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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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A B S T R A C T

Integrated solutions are needed for sustainable management of risks posed by recreational boats to coastal water quality and ecosystems. Fouling organisms roughen vessel hull surfaces, creating friction that slows sailboats and increases fuel consumption by powerboats. Hull fouling control strategies for recreational boats that are stored in the water may include antifouling hull paints, newer alternative hull coatings, periodic in-water hull cleaning, and excluding propagules by surrounding the boat with a slip liner or raising it above water on a lift. Copper discharged to harbor waters from antifouling paints via passive leaching and in-water hull cleaning may elevate dissolved copper levels above government standards. Invasive species carried among boat-hull fouling organisms may be introduced as boats move among coastal areas. Some of these species tolerate copper in antifouling paints and copper-polluted harbor waters. Policy development must consider supply-side capacity, as well as economic and environmental sustainability, in managing these issues. This paper presents a supply-side evaluation useful in developing policies to co-manage water quality and invasive species risks for recreational boats navigating along the coasts of California, the Baja California peninsula and California's Sacramento-San Joaquin Delta. Supply-side perspectives on services, materials, costs, and boat owner behaviors, such as residence and travel patterns, awareness of hull-coating choices and selection of hull coatings, are determined. Analyses include evaluation of risks, risk management capacity and costs, and role of education in risk management. The issues raised are broadly applicable, as they are appearing on research and policy agendas in diverse coastal areas.

1. Introduction

1.1. Management challenges

Integrated solutions are needed for sustainable management of risks posed by recreational boats to coastal water quality and ecosystems. Organisms that attach to boat hulls are called hull fouling or fouling growth. They roughen the hull's surface, creating frictional drag that slows sailboats and increases fuel consumption by powerboats (Schultz, 2007). Copper-based antifouling (pesticidal) hull paints are widely used to control fouling on recreational boats kept in saltwater. However, the European Commission (EC 2007), United States federal government (USEPA, 2000; USEPA, 2002), and the states of California (CRWQCB-SDR, 2005; Kiaune and Singhasemanon, 2011; Singhasemanon et al., 2008) and Washington (WDE 2010) are concerned about accumulation and environmental effects of copper and organic toxicants discharged from antifouling paints to marina waters.

The coatings industry has responded with newer technologies to control hull fouling on recreational boats that are stored in the water, e.g. zinc-based antifouling hull paints and newer hull coatings with properties such as nontoxic, non- or short-lived biocidal, slick, and nano-engineered surfaces.[3] Independent trials are needed to determine efficacy and cost effectiveness. The San Diego Unified Port District (2011) evaluated 46 alternative coatings comprising non-biocide, zinc oxide, organic biocide and zinc-

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[3] Findings are typically proprietary but may be discussed at fora such as the biennial International Congress on Marine Corrosion and Fouling.

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biocide materials in San Diego Bay and found that soft non-biocide coatings were most effective. University of California research found that nontoxic epoxy coatings lasted 5–8 years on four boats (Gonzalez and Johnson, 2007) versus copper antifouling paints' mean service life of 2.5 years and thus were cost effective alternatives (Carson et al., 2009) in San Diego Bay.

Boat residence times and hull-cleaning frequencies affect risks for polluting water by copper discharged from antifouling paints. Schiff et al. (2004) found that mean monthly passive leaching rates of dissolved copper from antifouling paints were 3.7–4.3 $\mu g/cm^2$/day. These rates were highest immediately following cleaning events at 15–18 $\mu g/cm^2$/day, dropping to 4–5 $\mu g/cm^2$/day within three days and to 3 $\mu g/cm^2$/day after 28 days. In contrast biocide-free coatings exhibited uniformly low to non-detectable copper concentrations. On a mass scale Valkirs et al. (2003) found that of 23,000 kg of copper discharged annually to San Diego Bay, 48% came from passive leaching and 24% came from in-water hull cleaning of antifouling paints.

