Hull Fouling:
Characterizing Magnitude and Risk of Species Transfers by Recreational and Fishing Vessels

Portland State University

Smithsonian Environmental Research Center

Hull Fouling: Characterizing Magnitude and Risk of Species Transfers by Recreational and Fishing Vessels

Final Report

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By

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Cover photo: Robyn Draheim

Executive Summary

To date, research into the role of vessels in marine species transfers has focused primarily on commercial shipping vessels, which move species in ballast tanks and on hulls (e.g., Ruiz et al. 2004, Davidson et al. 2008a). Management actions have also focused primarily on these large vessels. However, it is also evident that other vessel types, such as recreational and commercial fishing boats (small boats), can play an important role in both the initial introduction and subsequent coastwise spread of non-native species (Floerl and Inglis 2005, Minchin et al. 2006, Darbyson et al. 2008a). Although there are suggestions that water from bait wells, sea chests, and other conveyances may factor in the transfer of species by small boats, these vessels typically do not release large volumes of water, and biofouling (i.e., the growth of organisms on boat hulls and appendages) likely poses the greatest risk for spreading non-native species.

An assessment of the probability of non-species transfers from this vector must take into account two main factors: 1) small-boat movements among bays and 2) non-native species occurring on these vessels. In this study, we used a combination of literature searches, vessel arrivals data, written questionnaires, and field studies in an initial assessment of these two factors for recreational and fishing vessels along the US West Coast.

In terms of sheer number, small vessels appear to be a significant potential vector for moving invasive species on the US West Coast. Boaters living in coastal communities in Washington, Oregon and California own over 1 million vessels. The number of days small vessels from these states spent underway each year is in the tens of millions, with most boaters going out for one- to two-day excursions; Southern California recreational vessels alone account for 11 million boater days. Fishing vessels represent a much smaller segment of the small vessel traffic, reporting an annual average of ~100,000 arrivals to West Coast ports for unloading fish (although each arrival may represent many days at sea).

However, we are still lacking key information about the behavior of these small vessels which might either increase or decrease the likelihood of species transfers. For example, boats that are kept out of water and taken by trailer to coastal locations likely pose less of a risk than vessels kept continuously in saltwater; vessels that don't make overnight stays away from their home ports are likely less of a risk than those that do; and vessels that are kept clean are less risky than those that are heavily fouled. We also do not know the general patterns and magnitude

of connectivity among ports along the coast, which is critical to evaluating the opportunity for non-native species to colonize and spread.

Focusing on Central California, we examined the movement patterns, hull husbandry, and biofouling organisms associated with small boats at six marinas in more detail: three in San Francisco Bay which have active sailing communities, and three just outside the bay: Spud Point (Bodega Bay) to the north and Pillar Point (Half Moon Bay) and Monterey (Monterey Bay) to the south. This work builds on previous research in San Francisco Bay (Davidson et al. 2008b, 2010).

Our study shows a strong connection between San Francisco Bay and the three nearby study marinas. Using data from more than 400 boater questionnaires and 4,000 visiting boat records, we found that San Francisco Bay is the top overnight destination for boaters from Monterey and Pillar Point. The traffic travels the other way as well: boats from San Francisco Bay represent approximately half (or 300-400) of the visiting vessels at Spud Point and Monterey and three-quarters (or ~400) of the visitors at Pillar Point annually in the years for which we had data. This suggests that biofouling species established in any one of these marinas have opportunities to spread via small boats. It is therefore not surprising that the Asian kelp *Undaria pinnatifida,* which has been moved around the world primarily in association with small vessels and which had been well-established in Monterey since 2001, was found in San Francisco Bay marinas and at Pillar Point during this study.

We also investigated the biota associated with small vessels in the focal marina, both in terms of abundance and composition. We examined 2,254 vessels at their berth in six study marinas, assigning a rank based on degree of biofouling visible from the waterline. Additionally, we used an underwater camera mounted on a pole to photograph the hulls of 122 vessels. Degree of fouling was highly variable, with some study marinas tending toward higher amounts of total fouling cover as well as higher species richness. On the whole, vessels in our study tended to be more heavily fouled than those reported in previous studies using the same ranking system (Floerl et al. 2005a, Ashton et al. 2006, Davidson et al. 2008b). We found that fouling assemblages on small boats are species-rich and include non-native species. It is evident that some organisms survive trips between coastal locations, based on voyage histories and observed size structure of assemblages.

A search of the scientific literature readily identified over 100 species across a wide range of phyla have been reported from the hulls and appendages of recreational and fishing vessels at various locations around the world. This is clearly an underestimate of the total species pool associated with small vessels, as recreational and fishing vessels have received relatively little attention to date in many global regions, including North America. In our own surveys, we identified 33 taxa from 34 active recreational boats at two of our study harbors; about half of those identified to species level were non-natives.

We are still some distance off from having a complete picture of small-vessel traffic patterns, magnitude of flux, and associated biota along the US West Coast. Such a view would have to include vessels from Alaska, British Columbia and Mexico as well as an analysis of other foreign-flagged vessels transiting the coast. Future studies must also include quantitative estimates of connections among an expanded network of ports, hull husbandry practices and their effectiveness, as well as the species composition and condition of organisms on vessels that travel. Currently, available data suggest that about one million small boats are active on the US West Coast. While only a small portion of these boats make inter-bay transits each year, when scaled to the total population of vessels, this suggests a substantial number of vessels (>10,000) are moving among bays with the potential to transport biofouling (native and non-native species). Evaluating the full scope of the small boat biofouling vector and advancing strategies to minimize the risk of associated species transfers are therefore critical components for invasive species management along western North America.

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Introduction to the Report

In coastal ecosystems, the human-mediated transfer of organisms by vessels is a leading cause of biological invasions (Ruiz et al. 2000), which can lead to significant ecological and economic impacts (Pimentel et al. 2005). Moreover, the discovery rate of new invasions has increased exponentially in recent time, and this increase is driven primarily by invasions from vessels (Hewitt et al. 2008). While research and management have focused primarily on commercial shipping vessels, which move species in ballast tanks and on hulls (Ruiz et al. 2004, Davidson et al. 2008a); it is also evident that other vessels (recreational and fishing) play an important role in the initial introduction and subsequent coast-wide spread of non-native species (Wasson et al. 2001, Floerl and Inglis 2005a, Minchin et al. 2006, Darbyson et al. 2009a).

Recreational and fishing vessels typically carry little to no ballast water, and move organisms primarily on their hulls and underwater surfaces (Floerl and Inglis 2005a, Minchin et al. 2006). While hull-mediated introductions are a major cause of invasions, there are many aspects of this process and associated risks that remain unresolved (Floerl and Inglis 2003, Mineur et al. 2008) hampering development of management strategies to minimize future invasions.

Johnson et al. (2007) provided a useful overview of hull fouling on recreational vessels that focused on California. Their report provided some initial information about vessel movement; subsequent research has focused on San Francisco Bay (Davidson et al. 2008b) and southeast Alaska (Ashton et al. 2010). The objectives of this report are to synthesize what is known about the number and movement of recreational and fishing vessels on the west coast of North America, and to build on the work of Davidson et al. (2008b) in providing a more detailed description of boater movements between San Francisco Bay and nearby coastal harbors, hull husbandry practices, and biota associated with these vessels. This report is organized into three sections.

- Section 1: An analysis of the volume and flux of commercial fishing vessels in Washington, Oregon and California
- Section 2: An analysis of movement, hull-husbandry practices and fouling of small boats in Central California
- Section 3: A case study of a vessel-mediated invader, the Asian kelp *Undaria pinnatifida*

Section 1. Analysis of West Coast Commercial Fishing Landings Data

Photo: Jennifer McGowan

1.0 Background

The literature on biofouling vectors is dominated by commercial ship studies while recreational boats have come under increasing scrutiny in recent years. Very little has been reported in the scientific literature regarding biofouling of fishing vessels, their traffic patterns or transfers of species on their hulls and submerged surfaces. A notable exception is the report of a severe biofouling incursion in New Zealand on a large fishing vessel (Hay and Dodgshun 1997). Upon inspection, the Yefim Gorbenko trawler, which had previously fished in the Black Sea and Moroccan Coast, was found to have over 90 tons of biofouling covering the entire hull surface. This incident highlighted how fishing vessels, particularly those that traverse international waters and with seasonal lay-ups, can pose a significant threat of transferring nonindigenous species.

On the US West Coast, commercial vessel traffic has been analyzed for the three lower coastal states (Davidson et al. 2006) and Alaska (McGee et al. 2006). The present study and four others (Davidson et al. 2008a; Ashton et al. 2010; Davidson et al. 2010, and Clark-Murray et al. in review) have begun to evaluate recreational vessel traffic for some West Coast regions. However, a major gap in vessel traffic analyses on the West Coast exists for fishing vessels. We are not aware of any assessment of traffic and flux of fishing boats with respect to potential biofouling vector activity. The aim of this chapter is to provide a preliminary analysis of fishing vessel traffic along the West Coast, to begin examining the temporal and spatial patterns from the perspective of biofouling.

1.1 Data analyzed

The Pacific Fisheries Information Network (PacFIN) is a central hub for the management of fisheries data on the West Coast (http://pacfin.psmfc.org/). The Pacific States Marine Fisheries Commission (PSMFC) provided fishing vessel arrivals data for California, Oregon and Washington, from the PacFIN program, for a 4-year period from January 2005 to December 2008. Data were provided with the permission of the State PacFIN representatives responsible for fishery landings data management. For each reported arrival, the date, location (port) and an anonymous vessel identity were provided. Each vessel “dummy” identity was consistent across times and locations (e.g., Vessel 1 in Oregon in 2005 was the same Vessel 1 in California in 2007).

Below, we present an overview of traffic patterns of fishing vessels based on the PacFIN data. Additional background information on these vessels is discussed in Appendix A

1.2 Results

1.2.1 Temporal patterns

There were 403,975 fishing vessel arrivals recorded for California, Oregon and Washington over the four-year period. California accounted for just over half of the arrivals (51%), whereas Oregon and Washington had close to a quarter each (23% and 26%, respectively). Oregon and Washington also had very similar temporal patterns of arrivals with a steady increase from April to May and an observed decrease from September to November (Fig. 1.1). California had a different pattern. The first six months of each year were marked by a decline from January to April (by nearly 2000 arrivals), followed by an increase and another dip in June. The second half of the year was characterized by a relatively stable six-month period of approximately 4,500 arrivals per month.

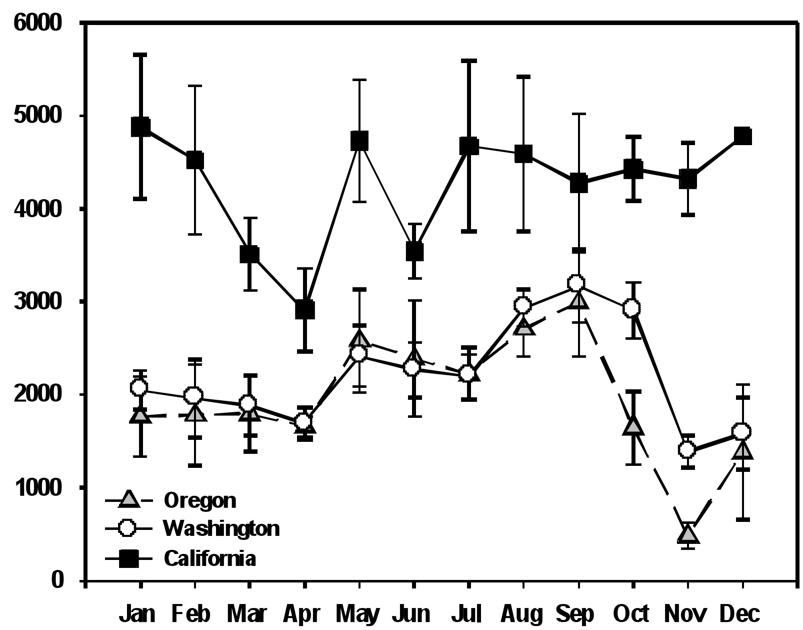


Figure 1.1 Monthly patterns of fishing vessel arrivals to California, Oregon and Washington. The mean (and standard deviation) number of fishing vessel arrivals per month is shown using a 4-year data set from 2005 to 2008 inclusive.

For California, the correlation between landings (in weight of fish) and arrivals per month for 2008 was not significant ($r^2 = 0.28$, $p > 0.05$), which is probably explained by differential use of vessels across different fisheries. Nonetheless, the peaks and troughs of monthly arrivals largely coincided with landings data with inter-annual variation playing an important role. For example, there was a significant drop in arrivals from May to June (averaging 1,179 fewer arrivals; Fig. 1.1); this coincided with an average reduction in landings of 10.96 million pounds of fish over the four years (CDFG 2009). This reduction was not evenly distributed among years, however; there was a reduction of 26.6 million pounds of fish landed in June compared to May of 2008 but the difference between those two months in 2007 was just 0.74 million pounds. Similarly, onshore deliveries data across different fisheries helped to explain arrival patterns for Oregon and Washington. In Oregon, the September peak and November trough in arrivals (Fig. 1.1) coincided with significant peak-and-trough patterns in salmon, groundfish, sardine, sablefish and shrimp landings (The Research Group 2009).

1.2.2 Spatial patterns

In California, 2,462 different vessels arrived 204,592 times over the four years. Santa Barbara was the highest ranked port with 21,762 arrivals (Fig. 1.3). Four other fishing ports: San Diego, San Pedro, Terminal Island, and Half Moon Bay, had more than 10,000 arrivals each while the combined landing sites of San Francisco Bay had 14,269 arrivals. These top five sites for fishing vessel arrivals accounted for 42% of arrivals across the state. A quarter of all vessels arriving to California landed fewer than 10 times whereas 27% arrived more than 100 times over four years.

Photo: Jennifer McGowan

Figure 1.2 A vessel rigged for crabbing in Half Moon Bay, CA.

There were 93,582 arrivals by 1,684 different fishing vessels in Oregon. Almost 80% of the arriving vessels arrived fewer than 100 times throughout the four-year period. Five vessels arrived more than 400 times. The dominant ports for fishing vessel arrivals in the state were Newport, Astoria, Coos Bay and Port Orford (Fig. 1.3). There were 18 arrival sites across the state but these four hubs accounted for 55% of all arrivals. With more than 16,000 arrivals over four years, Newport was the busiest Oregon fishing port (Fig. 1.3).

Westport was the highest ranked of 25 arrival sites in Washington with 14,709 arrivals over four years. The total for the state was 105,494 arrivals by 1,584 different vessels. Puget Sound ports received 17% compared to 27% of fishing vessel arrivals to West Coast ports (Fig. 1.3). The Columbia River and Strait of Juan de Fuca Coast also had substantial proportions of the state's arrivals (13% and 10%, respectively). The northern portion of the state, with major arrivals ports of Bellingham, Anacortes and Blaine, received 35,215 arrivals (33% of the state's total).

The spatial patterns of fishing vessel arrivals throughout the three states are particularly relevant in considering potential transfers of biofouling species because of the volume of arrivals across widespread landing sites. The dominant landing sites in each state were not necessarily the major hubs of commercial vessel traffic, but several major commercial port systems also received many fishing vessel arrivals. For example, Santa Barbara was ranked highest for fishing vessel arrivals in California but only received a handful of California's commercial traffic during the same four-year time period (three per year). However, San Francisco Bay's ports typically receive around 30% of the state's annual commercial vessel arrivals (Davidson et al. 2006) but also more than 14,000 fishing vessel arrivals.

Hence, there is a coast-wide range of arrival harbors for fishing vessels, some of which are not heavily used by commercial vessels and consequently more likely to be inoculated by non-native species from fishing vessels than other vessel types. Likewise, there are ports that receive substantial numbers of commercial ships and fishing boats, which suggests interactions between both vessel types (and populations of non-native species in the same bay) and a possible ratcheting effect of biofouling vector events.

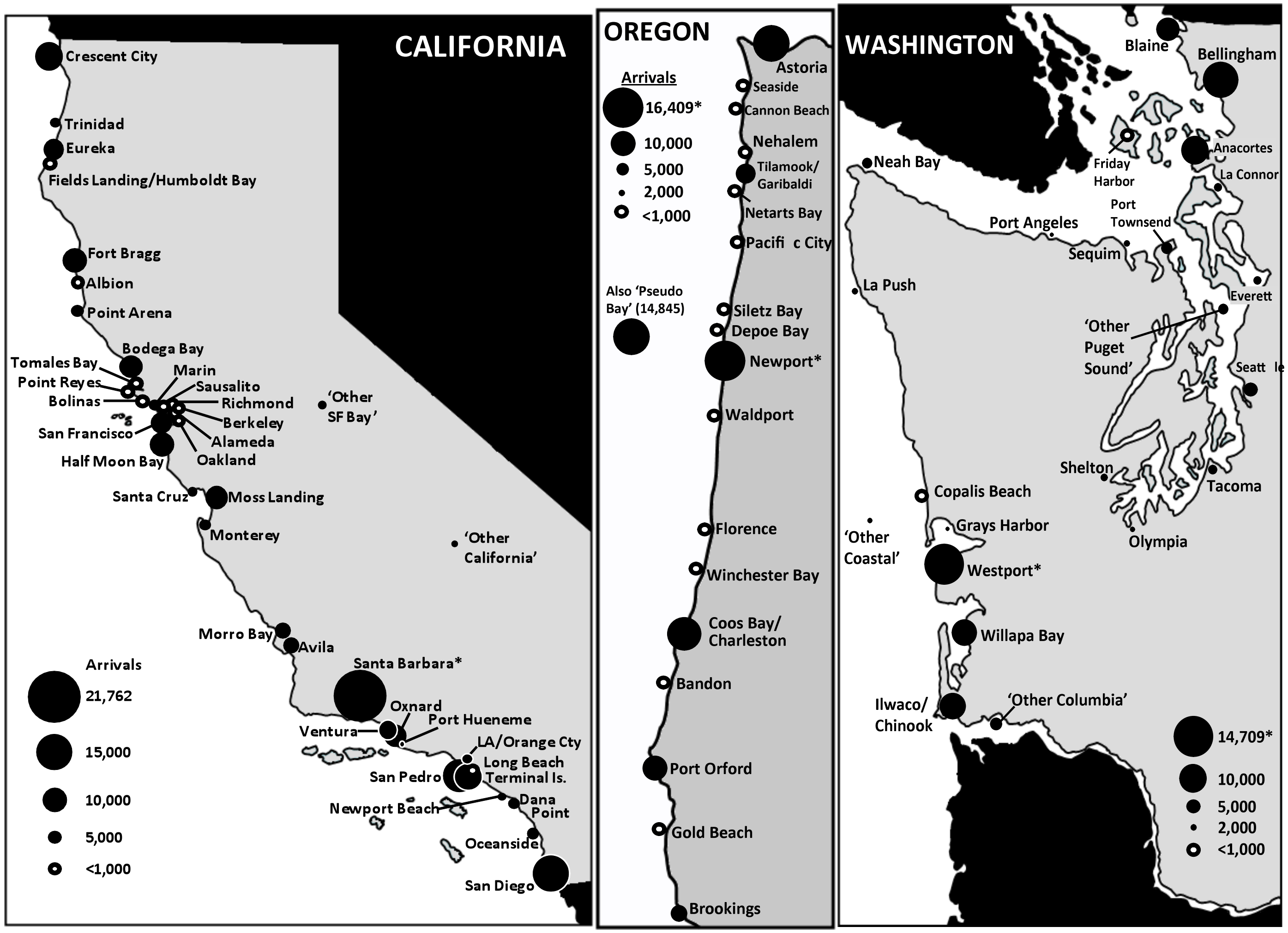


Figure 1.3 Fishing vessel arrivals among ports in California, Oregon and Washington. Bubble sizes in coastal maps for each state show the numbers of arrivals per port. Note, the scale for each state is different and each plot has its own key to indicate bubble size and arrival numbers. An asterisks indicates the fishing port in each state with the highest number of fishing vessel arrivals (over four years)

1.2.4 Vessel Flux

There were 4,920 fishing vessels recorded in this data set. Just over 86% of these vessels remained within one state, with 2,106 boats in California, 1,040 in Oregon, and 1,091 in Washington making all of their port visits within state (Fig. 1.4). Of the remaining 683 vessels (14% of the total), 327 had visited ports in Oregon and Washington, 190 had port visits in California and Oregon, and just 39 visited California and Washington. One hundred twenty-seven fishing vessels visited all three states.

