Elsevier Editorial System(tm) for Journal of Environmental Management
Manuscript Draft

Manuscript Number:

Title: A Binational, Supply-Side Evaluation for Managing Water Quality and Invasive Fouling Species on California's Coastal Boats

Article Type: Research Paper

Keywords: fouling control costs; antifouling paint pollution; aquatic invasive species; environmental policy; California and Baja California

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August 4, 2010

Journal of Environmental Management
c/o Elsevier Inc. (Branch Office)
525 B Street, Suite 1800
San Diego, CA 92101

Dear Editors:

After making the requested changes, I wish to resubmit the following manuscript to be considered for publication in the Journal of Environmental Management:

A Binational, Supply-Side Evaluation
for Managing Water Quality and Invasive Fouling Species
on California's Coastal Boats

The authors are myself, Leigh T. Johnson (first and corresponding) and Linda M. Fernandez.

I have added line numbers and will submit the numbered tables separately from the manuscript body.

Thank you for the opportunity to resubmit this work. I look forward to your reply.

Sincerely yours,

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A Binational, Supply-Side Evaluation for Managing Water Quality and Invasive Fouling Species on California's Coastal Boats

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Abstract

Recreational boats discharge copper from antifouling paints to marine harbors, in some cases exceeding government standards. Such boats are implicated in coastal transport of invasive species that occur among the fouling organisms attached to their hulls. Policy development must consider capacity, as well as economic and environmental sustainability, in managing these issues. This paper presents a supply-side evaluation useful in developing policies to manage water quality and invasive fouling species on recreational boats travelling along the coasts of California, Baja California and California's Sacramento-San Joaquin Delta. Analyses include evaluation of comprehensive costs to use antifouling and nontoxic hull coatings and the capacity of marine service businesses to apply them and control fouling on them. Supply-side perspectives on boat-owner behaviors, such as travel patterns, awareness of hull-coating choices and selection of hull coatings, are also examined. The issues raised will become broadly applicable as policy makers in coastal areas consider how to reduce pollution of harbor waters by copper discharged from antifouling paints, while preventing transport of aquatic invasive species on recreational boat hulls.

Keywords: fouling control costs; antifouling paint pollution; aquatic invasive species; environmental policy; California and Baja California

1. Introduction

1.1 Management Challenges

Organisms that attach to hulls of boats are called hull-fouling organisms and create friction or "drag" that slows sailboats and increases fuel consumption by powerboats (Townsin 2003). As a result, boat hulls have been identified as vectors for transporting aquatic invasive species along California's coast (Cohen *et al*. 2002, Wasson *et al*. 2001). California boats navigating along the Baja California peninsula of Mexico increase risks of transporting invasive species and may encounter differences in available supplies and services for fouling control. California water quality agencies are increasingly concerned about impacts of copper antifouling paint discharges on water quality in coastal marinas. Thus, a binational approach is needed for co-managing invasive species and water quality via control of fouling organisms that colonize hulls of California's coastal pleasure craft.

We conducted a supply-side, binational survey to provide necessary information for addressing this co-management challenge. Our study naturally follows from the demand-side study conducted earlier that focused strictly on water quality issues in San Diego Bay (Carson *et al*. 2009). First, we asked about the capacity of and costs charged by boat maintenance businesses to provide fouling control products and services that could reduce risks of invasive species transport on hulls of boats transiting the coasts and bays of California and Baja California and the Sacramento-San Joaquin Delta estuary of California. Second, we asked about the capacity of and costs charged by these businesses to provide alternative products and services that could reduce risks of pollution posed by copper-based paints that are typically applied to hulls for fouling control. Third, we asked managers of marinas a series of questions designed to capture information about boat owners as a group, for example, boat-slip rental costs, slip capacity and occupancy rate, boat activity patterns, types of alternative fouling control measures they allowed tenants to use, and so forth. Finally, we asked industry representatives for their perceptions of customers' awareness of alternatives to copper-based antifouling paints.

Note that in much of the study area, copper antifouling paints cannot entirely control hull fouling. Thus, "companion strategies" are also needed to control invasive and other fouling species. Periodic, hull cleaning removes early stages of fouling growth, preventing maturation and allowing gentler cleaning techniques that reduce abrasion of the hull's surface coating. Another approach is to isolate the boat from propagules of fouling organisms by surrounding it with a slip liner or elevating it on a boat lift. Such strategies are important when the hull is coated with copper antifouling paint and critical when it is coated with nontoxic or less-toxic material.

The paper is organized as follows. The Introduction offers the policy context of the study. The Methods section includes details of the survey and statistical analyses. The Results and Discussion section presents text and tables with results and interpretations of the analyses. The Conclusions section summarizes key findings and conclusions.

1.2 Policy Context

Our study is timely, as management agencies are interested in acting upon invasive species and water quality problems. California Department of Pesticide Regulation (CDPR), United States Environmental Protection Agency (US EPA) and the European Commission (EC) are re-evaluating pesticidal paints used to control hull fouling organisms (CDPR 2010, Singhasemanon 2007, US EPA 2010, EC 2007). Toxicants from these paints impair water quality and beneficial uses when they accumulate to levels that exceed 3.1 μg/l (US EPA 2000). A Total Maximum Daily Load program of the California State Water Resources Control Board (CSWRCB) requires a 76% reduction of copper discharges from antifouling paints in Shelter Island Yacht Basin of San Diego Bay by 2023 (CRWQCB-SDR 2004, CSWRCB 2005). State of Washington policies RCW 90.48.080 and WAC 173-201A prohibit in-water hull cleaning for vessels with soft (ablative and sloughing), toxic hull coatings (WDOE 2010).

Water quality assessments in Lower Newport Bay (Orange County Coastkeeper 2007, US EPA 2002) and a joint survey of 23 California marinas by CDPR and CSWRCB (CSWRCB 2008) found that toxicants discharged by antifouling paints affect coastal water quality in multiple regions of the state. The CSWRCB's proposed, regulatory permit for marinas would require reduction of copper discharges from antifouling paints (Munz 2009).

