be cleaned every two to three weeks. Hauling boats twice a month for cleaning would create considerable burdens of cost and time for recreational boaters who use nontoxic coatings, as shown in Tables 2 and 3. Although using copper-based antifouling paints would cut these burdens in half, they can create water quality problems in crowded boat basins.

TABLE 2. Annual, in-water, hull-cleaning costs for copper paints and nontoxic coatings on a typical, 40-foot boat

Hull Coating Type	In-Water Hull Cleaning Per Service[200]	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 3. Annual, haul-out, hull-cleaning costs for copper paints and nontoxic coatings on a typical, 40-foot boat

Hull Coating Type	Haul-Out/Hull Cleaning Per Service[201]	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

Putting it all together: How can we manage both antifouling paint pollution and bioinvasions effectively and reasonably?

The following sections provide highlights of possible answers to this question. The following publications provide more detail. On May 11, 2005 the UC Sea Grant Extension Program and California State Lands Commission held a workshop, *Managing Hull Transport of Aquatic Invasive Species.* The workshop's goal was to lay a foundation for developing solutions to prevent and/or control AIS on commercial and recreational vessels. It included presentations, discussion and recommendations by 65 representatives of boating, shipping and coating businesses, ports, harbors and marinas, boat and ship owners, government agencies, scientists, policy makers and environmental organizations.

In 2006 UC Sea Grant Extension Program published an extensive review paper, *Managing Hull-Borne Invasive Species and Coastal Water Quality for California and Baja California Boats Kept in Saltwater*, and a policy analysis, *Environmental Policy Conflicts on the Horizon: Vessel Antifouling Paints, Coastal Water Quality and Invasive Species.* Workshop proceedings and the UC review paper and policy analysis can be found at http://seagrant.ucdavis.edu

The following recommendations are based on our analysis of information presented in the review paper on which this booklet is based, our policy analysis and findings from the May 11, 2005 workshop. They also include insights gleaned from 20 years of experience in working with the boating and fishing communities on a variety of issues. They consider both water quality and AIS.

Can policy conflicts be reduced easily by tailoring hull maintenance to the boat?

Workshop participants commented that, due to shorter and less frequent voyages, recreational boats may pose less risk than ships for transporting AIS.[202] Table 1 shows that about one-half of all boaters in California's coastal counties took no trips over 100 miles from home in 2000. Because they are large in number and spend more time in the home marina, they likely contribute the lion's share to elevated copper levels. Thus, the most reduction in pollution and invasive species risk could be achieved if these boaters used nontoxic hull coatings and cleaned them often.

Boaters who travel long distances are more likely to acquire and transport invasive species on the hulls of their boats. Table 1 shows that 2%-7% of boaters in California's coastal counties take frequent trips over 100 miles from home. Their boats might be better candidates for copper-based or less-toxic antifouling paints, instead of nontoxic coatings. Because they are relatively few in number and spend less time in the home marina, they would discharge less toxicant to confined waters. Hull cleaning would be needed to control AIS, but less often than for nontoxic hull coatings.

Proper use of antifouling strategies will allow boat owners to select coatings and companion strategies appropriate to the situation. A system for controlling hull-borne AIS should be developed by collaboration among agencies, policy makers, and associations representing boat owners, port/harbor/marina/yacht club managers, and hull cleaning and boat repair businesses. It should be evaluated and updated periodically.

Even copper-based antifoulants slow, rather than prevent, fouling. Thus, AIS transport could be prevented by cleaning <u>all</u> boat hulls before departure for: distant areas; events where boats from many areas are likely to congregate; and islands (particularly vulnerable to AIS because of their geographic isolation). Boats returning from a long-distance cruise or boating event could carry potential invaders, so it would be wise to clean their hulls before heading home.

However, heavily fouled boats returning from a long-distance trip are much more likely to carry AIS. It may be appropriate to clean hulls of such boats before they enter the harbor. Another strategy may be to haul them immediately upon arrival, clean their hulls, contain the fouling debris and dispose it in a landfill.

Can general hull maintenance help to control invasive species?

We propose the following measures to control AIS on boats that are kept in saltwater and removed once every one to three years to replace paint and conduct other maintenance. [Owners of trailered boats may visit the excellent website, Stop Aquatic Hitchhikers! (see below).] The following recommendations are incorporated in our bilingual poster and fact sheet, "Stop Aquatic Invaders on Our Coast!/¡Detenga el transporte de especies invasoras acuáticas en nuestras costas!" [203] [204]

- 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 other areas.

Photo by: Jamie Gonzalez, UC SGEP

Racing Sailboats, San Diego Bay

- Clean them all again before moving to another region or returning home.
- If your boat is heavily fouled after such a trip, haul it for cleaning upon arrival and contain the fouling growth.
- Drain livewells, bait tanks, and bilge water before leaving and before returning.
- If you trailer your boat, please follow the guidelines at the Stop Aquatic Hitchhikers! website http://www.protectyourwaters.net
- In California, report AIS found on your boat or in your marina to:
  National Aquatic Nuisance Species Hotline
  1-877-STOP-ANS (1-877-786-7267)
- In Baja California, report AIS found on your boat or in your marina to: Comisión nacional para el conocimiento y uso de la biodiversidad (CONABIO) 01 (55) 5004-5000

What is the hoopla about HACCP?