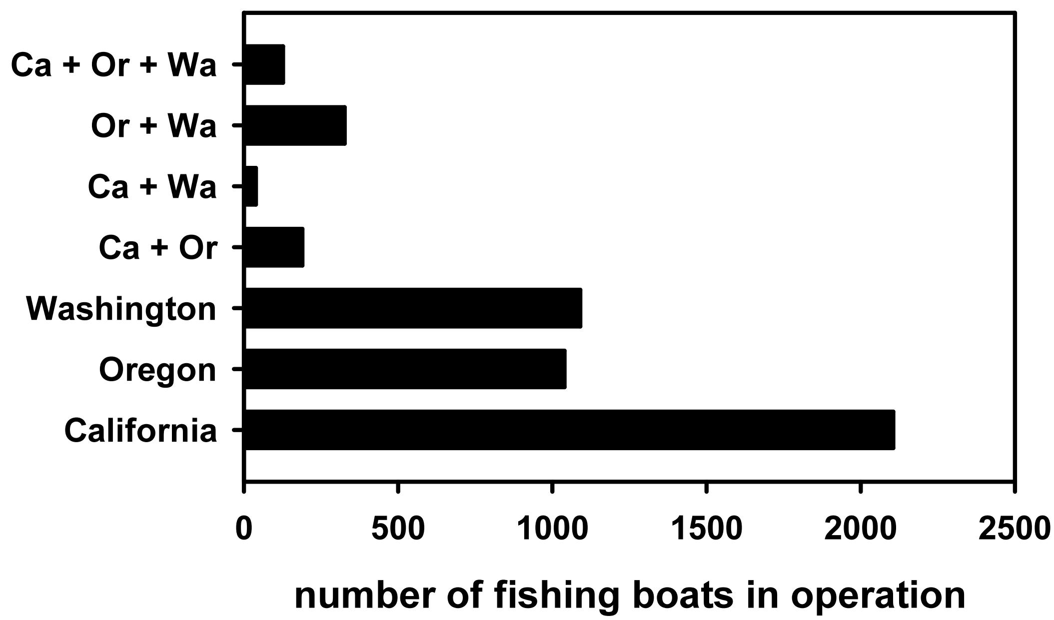


Figure 1.4 Number of boats according to arrival patterns within and among states. Boats that visited just one state only, just two states only, or all three states are shown (n = 4,920).

Within each state, there was also a high rate of homeport affinity whereby 45%, 58% and 41% of vessels arrived to just one port in California, Oregon and Washington, respectively (Fig. 1.5). In California and Washington, 5.5% and 8% of vessels (respectively) visited more than 5 ports within the state. The comparative figure for Oregon was just 0.5%. One vessel in California visited 15 different ports in four years (Fig. 1.5)

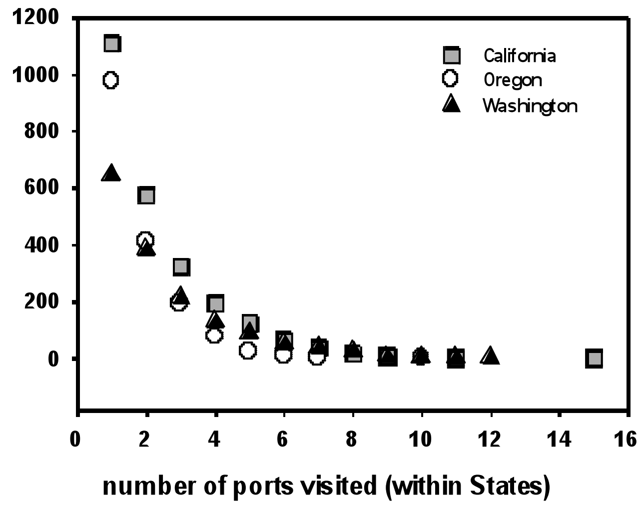


Figure 1.5 The number of different ports visited by vessels in California, Oregon and Washington.

1.3 Discussion

While the volume of traffic to a variety of widespread fishing harbors indicates that the potential for biofouling transfers within the fleet is high, the number of transits between states and among different ports is zero for large portions of the fleet. Many vessels simply work out of their home ports exclusively, meaning transfers of biofouling species between harbors does not occur for approximately 48% of the West Coast fishing fleet (i.e., those that only travel into and out of their home port). On the other hand, there were several highly transient vessels in the fleet that travel among several different ports within states, while 2.6% of vessels traversed all three states. These vessels are of particular interest in terms of non-native species transfers and would be the most important to target for sampling because their voyage patterns suggest a high risk for biofouling transfers.

Overall, the average number of fishing vessel arrivals annually (100,994) is much higher than commercial vessel arrivals across all three states (approximately 15,000 per year; Davidson et al. 2006). This analysis has shown that fishing vessels do not appear to be as transient within the West Coast compared to commercial ships, however. Of course, fishing vessels are also smaller and do not arrive from overseas. Nonetheless, there are large numbers of fishing vessels traveling between harbors and they remain a largely unknown quantity in terms of their frequency of maintenance, durations in ports, and typical voyage speeds. Each of these factors contributes to biofouling accumulation and transfer. Moreover, biofouling on transient fishing vessels is simply unknown and direct sampling would be required to provide even a cursory evaluation of vector risks.

Section 2. Characterizing Small-Vessel Movements and Hull Husbandry in Central California

Photo: Chela Zabin

2.0 Background

The importance of commercial ships in the transfer of species via hull fouling has been a focus of ongoing research around the world (i.e. Gollasch 2002, Fofonoff et al. 2003, Godwin 2003, Ruiz et al. 2004, Wonham and Carlton 2005, Drake and Lodge 2007, Mineur et al. 2007), although recreational vessels are increasingly being considered (i.e., Floerl and Inglis 2003, Floerl et al. 2005a,b, Ashton et al. 2006, Minchin et al. 2006, Mineur et al. 2008, Darbyson et al. 2009a, Davidson et al. 2010, R. Osman, personal communication). Given the growing evidence that invasive species are being moved coastwise between domestic bays and harbors, parallel analyses are also needed for recreational and fishing vessels ("small boats"). To evaluate likelihood of transfer for non-native species by these vectors, two basic types of information are needed:

1) the degree to which harbors and marinas are connected via small boat traffic
2) the abundance, composition, and frequency of fouling organisms on small boats traveling between locations.

However, these data are challenging to obtain. Unlike commercial vessels, small boats traveling within domestic waters are not required to report their movements or submit their boat maintenance records to any agency. Some individual harbors and marinas keep records of visiting boats that require berthing space, but do not submit these data to a central agency. The types of information collected from boaters and how these data are kept also vary by marina. Records are kept by the Department of Homeland Security on international travelers entering the United Sates by boat, but these represent only a small fraction of the total West Coast boating traffic and we have not been able to access these records. With the exception of some boats towed over land and/or entering fresh water bodies, no inspections are made at the borders for fouling species.

Unlike larger commercial enterprises, recreational boaters and fishermen are under no obligation to provide information on their travel patterns and hull-maintenance practices. These factors make an analysis of the small-boat vector challenging. There are some general summary statistics available for West Coast states for recreational boaters, which we summarize in Appendix A. In this section, we seek to provide higher resolution on traffic patterns for selected Central California locations, as a pilot study. Specifically, we used a combination of data sources to address some of the knowledge gaps concerning connectivity between locations and the degree of fouling of small boats traveling between them.

2.1 Methods

2.1.1 Study marinas

We focused our research on three marinas in San Francisco Bay (Fig. 2.1) and three harbors on the adjacent outer coast: Spud Point in Bodega Bay, Pillar Point in Half Moon Bay, and Monterey Harbor in Monterey Bay (Fig. 2.2). The three SF Bay marinas (Clipper Yacht Harbor, San Francisco Marina and South Beach Harbor Marina) were selected based on our earlier work (Davidson et al. 2008b, 2010), which indicated that they had active sailing communities. The earlier survey of recreational boaters in San Francisco Bay (Davidson et al. 2008b) indicated that the three nearby marinas were among the top destinations for SF Bay boaters. In addition, Monterey Harbor had a well-established population of the Asian kelp *Undaria pinnatifida,* a species generally thought to be spread via recreational boat traffic. This organism was selected for a case study (Section 3).

2.1.2 Visiting boat data

To examine travel patterns between harbors, we gathered data on visiting boats from records kept by four of our study marinas. Visiting boats are defined here as boats staying for short periods in guest berths. In some marinas, boats that are actually resident sometimes stay in guest berths. With the help of harbor staff, we eliminated most of these from our data set. For Monterey, Pillar Point and South Beach, we were able to gather two year's worth of data from vessels arriving by sea from a combination of written logbooks and computer programs. For Spud Point, we were only able to obtain one year's worth of data. Monterey Harbor, an official port of entry to the US, also provided copies of recent foreign vessel Customs forms that are kept on file.

Data collected by the marinas typically included the date of arrival, duration of visit, boat owner's home town/zip code, vessel type and vessel size. However, in many cases all these data were not available. Pillar Point was the only marina that recorded whether a visiting boat was a commercial fishing, recreational, or research vessel. Across all marinas data were missing for many records, but the large volume of vessel visits provided a good sample size for each marina to answer our main questions about frequency of visits between bays and typical length of visits.

None of the marinas gathered data on homeport or on previous or next port of call for a visiting vessel. As a proxy for homeport, we determined the bay closest to hometown of the registered boat owner. We excluded cases where a boater's hometown was approximately equidistant from separate bays or where a boat owner's hometown was farther than 30 miles from a bay. There is likely to be some level of error involved in this method; however, given that we have a robust data set (>4,600 boat visits), we consider this to be a good approximation. We used these data to estimate the level of connectivity (= number of visits) between the visitor's home bay and the marina collecting the data.

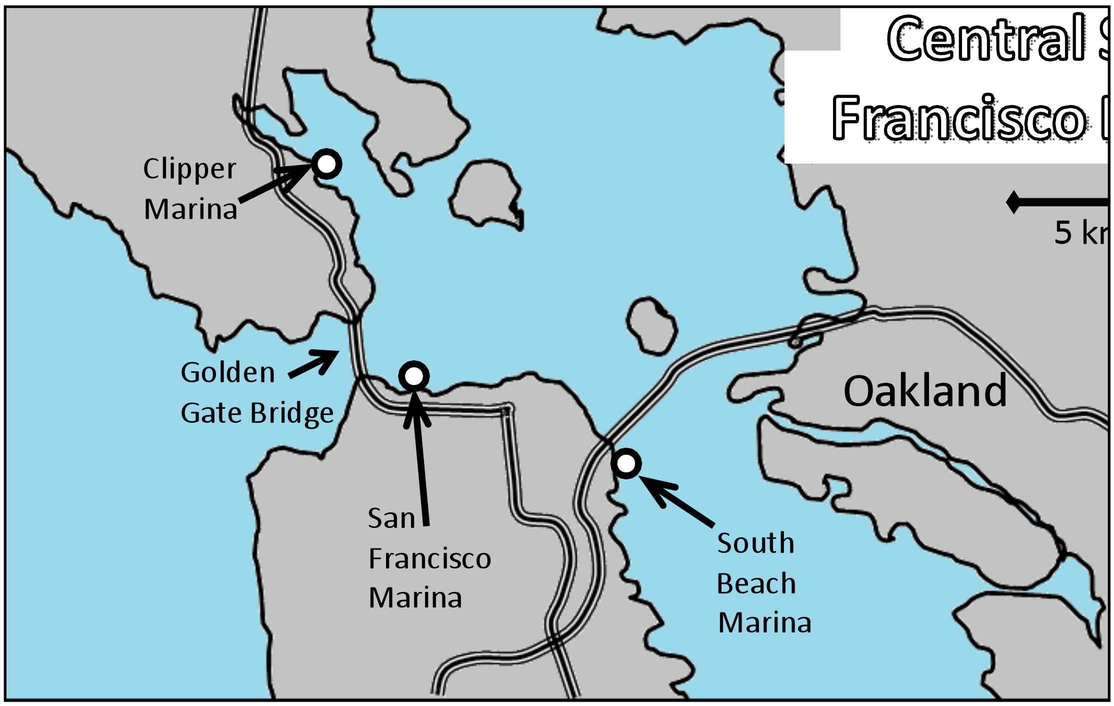


Figure 2.1 The locations of three marinas within San Francisco Bay where recreational boats were sampled and questionnaires distributed. Clipper Yacht Club, San Francisco Marina and South Beach Harbor Marina are indicated on the map with white dots.

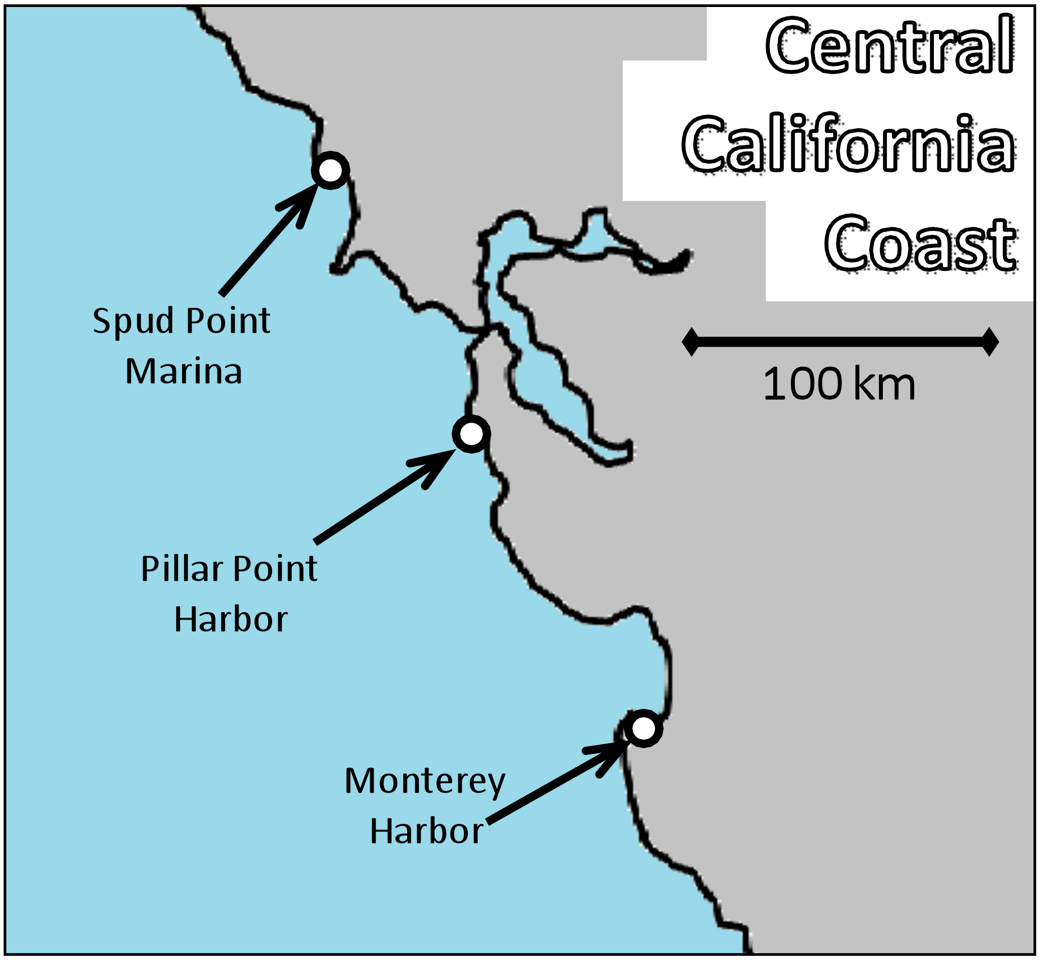


Figure 2.2 Marina locations on the outer coast of Central California. Spud Point Marina in Bodega Bay, Pillar Point Harbor in Half Moon Bay, and Monterey Harbor in Monterey Bay are indicated with white dots.

2.1.3 Boater surveys

Surveys were used to collect data regarding travel patterns and hull maintenance practices. Questionnaires were sent to all boaters renting slips in all six study marinas in February and March of 2009, mailed either by us directly or sent to boat owners by the marinas. Table 2.1 summarizes the content of the questionnaire; a copy of the questionnaire is included as Appendix D. As an incentive for completing the survey, we offered boat owners a chance of winning a $500 gift certificate from West Marine through a drawing. A total of 3,000 questionnaires were sent.

Table 2.1 Summary of information requested from boat owners. Questionnaires were distributed to boaters and marinas to provide information regarding six topics outlined in the table. When possible, questions were posed such that answers could be given in the form of multiple choice tick-box answers. This approach is useful for categorizing data for analysis. Table based on Davidson et al. 2008b.

Topic	Specific information requested
Type of craft	Whether the boat is used for commercial fishing, charter, recreation or other. Type: sailboat, motor boat, or other.
Home marina	The name of the marina at which the owner's boat was moored.
Antifouling paint	The date of most recent paint application. The type of paint used or specific product used.
Manual hull cleaning	Whether the boat was cleaned since the last paint application. The number of times it had been cleaned. The date of the most recent cleaning. The location of the most recent cleaning (e.g., in-water at a marina, on a trailer at a slip etc)
Voyage information/vessel use	The number of trips taken in the last 12 months. The destinations of trips (inside home bay, outside home bay). The duration (in days) of trips.
Hull survey participation	Whether the owner would permit a hull survey using the underwater camera and/or divers.

Data comparisons were made among vessels at the different study marinas and between recreational and fishing vessels, and between marinas within SF Bay and those outside of SF Bay. Chi-square tests were used for categorical data and analysis of variance tests (ANOVAs) for quantitative data. We also used a correlation to examine the potential relationship between frequency of use and frequency of hull cleaning. All statistical tests were used after ensuring that the data met appropriate test assumptions.

2.1.4 Hull surveys: level of fouling

Above-water hull surveys were used to assess the level of fouling of all vessels at berth in the six study marinas. Each vessel was categorized into one of six qualitative level-of-fouling (LoF) categories, following protocols used by Floerl et al. (2005a) and an earlier study of six additional SF Bay marinas (Davidson et al. 2008b). This method involves designating a rank of fouling (from 0 to 5) to each vessel based on an assessment of visible fouling made by a dockside observer. The ranking system ranges from 0, where a vessel has no visible fouling, to 5, in which a vessel has >40% cover of biofouling (Table 2.2). A total of 2,254 vessels were assigned a LoF rank across the six marinas surveyed.

Table 2.2 Level of fouling ranks (LoF) assigned to vessels based on the ordinal scale developed and described by Floerl et al. (2005a).

LoF	Description
0	No visible fouling at the waterline or on vessel appendages.
1	Slime/biofilm visible on some or all of the underwater surfaces. No macro algal or macro faunal species.
2	Slime/biofilm visible. Patches of macro algae or fauna covering up to 5% of the visible surface area.
3	Patches of macro fouling covering 6 to 15% of the surface area.
4	Macro fouling covering 16 to 40% of visible surface area, likely to include more than one taxon.
5	Macro fouling species covering 41 to 100% of the visible surface area.

2.1.5 Hull surveys: video analysis

Through the questionnaires, a number of boaters gave us permission to survey their boats using an underwater camera mounted on a pole (UPC). The UPC is a video camera in a waterproof housing, attached to an extendable pole and connected via wiring to a battery box and monitor with a recording device. These UPC hull surveys were used to make a more detailed assessment of hull-fouling extent and species richness.

We attempted to survey a minimum of 20 boats per marina. Whenever possible, we selected more actively used boats to survey. We also surveyed visiting boats as opportunities arose on our sampling days.

On each vessel, we took sixteen 8 x 12 cm photoquadrats (still images) of hull surfaces. We stratified sampling by depth, taking eight photos haphazardly along a transect running from bow to stern just below the waterline and eight photos along a parallel transect at the bottom (or as deep as we were able). Photoquadrats were downloaded to a computer and percent cover data were generated by projecting a grid of 100 points over each photograph. We also used the UPC to record footage of the stern appendages (rudder, propeller, etc.) for comparison with hull transects. Because they do not have much flat surface area, we could not use photoquadrats to determine percent cover on these appendages; we used this footage to make qualitative comparisons of taxonomic richness.

In most cases, we could not resolve organisms in the photoquadrats to the species level. Instead, we calculated percent cover of 20 coarse taxonomic groups (modified from Davidson et al. 2008b, 2010; Fig. 2.25). These data were used to test for differences in richness and composition at the level of the boat (i.e., waterline, bottom and stern appendages) and between marinas. We compared data generated from the videos to the corresponding LoF rank for each photographed vessel to determine whether these dockside ranks were good indicators of fouling cover. We did this in two ways: 1) using the actual percent cover estimated from the photoquadrats and 2) using the percent cover data to calculate an underwater LoF rank. We also examined the relationship between percent cover of fouling and frequency of use and between fouling and hull maintenance practices.

We used a two-sample paired T-test to compare taxonomic richness between waterline and bottom transects, using all data across all marinas. A one-way analysis of variance (ANOVA) was used to compare taxonomic richness between stern appendages, waterline and bottom transects. We also used a one-way ANOVA to test for differences in overall taxonomic richness between marinas (with boat as sample unit). An analysis of similarity (ANOSIM) in PRIMER 6 was used to determine whether there were differences between marinas in the taxonomic composition of fouling organisms.

2.1.6 Hull surveys: sampled hulls

To provide a better assessment of hull-fouling species richness, divers on SCUBA sampled specimens from the hulls of boats at two marinas (Monterey and South Beach Harbor). We collected samples from actively used local boats (pre-determined from questionnaire data) and on visiting boats: 21 boats were surveyed in Monterey and 13 from South Beach. Divers attempted to collect samples of all taxa present. The dive survey included all underwater structures of the vessel. Two divers swam the length of the vessel, collecting biological specimens as they were encountered. Particular attention was focused on propeller, rudder and other “niche” areas, where organisms are known to foul most frequently. A maximum of three one-gallon bags of material was collected from each vessel, focusing on different-looking taxa rather than collecting a large number of the same organism.

2.2 Results

2.2.1 Travel Patterns

2.2.1.1 Visiting boat data

We collected data on visiting boats over two years (2008-2009) from South Beach (1,208), Pillar Point (1,236) and Monterey Harbor (1,276); and for 2008 from Spud Point (884). The overwhelming majority of visiting boaters to each marina came from California (Fig. 2.3). Boaters from Washington and Oregon were second and third highest proportionally for all marinas except Pillar Point, where this was reversed. Visitors from Alaska and/or British Columbia made up larger proportions in Spud Point and Monterey Harbor than in Pillar Point and South Beach (Fig. 2.3).