The situation is complicated by existing and proposed policies such as the "California Aquatic Invasive Species Management Plan" (CDFG 2008) and the bill, "Great Lakes Collaboration Implementation Act of 2009" (US Senate 2009) that recognize the role of recreational boats in spreading invasive, hull fouling species. The federal bill recommends cleaning recreational boats on land to prevent transportation of freshwater invasive species such as Eurasian mussels and water weeds. Such measures are economically feasible for smaller boats that are easily carried on trailers among lakes and rivers. In contrast, in-water hull cleaning, slip liners and boat lifts are used in conjunction with antifouling paints or nontoxic hull coatings to control fouling on larger, recreational boats that are kept in coastal harbors. Based on our analysis for California Policy Research Center, hauling boats for hull cleaning would cost nine times as much as in-water cleaning and would increase time demands on busy boat owners (Johnson and Gonzalez 2005). Further, nontoxic coatings require periodic hull cleaning twice as often as copper antifouling paints, so the situation would be exacerbated if boaters switched to nontoxic and less toxic coatings to comply with pending and anticipated water quality regulations (Johnson and Gonzalez 2006).

Scientists have found that some aquatic invasive species, which foul hulls in San Francisco Bay (Crooks *et al. in press*) and in Australia (Piola and Johnston 2005), have developed tolerance for copper. Thus, some boaters may seek cost effective alternatives to copper paints, whether or not restrictions on copper antifouling paints increase.

Boat owners and boating business operators face increased costs from new water quality programs addressing pesticidal, antifouling, boat-bottom paints and from potential, hull-borne invasive species regulations. California boat owners enjoy a moderate, household income level that is somewhat higher than that of the general population (CDBW 2002b). Both groups have expressed to us a strong need for detailed, cost-effectiveness information on alternative hull coatings and companion, fouling-control strategies at meetings, by telephone and e-mail. Agencies, policy makers, boat owners and boating businesses, coating companies, academics, and environmental organizations will need such research-based information in the next few years to make cost-effective decisions and create sustainable policies for protecting water quality while controlling native and invasive, hull-fouling species.

We provide the supply-side capacity and cost data and analysis that are needed to support co-management decisions on water quality protection and control of native and invasive hull-fouling species that are economically, technically and environmentally effective for California boats kept in saltwater. Cost ranges for various parameters are needed to reflect variations in boat sizes, types, usage and maintenance patterns. Data also need to be aggregated for analysis on a per unit basis to compare across alternative supplies and services. Supply-side data on boat owner behavior is provided as context for industry capacity and cost analyses and discussions.

2. Methods

A Project Advisory Committee was convened in June 2007 and members were also consulted individually throughout the project. They represented California Department of Boating and Waterways (CDBW), CDPR, marinas/harbors/yacht clubs; boat repair, hull cleaning, coating and slip liner companies; and boat-owner and environmental organizations from regions of California that were included in the survey, except Central Valley.

Survey pre-test instruments, survey instruments, investigators and project staff members were approved by the UC Davis Institutional Review Board under Protocol No. 200816030-1. Five boating industry groups were surveyed in 2008, following pre-testing and revision of survey instruments. Groups included in the survey were: marinas (marinas, harbors and yacht clubs), in-water hull cleaners, boat repair yards, slip liner and boat lift companies. Because they were few in number, slip liner companies were sampled from the US West Coast and boat lift companies were sampled nationally; neither group was sampled in Mexico. The target sample size was set at 30% of subject populations. Surveys were administered via mail, e-mail, telephone and in person.

Marinas, boatyards and hull cleaners were sampled proportionately from California and Baja California coasts and bays; marinas and boatyards were also sampled from the Sacramento-San Joaquin Delta. Marina, boatyard and hull cleaner sampling efforts were stratified by regions of the California coast, bays, and Delta *as per* CDBW's survey (CDBW 2002a) and by the Ensenada, Los Cabos and La Paz areas of Baja California and Baja California Sur *as per* Packard

Foundation's survey (Conlon 2002). The sample included 92 Californian and 8 Mexican marina, harbor and yacht club managers; 28 Californian and 5 Mexican boat repair yard operators; 23 Californian and 4 Mexican hull cleaners; 3 slip liner companies on the US West Coast (California, Oregon, Washington); and 17 boat lift companies in the US.

Survey regions in California included: North Coast (Del Norte, Humboldt, Mendocino, Sonoma Counties); San Francisco Bay area (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano Counties); Central Coast (Santa Cruz, Monterey, San Luis Obispo Counties); South Coast (Santa Barbara, Ventura, Los Angeles, Orange Counties, Santa Catalina Island); San Diego (County); Sacramento Basin (Butte, Colusa, El Dorado, Glenn, Lake, Nevada, Placer, Plumas, Sacramento, Shasta, Sierra, Sutter, Tehama, Trinity, Yolo, Yuba Counties); and Central Valley (Amador, Calaveras, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Benito, San Joaquin, Stanislaus, Tulare, Tuolumne).

Survey regions in Mexico included: Baja California Ensenada area (Ensenada, Puerto Salina); Baja California Sur Los Cabos area (Cabo San Lucas, San Jose del Cabo); and Baja California Sur southern Sea of Cortes area (La Paz).

We analyzed economic data for marinas, in-water hull cleaners and boat repair yards. The data were compiled from the survey in Stata™ and organized according to the various categories of the boating industry. Stata™ was then used to calculate summary statistics of the data by category such as mean, median, standard deviation, corresponding to all answers from survey questions that are reported in the results section.

We also analyzed economic data for slip liner and boat lift companies, visitor data for marinas, and selected, qualitative responses. Quantitative data were compiled from the survey in SPSS.™ They were organized for slip liners and boat lifts by ranges of cost and dimensions and for marina visitors by regions of origin and destination. Qualitative responses were evaluated by summarization and comparative analyses.

3. Results and Discussion

3.1 Marinas

A total of 98 Californian and 8 Mexican marina (and harbor and yacht club) managers completed a survey instrument. Regions by percentage of total sample included: San Francisco Bay area (34%), California South Coast (32%), San Diego (12%), Delta (7%), Mexico (7%), Central Coast (4%) and North Coast (3%).

Marinas reported a wide range of 20-3,675 slips with a mean of 369, a median of 259 and a large, standard deviation of 433.83. Ninety-seven marinas reported their percentage of filled slips with a mean of 86.8%, median of 95% and standard deviation of 19.24. This suggests that in 2008 it was very common for marinas to be full; those that were not full had a low vacancy rate.

Sixty-two marinas reported that tenure for regular tenants was 5-48 years with a mean of 9.4 years, a median of 5 years and standard deviation of 10.8. Thus, tenants typically rented from a marina for 5-9 years but some stayed much longer. Ninety-two marinas reported that 0%-95% of regular tenants rarely left the slip with a mean of 47.9%, a median of 51.5% and standard deviation of 25.94. This mirrors CDBW's 2002 finding that about half of boat owners rarely travelled more than 100 miles from home port. Because half of boats rarely leave the marina, they would be good candidates for nontoxic or less-toxic fouling control strategies in areas where copper pollution from antifouling paints is a concern.