Aquatic Invasive Species – Hazard Analysis and Critical Control Points (AIS-HACCP) strategies are being used in the Midwestern U.S. to focus on the most important points where AIS can be controlled. It may also be suitable for controlling hull-borne AIS on boats traveling along the California coast and between California and other areas. We recommend that tailoring hull maintenance to the boat and its situation be considered in developing a HACCP process to prevent invasive species on boat hulls, while protecting water quality.

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. It views prevention as a seven-step process:

1. Analyze steps in the process where significant hazards occur and describe preventive measures.
2. Identify the critical control points (CCPs) in the process.
3. Establish controls for each CCP.
4. Establish CCP monitoring and use the results to adjust the process.
5. Establish actions to correct problems when monitoring indicates a critical limit has been exceeded.
6. Establish procedures to verify that the HACCP system is working correctly.
7. Establish effective record-keeping to document the HACCP system.[205]

Focusing efforts on CCPs will help to reduce costs and avoid unnecessary inconvenience. 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.

According to the May 2005 AIS workshop participants, **it is impossible to predict the next invasive species**, control is generally much more costly than prevention and eradication rarely successful. As a result, they recommended focusing on hulls, instead of particular species, to minimize AIS introductions among fouling. Risks should also be considered in creating strategies to prevent hull transport of AIS.[206]

Risk and Critical Control Points assessments for a HACCP system should consider at least:

- How often a boat is used or how long it has been kept at mooring since its 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 or islands,
  - participation in local events with local boats,
  - cruising to locations within the region,
  - travel among smaller harbors,
  - travel between a major port and a smaller harbor;
- Season of the year;
- Hull maintenance practices;
- Age and type of bottom coating;
- Companion strategies used to control fouling, for example frequent hull-cleaning, 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 the system are distributed among boat owners, boating and hull-coating businesses, and government/tax payers.

Photo by: Alisha Dahlstrom, UC SGEP

Cargo Ship Wharf, Port of Oakland

Why should we think globally and act regionally?

Clearly, a regional approach will be needed to control AIS introductions from hulls of pleasure craft and commercial fishing boats traveling along the Pacific coast of North America. A global perspective in which experiences and technologies are shared would be helpful in designing programs to control longer-distance transportation of AIS on hulls of such small craft.

May 2005 workshop participants emphasized that continued communication between government agencies and stakeholders will increase feasibility and effectiveness of policies to prevent hull-borne AIS transport, while protecting coastal water quality.[207]

Recreational Boats in Sacramento-San Joaquin Delta

Photo by: Vivian Matuk, California Department of Boating and Waterways & California Coastal Commission

Public education at a San Diego boatyard

Photo by: Carol Anderson, UC SGEP

How can we choose appropriate strategies?

To save public funds and avoid burdening boat owners with less effective practices, we recommend that managers and people in the boating and fishing communities:

- Choose effective management practices with reduced economic and environmental "side effects" and
- Focus the best management practices on situations that are more likely to achieve results.

Considerable effort is being devoted to assessing the full economic impacts of invasive species. The goal is to develop effective management programs that help to prevent, control, or mitigate such invasions. The emphasis is on benefits and costs of treatments to determine how best to manage the particular invasive species.[208]

Prevention is more ecologically and cost effective than control, mitigation or eradication. Although control does not eliminate entire communities of AIS, it may be more economically feasible than eradication. Control and containment are most appropriate when the species has become established and has begun to increase its range.[209] Mitigation may be feasible once an AIS has become established.[210]

Both short- and long-term costs of management strategies should be considered in policy development.

What research and education are needed?

May 2005 workshop participants and other representatives of boat owners and boating businesses have emphasized the importance of education and outreach in encouraging

Commercial Fishing and Recreational Boats, Humboldt Bay

Photo by: Maggy Herbelin, Coordinator of The Humboldt Bay Stewards boaters to improve their environmental practices. Immediate, collaborative, education programs will raise boater awareness of the invasive species problem, provide management practices they can readily apply and increase adoption of the recommended practices.[211] For example, practices to reduce risks of transporting invasive species might be incorporated into existing, "Clean Marina" programs.

However, scientific research is needed to understand the scope and nature of ecological, economic and social risks posed by AIS on hulls of California's coastal boats, how costs and other burdens should be distributed, and to develop an effective, long-term strategy to prevent and control introductions. Ideally, such research would help to develop cost- and environmentally effective management systems and effective hull maintenance practices for managing hull-borne AIS while protecting water quality.

Education, based on this research, will be needed to enable boat owners, boating and hull-coating businesses, government agencies, policy makers and environmental organizations to make appropriate and sustainable decisions. However, early education programs can begin to raise boater awareness of AIS and hull maintenance practices that can begin immediately to reduce risks of transporting them.

!ATTENTION FRESHWATER BOATERS!