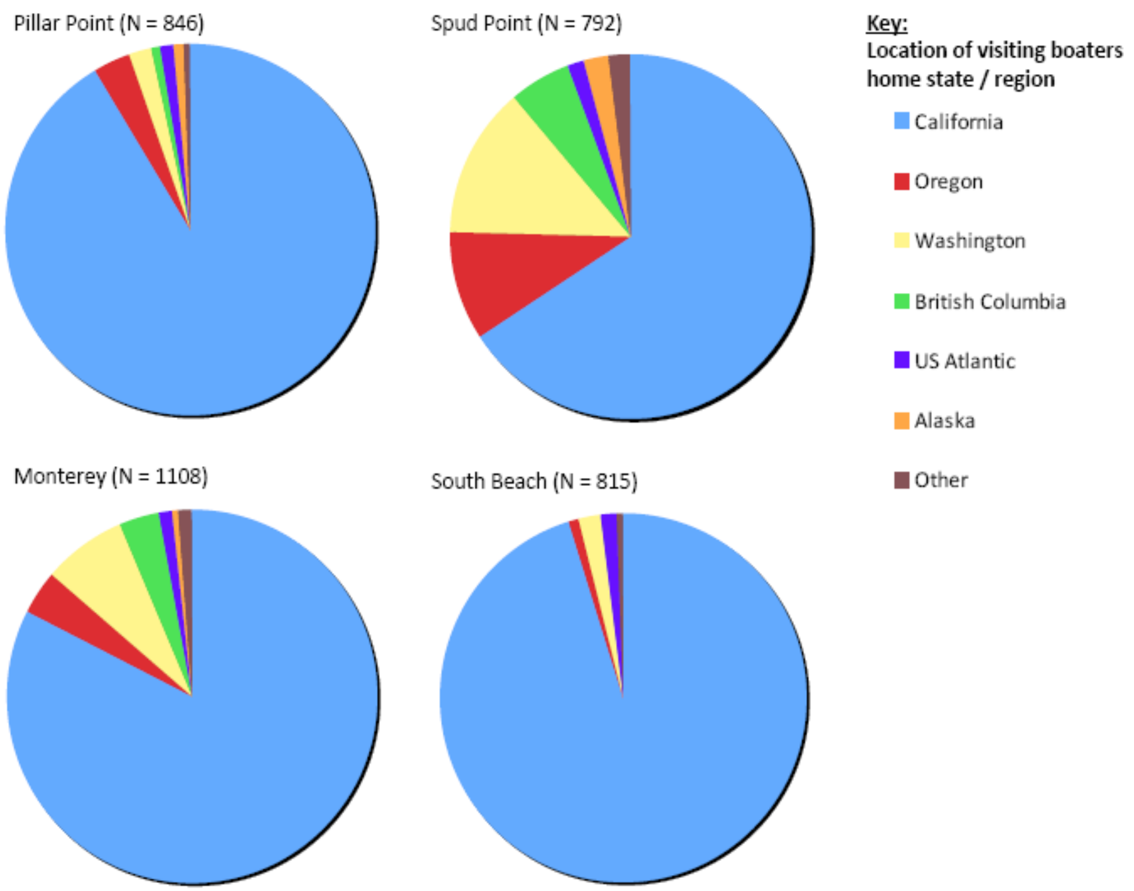


Figure 2.3 Proportion of visiting boaters by region for 2008-2009 (2008 only for Spud Point). In each of the four marinas, the majority of visiting boaters were from California. Spud Point and Monterey Harbor had a greater proportion of boaters from other regions than did Pillar Point or South Beach.

Of the California boaters visiting the focal marinas, the majority came from the San Francisco Bay Area (Fig. 2.4). The overwhelming majority of boaters visiting South Beach were from elsewhere in SF Bay (Fig. 2.4). SF Bay Area boaters also contributed significantly to Pillar Point and Spud Point visitors (73% and 52% respectively); but less so to Monterey visitors (46%). With the exception of Spud Point, arrivals from Monterey Bay represented the second highest proportion of transient boaters in all marinas. The degree of connectivity (number of arrivals) between San Francisco Bay (as source) and the outer coast study harbors are illustrated in Figure 2.5. Connections between the three outer coast bays are illustrated in Figure 2.6.

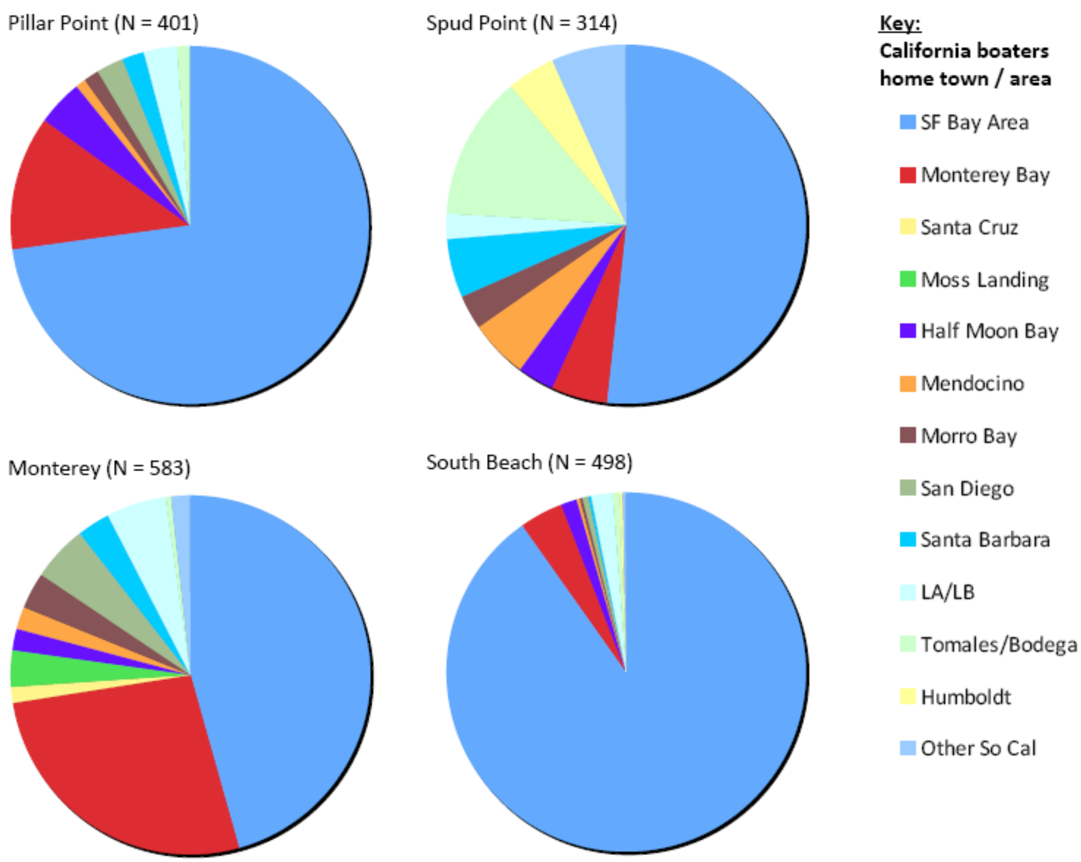


Figure 2.4 Among California boaters, those from the San Francisco Bay Area dominated the visitor traffic at each of the study marinas. Using our methods, Santa Cruz and Moss Landing boaters could really only be distinguished from other Monterey Bay boaters for Monterey. The Southern California category was used in cases where a visitor couldn't be confidently placed into the more regional breakdown. Visiting boaters from the same bay (i.e. visitors from Half Moon Bay at Pillar Point) may reflect: 1) locally based boaters who keep boats elsewhere 2) boaters who haul out their boats 3) resident boaters temporarily using visitor slots. We tried to remove these where possible by checking with harbor staff.

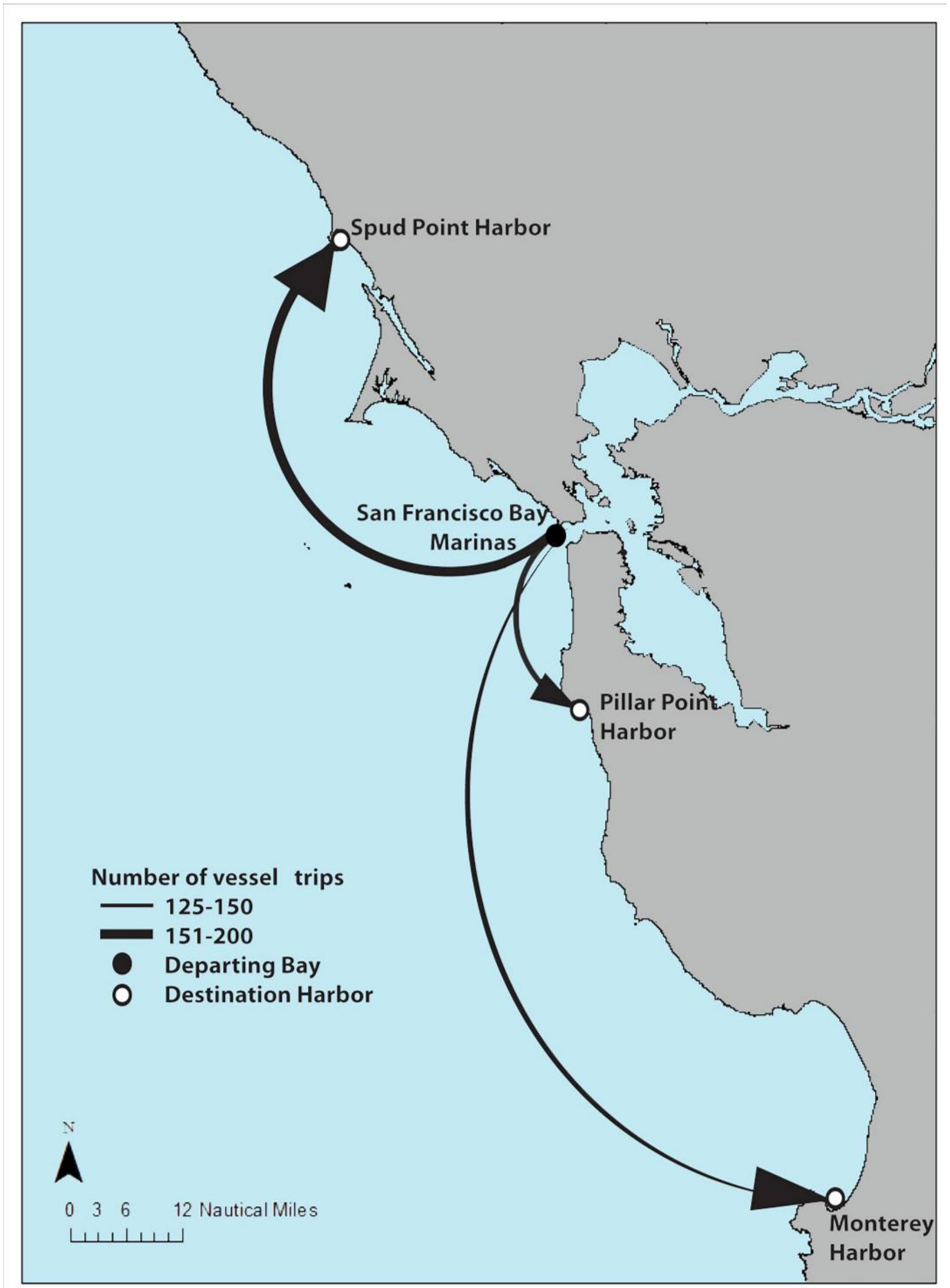


Figure 2.5 Numbers of trips made by vessels traveling from San Francisco Bay to outer coast harbors, as recorded in the transient boat records for these marinas.

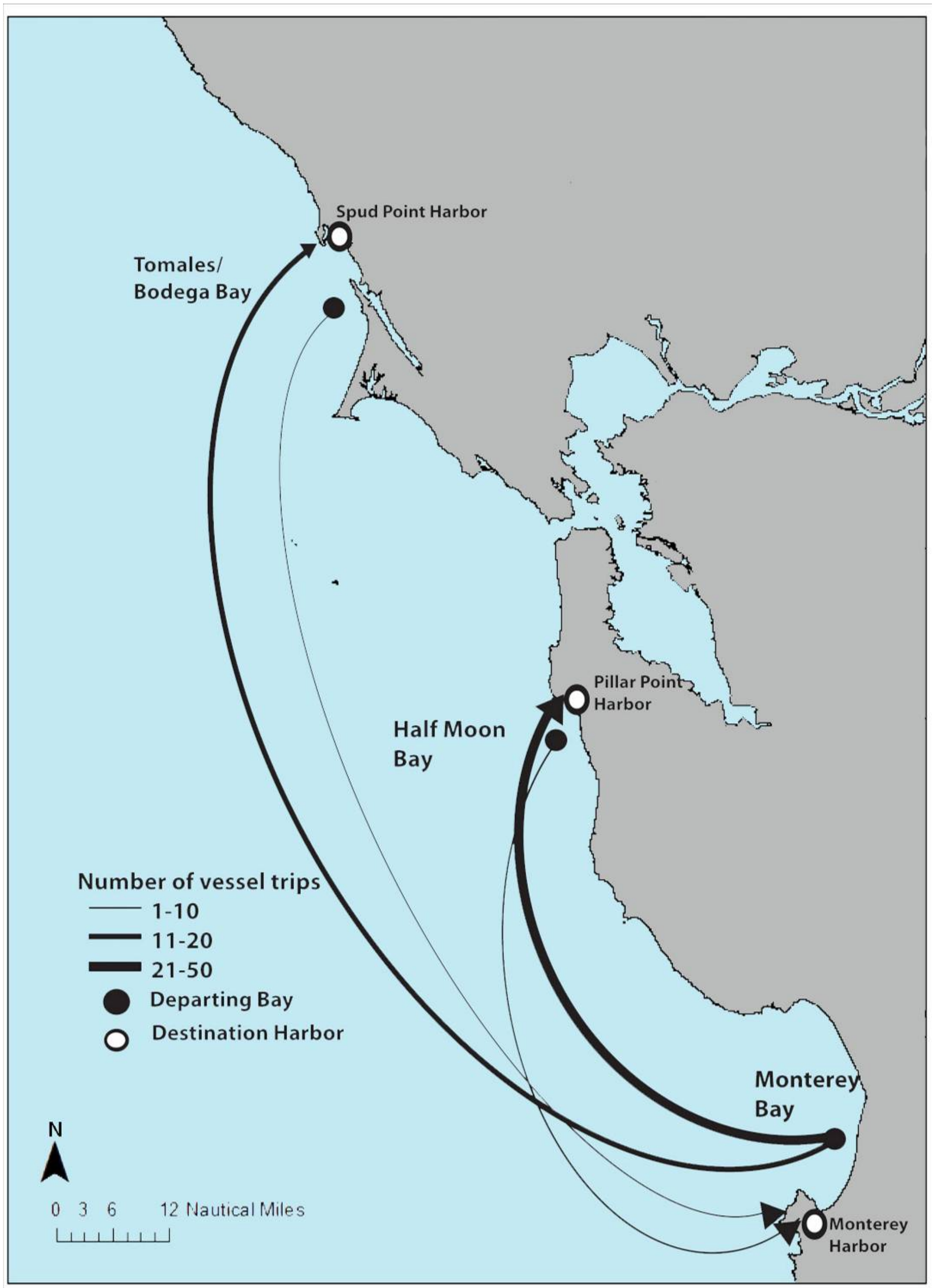


Figure 2.6 Numbers of trips made by vessels traveling between Monterey, Half Moon and Bodega/Tomales bays to Monterey Harbor, Pillar Point Harbor and Spud Point Harbor, as recorded in transient boat records from these harbors.

Most boaters stayed in each marina for one day, with a very high proportion of stays of three days or less (Figure 2.7), however there was some variation between marinas. Nearly all (>90%)

visitors to Spud Point were there for one day only, whereas Monterey had a higher percentage of longer stays than either South Beach or Pillar Point. At Pillar Point, visiting commercial fishing vessels tended to stay longer than recreational vessels (Fig. 2.8).

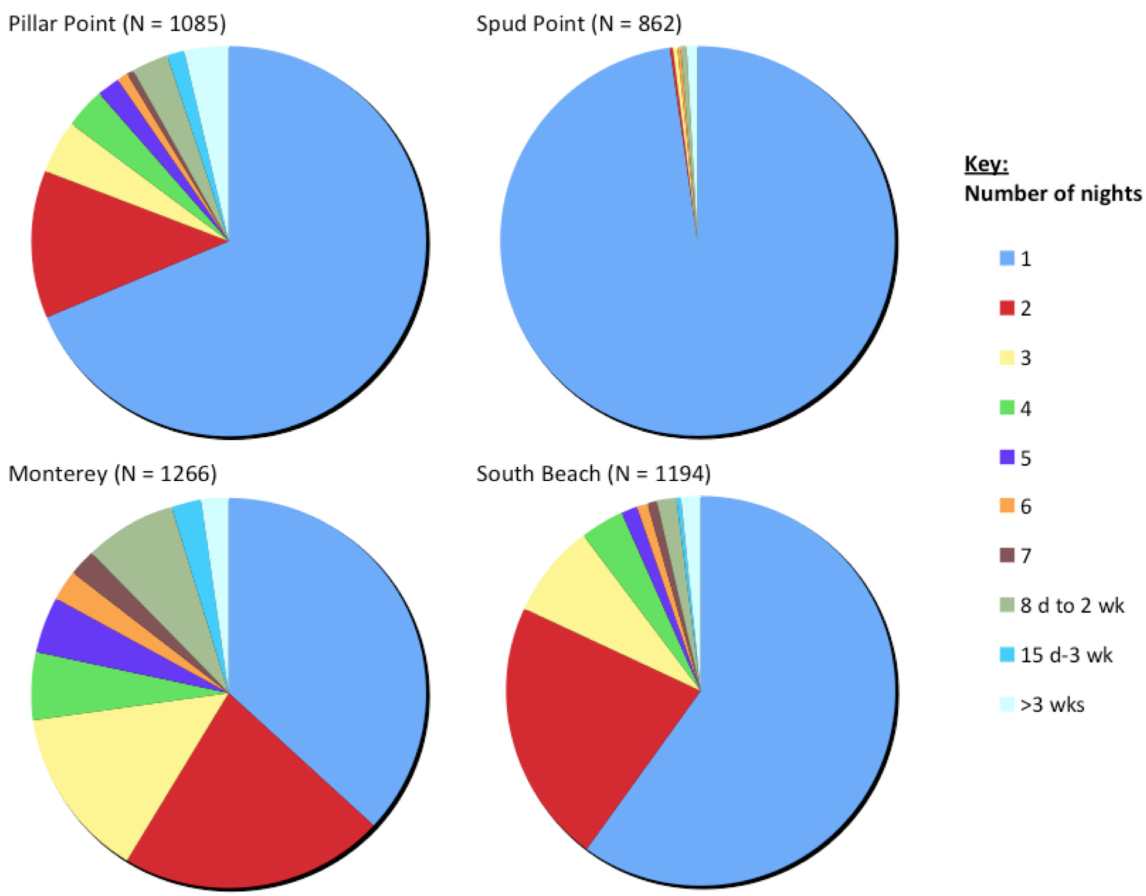


Figure 2.7 Number of days stayed by visiting boats. Across the four marinas, most visiting vessels stayed two days or less.

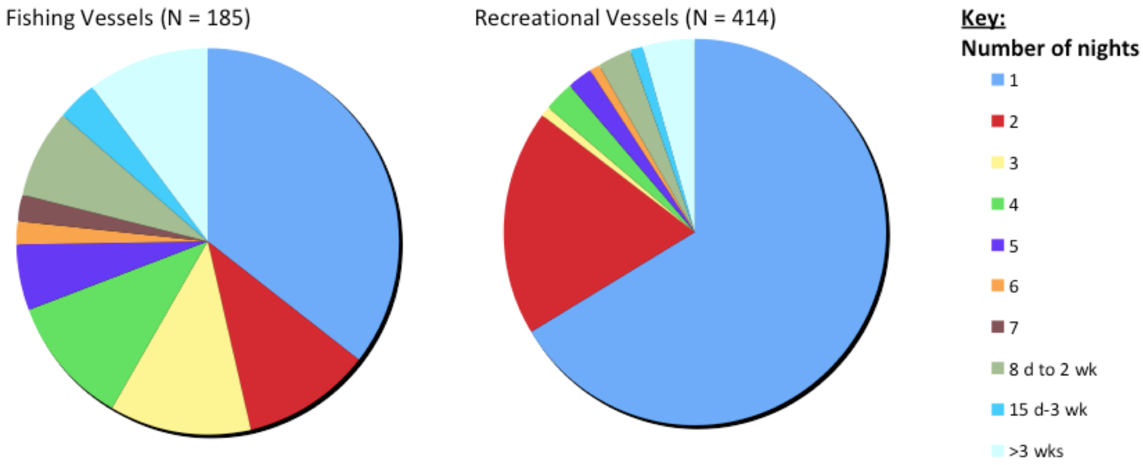


Figure 2.8 Number of days stayed by visiting boaters at Pillar Point, fishing vs. recreational vessels.

Over a period of 18 months ending September 22, 2008, 41 foreign flagged vessels visited Monterey Harbor. The Customs forms were not complete in all cases, and the forms were more detailed for the earlier dates. Thirty-two were sailing vessels; the rest were motor yachts. Most of the arriving vessels were from Canada (Fig. 2.9), and of these, most reported a homeport in British Columbia. A Washington State port (Port Angeles or Friday Harbor) was the first US port of entry for most of these vessels (Fig. 2.9).