Of 92 marinas reporting, the minimum monthly slip rate was $2.50-$27.60 per foot of boat length with a mean of $10.37, a median of $9.00 and standard deviation of 4.89. The maximum rate range was much greater: $6.55-$52.72 per foot with a mean of $18.88, median of $15.88 and standard deviation of 11.88.

Nearly all (84%) of 91 marinas overall and all 7 Baja Californian marinas reported that boat repair facilities were nearby; 21% in California and 25% in Baja California, respectively, reported they were onsite. Facilities to haul boats for fouling removal and hull refinishing are thus readily available to boaters traveling on California's coast and Delta and in Ensenada, Los Cabos and La Paz areas of Baja California.

Of 100 marinas reporting, 81% permitted in-water hull cleaning in their facilities; 88% of 8 Baja California marinas allowed it. Further, 35% of 99 marinas recommended hull-cleaning companies to customers and 63% of 8 Baja California marinas did so. Baja California hull cleaners were typically marina employees, thus hull cleaning was a marina revenue source. Of 89 marinas 51% allowed slip liners and 45% allowed boat lifts. None reported having in-water scrubbing stations. Thus, if restrictions on copper antifouling paints spread, boat owners with nontoxic or less-toxic hull coatings would have considerable access to hull-cleaning services and, to a lesser extent, slip liners or boat lifts to assist them in controlling fouling locally and while traveling.

Marinas were asked about their experience with various types of hull coatings. Of 73 marinas, 38% reported experience with nontoxic hull coatings. Their experience with specific types of nontoxic hull coatings included: 11% with ceramic-epoxy hull coatings; 5% with silicone hull coatings; and 4% with siliconized-epoxy hull coatings.

They were also asked about types of hull coatings on customers' boats. Of 55 marinas overall, the mean percentage of customers' boats with copper bottom paint was 70%; 8 Baja

California marinas reported that all of their customers' boats had copper bottom paint. 38 marinas reported a mean of 13% of customers' boats had zinc bottom paint; 1 Baja California marina reported 5% of customers had zinc paints and another reported 50% of customers had zinc paints. Given the dominance of copper bottom paints reported below by boat repair yards and hull cleaners, these figures suggest that customers do not consistently report their boat bottom paint types to marinas.

Of 37 marinas, the percentage of customers' boats with nontoxic hull coatings was 0%-100% with a mean of 10% and median of 0%. The mean is high, but the median estimate for marinas is in line with hull cleaners' and boat repair yards' reports of the share of their businesses represented by nontoxic epoxy and slick coatings.

Fifty-four marinas (51 Californian, 3 Mexican) reported on average that 41% of customers were aware of nontoxic hull coatings versus only 20% awareness one-two years ago (50 marinas, including 48 Californian, 2 Mexican). Of 78 marinas (74 Californian, 4 Mexican) 82% said they would recommend nontoxic hull coatings to their customers; of 66 marinas (63 Californian, 3 Mexican) 64% would recommend other alternatives to copper-based paints.

These findings suggest that, although they may not know details of customers' hull coatings, a substantial proportion of marinas had discussed hull coatings with their customers. Further, their belief that customers' awareness of alternatives to copper-based paints had doubled in the past 1-2 years suggests that educational programs have been effective.

Most marina managers would be willing to recommend alternatives to copper antifoulants, yet they would need more information on such products. The exception was at Shelter Island Yacht Basin of San Diego Bay, where a regulatory program to reduce copper emissions from boat bottom paints had begun and marinas' familiarity with such alternatives to copper boat bottom paints was high.

Overnight visitors are an indicator of risks for invasive species transport by recreational boats. Marinas were asked the percentages of slips rented by overnight visitors from Northern (San Francisco Bay area to Oregon border), Central (Santa Cruz, Monterey, San Luis Obispo Counties) and Southern (Santa Barbara County to Mexican border) California coastal areas, Sacramento-San Joaquin Delta area, Baja California, Baja California Sur, Mainland Mexico and other states or countries. Responses indicated considerable traffic of boats occurs along the California and Baja California coasts and between the coast and the Sacramento-San Joaquin Delta.

Northern California boats traveled widely, suggesting that the most active vessels represent a significant, potential vector for long-distance coastal transport of invasive species. One Central California marina reported that 60% of its slips were rented to overnight visitors from Northern California; in Southern California four marinas reported 5%- 25% of slips were rented to Northern California overnight visitors; one marina in Los Cabos and one marina in La Paz each reported 10% of slips were rented to Northern California visitors.

Delta boats traveled most commonly to San Francisco Bay, where 11 marinas reported that 5%-88% of slips were rented to overnight visitors from the Delta. One Central Coast marina reported 5% of slips and one North Coast marina reported 20% of slips were rented to Delta visitors. This suggests that Delta boats represent a smaller proportion of the risk for transporting invasive species along the coast. Further, as Delta waters range from brackish to fresh, invasive species are likely to be killed as boats move in either direction between the Delta and San Francisco Bay.

The heaviest traffic by Central California boats was to San Francisco Bay, where 10 marinas reported that 1%-100% of slips were rented to overnight visitors from Central California. One North Coast marina reported 10% of slips, five Southern California (South Coast and San Diego) marinas reported 0.25%-10% of slips, and one marina in La Paz reported 10% of slips were rented to Central California visitors. Reports of heavy traffic by Central California boats to San Francisco Bay are in line with studies of Elkhorn Slough (which drains to Monterey Bay) that found large numbers of invasive species common to San Francisco Bay, likely brought by local boats returning from that destination (Cohen *et al*. 2002).

The heaviest traffic by Southern California boats was to Mexico, where four Ensenada marinas reported that 80%-100% of slips and where one Los Cabos marina and one La Paz marina each reported that 50% of slips were rented to overnight visitors from Southern California. However, one North Coast marina reported that 30% of slips were rented to Southern California visitors. In contrast six San Francisco Bay marinas reported that 0.3%-15% of slips, one Delta marina reported 1% of slips, and one Central Coast marina reported that 8% of slips were rented to Southern California visitors.