Please help stop the spread of Zebra Mussels and Quagga Mussels in our lakes, rivers and streams. They have harmed freshwater ecosystems and clogged irrigation, power and municipal water systems in the Eastern and Midwestern United States and Canada. Quagga Mussels have now invaded Southern California. Boaters can help keep Zebra Mussels out and stop Quagga Mussels from spreading statewide. According to California Department of Fish and Game, when leaving the water:

- Inspect all exposed surfaces
- Wash the hull thoroughly
- Remove all plants and animal material
- Drain all water and dry all areas
- Clean and dry all live-wells
- Empty and dry any buckets
- Dispose of all bait in the trash
- Wait 5 days and keep watercraft dry between launches into different fresh waters

Please visit the following websites for specific tips on how to stop these freshwater invaders!
California Department of Fish and Game http://www.dfg.ca.gov/quaggamussel/
Stop Aquatic Hitchhikers! http://www.protectyourwaters.net/
Habitattitude™ http://www.habitattitude.net/

References

1 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.

2 Russell, G. and O.P. Morris. 1973. Ship fouling as an evolutionary process. *Proceedings of the 3rd International Congress of Marine Corrosion and Fouling*: 719-730. Washington, DC, 1972.

3 Crooks, J. 2005. Oral commentary. Vessel Fouling Technical Advisory Group, October 13, 2005: Meeting Summary. California State Lands Commission, Sacramento, CA.

4 Carlton, J.T. 2001. *Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities*. Pew Oceans Commission, Arlington, VA.

5 Bax, N., A. Williamson, M. Aguero, E. Gonzalez and W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. *Marine Policy* 27:313-323.

6 Simon, D. 2007. Biodiversity in the National Parks: Looming Threats to America's Most Valued Plants and Animals http://www.npca.org/wildlife_protection/biodiversity/report/biodiversity.html Accessed February 22, 2007.

7 Daily, G.C., ed. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press: Washington, DC.

8 Convention on Biological Diversity. Invasive Alien Species Introduction. http://www.biodiv.org/programmes/cross-cutting/alien/ Accessed October 4, 2005.

9 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.

10 Peterson, C.H. and J. Lubchenco. 1997. Marine Ecosystem Services. In: G.C. Daily, ed. *Nature's Services: Societal Dependence on Natural Ecosystems*. p. 177-194. Island Press, Washington, DC.

11 Cranfield, H.J., D.J. Gordon, R.C. Willan, B.C. Marshall, C.N. Battershill, M.P. Francis, W.A. Nelson, C.J. Glasby, and G.B. Read. 1998. Adventive marine species in New Zealand. National Institute of Water and Atmospheric Research, Wellington, New Zealand. Technical Report #34. 48pp.

12 Thresher, R.E., C.L. Hewitt, and M.L Campbell. 1999. Synthesis: Introduced and cryptogenic species in Port Philip Bay. In: Hewitt, C.L. M.L. Campbell, R.E. Thresher, R.B. Martin (eds). *Marine Biological Invasions of Port Philip Bay, Victoria*. Commonwealth Scientific and Industrial Research Organization (CSIRO). Hobart, Australia. Technical Report #20. pp.283-295.

13 Hewitt, C.L. 2002. The distribution and biodiversity of tropical Australian marine bioinvasions. *Pacific Science* 56(2): 213-222.

14 Gollasch, S. 2002. The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. *Biofouling* 18(2): 105-121.

15 Coutts, A.D.M., K.M. Moore, and C.L. Hewitt. 2003. Ships' sea chests: an overlooked transfer mechanism for non-indigenous species? *Marine Pollution Bulletin* 46: 1504-1515.

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

17 Fofonoff, P.W., G.W. Ruiz, B. Steves, and J.T. Carlton. 2003. In ships or on ships? Mechanisms of transfer and invasion for non-native 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, DC.

18 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.

19 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.

20 California Department of Fish and Game, Marine Region, "California Ocean Sport Fishing Regulations Map," http://www.dfg.ca.gov/mrd/fishing_map.html Accessed: August 30, 2005. Reprinted with permission.

21 Hewitt, C. L., R. B. Martin. 1996. Port Surveys for Introduced Marine Species-Background Considerations and Sampling Protocols. Centre for Research on Introduced Marine Pests. Technical Report Number 4.

22 Gollasch, S. Z. 2002. The Importance of Ship Hull Fouling As a Vector of Species Introduction Into the North Sea. *Biofouling* 18.

23 Wonham, M.J., J.T. Carlton, G.M. Ruiz, L.D. Smith. 2000. Fish and Ships: Relating Dispersal frequency to Success in Biological Invasions. *Marine Biology* 136:1111-1121.

24 Baskin Y. 1998. Winners and Losers in a Changing World: Global Changes may Promote Invasions and Alter the Fate of Invasive Species. *Bioscience* 48(10).

25 Carlton, J. T. 1996. Pattern, Process, and Prediction in Marine Invasion Ecology. *Biological Conservation* 78:97-106.