Several vessels reported other domestic stops prior to arrival in Monterey, for a combined total of 62 stops (Fig. 2.10). Vessels reported stops at 14 different ports before arriving to Monterey. Port Angeles, WA was the most frequent stop (26%) and San Francisco Bay was the second highest (18%).

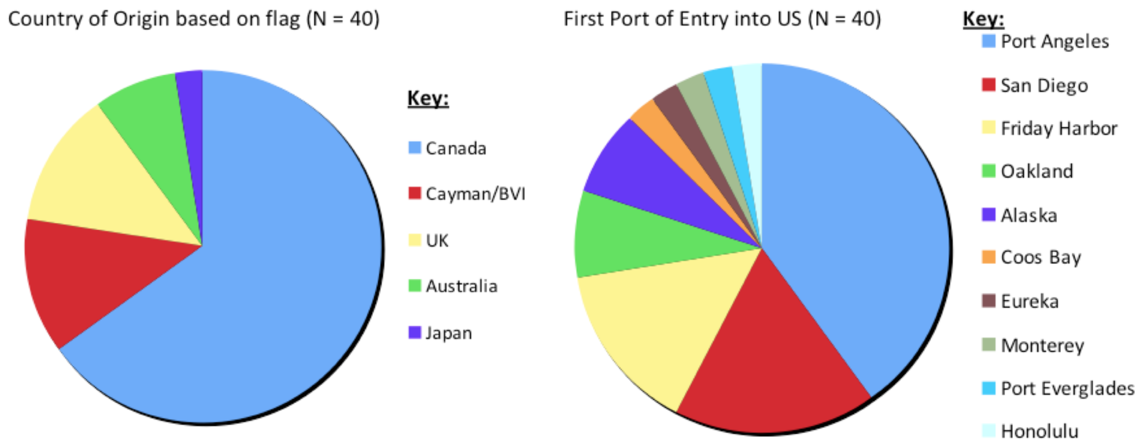


Figure 2.9 Countries of origin (left) and first US port of entry (right) for vessels arriving to Monterey Harbor over an 18-month period.

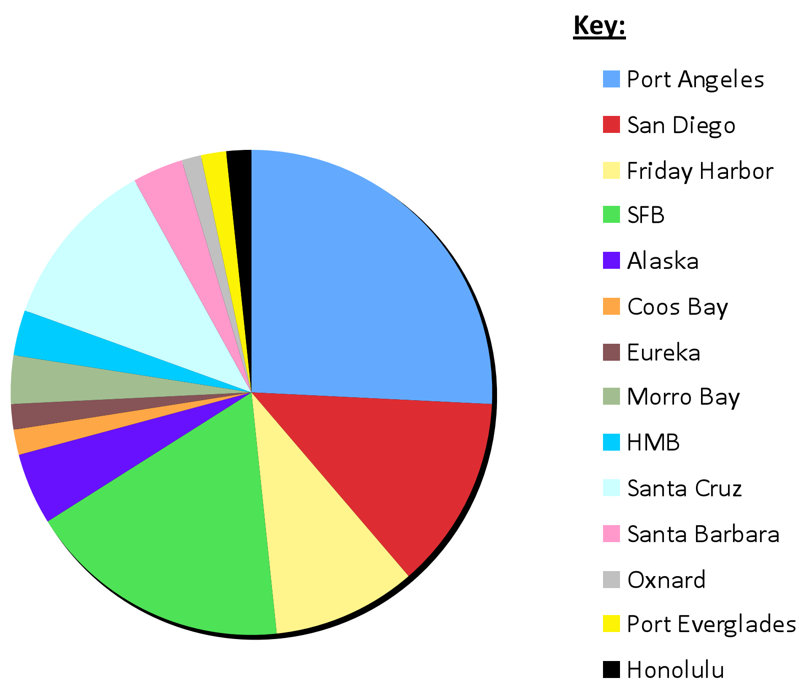


Figure 2.10 All domestic stops (n=62) prior to arrival in Monterey Harbor. Some vessels reported more than one stop.

2.2.1.2 Boater surveys

Boat owners returned 394 questionnaires out of the 3,000 mailed; we collected an additional 20 surveys from owners of transient vessels prior to hull inspections on SCUBA (see Methods Section 2.1.6). Seventy-one percent of questionnaires were from owners of sailboats and 29% from motorboat owners. This reflects fairly closely the percent of sailboats and motorboats in the study marinas: 60% and 40% respectively, based on data we collected in the level of fouling surveys. Eleven percent of the respondents were owners of commercial fishing vessels and less than 1% were owners of charter or educational/research vessels. There were too few responses from owners of fishing vessels to compare data from these vessels between marinas. For the following analyses, we pooled all fishing vessels; data from recreational vessels only were used for cross-marina comparisons.

Across all six study marinas, 81% of boaters reported trips exclusively in their home bay during the past 12 months. This percentage was not consistent across all marinas: more recreational boaters at Spud Point, Pillar Point and South Beach and fishing vessels (pooled across all marinas) reported having made trips outside their home bay (Fig. 2.11). These differences were statistically significant (chi-square = 44.5, df = 6, P-value < 0.0005).

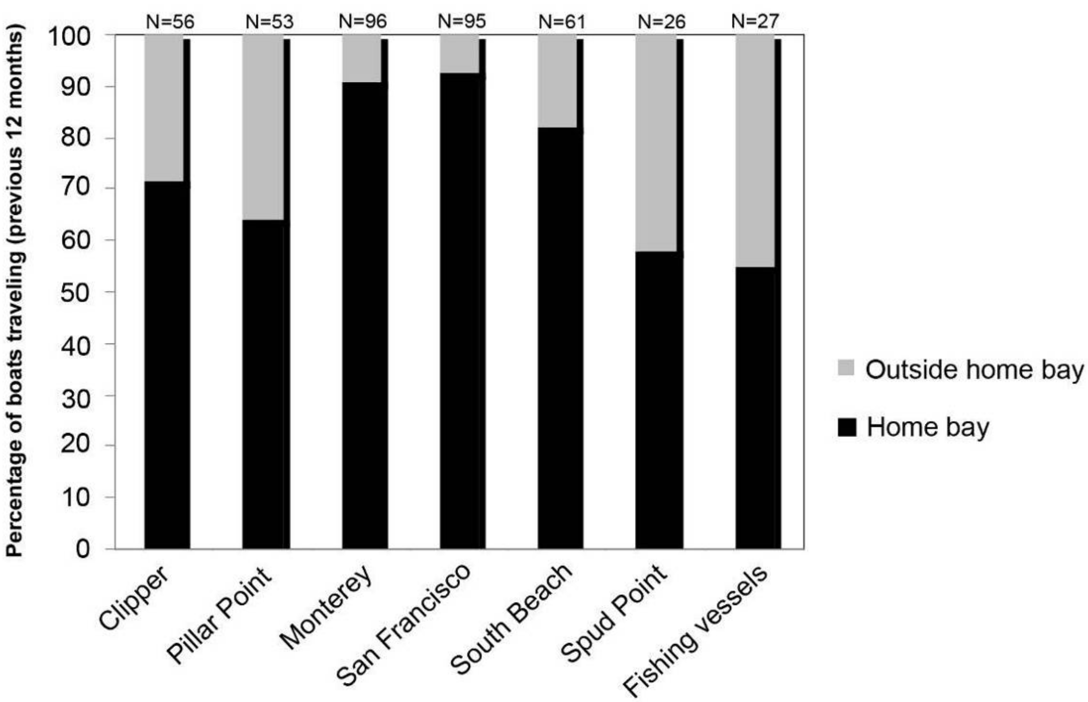


Figure 2.11 Percentage of boaters reporting travel 1) within their home bay only or 2) outside their home bay. A higher proportion of fishing vessels as a group and of recreational boaters at Spud Point, Pillar Point and South Beach made trips outside of their home bays than did recreational boaters in Monterey, San Francisco and South Beach.

Of the 78 boaters who reported making trips outside of their home bay, 58 provided details. These boaters reported making 171 trips outside of their home bay in the past 12 months (Fig. 2.12); 25 of these were made by four fishing vessels. Boaters from Spud Point reported the most trips, 71, including 21 trips made by two fishing vessels. Boaters from Pillar Point made 29 trips (including four trips made by two fishing vessels) and boaters from Clipper made 27.

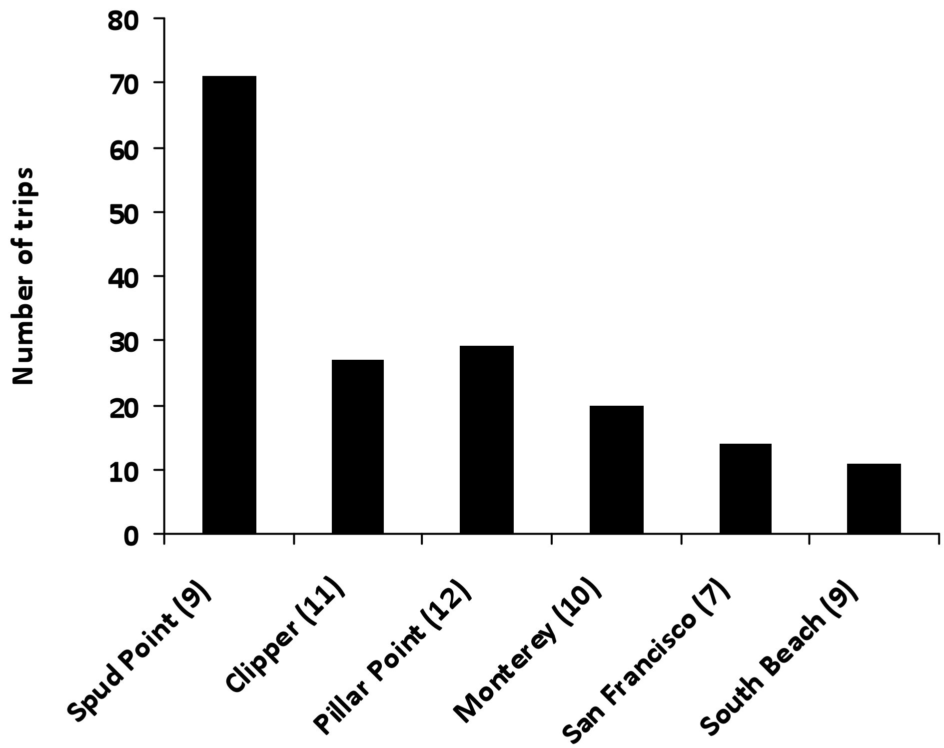


Figure 2.12 Number of trips boaters made outside their home bays in the previous 12 months. Numbers in parentheses are the number of boats responsible for the trips.

On average, the duration of trips outside of home bays was relatively short, but occasionally longer trips were reported. Typical trip durations ranged from 1-6 days, with only five vessels (9% of the total) reporting trip durations longer than 10 days (up to 90 days). There was no significant difference between the mean trip durations of vessels from marinas in San Francisco Bay and those outside the Bay.

Half Moon Bay (Pillar Point) and the Farallon Islands were the top two destinations, respectively, for boaters based in San Francisco Bay (Fig. 2.13). Additional trips were reported to Monterey Bay and points just north of San Francisco: Drakes, Tomales and Bolinas bays. Boaters from Spud Point mostly traveled north to destinations along the Sonoma Coast: nearby Tomales Bay and Drake's Bay ranked second and third, and five boaters traveled to San Francisco Bay. San Francisco was the top destination for boaters from both Pillar Point and Monterey. There was some traffic between Pillar Point and Monterey. The remainder of

Monterey boaters tended to travel south to Morro Bay and the Channel Islands. The connections between the study marinas as reported by boaters are illustrated in Fig. 2.14.

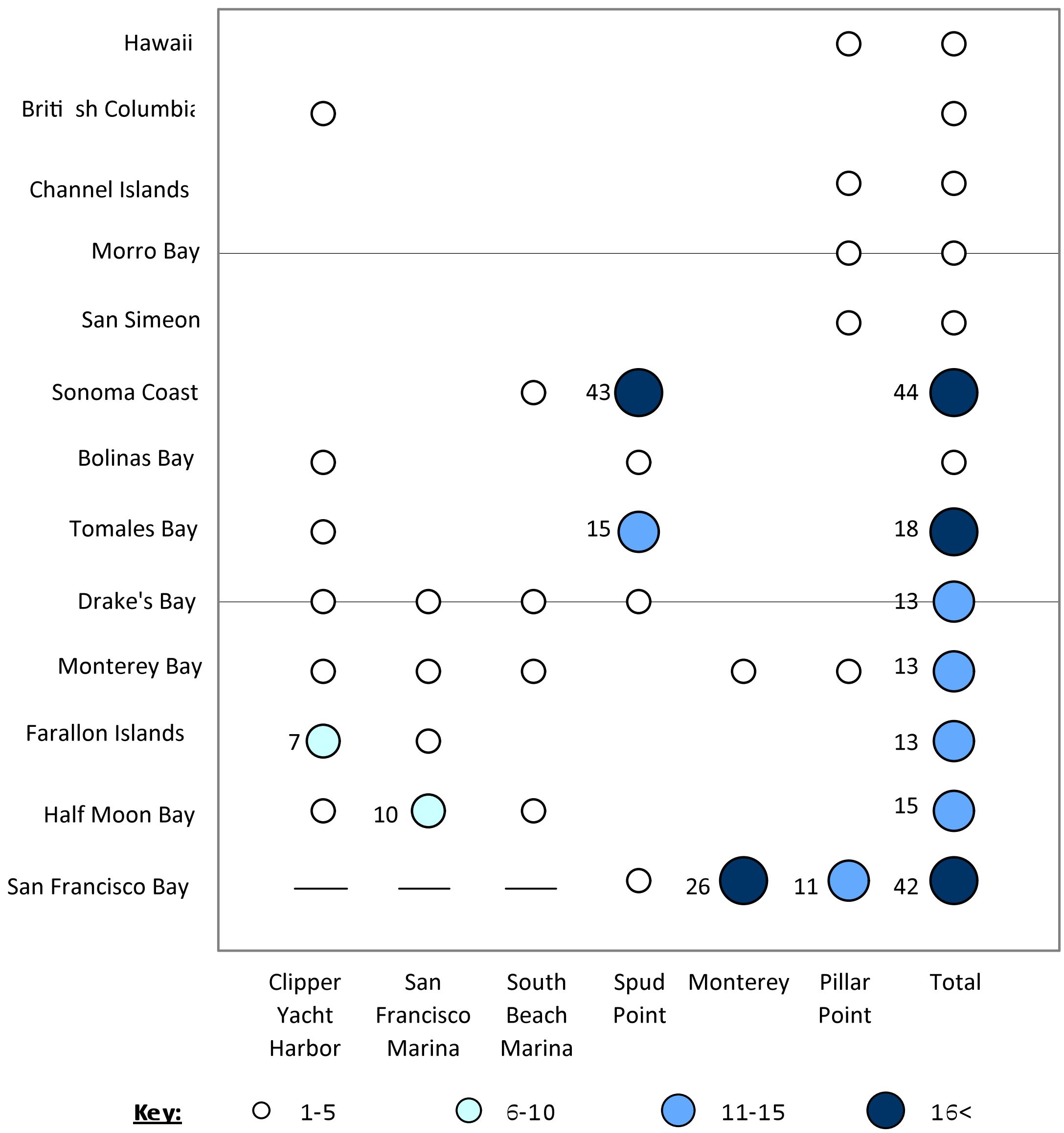


Figure 2.13 Number of trips away from home bay reported by boaters from study marinas. Destinations of boaters are shown on the y axis. (For Monterey, overnight stays in other harbors in Monterey Bay are included as away from home.) Size and color of the points indicates connection strength, actual numbers are given for values greater than 5.

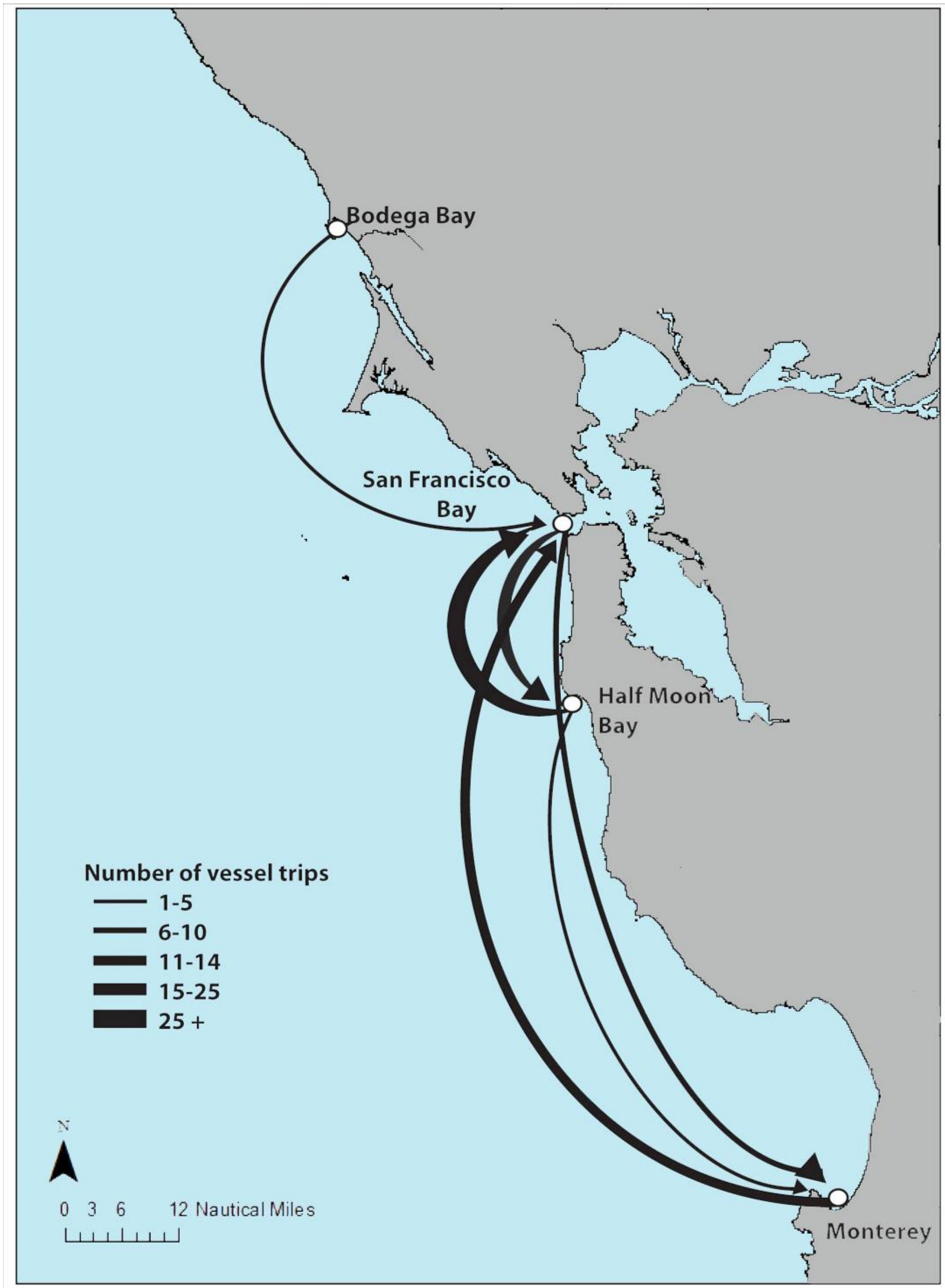


Figure 2.14 Numbers of trips made by vessels traveling between all study marinas, as reported by boaters answering the questionnaire.

Few boaters reported moving boats overland by trailer (Table 2.3). Pillar Point reported the most trailer activity, with 17 trips by trailer to salt water locations and four to freshwater locations.

Table 2.3 Number of trips reported by boaters trailering boats to salt water and freshwater locations over the past 12 months. Color intensity indicates connection strength. No boaters from South Beach moved their boats by trailer.

Marina	**Salt water locations**				**Freshwater locations**			
# of trips	San Francisco Bay	Santa Cruz	Bodega Bay	Pt Reyes	Lake Sonoma	Carmel	Coyote Lake	Miller Park
Pillar Point	6	9	2				1	2
Spud Point					7			
Clipper				2				
San Francisco					2			
Monterey						1		

Across all types of vessels, the majority of boaters (76% of the 342 who answered this question) used their boats less than 20 times in the past 12 months (Fig. 2.15). While 49% of boaters reported an average of less than one trip per month (<10 trips in the year), some high usage was also reported whereby 2% of respondents estimated over 100 trips in the year prior to this study.