Events, such as races, celebrations, holidays and fishing seasons may attract boats from many areas. The 4th of July was the single, most important event as it was cited by 29%-33% of marinas in the San Francisco Bay, South Coast and San Diego areas and by 20%-25% of marinas in the North and Central Coast areas. Most marinas reported that boaters stayed 2-3 nights for this event; two marinas reported 4-night stays. Other events that drew boats included Fleet Week, boat shows and parades, local festivals, Labor Day and Kaboom (San Francisco Bay). Races generally drew boaters from other areas for 2-5 nights, including numerous local sailboat, powerboat, Jet Ski™, hydroplane and yacht club races. Named races were Spinnaker Cup, ATT

Pro Am, PHRF Championships, Marina Del Rey, King Harbor, Oceanside to Southwestern Yacht Club, and Cabrillo Series.

Bi-national races were particularly popular. The annual Baja Haha race proceeds by stages from San Diego to the southern Baja California peninsula. It was cited as a source of overnight visitors by 39% of San Diego marina managers, 50% of Los Cabos area marina managers and 100% of La Paz area marina managers who responded to the survey. Fleet Underway to Baja Rally (FUBAR) race begins in San Diego and ends in La Paz, where one marina reported that boaters might stay for 30 nights after this event. Mexican marina managers reported that Baja Haha race visitors stayed for 5-6 nights. The Newport to Ensenada race was cited by 75% of Ensenada marina managers who reported that visitors stayed 2-4 nights. One South Coast and one San Diego marina each reported that visitors stayed 3 nights for this race. Thus, boaters gathered before the races and some lingered at waypoints and/or destinations for a few days.

Two seasons were cited as drawing boats from other areas. Fishing season was reported by 67% of North Coast marinas, 15% of San Francisco Bay marinas and 25% of Central Coast marinas. This is likely the commercial fishing season, as one San Francisco Bay marina reported that boats stayed 90 nights for crab season and 30 nights for salmon season. Summer season was reported by 10% of South Coast marinas.

These findings suggest that actively traveling, Northern, Central and Southern California boats represent a significant, potential vector for long-distance transport of invasive species along California's coast and between California and Baja California. Active Central California vessels also represent a significant, potential vector for invasive species from and to San Francisco Bay. Delta boats represent a much smaller share of coastwise traffic and invasive species are likely to be killed by changes in salinity as boats move from and to the Delta. Anecdotal comments suggest that some vessel owners use these salinity variations to enhance control of hull fouling.

Findings also suggest that events may increase risks for long-distance, invasive species transport by encouraging trips beyond the home area to locations where boats from multiple areas may mingle, increasing exposure to various species that may not be present in the home port. Longer stays further heighten risks that invasive species will become established on hulls of visiting boats and be transported to the next waypoint or to the boat's home port. Yet, events also provide points of contact for targeted education programs that explain invasive species risks and encourage participants to be especially diligent about fouling control and seawater system flushing in association with the event.

3.2 Hull-Cleaning Companies

A total of 23 Californian and 4 Mexican hull cleaners responded, including 37% from the South Coast, 30% from the San Francisco Bay area, 15% from Mexico, 11% from San Diego County and 7% from the Central Coast. Thus, nearly half of the hull cleaners responding to the survey were located in Southern California and nearly a third were in the San Francisco Bay area. They were sampled proportionately among California regions, except for the North Coast and Delta, for which no surveys could be completed. California hull cleaners were typically independent businesses; Mexican hull cleaners were typically marina employees. Hull cleaner's customers were primarily from Southern California; a mean of 54% of Californian hull cleaners' customers and a mean of 69% of Mexican hull cleaners' customers were from this area.

The median number of boats serviced was 260 in California and 100 in Mexico. Copper hulls on average represented 83% of hull cleaners' business and the median was 100%. Mexican data was only available for copper hull coatings; all non-copper data was Californian and came from only 10 respondents. Clearly, copper hulls dominated the market. Only 10 hull cleaners provided data on most variables for non-copper hull coatings. Zinc hulls on average represented 9% of business, but the median was 0%. Overall, the percentage of boats with nontoxic coatings represented a very small part of the hull cleaning business with a mean value of 4.35%. Almost all respondents claimed to have experience with epoxy (nontoxic) coatings and a little more than half specified ceramic-epoxy. Less than 40% reported experience with slick (nontoxic) hull coatings, specifically silicone, siliconized epoxy or siloxane. Mexican hull cleaners reported no experience with zinc and nontoxic slick coatings; only one reported any experience with nontoxic, ceramic-epoxy coatings.

Generally, cleaning times and costs were influenced by length and type of boat, type of hull coating and season of the year. Hull cleaning charges were quoted per foot of boat length for 25-foot to 60-foot boats. Hull cleaning in California required on average 1 person and 28-78 minutes and in Mexico required on average 1.5 persons and 50-150 minutes. These binational differences likely reflect the fact that powered cleaning tools were more common among California hull cleaners. They may also reflect differences in labor costs.

Hull-cleaning times varied considerably (Table 1), although on average sailboats cost less and took less time to clean than powerboats. Overall, copper hulls cost less and were cleaned faster than other coatings. Although it is not apparent in the ranges shown in the table, data analysis found that on average Mexican hull cleaners charged less than their California counterparts to clean copper hull coatings. Zinc coatings were second cheapest to clean. Prices ranged from $1.65 per foot for copper coatings on smaller sailboats to $2.55 per foot for epoxy (nontoxic) coatings on powerboats.

If cleaning time exceeded the average by 25-30 minutes or more, additional charges ranged from $2.68 per foot for copper to $4.74 per foot for epoxy (nontoxic). Roughly 80% of hull cleaners would recommend that the boat have its hull coating replaced, if the average cleaning time was exceeded by at least 25-30 minutes. Similar responses were received from Mexican and Californian hull cleaners.

On average metal-based coatings were cleaned less often than nontoxic coatings (Table 2). Each coating type was cleaned most often in summer, except that nontoxic slick coatings were cleaned with the same frequency year-round, possibly reflecting their popularity for year-round, racing boats. Epoxy coatings were cleaned more often than all other coatings in California. Higher cleaning frequencies for copper coatings in Mexico may be influenced by the overall higher water temperatures in Mexico; we found in 2002-2003 that water temperature was the most important factor in growth rates of hull fouling. (Johnson and Gonzalez 2004) It may also reflect our current finding that Mexican hull cleaners were often marina employees, creating an incentive for marinas to remind customers about hull cleaning services.