26 Stachowicz, J. J., R. B. Whitlach, R. W. Osman. 1999. Species Diversity and Invasion Resistance in a Marine Ecosystem. *Science Magazine* 286:1577-1579.

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

28 Conlon, M. 2002. Northwest Mexico Marina Market Analysis. Prepared for the Packard Foundation, EDAW, i-2.

29 Serrano, I. "Sin cuajar, turismo náutico." *El Universal*, August 7, 2005, http://www2.eluniversal.com.mx/pls/impreso/noticia_supl.html?id_articulo=24117&tabla=articulos Accessed August 11, 2005.

30 'Lectronic Latitude, "Domestic Clearing is Over in Mexico," http://www.latitude38.com/LectronicLat/2005/0405/Apr19/Apr19.html Accessed July 2005.

31 Conlon, Michael. 2002. Northwest Mexico Marina Market Analysis. Prepared for the Packard Foundation, EDAW, i-2. Reprinted with permission.

32 Pimentel, D., L. Lach, R. Zuniga and D. Morrison. 2000. Environmental and Economic Costs of Non-indigenous Species in the United States. *BioScience* 50 (1).

33 Grosholz, E.D., G.M. Ruiz, C.A. Dean, K A. Shirley, J.L. Maron and P.G. Connors. 2000. The impacts of a non-indigenous marine predator in a California bay. *Ecology* 81 (5):2106-1224.

34 Cohen, A.N. and J.T. Carlton. 1995. Non-indigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. United States Fish and Wildlife Service, Washington D.C. and The National Sea Grant College Program, Connecticut Sea Grant.

35 Falkner, M., L. Takata and S. Gilmore. 2005. Report on the California Marine Invasive Species Program. Produced by the California State Lands Commission, Marine Facilities Division for the California State Legislature.

36 Cohen, A.N. and P.B. Moyle. 2004. Summary of Data and Analyses Indicating that Exotic Species have Impaired the Beneficial Uses of Certain California Waters. A Report Submitted to the State Water Resources Control Board.

37 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.

38 Jirik, A. 2005. Aquatic Invasive Species in the Port of Los Angeles. Personal communication, August 11, 2005.

39 Meinesz, A. 1999. *Killer Algae*. Chicago, U.S.: University of Chicago Press.

40 Relini, M. and Trochia, G. 2000. The role of fishing gear in the spreading of allochthonous species: the case of *Caulerpa taxifolia* in the Ligurian Sea. *ICES Journal of Marine Science* 57:1421-1427.

41 Brancato, M.S. and D. MacLellan. 1999. Impacts of Invasive Species Introduced through the Shipping Industry (abstract). Oceans 1999 MTS/IEEE. Riding the Crest into the 21st Century. Volume 2: 676. September 13-16, 1999. Seattle, WA. ISBN: 0-7803-5628-4.

42 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.

43 Simberloff, D. and B. von Holle. 1999. Positive interactions of non-indigenous species: invasional meltdown. *Biological Invasions* 1:21-32.

44 California Department of Fish and Game. 2002. A Survey of Non-Indigenous Aquatic Species in the Coastal and Estuarine Waters of California. Submitted to the California State Legislature as required by the Ballast Water Management Act of 1999. Prepared and submitted by the Department of Fish and Game, Office of Spill Prevention and Response, December 2002. 33pp.

45 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.

46 Cohen, A. N. and J. T. Carlton. 1998. Accelerating Invasion Rate in a Highly Invaded Estuary. *Science* 279:555-558.

47 Cohen, A.N. 2005 *Guide to the Exotic Species of San Francisco Bay.* San Francisco Estuary Institute, Oakland, CA, www.exoticsguide.org Accessed August 31, 2005

48 Cohen, A.N. and J.T. Carlton. 1998. Accelerating Invasion Rate in a Highly Invaded Estuary. *Science* 279:555-557.

49 California Department of Fish and Game. 2002. A Survey of Non-Indigenous Aquatic Species in the Coastal and Estuarine Waters of California. Submitted to the California State Legislature as required by the Ballast Water Management Act of 1999. Prepared and submitted by the Department of Fish and Game, Office of Spill Prevention and Response, December 2002. 33pp.

50 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.

51 Cohen, A.N., L.H. Harris, B.L. Bingham, J.T. Carlton, J.W. Chapman, C.C. Lambert, G. Lambert, J.C. Ljubenkov, S.N. Murray, L.C. Rao, K. Reardon and E. Schwindt. 2002. A Rapid Assessment Survey of Exotic Species in Sheltered Coastal Waters. For the California Department of Fish and Game, Sacramento, CA, the State Water Resources Control Board, Sacramento, CA and the National Fish and Wildlife Foundation, San Francisco, CA.

52 Cohen, A.N. 2004. Invasions in the Sea. *Park Science* 22 (Fall): 37-41.

53 Heimowitz, P. United States Fish and Wildlife Service, Portland, OR. Personal communication. January 19, 2006.

54 Minchin, D., F. Lucy, and M. Sullivan. 2002. *Zebra Mussel: Impacts and Spread. In Invasive Aquatic Species of Europe. Dirstribution, Impacts and Management*. Leppäkoski, E. and S. Gollasch, and S. Olenin (eds). Dordrecht: Kluwer Academic Publishers.