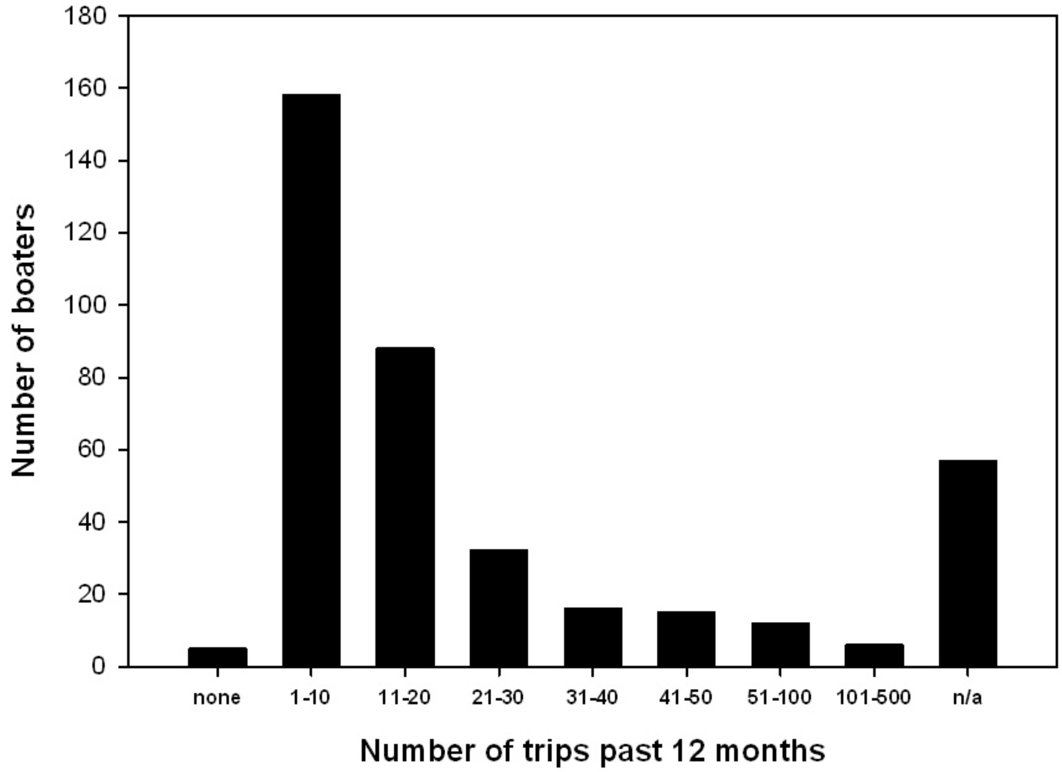


Figure 2.15 The number of trips made reported by boaters for the past 12 months.

2.2.2 Biofouling and hull maintenance

2.2.2.1 Boater surveys

Forty-three percent of boat owners reported using copper-based paints, 1.8% reported using non-copper paints, and the remainder didn't know or didn't say what type of paint they used. Mean age of anti-fouling paint was 23 months, 37% of boaters reported having applied paint within the previous 12 months. There was variability across marinas in mean age of antifouling paint on recreational vessels and mean age of paint on fishing vessels (Fig. 2.16); differences between groups were not statistically significant.

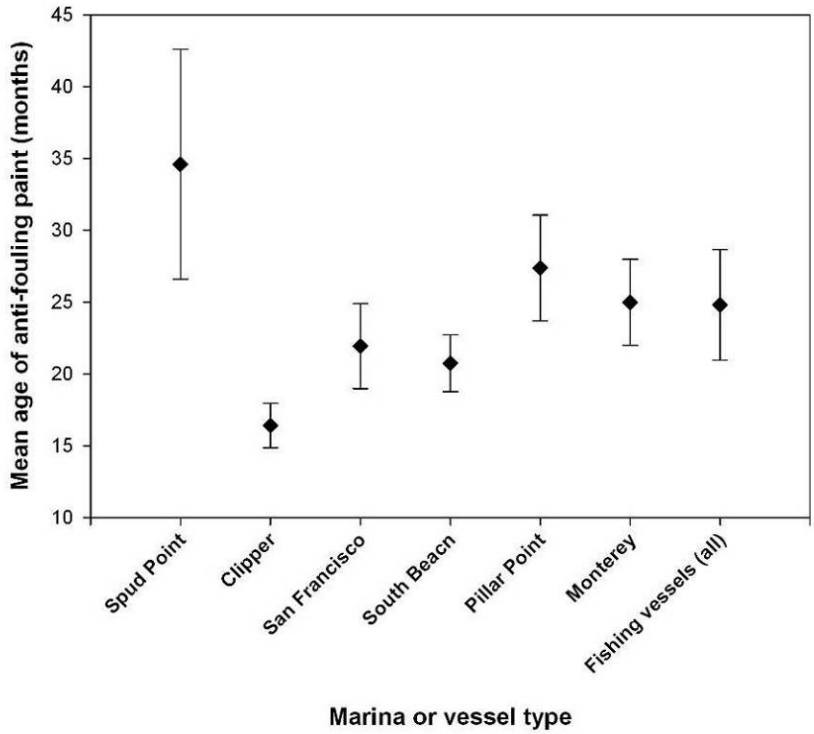


Figure 2.16 Reported mean age of antifouling paint by marina (recreational vessels only) compared with fishing vessels (all marinas combined). Bars are standard errors.

Ninety-two percent of boaters cleaned their boats in-water between anti-fouling paint treatments; the remainder cleaned out of water on a trailer or a boat yard. Ninety-three percent of boaters had either applied anti-fouling paint or cleaned their boats within the previous 12 months; mean time since last cleaning was 5 months. Differences between marinas for mean time since last hull maintenance were statistically significant (one-way ANOVA, $F = 8.26$, $P < 0.001$, $df = 6$, Tukey's post hoc, family level at alpha 0.05). Recreational boats at Pillar Point had gone longer without hull maintenance than those at other marinas, but were not different from fishing vessels in terms of maintenance intervals. Clipper and South Beach marinas had shorter hull maintenance intervals than fishing vessels as a group (Fig. 2.17). Owners that described no hull maintenance in the past four years included one who raised his boat on a floating support whilst at dock and a further vessel that described in-water cleaning by diver, but did not give a date.

Many of the vessels that were used most frequently were also maintained within the past 2 years, but there were plenty of exceptions, and there was no correlation between hull maintenance and boat use (Pearson's Correlation, P = 0.26). Most vessels surveyed made less than 25 trips a year (Fig. 2.18).

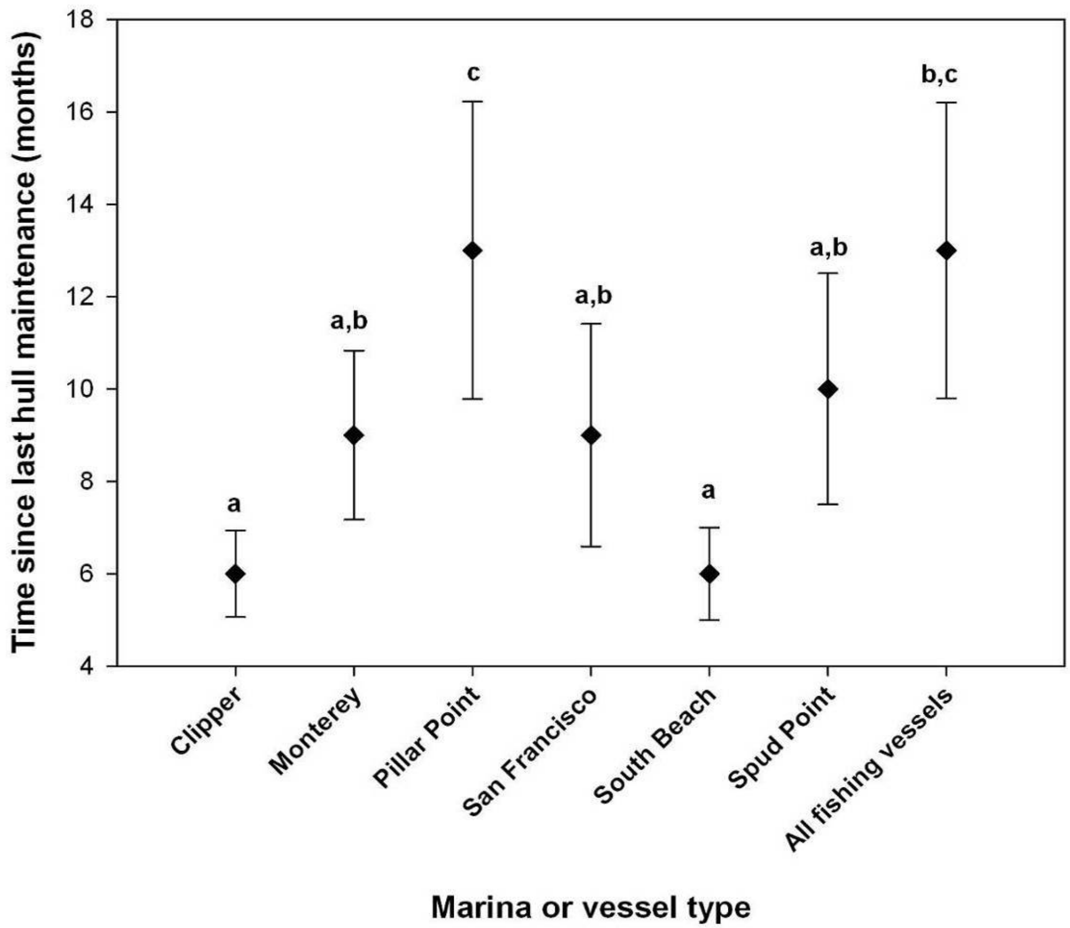


Figure 2.17 Time since most recent hull maintenance (either cleaning or antifouling paint application) for recreational craft by marina and all fishing vessels combined. Bars are standard error. Letters indicate groups that are different from one another.

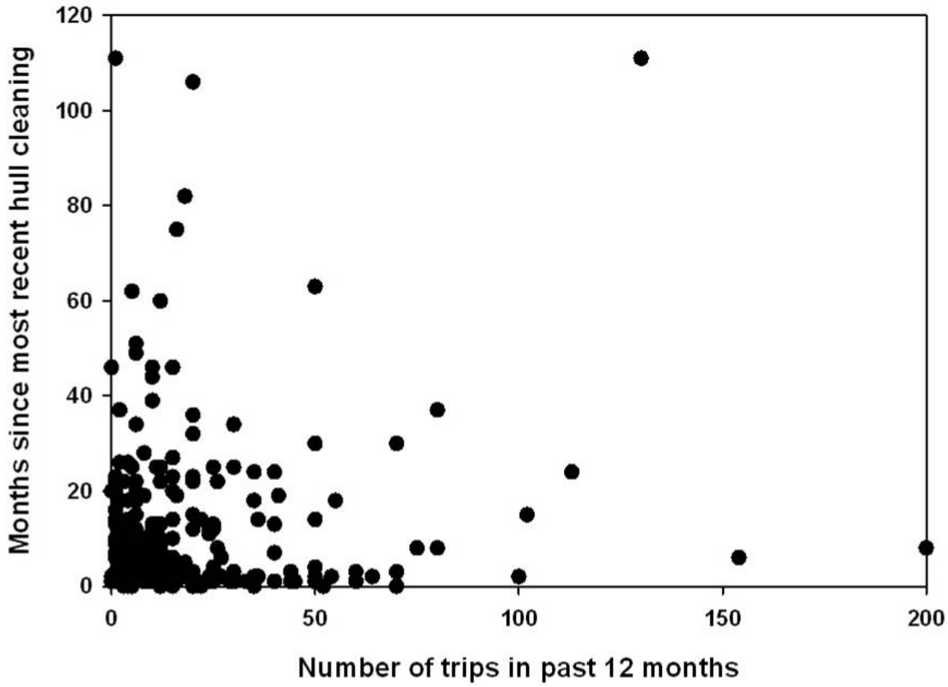


Figure 2.18 Number of trips in past 12 months made by vessels with different hull maintenance histories Time since last hull maintenance (antifouling treatment or cleaning, whichever was most recent) plotted against frequency of use.

2.3.2.2 Level of Fouling Rankings

Level of fouling ranks (LoFs) were recorded for 2,254 vessels at berth. LoFs varied between marinas inside and outside of San Francisco Bay and among each marina. For the three marinas within SF Bay (n= 1,483), the highest percentage of boats (29%) were ranked level 2; the remainder of the boats were more or less evenly distributed within the other ranks, with slightly higher numbers for levels 3-5 (Fig. 2.19). Boats in the three marinas outside of SF Bay (n = 771) were on the whole more fouled than those in the Bay (chi-square = 93.14, df = 5, P < 0.0005). Rank level 5 had the highest percentage of boats in these marinas (29%), and a lower percentage in level 2 (17%) compared with the SF Bay boats (Figure 2.19).

Compared with earlier studies, including a previous study of six SF Bay marinas (Davidson et al. 2008b), percentages of heavily fouled vessels, particularly for the three marinas outside of SF Bay were high (Fig. 2.19), although the percentage of very clean vessels (level 0) was also higher.

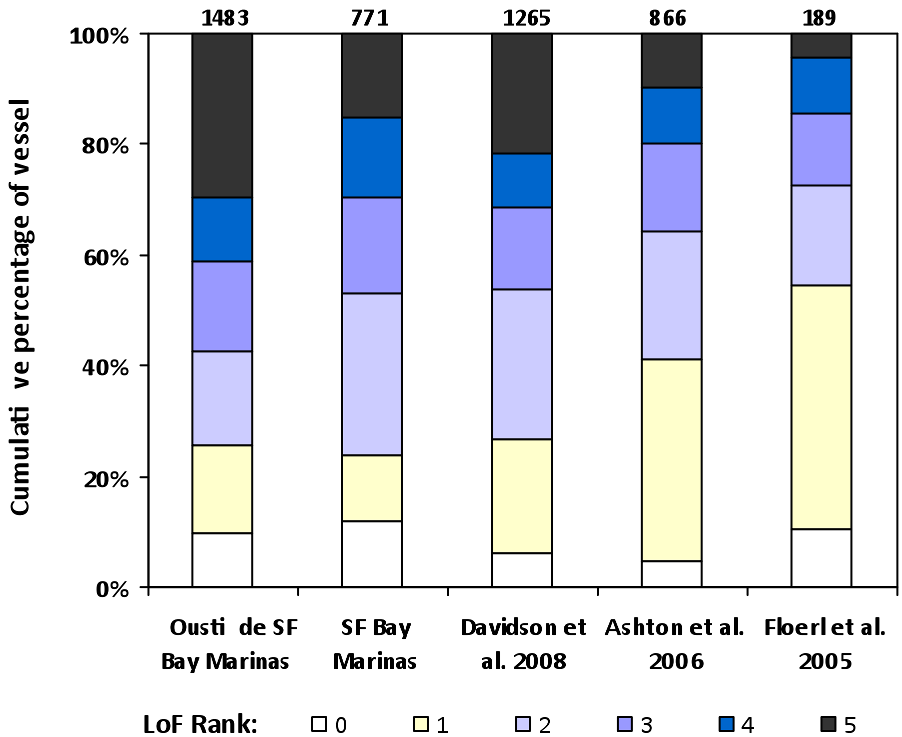


Fig 2.19 Percentage of vessels observed in each level of fouling rank from current study and three previous studies (see text for details). Numbers above the plots show N values.

On a finer spatial scale, levels of fouling varied substantially across marinas (Fig. 2.20). Spud Point and Pillar Point had the highest percentage of heavily fouled boats (42.9% and 42.3% respectively at level 5). Only one vessel at Spud Point was ranked at 0; only 5.6% of vessels at Pillar Point were level 0. Outside of the SF Bay, Monterey had the highest percentages of clean boats, with 17.4% and 23.4% of vessels at levels 0 and 1 respectively. Marinas inside SF Bay also had a high percentage of clean boats at levels 0 and 1 (16.2% and 8.6% respectively).

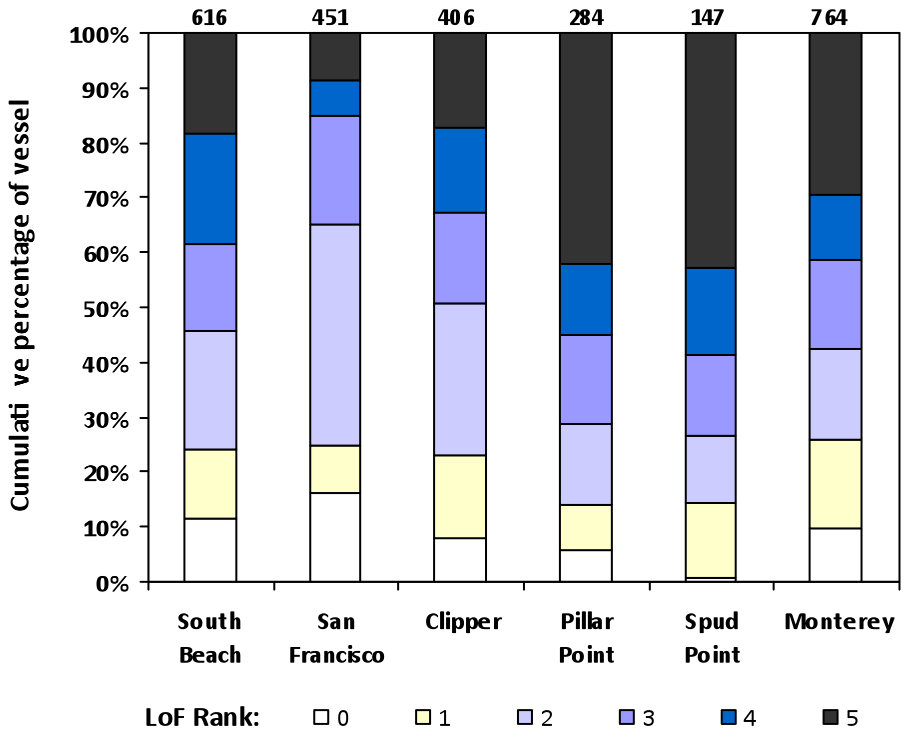


Figure 2.20 Percentage of vessels observed in each level of fouling rank at all marinas in the current study. Numbers above the plot are N values.

2.2.2.3 Video analysis

We recorded video transects on 122 vessels using the handheld pole cam. Nearly all of these were active vessels which had traveled recently (either inside or outside of their home bay) and for which we had hull husbandry data.

To test the relationship between the dockside LoF ranks and observed macrofouling, we used these video images to generate LoF ranks based on percent cover of macrofouling and compared these to dockside LoFs. Dockside LoF ranks were strongly correlated with in-water LoF ranks but only explained about half of the variability in in-water LoF ranks (least squares regression, $R^2 = 0.50$, $P < 0.0005$, Fig. 2.21). They were even poorer predictors of percent cover ($R^2 = 0.40$, $P < 0.0005$, Fig. 2.23). Very clean vessels were accurately ranked, but vessels ranked from 2 to 5 had a wide range of actual cover.

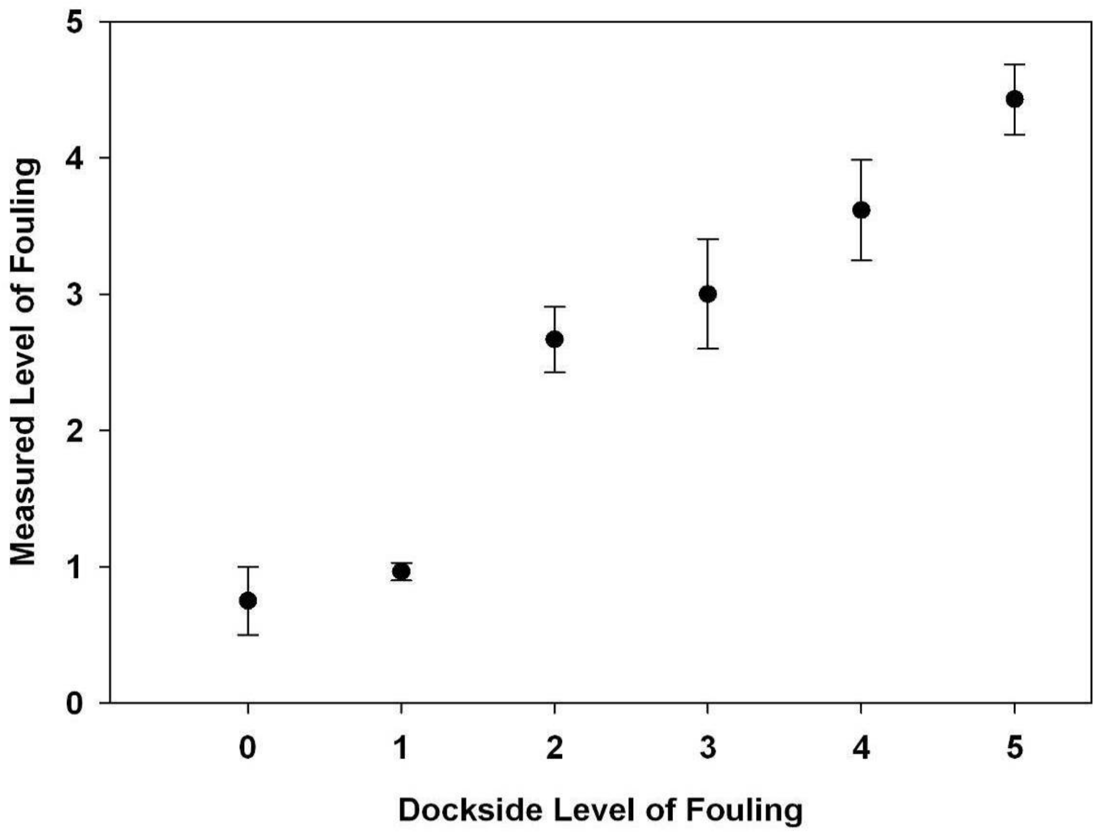


Figure 2.21 Mean measured LoF for vessels placed into the six LoF categories based on dockside observations. Bars represent standard errors.