Hull cleaners reported that on average approximately 34% of their customers were aware of nontoxic hull coatings versus 26% one year ago. Mexican hull cleaner responses were similar with respective means of 30% and 27.5%. 77% of respondents said they would recommend nontoxic hull coatings and 73% said they would recommend other alternatives to copper. Mexican hull cleaners were less inclined than the total population to recommend non-toxic or alternative coatings with respective means of 67% and 33%.

In summary, copper hull coatings dominated the market for hull cleaning services. Copper coatings were cheapest to clean among all coatings in California and Mexico on sailboats, powerboats and for additional cleaning charges when time exceeded the average by at least 25-30 minutes. Mexican hull cleaners charged less on average and took longer to clean copper hull coatings than did California hull cleaners. Shorter, average cleaning times in California may reflect greater use of powered, hull-cleaning tools than in Mexico.

Results indicate that hull-cleaning services are readily available for recreational boats in the areas of San Francisco Bay, California South Coast, San Diego, Ensenada, Los Cabos and La Paz. Thus, a base, hull-cleaning capacity exists in the major Californian and Baja Californian saltwater, recreational boating harbors for preventing transport of invasive species on recreational boats. However, since few hull cleaners reported having experience with nontoxic hull coatings, especially in Mexico, the industry would need to increase capacity to control fouling on such coatings if restrictions on using copper-based, antifouling paints spread beyond Shelter Island Yacht Basin of San Diego Bay.

3.3 Boat Repair Yards

A total of 33 boat repair yards (28 Californian and 5 Mexican) responded to the survey. The South Coast region represented approximately 42% of the total with the rest distributed as 15% San Francisco Bay area, 15% Mexico, 10% San Diego, 10% Central Coast and 6% Sacramento-San Joaquin Delta. The South Coast was somewhat over-represented in the sample; other regions were at or near the 30% sampling target. Boatyards reported that locations from which their customers originated were similar to the locations of the yards. However, customers from Southern California (South Coast, San Diego) and Northern California (North Coast, San

Francisco Bay) were over-represented relative to the actual number of boatyards in those areas (50% and 23% of customers respectively). Mexican boat owners comprised 11% of customers reported in the survey. No boat repair yards were located in Humboldt Bay in Northern California; the Harbor District will haul boats from the water and place them on blocks where owners can conduct maintenance, repairs and hull refinishing.

Copper coatings dominated the market for coating applications, representing a mean of 78% and a median of 90% of business among all boat repair yards (Table 3). Among California boatyards, nontoxic epoxy coatings represented only 3% of mean business, zinc coatings represented only 1% of mean business and nontoxic slick coatings were rare at 0.04% of mean business. The scarcity of alternative coating applications in California was underscored by median values of 0% of business. Alternative coatings were even rarer in Mexican boat repair yards; none reported applying nontoxic epoxy or slick coatings and only one reported applying zinc coatings to just 10 boats per year, representing 10% of that yard's business.

Questions on the amount of business represented by alternative coatings received 28 responses for zinc coatings, 27 responses for nontoxic epoxy coatings and 27 responses for nontoxic slick coatings. All other questions received 10 or fewer responses for each of these alternative hull coatings.

Table 4 presents mean costs per foot of boat length versus categories of boat lengths. The mean total cost to prepare for and apply copper paints to sailboats increased with boat length, ranging from approximately $33/ft for a 15-20 foot boat to $52/ft for a 91-100 foot boat. Mexican boatyards gave a range of $16.71/ft for 31-35 foot sailboats to $65/ft for 91-100 foot sailboats. Powerboat costs were similar, increasing with length from $34/ft for the shortest boat to $52/ft for the longest. There were many responses for boats up to 60 feet in length and few responses for boats over 60 feet, which suggests that few boaters have such large boats. Mexican boatyards gave a range from $17.21/ft for 31-35 foot sailboats to $65/ft for 91-100 foot sailboats. Data were rare for slick coatings, including one report of $150/ft for 15-20 foot long boats and one report of $101/ft for 61-70 foot long boats.

Although approximately half of respondents said they would recommend nontoxic hull coatings and other alternatives to copper, very few reported applying non-copper coatings. Data must be considered in that light. However, boatyards that worked with nontoxic epoxy or slick hull coatings reported that copper represented only 70% of business versus 95% of business for other yards. They were also significantly larger than average, coating a median of 700 boat bottoms per year compared to 200 copper boat bottoms for a typical boatyard. None were in Mexico.

The mean total cost to prepare for and apply zinc paints increased with boat length, ranging from approximately $34 per foot for a 15-20 foot boat to $66 per foot for a 91-100 foot boat. Mean total cost per foot to prepare for and apply epoxy (nontoxic) coatings increased as boat length increased, except that it was much lower for the largest boats. Mean cost per foot was $112.33 for 15-20 foot boats, $114.50 for 21-25 foot boats, and $115.50 for 26-35 foot boats. However, it was $82.50 per foot for 91-100 foot boats. The minimum cost for all boat lengths was $50 per foot. The mean total cost to prepare for apply slick (nontoxic) $150 per foot for 15-20 foot boats and $101 per foot for 61-70 foot boats.

Preparation costs for nontoxic coatings likely reflect the fact that old, metallic coatings typically must be stripped at a mean cost of $89/ft before nontoxic epoxy or slick coatings can be applied. The median number of boats whose hulls were stripped was 17.5 per year; the mean was 32 boats, reflecting a few, high-capacity boatyards.

Table 5 shows detailed cost breakdowns for boat repair yards to apply hull coatings. Overall, labor comprised the largest share of costs to prepare for and apply hull coatings with means of 55%-57% for metallic coatings and 63% for nontoxic coatings. Mean materials costs as a percentage of total costs ranged from 30% for nontoxic slick to 41% for zinc coatings. Environmental fees as a percentage of total costs ranged from 2% for nontoxic epoxy to 5% for copper coatings. Other costs as a percentage of total costs ranged from 0% for nontoxic epoxy to 3% for nontoxic slick coatings. Higher labor costs for nontoxic coatings may reflect that many must be applied after metallic coatings have been stripped off the hull and that special application techniques are needed for some products. Improvements in products and stripping techniques may reduce these cost factors for nontoxic coatings.