55 100th Meridian Initiative. http://www.100thmeridian.org/about100mi.htm Accessed August 3, 2005.

56 Elkhorn Slough National Estuarine Research Reserve, "Least Wanted Aquatic Invaders," http://www.elkhornslough.org/research/aquaticinvaders/aquatic6.htm Accessed September 7, 2005.

57 Meacham, P. 2001. Washington State Aquatic Nuisance Species Management Plan. Washington Department of Fish and Wildlife for the Washington Aquatic Nuisance Species Coordinating Committee.

58 Cohen, A.N. 2005. *Guide to the Exotic Species of San Francisco Bay.* San Francisco Estuary Institute, Oakland, CA. http://www.exoticsguide.org Accessed August 30, 2005.

59 Raaymakers, S. 2002. The Ballast Water Problem: Global Ecological, Economic, and Human Health Impacts. Paper Presented at the RECSO/IMO Joint Seminar on Tanker Ballast Water Management & Technologies Dubai, UAE 16-18 Dec 2002.

60 Grosholz, E.D. and G.M. Ruiz. 1995. The spread and potential impact of the recently introduced European green crab, *Carcinus maenas*, in central California. *Marine Biology* 122:239-247.

61 Grosholz, E.D., G.M. Ruiz, C.A. Dean, K.A. Shirley, J.L. Maron and P.G. Connors. 2000. The impacts of a non-indigenous marine predator in a California bay. *Ecology* 81 (5): 2106-1224.

62 Wasson, K., C. Zabin, L. Bedinger, M. Diaz, J. Pearse. 2001. Biological invasions of estuaries without international shipping: the importance of intraregional transport. *Biological Conservation* 102:143-153.

63 Cohen, A.N. and J.T. Carlton. 1995. Non-indigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. United States Fish and Wildlife Service, Washington D.C. and The National Sea Grant College Program, Connecticut Sea Grant. CONN-T-95-002.

64 Lambert, C. and G. Lambert. 1998. Non-indigenous ascidians in southern California harbors and marinas. *Marine Biology* 130: 685.

65 National Introduced Marine Pest Information System, "*Botryllus schlosseri*," http://www.marine.csiro.au/crimp/nimpis/spImpact.asp?txa=6854 Accessed August 23, 2005.

66 Guide to the Exotic Species of San Francisco Bay, "*Botryllus schlosseri*," http://www.exoticsguide.org/species_pages/b_schlosseri.html Accessed August 30, 2005.

67 Lambert, C. and G. Lambert. 1998. Non-indigenous ascidians in southern California harbors and marinas. *Marine Biology* 130: 684.

68 Sea Grant Non-indigenous Species Site, "Status and Impacts of Marine Alien Species in South Africa," http://sgnis.org/publicat/grifrobi.htm Accessed: August 23, 2005.

69 Aquaculture Association of Nova Scotia, "Tunicates Affecting the Nova Scotia Shellfish Industry," http://www.aansonline.com/r&d/tunicateseffecting.pdf Accessed: November 1, 2005.

70 Lambert, C. and G. Lambert. 1998. Non-indigenous ascidians in southern California harbors and marinas. *Marine Biology* 130:684.

71 National Introduced Marine Pest Information System, "*Styela clava*," http://www.marine.csiro.au/crimp/nimpis/spImpact.asp?txa=6836 Accessed August 23, 2005.

72 Guide to the Exotic Species of San Francisco Bay, "*Styela clava*," http://www.exoticsguide.org/species_pages/s_clava.html Accessed: August 30, 2005.

73 Bastida-Zavala, R.J. and H.A. Ten Hove. 2003. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Eastern Pacific Region and Hawaii. *Beaufortia* 53 (4): 68.

74 Bastida-Zavala, Rolando J. and H.A. Ten Hove. 2002. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Western Atlantic Region. *Beaufortia* 52 (9):164.

75 CSIRO Marine Research, "Marine Pest Information Sheet: *Hydroides sanctaecrucis*," http://www.marine.csiro.au/crimp/Reports/Infosht15_Hydroides.pdf Accessed September 8, 2005.

76 Bastida-Zavala, R.J. and Harry A. Ten Hove. 2002. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Western Atlantic Region. *Beaufortia* 52 (9):167.

77 Bastida-Zavala, R.J. and H.A. Ten Hove. 2003. Revision of *Hydroides* Gunnerus, 1768 (Polychaeta: Serpulidae) from the Eastern Pacific Region and Hawaii. *Beaufortia* 53 (4):87.

78 CSIRO Marine Research, "Marine Pest Information Sheet: *Hydroides sanctaecrucis*," http://www.marine.csiro.au/crimp/Reports/Infosht15_Hydroides.pdf Accessed September 8, 2005.

79 Bastida-Zavala, R.J. September 23, 2005. Personal communication.

80 Elkhorn Slough National Estuarine Research Reserve, "Least Wanted Aquatic Invaders" http://www.elkhornslough.org/research/aquaticinvaders/aquatic5.htm Accessed July 5, 2005.