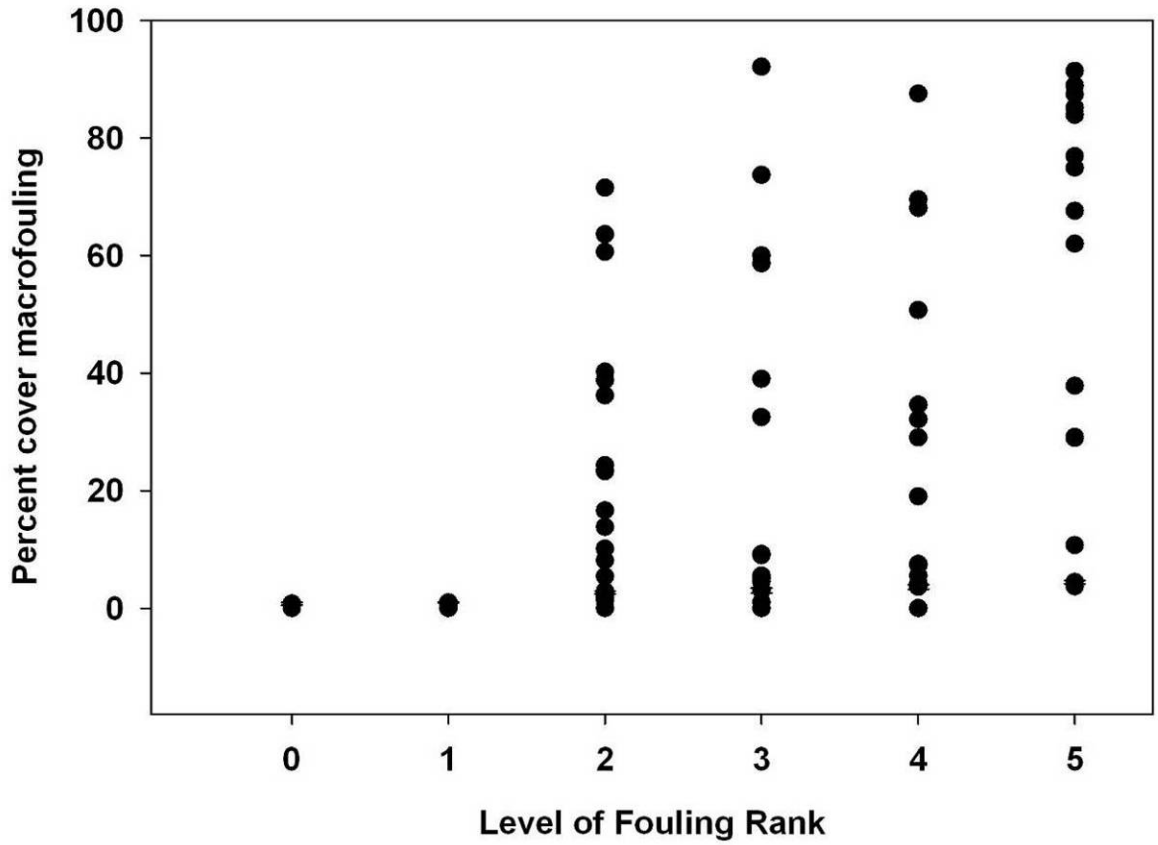


Figure 2.22 Percent cover, estimated from underwater videos plotted against the Level of Fouling rankings made from dockside. Individual boats are shown in this plot to illustrate variation in the relationship between dockside LoF ranks and percent cover on a per-boat basis.

We used a multiple regression test to determine whether percent cover of fouling could be explained by 1) age of paint 2) time since most recent hull cleaning, or 3) number of voyages taken in the past year. Each of these factors were correlated, but none (either singly or combined) explained more than 12% of the variability in fouling cover.

There was no difference in taxonomic richness or percent cover between transects at the waterline and deeper transects. However, the stern appendages had significantly higher taxonomic richness compared to the hull transects (one-way ANOVA, $F = 20.460$, $P < 0.0005$, $df = 2$, Tukey's post hoc with family level at alpha 0.05; Fig. 2.23). This was likely because of increased prevalence of invertebrates and red and green macroalgae in the stern appendages (Fig. 2.24).

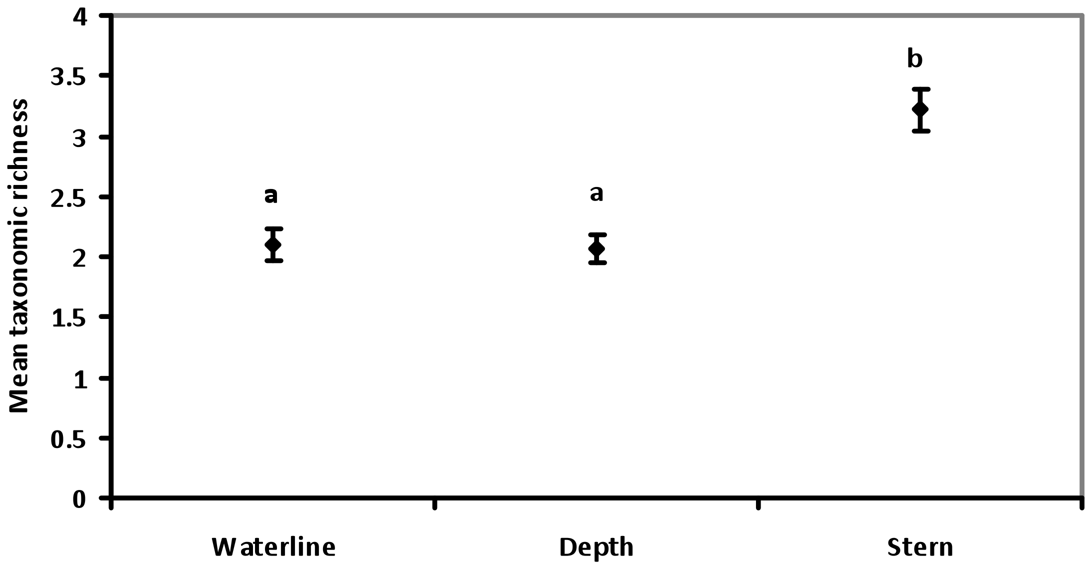


Figure 2.23 Mean (+/- SE) taxonomic richness for the hull transects and stern appendages. Letters above error bars indicate statistically significant differences between groups (N = 122).

All 20 taxonomic groups were recorded from videos of boat hulls. Hull fouling taxonomic richness on a per-boat basis ranged from 0 to 15 and varied by marina. Boats in South Beach and Monterey had the lowest number of taxa, with means of 2.9 (±0.25 SE) and 3.3 (±0.40 SE) taxa per vessel, respectively. Half Moon Bay boats had the richest assemblages with a mean of 6.1 taxa per vessel (±0.78 SE). The difference in taxonomic richness between Spud Point and Pillar Point was statistically significant (one-way ANOVA, F = 4.15, P = 0.002, df = 5, Tukey's post hoc with family level at alpha 0.05, Fig. 2.24).

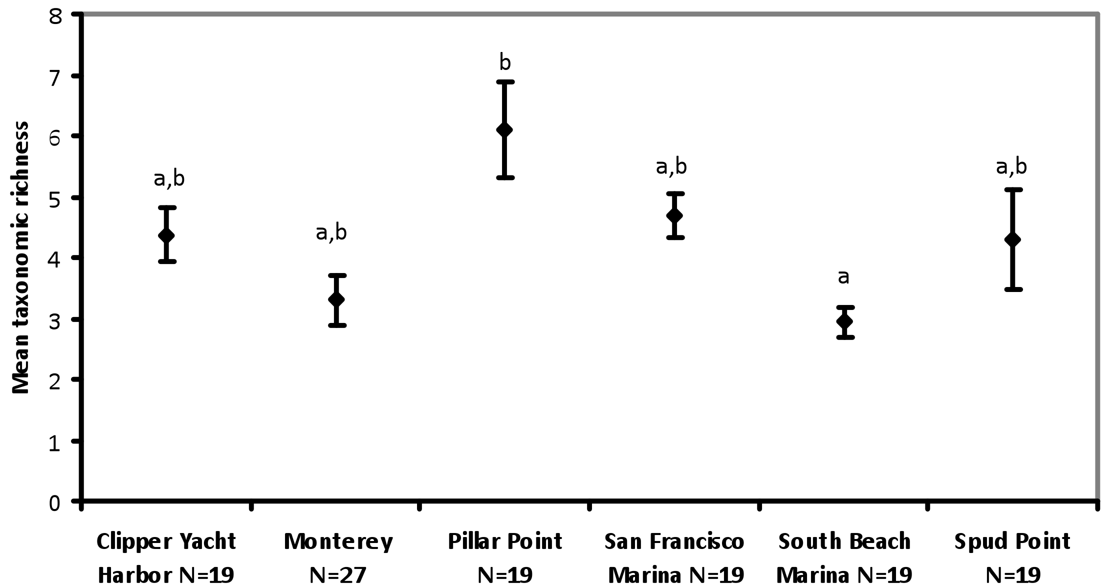


Figure 2.24 Mean (+/- SE) taxonomic richness per vessel (total N = 122). Letters above error bars indicate statistically significant differences between groups.

Biofilm was the most widely occurring taxonomic category among the 122 vessels surveyed, followed by amphipod mud tubes and detritus (Fig. 2.25). Green macroalgae and caprellids were found on ~30% of stern appendages, appearing less commonly elsewhere on vessels. Red macro algae and soft fouling species in general (tunicates, sponges and hydroids) appeared to be more prevalent on stern appendages than on the boat sides. Beyond the stern appendages, these groups and all other taxa were found on less than 10% of surveyed vessels.

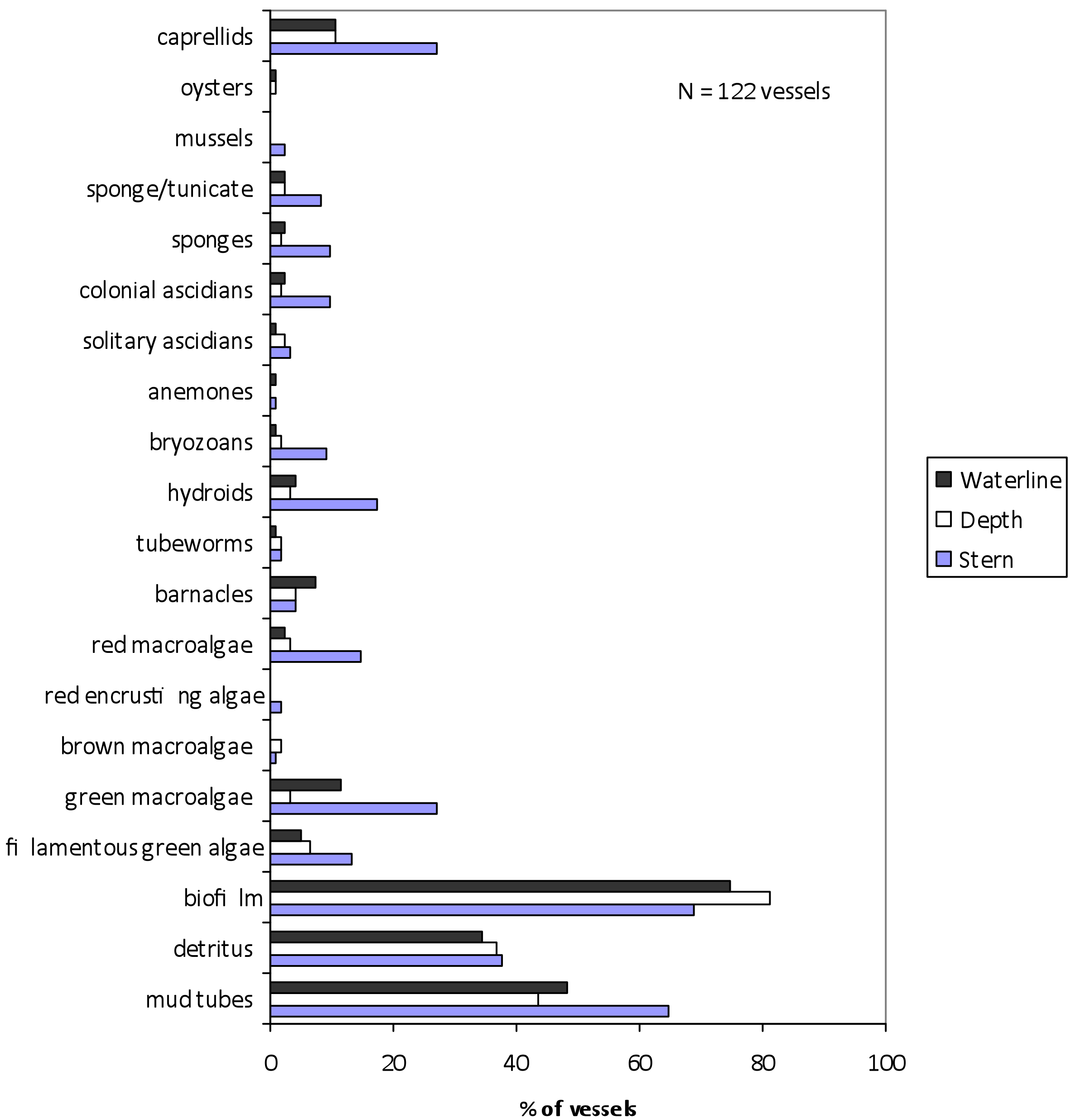


Figure 2.25 The prevalence of taxonomic groups on the hulls and stern appendages of vessels in this study. The occurrence of 20 biofouling taxa (taxonomic groups) was plotted as a percentage of the total number of vessels (122) surveyed using the pole cam. Prevalence is shown for stern appendages (purple bars), waterline hull transects (black bars) and bottom depth hull transects (white bars). The category "sponge/tunicate" was used when it was not possible to distinguish between these phyla in the photographs. Detritus was used to describe a flocky, light-colored coating on vessels that was easily removed with the framers of the pole cam (biofilm was more firmly attached to the hull surface). It appeared to be biogenic and was perhaps degenerated amphipod tubes. Mud tubes were three-dimensional structures with an apparent entrance/exit, but the organism associated with the structure could not be determined (e.g., amphipods, polychaetes etc). The sponge/tunicate category was used in cases where we could not make a distinction between these two phyla.

The most prevalent groups across all marinas were biofilm, amphipod tubes and detritus (Fig. 2.26). Red macroalgae and caprellids were the only other groups found across all study marinas. Mussels were found in only one marina (Pillar Point). Three species were found only at two marinas: oysters (San Francisco and South Beach), anemones (Pillar Point and Spud Point), and brown macro algae (San Francisco and Monterey). Pillar Point was the taxonomically richest marina, with high numbers of green macro algae, filamentous green algae, the sponge/tunicate category, and hydroids.

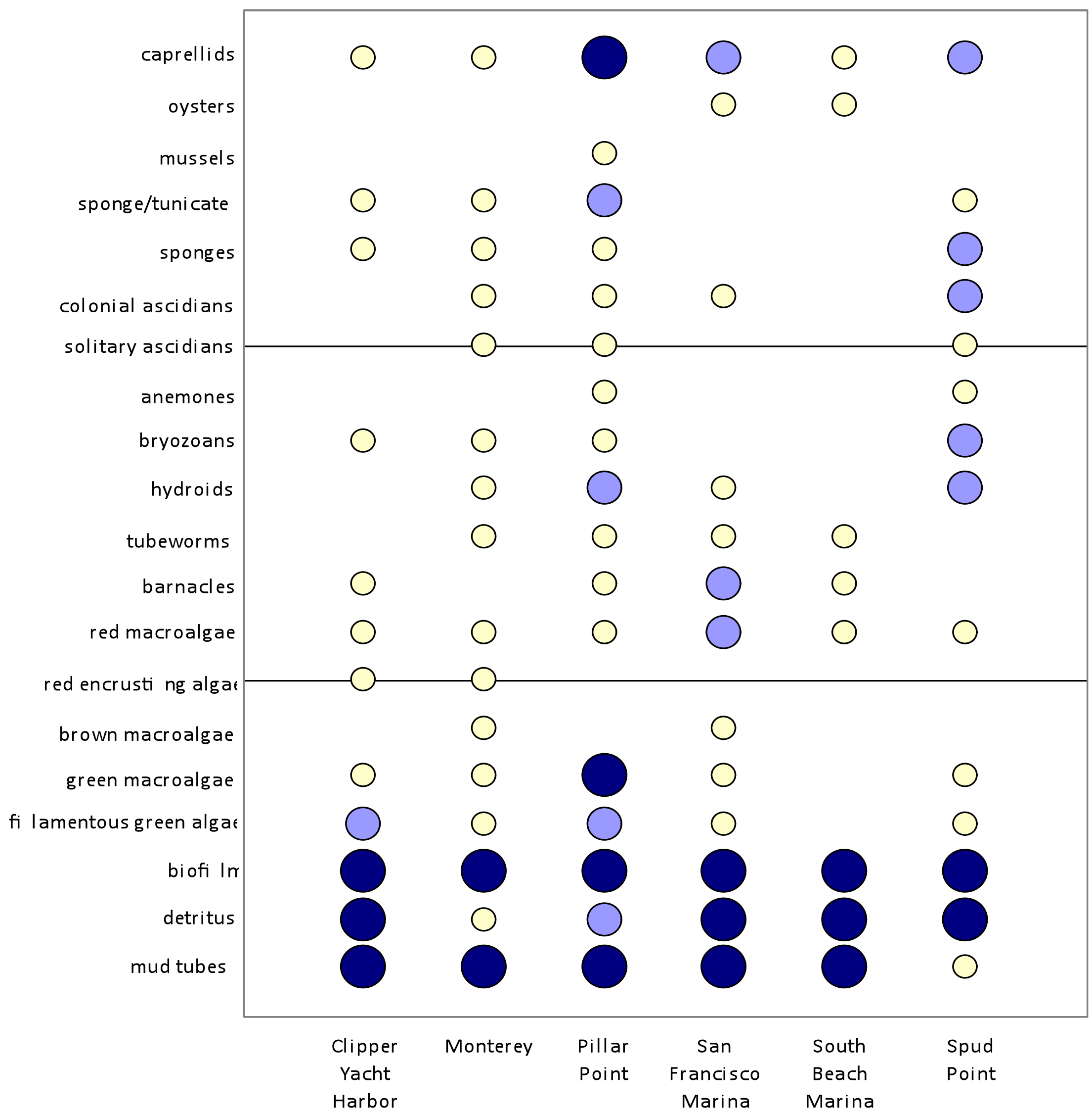


Figure 2.26 Occurrence of taxa on vessel hulls among marinas. The occurrence of 20 taxa is plotted for each of six marinas with dot size and color representing rare, frequent and abundant occurrence of the taxon across vessels.

2.3.2.4 Sampled hulls

Based on in-water collections, specimens were examined from thirty-four vessels (21 from Monterey Harbor and 13 from South Beach Marina), which we knew from boater surveys were in use. Thirty-three taxa were identified from these samples. We were able to identify 17 organisms to species level; eight of these are not native to Central California (Appendix E). Bryozoans, tunicates, polychaetes and arthropods were the richest taxa (Fig. 2.27).

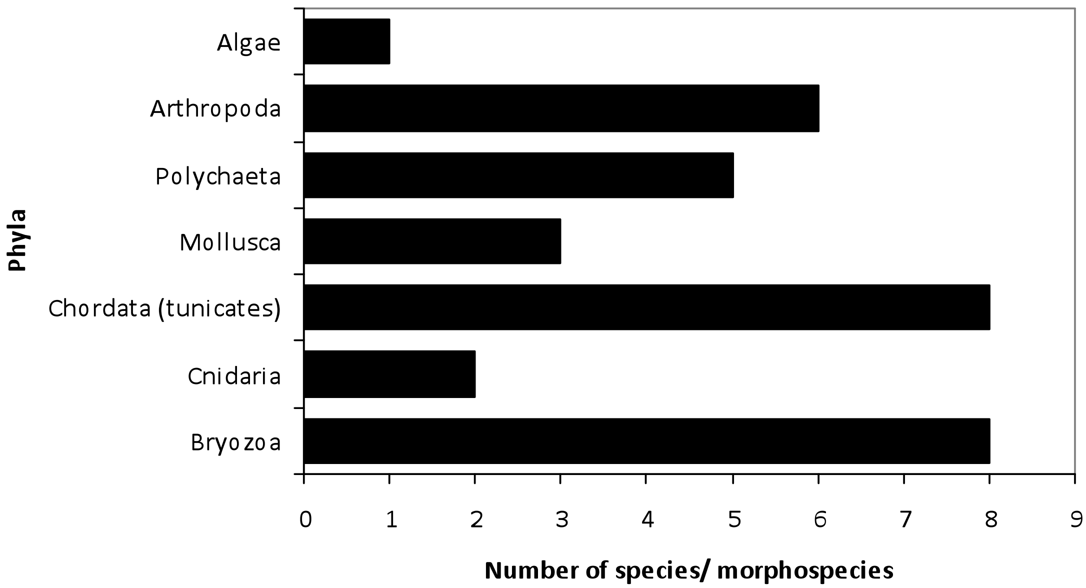


Fig. 2.27 Number of species by phyla from hulls of active boats in Monterey and South Beach harbors.

2.4 Discussion

Small-vessel traffic volume and patterns

Boats kept continuously in saltwater, such as those at our focal marinas, are likely to pose a greater potential risk of accidental species transfer than boats that are kept on land and moved on trailers, due to differences in the time available for colonization and susceptibility to desiccation for many species. However, nearly half of the boaters we surveyed take their boats out fewer than once a month, and over 80% of boaters made trips exclusively within their home bays, suggesting that most of the small vessels in our study represent a relatively low likelihood of mediating transfers across bays.