The mean frequency of new copper coating applications was once every 2.5 years for the whole population and once every 3.5 years for Mexican boatyards. Very few boatyards provided replacement frequency for non-copper coatings, so data must be considered in that light. The mean frequency of new zinc coating applications was once every 1.8 years. The mean frequency of new nontoxic epoxy coatings was once every 3 years. The mean frequency of new, nontoxic slick coating applications was 5 years. Note that our research in San Diego found that a nontoxic epoxy coating lasted eight years on one boat. (Gonzalez and Johnson 2007)

Boat bottoms must be stripped of old paint, if water has penetrated the coating, creating blisters, if paint is chipping, and often before applying nontoxic coatings. The mean charge to strip a boat bottom was $89/ft. The median number of boats stripped per year was 17.5 with the mean being 32 boats due to a few, high-capacity boatyards. The mean number of boats stripped by Mexican boatyards was 22, roughly in line with the numbers handled by California boatyards. Thus, capacity to prepare hulls for nontoxic coatings exists in California and Mexico.

Results point to a low, boatyard capacity for applying alternatives to copper antifouling paints. Some alternatives require processes and/or equipment that differ from those used for copper paints. Should local, regional or state restrictions be instituted for copper antifoulants in response to water quality concerns, more boatyards would need to develop this capacity in order to meet demand. At least some of the boatyards in the San Diego region have developed this capacity. One boatyard in the San Francisco Bay has contacted the authors regarding their intent to shift much or all of their coating application business to nontoxic coatings. Such “early adopters” may serve as models should demand increase for alternatives to copper antifouling paints.

Sixty-three percent of respondents offered haul-out and cleaning packages with no noticeable difference in frequency between California and Mexico. The cost per foot ranged from approximately $11/ft for the shortest boat to $12.94/ft for the longest boat. By comparison, hull cleaning companies (see above) charged from $1.65/ft for the smallest sailboats to $2.52/ft for the largest powerboats. Thus, substantial savings could be achieved by using hull cleaning services, instead of hauling boats out of the water, for routine fouling control on boats that are already in the local area. Only 10% of respondents, all of which were in Mexico, offered underwater hull cleaning services. No boatyards reported offering in-water scrubbing stations for boat hulls.

All except one boatyard claimed to use pressure hoses to remove biofouling. Fourteen percent of all and 25% of Mexican respondents claimed to leave boats out of water to remove biofouling. Just over half of boatyards disposed of biofouling by filtering it and throwing it into the trash; some disposed it as hazardous waste (28%). No Mexican boatyards reported on biofouling disposal. Thus, some capacity already exists among boatyards for proper disposal of invasive species removed from hulls. Education of the remaining boatyards will be needed to further reduce risks from disposal of biofouling.

3.4 Industry Perceptions: Customers' Awareness of Nontoxic Hull Coatings

Marina, hull cleaning and boat repair industry representatives believed that customers' awareness of nontoxic hull coatings had increased in the past one to two years (Table 6). Boatyard figures were probably most reliable, as they discuss with customers which coatings will be applied during hull refinishing. However, marinas in Shelter Island Yacht Basin of San Diego Bay were also having specific discussions with their tenants about bottom paints because they were required to reduce copper emissions in their facilities. The three Mexican boatyards that responded to this question reported mean customer awareness of 50% now and 42% one to two years ago, possibly indicating a preponderance of customers from Southern California who face restrictions on copper paints. Results suggest that educational programs have been effective. Data on current awareness levels were included in the analysis of influences on coating choice discussed in section 3.4 below.

3.5 Comprehensive, Average Cost To Use Each Paint Type

The average cost to use each type of paint was calculated to provide a single, comprehensive unit of comparison among the paint types. The analysis included costs provided by marinas, hull cleaners and boat repair yards. Average costs were calculated in dollars per foot of boat length across both sailboats and powerboats and for all length categories. Time units varied among cost types.

Calculations were based on 51 observations for boats with copper antifouling paint, 12 for boats with zinc antifouling paint and 12 for boats with nontoxic epoxy paint. Costs for boats with nontoxic slick paint were not calculated, because there were so few observations for this coating type.

Relative, comprehensive, average costs were found to be $20.49/foot for copper antifouling paints, $24.99/foot for zinc antifouling paints and $36.33/foot for nontoxic epoxy paints. In other words, using a zinc antifouling paint would cost $4.50/foot more on average than using a copper antifouling paint. Using a nontoxic antifouling paint would cost $15.84/foot more on average than using a copper antifouling paint.

When choosing among paint types, based on cost of use, boat owners should also consider the expected service life. Economic research on phasing out metal-based antifouling paints on recreational boats in San Diego Bay also found copper-based antifouling paints are initially less expensive. However, nontoxic epoxy coatings tend to last much longer and thus may become more cost effective in the long run. (Carson *et al*. 2009) Boatyards reported mean service life of 2.5 years for copper paints, 1.8 years for zinc paints, 3.0 years for nontoxic epoxy paints and 5.0 years for nontoxic slick paints. This finding is also supported by our field research that found three nontoxic epoxy coatings had lasted from 5 to 5.5 years and a fourth lasted 8 years on boats in San Diego Bay by October 2007. (Gonzalez and Johnson 2007) In contrast we identified a mean service life of 2.5 years for copper antifouling paints in our 2002 survey of 200 boat owners. (Carson *et al*. 2009) The longer service life of nontoxic epoxy paints may balance the higher, average costs calculated in this analysis. In the current study, 48% of boat repair yards were uncertain whether boat owners could achieve cost savings by using nontoxic coatings; 26% expected savings and 26% did not. This suggests a need for educating boat repair yards on this topic.

3.6 Analysis of Influences on Coating Choice

Statistical analyses (regressions) were conducted to test the influences of average coating cost, awareness of nontoxic coatings and location of the marina, hull cleaning or boat repair industry respondent in California or Mexico on choice of coating. Note that coating choice reflected the share of each respondent's business represented by the particular type of coating. With coating choice as the dependent variable, regressions were conducted using observations from both countries that were grouped by coating type (copper, zinc, nontoxic). The independent variables, average cost of the coating and awareness of nontoxic coatings, were measured in different units. The independent variable, binationalness, indicated whether the respondent was located in California or Mexico.

First, the average costs for copper, zinc and nontoxic coatings were calculated as the overall, mean charge for all boat sizes, for both sail and powerboats, and for marinas, boatyards and hull cleaners. Note that the average cost for nontoxic coating was calculated only for the epoxy coatings because very few surveys reported prices for slick coatings. Awareness of nontoxic coatings was measured in terms of the percentage of customers who knew about nontoxic coatings, according to each industry respondent's perception. The statistical analyses were conducted using a log-log form of the data, in order to deal with the different units of measure for the variables and still be able to compare the relative sizes of the estimated statistical coefficients of influence. (In other words, before the regressions were conducted, data were transformed to logarithmic values that have no units. Note, however, that average costs discussed above for each coating type are based on actual figures, not their log transformations.)