81 Elkhorn Slough National Estuarine Research Reserve, "Least Wanted Aquatic Invaders," http://www.elkhornslough.org/research/aquaticinvaders/aquatic21.htm Accessed September 8, 2005.

82 Cohen, A., L. Harris, B. Bingham, J. Carlton, J. Chapman, C. Lambert, G. Lambert, J. Ljubenkov, S. Murray, L. Rao, K. Reardon and E. Schwindt. 2002. A Rapid Assessment Survey of Exotic Species in Sheltered Coastal Waters. For the California Department of Fish and Game, Sacramento, CA, the State Water Resources Control Board, Sacramento, CA and the National Fish and Wildlife Foundation, San Francisco, CA.

83 Cohen, A.N. 2005. Guide to the Exotic Species of San Francisco Bay. San Francisco Estuary Institute, Oakland, CA, www.exoticsguide.org

84 Aguilar-Rosas, L.E. and R. Aguilar-Rosas. 2004. The Marine Algae *Undaria pinnatifida* Invades Baja California Coast. *Bight Bulletin* (8):1.

85 Commonwealth Scientific and Industrial Research Organization. 1998. Introduced Marine Pests. *CSIRO Marine Research Information Sheet No. 2*. http://www.csiro.au/index.asp?type=faq&id=IntroducedMarinePests&stylesheet=sectorInformationSheet Accessed August 29, 2005.

86 Raaymakers, S. 2002. The Ballast Water Problem: Global Ecological, Economic, and Human Health Impacts. Paper Presented at the RECSO/IMO Joint Seminar on Tanker Ballast Water Management & Technologies Dubai, UAE 16-18 December 2002.

87 Global Invasive Species Database. Ecology of *Undaria Pinnatifida* Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission http://www.invasivespecies.net/database/species/ecology.asp?si=68&fr=1&sts= Accessed November 1, 2005.

88 Wittenberg, Rüdiger and Matthew J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

89 Biosecurity New Zealand. 2005. Is your boat spreading marine pests? http://www.maf.govt.nz/quarantine/ships-yachts/yacht-fact-sheet-2005version-with-yacht-1.pdf Accessed November 8, 2005.

90 Australian Quarantine and Inspection Service. 2004. Quarantine Pre-Arrival Report for Vessels. Quarantine Act 1908 Section 27A. http://www.daff.gov.au/corporate_docs/publications/html/quarantine/quarantine/qpar_1_march_2004.pdf Accessed November 8, 2005.

91 Australian Quarantine and Inspection Service. 2005. First port of entry into Australia. http://www.affa.gov.au/corporate_docs/publications/html/quarantine/factsheets/first_port_of_entry.pdf
Accessed November 8, 2005.

92 AQIS. 2007. The Australian Biofouling Protocol for Vessels Less than 25 Meters in Length: What I Need to Know. Information Guide for Operators of Small Yachts and Motor Cruisers.

93 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

94 Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants*. University of Chicago Press, Chicago, Illinois.

95 Grosholz, E. and G. Ruiz (eds). 2002. *Management Plan for the European Green Crab*. Submitted to the Aquatic Nuisance Species Task Force.

96 Bax, N. K. Hayes, A. Marshall, D. Parry, and R. Thresher. 2004. Man-made marinas as sheltered island for alien marine organisms: Establishment and eradication of an alien invasive marine species. Paper from *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives*.

97 CSIRO Centre for Research on Introduced Marine Pests 2001. Marine Pest Information Sheet-Vessel and Gear Fouling. http://www.marine.csiro.au/crimp/Reports/Infosht3_Fouling_A3S.pdf Accessed August 24, 2005.

98 Bax, N., K. Hayes, A. Marshall, D. Parry, and R. Thresher. 2004. Man-made marinas as sheltered island for alien marine organisms: Establishment and eradication of an alien invasive marine species. Paper from *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives.*

99 Ferguson, R. 2000. The effectiveness of Australia's response to the Black Striped Mussel incursions in Darwin, Australia. A Report of the Marine Pest Incursion Management Workshop August 27-28 1999. Research report produced by the Department of Environment and Heritage.

100 Bax, N.J. 1999. Eradicating a dreissenid from Australia. *Dreissena!* 10(3):1-5.

101 Ferguson, R. 2000. The effectiveness of Australia's response to the Black Striped Mussel incursions in Darwin, Australia. A Report of the Marine Pest Incursion Management Workshop August 27-28 1999. Research report produced by the Department of Environment and Heritage.

102 Marshall, A.J., H. N. Cribb, and M. J. Thompson. 2003. Exotic marine pests: what is being done about preventing their introduction. Darwin Harbour Plan of Management Workshop Presentation.

103 Cohen, A.N. 2004. Invasions in the sea. National Park Service: *Park Science* 22(2).

104 Culver, C.S. and A.M. Kuris. 2000. The apparent eradication of a locally established marine pest. *Biological Invasions* 2:245-253.