Recreational boats are also implicated in coastal transport of invasive hull-fouling species (Piola et al., 2009; Wasson et al., 2001). Boat residence times, level of fouling and travel patterns affect risks for transporting invasive species. An alien species may be introduced when an infested boat enters a port or marina (Floerl et al., 2009). The supply of propagules plays an important role in the dynamics of invasions, where larger numbers are more likely to result in establishment of an introduced species (Verling et al., 2005). Fouling organisms may spawn in response to changes in temperature or salinity or detach to colonize during even brief visits in ports (Minchin and Gollasch, 2003). Non-native species often establish first in transportation hubs with a high traffic volume and high connectivity to other nodes in the network (Floerl et al., 2009). Recreational boats may foster such connectivity among harbors, by serving as a primary vector for pre-border incursions and post-border spread of invasive species, such as the tunicate *Styela clava* among regions of New Zealand (Goldstien et al., 2010). Preliminary assessments of hull fouling on Connecticut boats that had wintered in Florida found species associated with the winter port (Balcom, 2005). Boats returning from San Francisco Bay likely introduced invasive species to Elkhorn Slough near Monterey Bay (Wasson et al., 2001).

California boats navigating among domestic harbors or to and from Mexico's Baja California peninsula may create such connections among transport hubs, facilitating the spread of invasive hull-fouling species along this coast. Ports and marinas that attract large numbers of boats to local events or that serve as a gathering point from which boats disperse to waypoints and final destinations may represent such hubs. Extended stays at waypoints and destinations may increase the risk of introducing non-native species (Minchin and Gollasch, 2003).

In much of the study area, copper antifouling paints cannot entirely control hull fouling. One factor may be development of tolerance to copper by some invasive hull-fouling species (Crooks et al., 2011; Piola et al., 2009). Incomplete control by copper antifoulings has led to use of "companion strategies." Periodic in-water hull cleaning removes early stages of fouling growth, preventing maturation and allowing gentler cleaning techniques that reduce abrasion of the hull's surface coating (Johnson and Gonzalez, 2004). Another approach is to isolate the boat from propagules of fouling organisms by surrounding it with a slip liner or by elevating it on a boat lift. Nontoxic hull coatings require more frequent cleaning or use of a slip liner or boat lift; retaining them long enough could amortize costs of transitioning to and maintaining them versus costs for using copper antifouling paints (Carson et al., 2009).

Boat repair yards represent a potential risk for discharging invasive species to local waterways if viable organisms or propagules that are removed from boat hulls are not properly contained and disposed (Coutts et al., 2010). We have observed that San Diego area boatyards employ berm and drainage systems to channel all boat hull wash-waters to a sump and through a processing system. There, paint particles and dissolved copper are coagulated, filtered and removed. Finally, collected waters are discharged to a sanitary sewer system and removed solids are disposed as hazardous waste. Such systems might also be employed to prevent viable invasive fouling organisms or propagules from entering local waterways.

Boat owners may encounter differences in availability and costs of supplies and services for fouling control as they transit the coasts of California, the Baja California peninsula and California's Sacramento-San Joaquin Delta. Thus, a binational approach is needed to co-manage invasive species and water quality via hull-fouling control for coastal pleasure craft.

1.2. Policy context

Our study is timely and broadly applicable, as management agencies and legislators in the United States (US) and Europe are addressing invasive species and water quality problems. California Department of Pesticide Regulation (CDPR), US Environmental Protection Agency (USEPA) and the European Commission (EC) are re-evaluating pesticidal paints used to control hull-fouling organisms (CDPR, 2010; EC, 2007; USEPA, 2010). Copper toxicants from these paints impair water quality and beneficial uses when they accumulate to levels that exceed 3.1 μg/l (USEPA 2000). A Total Maximum Daily Load program of the California State Water Resources Control Board (CSWRCB) requires 76% reduction of copper discharges from antifouling paints in Shelter Island Yacht Basin of San Diego Bay by 2023 (CRWQCB-SDR, 2005). Water quality studies in Lower Newport Bay (USEPA, 2002) and a survey of 23 marinas (Singhasemanon et al., 2008) found that toxicants discharged by antifouling paints affect coastal water quality in multiple areas of California. 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 (WDE, 2010). By 2020 Washington will ban sale and application of antifouling paint with more than 0.5% copper for recreational boats under 65 feet long (Washington State Legislature, 2011). If passed, California Senate Bill 623 would impose new restrictions on use of antifouling paint containing copper on recreational boats (California State Legislature, 2011).

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" (United States Senate, 2009). 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 with antifouling paints or nontoxic hull coatings to control fouling on larger recreational boats kept in coastal harbors. Hauling boats for hull cleaning would cost nine times as much as in-water cleaning and would increase time demands on boat owners (Johnson and Gonzalez, 2005). Further, nontoxic coatings require periodic hull cleaning twice as often as copper antifouling paints (Johnson and Gonzalez, 2006). The situation will be exacerbated as boat owners switch to nontoxic and less-toxic hull coatings to comply with pending and anticipated water quality regulations.