A minority of vessels do travel outside of their home bays and these may represent a substantial cumulative volume of traffic. One hundred and seventy-two outside trips were reported by ~300 boaters from six marinas who responded to our questionnaire. Between 600 and 800 visiting boats stayed overnight annually at the marinas for which we were able to obtain data. Given that there are more than 85 marinas in the San Francisco Bay estuary alone, this suggests that there are tens of thousands of trips made between bays in the area each year.

In contrast to the majority of boats, which don't move frequently and rarely leave their home bays, some vessels are quite active. In our study, six boat owners reported making over 100 trips in the past year; nine boaters alone were responsible for all of the 71 out-of-bay trips reported by boaters at Spud Point. If these very active vessels are fouled, they certainly pose a high risk for species transfer.

California boaters, most of them from the San Francisco Bay Area, were the overwhelming majority of visitors to local marinas. However, the few Customs records we reviewed and the visiting-boater data gathered from marinas revealed a strong connection between Central California marinas and many points along the US and Canadian West Coast, along with weaker connections to elsewhere in the Pacific and the Atlantic. During a cruising season, these vessels, if they are fouled, could potentially inoculate multiple harbors as they travel along the coast.

The questionnaire data and visiting-boater data both indicate a strong link between San Francisco Bay and the three study bays. San Francisco boaters who traveled outside of SFB indicated that Pillar Point Harbor was their top destination, Monterey Harbor was the third most-visited site and Marin County bays (Drakes, Tomales, Bodega) were also frequented. Boaters from Monterey and Pillar Point harbors indicated that San Francisco Bay was their top destination for trips outside of their home bays. While we had to make some assumptions about the origins of the boats based on boat-owner's home addresses, the data collected from visiting-boat records corroborate the survey data. Visiting boat records indicated that SFB boaters made up nearly three-quarters of the visitors to Pillar Point, slightly less than half of the visitors to Monterey Harbor, and half of the visiting boats at Spud Point Harbor. Given that SFB is highly invaded (Cohen and Carlton 1995), taken together, these data underscore that considerable opportunity exists for transfers of non-native species by small boats. Such a connection has previously been hypothesized based on the similarities in the non-native fouling fauna between San Francisco Bay and nearby small harbors (i.e. Cohen and Carlton, 1995, Wasson et al. 2001).

Most vessels in our study that made trips away from home stayed only 1-2 nights away. Short stays may reduce the likelihood of species transfer. However, in each marina, a minority of boats stayed away for a week or more, increasing the chance of both discharging and gaining additional fouling species. A few boaters reported stays of several months away from home. These boats certainly represent a high risk of species transfer if they are not cleaned before returning home.

While our sample size is not large, it appears that as a group fishing vessels may travel more frequently outside their home bays than do recreational vessels, and stay longer in other bays. This warrants further investigation, as it may indicate that fishing vessels may pose different opportunities for species transfers than do recreational vessels. We also note here that although we are aware that the fishing fleet in Monterey travels to Southern California yearly, this was not reflected in the questionnaires returned to us by the fishing vessels, leading to an underestimation of the amount of inter-bay travel by the fishing fleet. This underscores the need to interpret data carefully and to attempt to gather information using several different approaches (such as a combination of boater questionnaires, commercial fishing data and visiting boat information gathered by harbors).

Within the state, 80% of boats are kept at home and moved via trailer (California Department of Boating and Waterways 2002). However, our respondents used trailers infrequently. While there is some overlap, it appears that boats kept in saltwater may represent a separate population from trailered boats. Patterns of hull husbandry and movement, and thus risk of spreading invasive species may not be the same between these two groups of boats. The majority of boats in the state are also motorboats (California Department of Boating and Waterways), while most of the respondents in our study were sailboats. There may also be some differences in behavior and thus degree of risk between these boat types.

Hull Fouling

In the above section, we have identified certain types of boat behavior as potentially high or low risk for the transfer of invasive species between bays. Of course, the abundance, richness and composition of fouling on a vessel are also important variables in the evaluating the likelihood of invasions.

While many of the boats that traveled most frequently were also the most frequently maintained, there were examples both of clean boats that rarely moved and fouled boats that are active. Of particular concern are vessels such as the one in our study that hadn't been cleaned for nearly 10 years, which had made 140 trips in the previous year. While this individual is clearly an outlier (Fig. 2.18), several other boats that hadn't been cleaned for more than 2 years were reporting 50+ trips a year.

Overall, there appear to be more boats in the high LoF ranks in Central California than in other locations (Floerl et al. 2005a, Ashton et al. 2006) and as a group, boats in the three outer coast harbors had greater fouling than those in SF Bay. Why this would be is not clear; SF Bay experiences more frequent periods of lowered salinity than the outside harbors, which might reduce cover of certain organisms, although Clipper and San Francisco marinas are close to the mouth of the bay and as a result are more oceanic than most other marinas in SF Bay. Boats at Pillar Point had been cleaned less recently than at other harbors, and although this was not statistically significant, there was a trend toward less recent maintenance at Spud Point as well. This might account for some of the differences in cover, although cleaning intervals are only one factor influencing fouling.

In fact, in our study, time since last cleaning and vessel activity did not serve as good predictors of level of fouling for individual vessels. As anti-fouling paints and interim cleanings are the main methods used by boaters to prevent and remove fouling, this is a surprising result. In our case this outcome may have been influenced by the fact that we did not capture much variation in paint age (most boats had been painted within the previous 2 years) or time since last cleaning (most had been cleaned within 1, 2 or 3 months) and we only had complete information for 39 of these vessels photographed for analysis. However, Davidson et al. (2008b) came to the same conclusion using vessels with more variation in cleaning times. Inglis et al. (2010) have shown that the factors that can influence fouling are very numerous and attaining adequate sample sizes to determine predictors is very difficult. Further research into the connections between these variables and others in the degree of hull fouling will clearly be important for the development of effective management recommendations.

Biofilm, mud tubes (likely made by amphipods) and detritus (mostly dislodged but still sticky bits of amphipod tubes) were the three largest space occupiers on the hulls of vessels we surveyed. Filamentous green algae, sponges, tunicates and bryozoans, all common elements of fouling communities, made up a relatively small percent of the total fouling cover. With the exception of the prevalence of biofilm, this contrasts with taxonomic composition reported by Davidson et al. (2008b) who did not report mud tubes or the resulting detritus and who found tunicates, bryozoans, sponges and green algae in greater abundance. Some differences are to be expected between these studies, as composition varies by marina (Floerl and Inglis 2005a, Davidson et al. 2008b, 2010, this study). It is also likely that compositional differences are seasonal, as our sampling occurred in spring and that of Davidson et al. in late summer and fall. In Central California, the fouling community generally reaches peak cover and richness in the summer to early fall and decreases in both richness and cover over the winter (personal observations). Thus risk of spreading invasives in this region might be higher in the late spring to early fall months, when boaters are also likely to be traveling the most.

The ability to screen arriving vessels for fouling is potentially an important tool for managing the risk of invasive species. Unfortunately, the dockside ranking method does not appear to work well in Central California as a way to quickly assess fouling levels on a given vessel. Some of the overestimation of cover might be due to the fact that fouling species richness and cover was higher on stern appendages than on the hull surfaces themselves and transects were done using the hull surfaces only. These surfaces are generally not treated with anti-fouling paints, are harder to clean than hulls, and provide "niche" areas protected from shear forces that might remove attached organisms while the boat is underway. Many boaters use a long-handled brush from dockside to clean their boats. It is possible that some vessels that appeared clean at the waterline and were thus given a low LoF rank were actually fouled below, leading to underestimates of below-water cover. Nevertheless, it is clear that in the murky waters of the Central California coast, above water inspections are not sufficient for determining whether individual vessels are free from biofouling.

Section 3. The Asian kelp *Undaria pinnatifida*: a case study of a vessel-mediated invasion

3.0 Background

The non-native Asian kelp *Undaria pinnatifida* is a quick-growing, opportunistic species that poses a threat to both boating operations and natural ecosystems. An aquaculture species in its native range in northeastern Asia, it is an invader in multiple locations throughout the world. Transfer via boat hull fouling is implicated in many of these invasions (Forrest et al. 2000, Silva et al. 2002, Thornber et al. 2004). *U. pinnatifida* can be a serious fouling pest, growing up to 6 feet in length within two months. Unlike many other invasive species that are limited to sheltered areas, *U. pinnatifida* also thrives in semi-protected locations. *U. pinnatifida* has spread into natural settings (including kelp forests on Catalina Island, J. Smith, pers. comm. May 2009) where it poses a potential threat to native algae and the ecosystems that depend on them.

U. pinnatifida arrived on the US West Coast in 2000, appearing first at the Los Angeles/Long Beach harbor (Silva et al. 2002). It quickly spread to other harbors and marinas in Southern California, reaching as far south as Ensenada, Mexico and as far north as Monterey by 2002 (Silva et al. 2002, Aguilar-Rosas et al. 2004). In May 2009, the first reported populations of *U. pinnatifida* north of Monterey were found during the course of this study at Pillar Point Harbor (Half Moon Bay) and at San Francisco and South Beach Harbor marinas (Zabin et al. 2009). In each location where the kelp was found, the population appeared to be limited to 1-2 docks, but included many large, reproductive individuals.

The discovery of these new populations of *U. pinnatifida* represents a significant northern range expansion. The potential establishment of this species in SF Bay, a major hub of both recreational and commercial boating activity, is of serious regional concern for increasing its spread to other estuaries. *U. pinnatifida* can thrive in a wide range of physical conditions and could survive along the entire US-Canadian west coast at least as far north as Southeast Alaska.

We implemented a rapid assessment to determine the distribution of *U. pinnatifida* within San Francisco Bay. Additionally, we launched a removal program for the three marinas, working with volunteers from a number of agencies and non-profit organizations. Additional funding for the removal efforts, to further delineate the San Francisco Bay population, and to carry out education and outreach, was provided by the San Francisco Regional Water Quality Control Board and the Alexander and Elizabeth Swantz Endowment at UC-Davis. This effort is currently ongoing. In this section, we summarize work through May 2010 (although we include the most current map of the extent of the population in San Francisco, as of November 2010.)

A major limitation to the monitoring and management of *U. pinnatifida* is the difficulty of detection and identification of the microscopic gametophyte stage. Genetic methods in the form of molecular probes have shown some promise in the early, rapid and accurate detection of microscopic organisms, including algae in ballast water (Patil et al. 2005) and larvae in plankton samples (Deagle et al. 2003; Darling and Tepolt 2008). We investigated the feasibility of using molecular methods as a tool for the detection of microscopic life stage of *U. pinnatifida* in hull samples.

3.1 Methods

Over the course of the past year and a half, we completed rapid assessments of marinas and the San Francisco Bay waterfront extensively for additional populations. Surveys involved 2-3 people walking the entire marina, examining every boat at berth and looking along the edges and ends of each slip for *U. pinnatifida.* As a sporophyte, *U. pinnatifida* is quite distinct from other macroalgae native to San Francisco Bay, particularly in the reproductive stage, when the blade is divided into pinnae and the convoluted sporophyll is present. Smaller individuals were identified using color, shape, texture and the presence of a midrib. We began by searching marinas and maritime structures along the SF waterfront between the two known points of introduction, and continued surveys targeting marinas in the Central Bay where physical conditions would be most favorable for *U. pinnatifida.* We resurveyed some of the sites checked earlier in this study. We also checked Spud Point in the course of our other planned work there. Most of the hard substrate in Tomales Bay was surveyed by a colleague from the USDA in the summer of 2009.

Regular removals of the invasive kelp began in the fall of 2009. We were able to work monthly to semi-monthly at San Francisco and South Beach marinas, but due to logistical difficulties went to Pillar Point Harbor less frequently. Work in San Francisco Marina was limited to the East Basin (the kelp was not found in the West Basin during the study period). The population at South Beach Marina expanded rapidly and we were typically only able to work 2-4 docks per removal event, depending on staff availability. We focused our effort there on the two docks where the kelp was first seen and where it was most abundant, removing kelp from additional docks when we were able. The entire marina at Pillar Point was surveyed on each occasion.

We removed all algae visible from the dockside and were aided on some occasions by divers. Each alga was measured (length from holdfast to end of blade) and its reproductive status was noted. T-tests were used to determine whether there were differences between mean length at the start of removal efforts and 12 months later. We scored an alga as reproductive if it had developed a sporophyll, as non-reproductive if no sporophyll was present, and as developing if the stipe margin had developed scalloped edges, but had not begun to curl in on itself.

The ribosomal internal transcribed spacer (ITS) region has been studied extensively in the context of Laminariales phylogenetics (Yoon et al. 2001; Saunders and Druehl, 1993). Compared with commencing work on a new region, the availability of information generated by prior studies gives a substantial foundation for developing and testing the suitability of this region for molecular analyses. In addition, previous work in Tasmania demonstrated that a molecular probe within the ITS region was able to discriminate between *U. pinnatifida* and native Laminariales there (Hayes et al. 2007). We know of no prior assessment of the ITS region as a molecular tool for the non-native species in California.

The species-specific primers Undar102F (5' GCGCCTCGCCGAGGGTTAATTC) and Undar492R (5'TGCACTCGGAGCGCGGAC) were designed using sequences lodged in GenBank (www.ncbi.nlm.nih.gov/Genbank). These primers are located in the ITS 1 and 2 regions of the ribosomal DNA (Undar102F in ITS1 and Undar492R in ITS2) and cut a 390bp fragment. The primers were verified using a sample known to be *U. pinnatifida* from Monterey and the native kelp, *Macrocystis pyrifera* was used as a negative control. PCR products were confirmed by electrophoresis in a 1% agarose gel.

3.2 Results

To date, 49 locations in San Francisco Bay have been surveyed at least once for *U. pinnatifida;* the kelp was present at 8 of these (Fig. 3.1). Of the locations surveyed more than once, Pier 40 (which is immediately adjacent to South Beach Marina) was the only one where we did not detect *U. pinnatifida* in initial surveys but did subsequently find it. We did not find *U. pinnatifida* in Tomales Bay or Spud Point. Colleagues who have surveyed Santa Cruz and Moss Landing harbors have not found it in either location.

Individuals were found attached to boats, floating docks, fixed seawalls and other maritime structures, ropes, floats and other sessile fouling organisms. Several cohorts were evident at all locations, with individuals ranging from over 3 m to less than 2 cm, and reproductive individuals represented 10-70% of all individuals collected at infected sites.

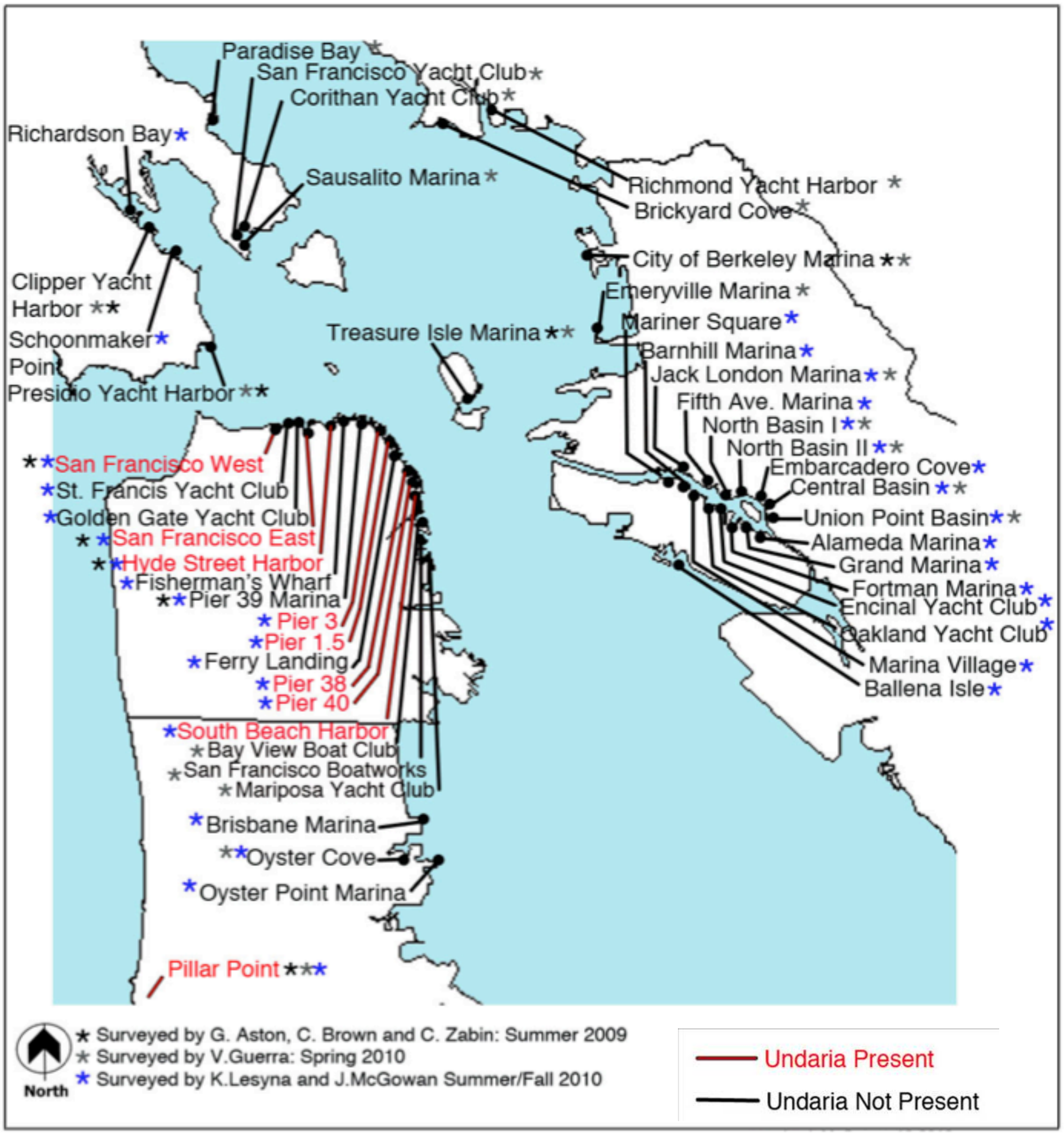


Figure 3.1 Map of San Francisco Bay showing locations surveyed for *U. pinnatifida*. Red labels indicate presence of *U. pinnatifida* (map by Jennifer McGowan).

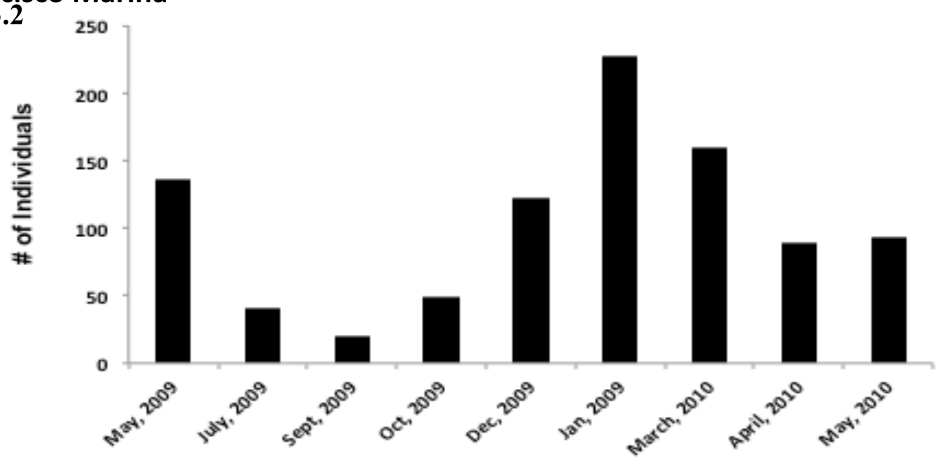
The amount of algae removed at each marina decreased by the end of the12-month period (Figs. 3.2-3.4), but at South Beach Marina, this was the result of a decrease in effort rather than a decrease in algae.

The mean size of algae decreased over the fall with a peak in the spring at San Francisco and South Beach marinas. Mean size in May 2010 was lower than in May 2009 at the two marinas we visited consistently (Figs 3.5-3.7). This difference was statistically significant at San Francisco ($t= 17$, $df = 135$, $P < 0.001$) and South Beach ($t = 5.6$, $df = 30$, $P <0.0001$). At South Beach, we used July 2009 data to increase sample size, but the decrease from May 2009, when 8 individuals were found, to May 2010 was also statistically significant. There was no difference in mean size at the end of the year at Pillar Point. The greatest number and proportion of reproductive individuals were found in September 2009 in San Francisco and July 2009 in South Beach, with lower numbers but similar proportions found in both locations in the spring months (March-May 2010, Figs. 3.8-3.9). Reproductive individuals were found on all dates except January 2010 at Pillar Point, with the greatest number and proportions on the first date we worked there in May 2009 (Fig. 3.10).