105 Jirik, A. 2005. Aquatic Invasive Species in the Port of Los Angeles. Personal communication, August 11, 2005.

106 Merkel, K., and R. Woodfield. 2003. *Eradication and Surveillance of Caulerpa taxifolia within Agua Hedionda Lagoon, Carlsbad, California.* Second Year Status Report, Fall 2001 through Summer 2002. Prepared for Steering Committee of the Southern California Caulerpa Action Team.

107 Southern California Caulerpa Action Team. Program Funding. http://www.sccat.net/funding.php Accessed August 29, 2005.

108 Ellis, S. California Department of Fish and Game, Sacramento, CA. January 23, 2006.

109 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

110 Michin, D. and S. Gollasch. 2003. Fouling and Ships' Hulls: How Changing Circumstances and Spawning Events May Result in the Spread of Exotic Species. *Biofouling* 19 (Supplement): 111-122.

111 Snell, T. 2005. Australian Quarantine and Inspection Services (AQIS), National Ballast Water Adviser, personal communication, September 27, 2005.

112 Hoffman, M. 2005. California Marine Services, personal communication, September 29, 2005.

113 Rashick, B. 2005. Alpha One Diving, personal communication, September 29, 2005.

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

115 Floerl, O. 2005. National Institute of Water and Atmospheric Research (NIWA), National Centre for Aquatic Biodiversity and Biosecurity, personal communication, September 27, 2005.

116 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

117 Grosholz, E. and G. Ruiz (eds). 2002. *Management Plan for the European Green Crab*. Submitted to the Aquatic Nuisance Species Task Force.

118 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

119 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

120 Convention on Biological Diversity. 2005. Alien species that threaten ecosystems, habitats or species. United Nations Environment Programme. http://www.biodiv.org/decisions/Default.aspx?dec=VI/23 Accessed November 8, 2005.

121 Wittenberg, Rüdiger and Matthew J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

122 Wittenberg, R. and M.J.W. Cock. (eds.) 2001. *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. CAB International, Wallingford, Oxon, UK, xvii-228.

123 Ellis, S. 2006. California Department of Fish and Game, Habitat Conservation Planning Branch, Personal communication.

124 California Department of Fish and Game DRAFT California Aquatic Invasive Species Management Plan. 2006. http://sfep.abag.ca.gov/pdf/AISmgmtplan.pdf Accessed December 19, 2006.

125 Ellis, S. 2006. California Department of Fish and Game, Habitat Conservation Planning Branch, Personal communication.

126 California Department of Fish and Game DRAFT California Aquatic Invasive Species Management Plan. 2006. http://sfep.abag.ca.gov/pdf/AISmgmtplan.pdf Accessed December 19, 2006.

127 Sea Grant Nonindigenous Species website http://www.sgnis.org/ Accessed February 3, 2006.

128 Aquatic Nuisance Species Task Force website http://www.anstaskforce.gov/default.php Accessed February 3, 2006.

129 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.

130 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.

131 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.

132 Hewitt, C.L. and M.L. Campbell. 2001. The Australian distribution of the introduced sphaeromatid isopod *Paracerceis sculpta* (Homes 1904). *Crustaceana* 78: 925-936.

133 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.

134 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.

135 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.

136 Piola, R.F. and E.L. Johnston. 2005. Differential tolerance to metals among populations of the introduced bryozoan *Bugula neritina. Marine Biology* (Published Online, November 2005).

137 Piola, R.F. and E.L. Johnston. 2005. Differential tolerance to metals among populations of the introduced bryozoan *Bugula neritina. Marine Biology* (Published Online, November 2005).

138 Mackie, J.A. 2003. A Molecular Analysis of Bryozoan Dispersal. PhD Thesis, Department of Zoology, University of Melbourne.

139 Stachowicz, J.J., H. Fried, R.W. Osman, and R.B. Whitlatch. 2002. Biodiversity, invasion resistance, and marine ecosystem function: Reconciling pattern and process. *Ecology* 83(9): 2575-2590.

140 Crooks, J. 2005. Oral commentary. Vessel Fouling Technical Advisory Group, October 13, 2005: Meeting Summary. California State Lands Commission, Sacramento, CA.

141 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.

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

143 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.

144 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.

145 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.

146 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.

147 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.

148 Harding, M.J.C., G.K. Rodger, 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.

149 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.

150 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.

151 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.

152 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.

153 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.

154 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.

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

156 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.

157 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.

158 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.

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

160 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.

161 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.

162 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.

163 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.

164 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.

165 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.

166 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.

167 Howard Clemente, M.J. 2006. Discharges of dissolved zinc from zinc-based antifouling paint in Shelter Island Yacht Basin, San Diego Bay. Thesis presented to Faculty of San Diego State University.

168 Conradi, M. and M.H. Depledge. 1999. Effects of zinc on the life-cycle, growth and reproduction of the marine amphipod *Corophium volutator. Marine Ecological Progress Series* 176:131-138

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

170 52 Federal Register 37,518 (Oct. 7, 1987).

171 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.