Cost of the coating type and binationalness were not significant influences in any of the regressions. (Note that the regression for each coating type was run twice, once with and once without binationalness.) Awareness of nontoxic coatings was not a significant influence in the regressions for choice of copper or zinc coatings.

However, the regression for nontoxic coatings did yield a statistically significant result. In this analysis only the nontoxic epoxy coating observations were used, as there were so few observations for nontoxic slick coatings. With 29 observations in this case, at the 10% confidence interval level of statistical significance, an increased awareness of nontoxic coatings influenced the choice of nontoxic coating positively. This suggests that educational programs may be effective in influencing boat owners' decisions of coating choice. Further, boating industries may be effective in assisting customers to learn about and choose nontoxic coatings, should restrictions on copper-based bottom paints become more widely spread.

3.7 Slip Liner and Boat Lift Companies

Slip liners and boat lifts provide alternatives to periodic, in-water or haul-out hull cleaning for boats in saltwater. In California slip liner business appears to be concentrated in Southern California (South Coast and San Diego regions), whereas boat lift business appears to be concentrated in Northern California (North Coast and San Francisco Bay regions) and the Delta. Both products are available in a wide range of prices, sizes and shapes, customizable to individual boats. Slip liners (3 respondents) were on average less expensive with mean minimum cost $1,046, standard deviation 372.26 and mean maximum cost $6,800, standard deviation

1,311.41 than were boat lifts (17 respondents) with mean minimum cost $3,319, standard deviation 4,642.23 and mean maximum cost $27,150, standard deviation 26,797.9. Slip liner companies responding to the survey were far more likely (100%) to remove equipment abandoned at a marina than responding boat lift companies (12%). Slip liner removal would cost $0-$250.

Only one of the three, responding slip liner companies and none of the seventeen boat lift companies had experience with boats having nontoxic hull coatings. Yet, all three slip liner companies and 29% of boat lift companies would recommend nontoxic hull coatings and other alternatives to copper-based bottom paints to their customers. Both types of companies reported increased, customer awareness of nontoxic coatings now versus one or two years ago. (Note that their responses were not included in the statistical regression discussed in section 3.6.) Concentration of slip liner companies in Southern California, where regulatory scrutiny of copper-based, antifouling paints is increasing, may have influenced their comments on nontoxic and other alternatives to copper paints.

Thus, capacity existed in some regions to provide slip liner and boat lift equipment for boat owners needing alternatives to copper bottom paints and to assist in preventing transport of aquatic invasive species. Such types of equipment may be cost effective, especially for smaller boats in areas where copper bottom paints may be restricted and if the marina permits them.

4. Conclusions

Options for fouling control on recreational boat hulls were explored in California and Baja California through a supply-side analysis of private and public sector marina (and harbor and yacht club), hull cleaning, boatyard, slip liner and boat lift supply and service providers. The survey and subsequent summary statistics offer a perspective of current and potential use of antifouling options with some characteristics of the binational boating traffic relevant for addressing two different realms of environmental policy: invasive species and copper accumulation in coastal marinas.

Approximately half of boats rarely leave the typical California coastal marina. Among those that do leave the marina, approximately half rarely travel more than 100 miles from home port. Such boats would be good candidates for nontoxic or less-toxic fouling control strategies in areas where copper pollution from antifouling paints is a concern. In contrast active, long-distance racing, cruising and fishing boats discharge relatively less copper pollution to a marina and pose greater risks for transporting invasive species. They may be better candidates for copper-based and other, pesticidal hull coatings.

Overnight visitors from other regions, states and nations were attracted by events such as holidays, celebrations, races and commercial fishing seasons. Events both increase risks of and provide an opportunity to educate participants on best practices to prevent introductions and transportation of invasive species along the coast.

A base, hull-cleaning capacity exists in the major Californian and Baja Californian saltwater, recreational boating harbors for preventing transport of invasive species on recreational boats. However, few hull cleaners have experience with nontoxic hull coatings, especially in Mexico. If restrictions on copper antifouling paints spread, the industry would need to increase its capacity to serve boat owners who had selected nontoxic or less-toxic hull coatings. To a lesser extent, slip liners or boat lifts are available to assist boat owners in controlling fouling in the home marina.

Hauling boats to remove fouling is substantially more costly than in-water hull cleaning. Thus, in-water cleaning services may be most appropriate for periodic fouling control on boats that remain in the home marina, harbor or port and thus do not pose a risk for transporting invasive, fouling species.

Boat repair facilities to haul boats and to provide fouling removal and hull refinishing are readily available to boaters traveling California's coast, Delta and the Ensenada, Los Cabos and La Paz areas of Baja California. The exception is Humboldt Bay, where the Harbor District will only haul boats from the water and place them on stands; boat owners must perform or hire contractors for fouling removal and hull refinishing services.

Boat hulls must often be stripped of old paint before nontoxic coatings are applied. Hull stripping capacity exists in California and Baja California but such services are costly. More cost-effective techniques or subsidies for hull stripping may be needed to foster conversions to nontoxic hull coatings by California's typically middle-income, recreational boat owners.

Relative, comprehensive, average costs to use hull coatings were found to be $20.49/foot for copper, $24.99/foot for zinc and $36.33/foot for epoxy (nontoxic). However, the longer, service life of epoxy (nontoxic) hull coatings may balance the higher, average cost to apply and maintain them that was calculated in this analysis.

Results point to a low, boatyard capacity for applying alternatives to copper antifouling paints. Some alternatives require processes and/or equipment that differ from those used for copper paints. Should local, regional or state restrictions be instituted for copper antifoulants in response to water quality concerns, more boatyards would need to develop this capacity in order to meet demand. At least some of the boatyards in the San Diego region and one in the San

Francisco Bay area have developed this capacity. Such “early adopters” may serve as models should demand increase for alternatives to copper antifouling paints.

Some capacity exists among boatyards for proper disposal of aquatic invasive species removed from hulls. Over one-fourth dispose biofouling as hazardous waste and over half dispose it in the trash.

All five boating industry groups believed that boat owners’ awareness of nontoxic hull coatings had increased compared to one or two years ago, although the level of change varied among the groups. This suggests that they are talking with customers about alternatives to copper bottom paints.

A statistical regression found that increased, customer awareness of nontoxic coatings influenced the choice of nontoxic coating positively. This suggests that education programs have been effective and that boating industries may play a role in assisting customers to learn about and choose nontoxic coatings, should restrictions on copper-based bottom paints become more widely spread.