172 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: August 30, 2006.

173 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 Accessed August 30, 2006.

174 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.

175 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: August 30, 2006.

176 California State Water Resources Control Board. 2005. State Water Board Resolution No. 2005-0071. 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://waterboards.ca.gov/resdec/resltn/2005/rs2005-0071.pdf Accessed October 18, 2005.

177 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.

178 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.

179 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.

180 NCDEM. 1990. North Carolina Coastal Marinas: Water Quality Assessment. North Carolina Division of Environmental Management, Raleigh, NC. Report No. 90-01.

181 NCDEM. 1991. Coastal Marinas: Field Survey of Contaminants and Literature Review. North Carolina Division of Environmental Management, Raleigh, NC. Report No. 91-03.

182 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.

183 Singhasemanon, N. 2005. Copper Antifouling Paint Sub-Workgroup 5/26/05 Meeting Notes. California Department of Pesticide Regulation, Sacramento, CA.
184 Singhasemanon, N. 2005. Copper Antifouling Paint Sub-Workgroup 5/26/05 Meeting Notes. June 13, 2005. 6 p.
185 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 November 10, 2005.
186 Cruz, L. 2005. Environmental Protection Agency. Office of Water: Health and Ecological Criteria Division, personal communication.
187 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.
188 College Toelating Bestrijdingsmiddelen. Pesticides Database Online. 2004. http://www.ctb-wageningen.nl/
189 Swedish Chemicals Inspectorate. For a Non-Toxic Environment. 2004. http://www.kemi.se/templates/Page____498.aspx Accessed October 31, 2005
190 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.
191 Keystones, Inc. 2001. Anti-Fouling Paint Desk Market Research Report. http://www.keystones.dk/
192 Haslbeck, E. 2005. Naval Surface Warfare Center, Carderock Division, personal communication.
193 Clare, A.S. 1996. Marine natural product antifoulants: status and potential. *Biofouling* 9:211-229.
194 E Paint. 2005. http://www.epaint.net/faq.shtm Accessed November 8, 2005.
195 E Paint Company. 2005. EP2000 brochure. http://www.epaint.net/index.shtm Accessed August 30, 2006.
196 Johnson, L and J. Miller. 2003. Making Dollars and Sense of Nontoxic Antifouling Strategies for Boats. California Sea Grant College Program Technical Report No. T-052. 13p.
197 Gonzalez, J.A. and L.T. Johnson. 2006. Nontoxic Hull Coating Field Demonstration: Long-Term Performance. University of California Sea Grant Extension Program, San Diego, CA. UCSGEP-SD Fact Sheeet 06-3. 2 p.
198 Johnson, L and J. Miller. 2003. Making Dollars and Sense of Nontoxic Antifouling Strategies for Boats. California Sea Grant College Program Technical Report No. T-052. 13p.
199 United States Senate. 2007. S. 725. National Aquatic Invasive Species Act of 2007. Sec. 305 (2) (B) (ii) (III). http://thomas.loc.gov/cgi-bin/thomas Accessed May 23, 2007.
200 Hoffman, Marlan, California Marine Services and William Rocco, Aquarius Yacht Maintenance, San Diego, CA. Personal communications, December 2005.
201 Roberts, William, Shelter Island Boatyard, San Diego, CA and Bruce Miller, South Bay Boatyard, Chula Vista, CA. Personal communications, December 2005.
202 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.
203 Johnson, L., J. Gonzalez, C. Alvarez and M. Takada. 2006. *Stop Aquatic Invaders on Our Coast!/Detanga el Transporte de Especies Invasoras Aquáticas en Nuestras Costas!* Poster. California Sea Grant College Program Report.
204 Johnson, L., J. Gonzalez, C. Alvarez and M. Takada. 2006. *Stop Aquatic Invaders on Our Coast!/Detanga el Transporte de Especies Invasoras Aquáticas en Nuestras Costas!* UCSGEP-SD Fact Sheet 06-2.
205 Gunderson, J.L. and R.E. Kinnunen, eds. 2004. *AIS-HACCP: Aquatic Invasive Species – Hazard Analysis and Critical Control Point Training Curriculum, 2nd Edition*. Minnesota Sea Grant Publications Number: MN SG-F11.
206 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.
207 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.
208 Evans, E. A. 2003. "Economic Dimensions of Invasive Species." *Choices*. A publication of the American Agricultural Economics Association. http://www.choicesmagazine.org/2003-2/2003-2-02.pdf Accessed February 3, 2006.
209 Grosholz, E. and G. Ruiz (eds). 2002. Management Plan for the European Green Crab. Submitted to the Aquatic Nuisance Species Task Force.
210 Grosholz, E. and G. Ruiz (eds). 2002. Management Plan for the European Green Crab. Submitted to the Aquatic Nuisance Species Task Force.
211 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.

Sea Grant California

Sea Grant Law Center

ANR University of California

The Noblest Motive is the Public Good
County of San Diego
MDCCCLI

UCCE University of California Cooperative Extension

Cal Boating
California Department of Boating and Waterways
Established 1957