Capacity to provide slip liners is best developed in Southern California and capacity to provide boat lifts is best developed in Northern California and the Sacramento-San Joaquin Delta for boat owners needing alternatives to copper bottom paints and to assist in preventing transport of aquatic invasive species. Such types of equipment may be cost effective, especially for smaller boats in areas where copper bottom paints may be restricted and if the marina permits them.

In conclusion a base capacity to control invasive and other, fouling species exists among boating industries located in major, Californian and Baja Californian, coastal recreational boating harbors and in the Sacramento-San Joaquin Delta of California. However, capacity needs to be expanded to assist boat owners with control of fouling on nontoxic and less toxic hull coatings. Further, cost-effectiveness will be critical in developing policies to co-manage invasive species and water quality via fouling control for boats owned by California's typically middle-income, recreational boaters. Education has proven effective in influencing coating choices and may thus be expected to be effective in influencing best practices for controlling invasive, hull-fouling species while protecting water quality.

Acknowledgments

We wish to acknowledge the following people who also contributed to the research reported in this paper: Cesar Alvarez, Kevin Campbell, Jennie Daniels, Brad Franklin, Jamie Gonzalez and Monobina Mukherjee. We gratefully acknowledge the members of the Project Advisory Committee and the many boating industry members who provided data. The research was supported in part by: California Department of Boating and Waterways under Agreement No. 06-106-109; California Department of Pesticide Regulation under Agreement No. 06-0069C; NOAA Grants No. NA08OAR4170669 and NA04OAR4170038, California Sea Grant Project No. A/EA-1 through NOAA's National Sea Grant College Program, U.S. Dept. of Commerce; University of California Agriculture and Natural Resources; California Resources Agency; and County of San Diego. The statements, findings, conclusions and recommendations are those of the authors and do not necessarily reflect the views of the aforementioned organizations and individuals.

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Table 1

Table 1. Hull Cleaning Mean Costs and Times for Various Coatings on Sail and Power Boats[c]

Coating Type and Location	Sail Boat Cost/Foot Mean std. dev.	Sail Boat Minutes Mean std. dev.	Power Boat Cost/Foot Mean std. dev.	Power Boat Minutes Mean std. dev.
Copper – ALL	\$1.65 0.66	31-89 18.42-37.82	\$1.83-\$2.03 0.71-0.63	37-103 16.55-37.30
Copper – MX	\$1.03-\$2.00 0.24-0.49	50-150 1.04-26.34	\$1.03-\$2.17 0.12-0.33	60-150 13.59-25.63
Zinc – CA	\$2.06 0.54	25-67 11.26-35.19	\$2.26-\$2.31 0.43-0.22	33-76 16.23-40.88
Epoxy – CA	\$2.04-\$2.15 0.53-0.66	34-94 13.33-25.57	\$2.52-\$2.55 0.56-0.31	45-108 3.78-40.71
Slick – CA	\$2.14-\$2.20 0.28-0.31	29-84 9.70-22.75	\$2.38-\$2.52 0.50-0.35	42-93 13.04-22.25

[c] Boat length range was 25-60 ft for estimates and std. dev.

Table 2

Table 2. Hull Cleaning Mean Frequencies for Each 3-Month Season

Coating Type and Location	Spring Mean	std. dev.	Summer Mean	std. dev.	Fall Mean	std. dev.	Winter Mean	std. dev.
Copper – ALL	2.48	1.34	3.04	1.92	2.30	1.36	2.21	1.10
Copper – MX	4.00	0.86	5.33	0.79	3.33	0.51	3.33	0.47
Zinc – CA	2.50	2.12	3.00	1.73	2.50	2.12	2.67	1.53
Epoxy – CA	5.33	3.78	5.43	3.46	5.33	3.78	4.57	1.99
Slick – CA	3.50	2.08	3.50	2.08	3.50	2.08	3.50	2.08

Table 3

Table 3. Boat Repair Yard Coating Applications

Coating Type and Location	Boats/Yr Mean	Boats/Yr std dev.	Boats/Yr Median	% of Business Mean	% of Business std. dev.	% of Business Median
Copper – ALL	470	511.09	270	78%	28.07	90%
Zinc – CA	13	31.15	0	1%	2.71	0%
Epoxy – CA	23	79.87	0	3%	11.01	0%
Slick – CA	0.54	1.76	0	0.04%	0.19	0%

Table 4

Table 4. Boat Repair Yard Costs to Apply Coatings: Mean Cost/Foot Versus Boat Length[d]

Coating Type	Boat Type and Location	15-20 Ft Boats Mean	15-20 Ft Boats std. dev.	31-35 Ft Boats Mean	31-35 Ft Boats std. dev.	91-100 Ft Boats Mean	91-100 Ft Boats std. dev.
Copper	Sail – All	$33	12.22			$52	28.53
Copper	Power – All	$34	11.90			$52	28.53
Copper	Sail – MX			$16.71	7.10	$65	16.20
Copper	Power – MX			$17.21	8.04	$65	16.20
Zinc	Any – CA	$34	13.50			$66	39.32
Epoxy[e]	Any – CA	$112.33	54.37	$115.50	39.05	$82.50	49.96

[d] Data not available for all cells.

[e] Preparation costs for nontoxic coatings may include stripping old, metallic paint.

Table 5

Table 5. Boat Repair Yard Cost Categories for Applying Different Hull Coatings

Cost Category as % of Total Cost	Copper N = 23		Zinc N = 5		Epoxy N = 3		Slick N = 3	
	Mean	std. dev.	Mean	std. dev.	Mean	std. dev.	Mean	std. dev.
Labor	55.46%	16.14	57.00%	16.43	63.00%	20.42	62.67%	11.02
Materials	36.42%	14.23	40.60%	15.27	34.67%	18.45	30.00%	0.00
Environmental Fees	5.00%	4.90	3.20%	2.86	2.33%	2.52	4.00%	5.29
“Other”	2.35%	6.75	0.60%	1.34	0.00%	0.00	3.33%	5.77

Table 6

Table 6. Mean Percentages: Boating Industry Customers' Awareness of Nontoxic Hull Coatings

Industry Group	Perceived Awareness by Customers Now	Perceived Awareness by Customers 1-2 Years Ago	Perceived Increases in Customer's Awareness
Marina, Harbor, Yacht Club	41%	20%	21%
Hull Cleaning Company	34%	26%	18%
Boat Repair Yard	23%	14%	9%