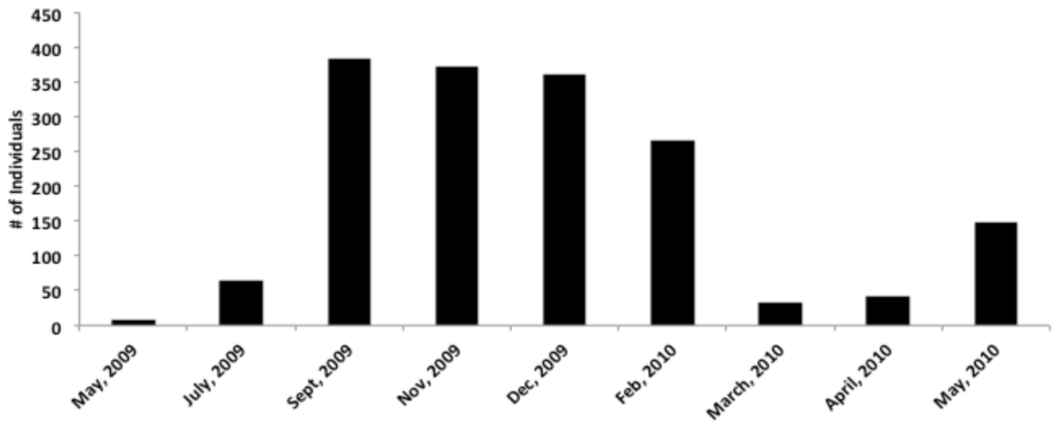
The primers successfully distinguished between *U. pinnatifida* and the native *Macrocystis pyrifera*, only giving a positive result when the former was present.

3.2 San Francisco Marina

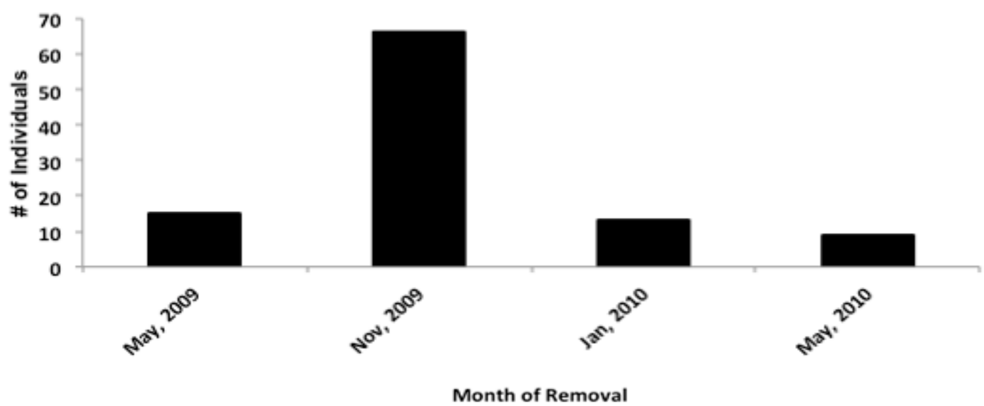
3.2



3.3 South Beach Marina

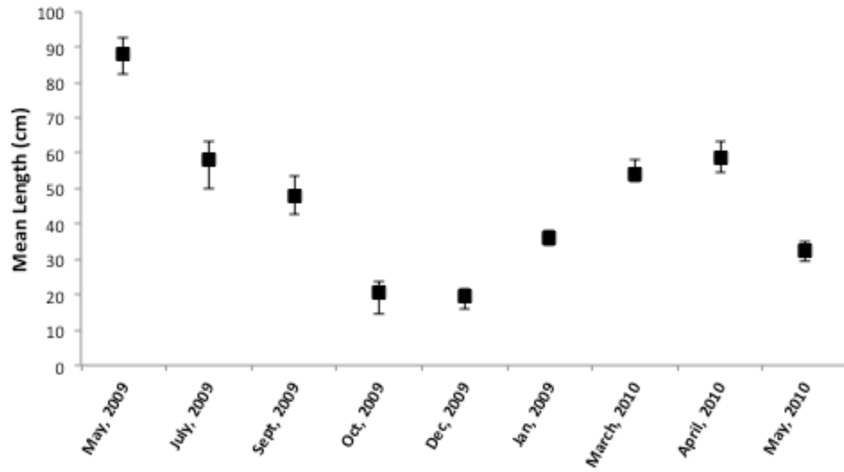


3.4 Pillar Point Harbor

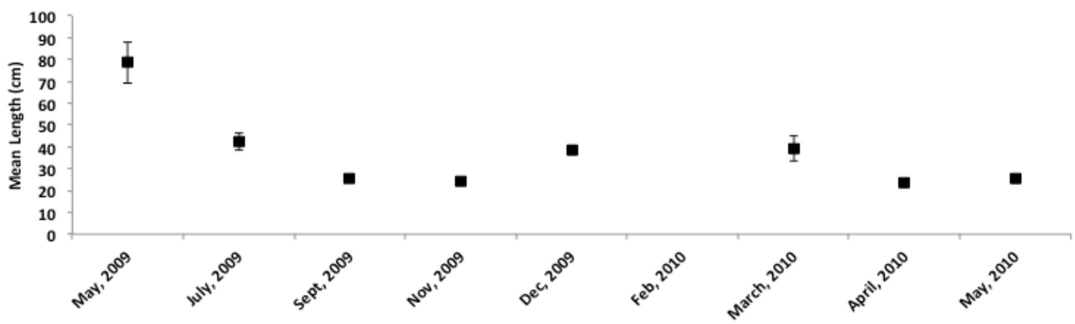


Figs 3.2-3.4 Number of individuals removed from each study marina. In some months, we collected semi-monthly in the marinas in San Francisco; data combined for ease of comparison. Note difference in y-axis scale among locations.

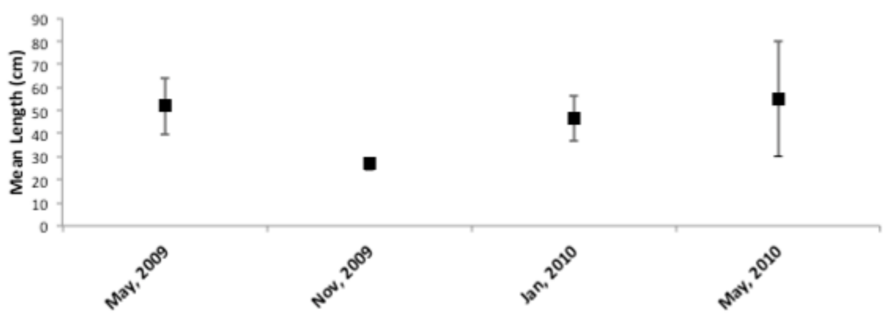
3.5 San Francisco Marina



3.6 South Beach Marina

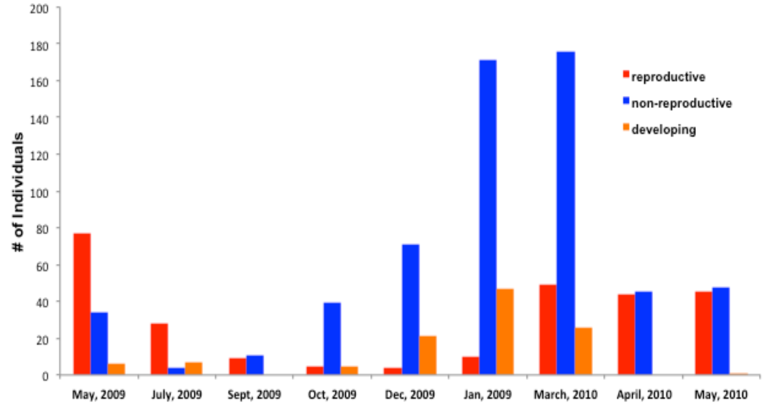


3.7 Pillar Point Harbor

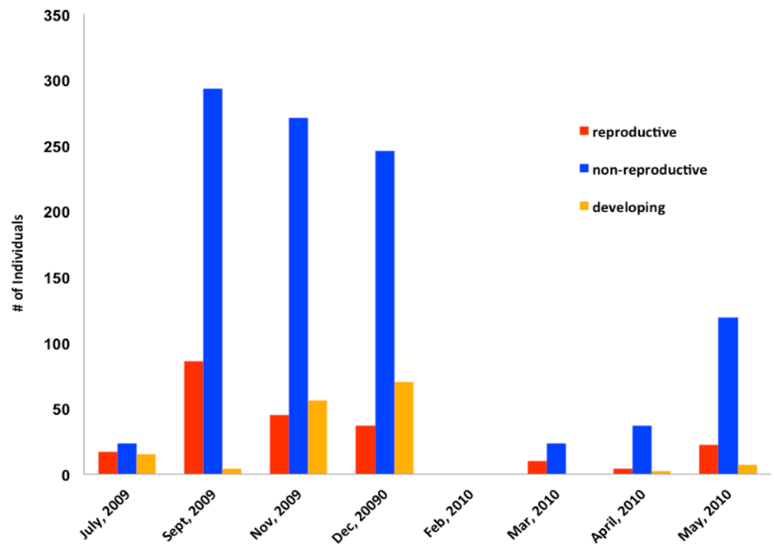


Figures 3.5-3.7. Length of *U. pinnatifida* over at the three study marinas over the course of a year. Bars represent standard error. Size data for Feb. 2010 at South Beach were lost.

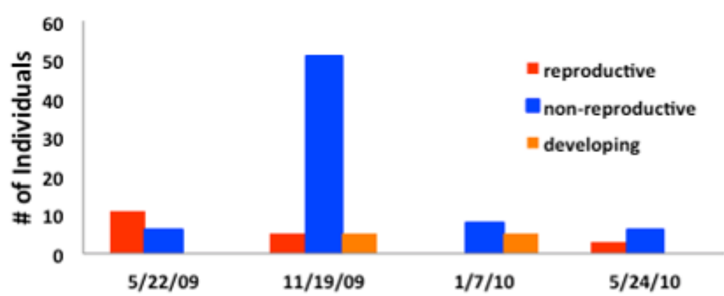
3.8 San Francisco Marina



3.9 South Beach Marina



3.10 Pillar Point Harbor



Figures 3.8-3.10 Numbers of *U. pinnatifida* with sporophylls (= reproductive) without such structures (non-reproductive) and developing reproductive sporophylls (= developing). Reproductive data for Feb. 2010 at South Beach were lost.

3.3 Discussion

Within San Francisco Bay, *U. pinnatifida* appears at this time to be restricted to the San Francisco waterfront (Fig. 3.1). The full extent of the SF waterfront population is still unknown, as many of these locations can only be accessed from the water, and we have just recently obtained boat access to more thoroughly survey these areas. At all of the marinas, the kelp distribution increased from 1 or 2 docks to multiple docks during the course of this study. However, our survey work to date indicates that *U. pinnatifida* is not yet rapidly spreading between marinas. This is consistent with observations elsewhere that natural spread occurs at distances of 10s of meters; further spread is rare unless mediated by boat traffic or other human activities.

In response to this invasion, we began regular hand removals at three infested marinas, coupled with an education campaign for boaters and others involved in water activities. Although a full discussion of this effort is beyond the scope of this report, over the past few months removal efforts appear to be reducing the number of individuals at two out of the three marinas. The data from the first year indicate an overall decrease in mean size at the two San Francisco marinas; this trend has continued at all three marinas to date, despite seasonal fluctuations. Similarly, the number of reproductive individuals has declined, suggesting that hand removals have been effective in removing the largest (and most fecund) individuals.

However, complete eradication of *U. pinnatifida* from SF Bay will likely require a sustained effort and application of additional, such as wrapping and treating structures with fresh water or dilute acetic acid. The data collected as part of this study will be used to develop a management plan for San Francisco.

Considering the strong connection between San Francisco Bay and Monterey Harbor, where *U. pinnatifida* had been for at least 8 years, it is somewhat surprising that the kelp did not appear in SF Bay earlier. This, coupled with the apparent success of removal efforts at Pillar Point and San Francisco Marina, suggests that successful inoculation events are rare, which bodes well for the possibility of eradication. A successful eradication effort will need a strong education and monitoring component to reduce the chances of re-inoculation and re-introduction.

Our results demonstrate that the ribosomal ITS region may be useful for discriminating *U. pinnatifida* from Laminariales native to California, including detection of the microscopic gametophyte stage. Before application, tests should be done using other native algae to confirm the absence of false positives using these primers; the detection limits of the technique should also be investigated (e.g., at what concentration of *U. pinnatifida* relative to background material is the method still successful). Ideally, the primers could then be applied to a portable, real-time detection system such as that proposed for analysis of non-native species in ballast water (Senapati et al. 2009). Senapati et al. do not describe how DNA could be extracted from the sample in the field, but the PCR reaction would be reduced onto a PCR-chip (e.g., Lund-Olesen 2008), followed by hybridization with the fluorescently-labeled primers. Detection of non-native species from hull fouling samples may prove to be more complex due to potential inhibition by chemicals used in antifouling paints, the large volume of material that can be found on some vessels, and the bulk of the fouling material compared to smaller planktonic organisms in ballast water. Even if these hurdles were overcome and a tool was developed, it would be difficult to sample vessel hulls before they arrive to a location to prevent the arrival of non-native species. Once again, ballast water analyses show more promise in this regard because ballast can be contained until the screening results are available.

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Appendix A. Desktop Synthesis of Existing Literature on Recreational and Commercial Fishing Vessels

Introduction

The objective of this section was to review existing literature for data that could lead to the quantification of the potential strength of the small-boat vector. To this end, we looked for information on the number of vessels, the number of days they were in use, vessel sizes, travel patterns, hull maintenance methods and fouling biota associated with vessels.

Methods

We conducted a literature review of several major databases in ecology and environmental science including Agricola, BioOne, Environmental Science and Pollution Management, and Web of Science. We searched by subject using the following 15 search terms***: biological invasion, marine invasion, invasive species, non-indigenous species, introduced species, hull fouling, biofouling, recreational boat, recreational vessel, yacht, fishing, marina, vector, interview, survey.*** We also included a cited reference search of a number of seminal papers in invasion ecology. We searched state and federal government agency websites for pertinent gray literature. Agencies included the Pacific States Marine Fisheries Commission, National Marine Fisheries Service, Environment Canada, Sea Grant Programs, California Department of Boating and Waterways, California Department of Fish and Game, Oregon Department of Environmental Quality, Oregon Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Fish and Wildlife. As relevant papers, articles and documents were identified, those papers related to hull fouling were reviewed, catalogued and abstracts made available in Appendix B. Additionally, we hosted a meeting with researchers from other institutions to learn about and discuss current hull fouling research projects in the region.

Results

Vessel Types and Numbers

Commercial Fisheries

We found very little literature on fishing vessels and their potential role as vectors of marine invasions. Reports from various agencies including the Pacific Coast Marine Fisheries Commission were useful in describing some of the parameters relevant to evaluating the strength of this potential vector, such as number of fishing vessels and some aspects of their travel patterns. However, we were not able to quantify volume and flux of these vessels based on existing data. Raw data on landings collected from PCMFC are analyzed in Section 1 of this report.

The US West Coast fishing fleet is complex and can be classified in several ways based on homeport, vessel type, gear type, target species, etc. In addition, vessels that participate in US West Coast fisheries may not have a homeport in the region and vessels that do have homeports in the region may not land their catch at US West Coast ports or processors. While some commercial fishing operators specialize in single species or species groups (e.g., salmon) using one type of gear, many commercial fishing operators engage in a variety of fisheries throughout the year, changing gear with the changing season (Radtke and Davis 2000). These decisions depend on current fisheries policy, availability of primary versus alternative fisheries, and market forces (Radtke and Davis 2000, D Waldeck 2010, pers. comm., 28 Dec.).

There are five main types of fishing gear used in US West Coast fisheries: hook and line, net, pot, trawl, and troll (Radtke and Davis 2000). Oregon Sea Grant published a series of fact sheets, titled "Getting to Know Oregon's Commercial Fisheries"[1] in 2003 that describe the fisheries and associated gear. Vessel lengths, relevant to vector analysis as they can be used to calculate potentially fouled surface area, vary but are generally less than 75 feet (Table A.1, Radtke and Davis 2000).

A specific fishery may be limited to one gear type (e.g., crabpot) or employ several methods of harvest (Table A.2, Radtke and Davis 2000).

[1] http://seagrant.oregonstate.edu/sgpubs/onlinepubs/g03011.pdf

Table A.1. Vessel lengths of select commercial fishing vessels. From Radtke and Davis 2000.

	Mean Length (ft)	% < 30 ft	% 30-50 ft	% 50-75 ft	% > 75 ft
Salmon Netter (gillnet and seine)	34	49	34	17	0
Salmon Troller	35	30	65	5	0
Crabber	39	27	54	17	2
Tuna	49	10	51	32	8
Coastal pelagics (e.g., anchovy, mackerel, sardine, squid)	50	15	29	47	8
Shrimper	54	11	27	51	11
Groundfish – Trawl	63	1	17	61	22
Whiting	77	1	3	33	62

Table A.2. US West Coast fisheries and gear types from Radtke and Davis 2000 (bold capital Xs=primary method of harvest)

	Hook & Line	Net (Gillnet or Seine)	Pot	Trawl	Troll	Other (e.g., Diveboat)
Groundfish	**X**	X	x	x	**X**	x
Whiting				**X**		
Salmon	x	**X**				**X**
Crab			**X**			
Shrimp		**X**	**X**	**X**		x
Coastal Pelagic (e.g., anchovy, mackerel, sardine, squid)	x	**X**		x		
Other Pelagic (e.g., herring)	x	**X**		x	x	x
Highly Migratory (e.g., tuna, shark)	x	**X**		x	**X**	x
Halibut	**X**				x	
Sea Urchins		X				**X**
Other (e.g., clams, octopus, oysters, scallops, smelt, sturgeon)	**X**	**X**	x	x	x	x

In 1997, 65% of commercial fishing vessels on the US West Coast used one type of gear, 24% used two types of gear, 9% used three gear types, and 2% used four or more gear types (Radtke and Davis 2000). Groundfish (e.g., widow rockfish, yellowtail rockfish, sablefish) was the dominant fishery, representing 24% of revenue. The primary method of harvest for groundfish is trawling (71%) followed by hook and line (27%). Three additional harvest methods were reported in Radtke and Davis (2000), and although they represent only 2% of the harvest, it demonstrates the flexibility of this fishery to different gear types. Dungeness crab was the second largest fishery (21% of revenue). This fishery is limited to one method of harvest, baited pot traps, but because the equipment is relatively minimal, using just pots, crab block (winch), and live wells; many vessel types can be outfitted to fish for crab provided they have adequate deck space for storage and sorting. For Washington, Oregon and California, the peak groundfish season occurs between May and September, and the peak crab harvest occurs in the first 8 weeks of the season in December and January, making it possible for individual vessels to fish both seasons (Table A.3). Alaska fishermen have a longer season for shrimp and fish for herring throughout much of the year (Table A.4).

Table A.3 Generalized West Coast fishing seasons, excluding Alaska (Bold capital Xs=peak season, PS=Puget Sound only, T=Trawl only). From Radtke and Davis 2000.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Groundfish	x	x	x	x	**X**	**X**	x	X	x	x	x	**x**
Whiting				**X**	**X**	**X**	**X**	X				
Salmon					x	**X**	**X**	**X**	x			
Crab	**X**	x	x	x	x	x	x	X		PS	PS	**X**
Shrimp				**X**	**X**	**X**	**X**	X	x			
Squid				**X**	x	x	x	X				
Tuna						x	x	X	x	x		
Anchovy, Mackerel, Sardine				**X**	x	x	x	X				

Table A.4 Generalized commercial fishing seasons in Alaska (Alaska Department of Fish and Game 2007).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Groundfish	X	X	X	X	X	X	X	X	X	X	X	X
Salmon					X	X	X	X	X			
Crab	X	X	X	X	X	X	X	X			X	X
Shrimp	X	X			X	X	X	X	X	X	X	X
Herring	X	X	X	X	X					X	X	X

In informal surveys of owner/operators conducted by a consulting firm, respondents reported that they based their decision on where and when to fish on access and availability of the resources, and their vessel size and gear combinations (William Jensen Consulting 1998, in Radtke and Davis 2000). They found that some owner/operators are opportunists who switch gear on a single vessel to accommodate several local fisheries (e.g., groundfish in summer and crab in winter), and others are gear specialists (e.g., purse seiners) who will travel between Washington, Oregon, California and Alaska fishing several different fisheries (e.g., salmon, squid, herring).

Recreational Boating

Based on individual state boating reports[2] and the population reported by the US Census Bureau[3] we estimated that approximately 1 million boats are owned along the West Coast (between 1,014,824 and 1,073,765). The mean number of boater days was highly variable between states, and among regions within states. California had the highest mean boater days (>41 million) per annum, and despite the fact that the South Coast Region of California has the lowest ownership rate, 1.8%, due to its large population size, it had the highest annual mean boat days (> 11.5 million) compared to other regions. As a result, Southern California had almost four times as many boater days than all of Oregon (5% ownership and ~3 million mean boat days statewide).

Information characterizing the recreational boating community is available through each state that regulates boating and/or fishing. California, Oregon and Washington have conducted boater needs assessments in the last 3 to 7 years. The method for collecting boater use and movements is different for each state and is therefore summarized here by state or region within a state, rather than reported as the West Coast as a whole. We summarize information below that is relevant to this vector, but key data which would allow quantification were not available. Ideally, we would like to be able to estimate wetted (underwater) surface area of recreational vessels kept in saltwater (as these are the most likely to transport fouling organisms), to know the number of boater days for such vessels and to understand connectivity between ports along the coast.

California

The California Boating Facilities Needs Assessment (California Department of Boating and Waterways 2002) provides detailed summaries of boating activity broken down across 10 regions, of which five are coastal (Table A.5). Facilities were surveyed with the goal of understanding boater and facility demography, and facility needs with a focus on safety. These findings are summarized below.

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[2] California: http://www.dbw.ca.gov/PDF/Reports/CBFNA/CBFNA_Vol2.pdf
Oregon: http://www.boatoregon.com/OSMB/library/docs/TriSuv2008.pdf
Washington: http://www.rco.wa.gov/documents/rcfb/boating/Data_Summary.pdf

[3] http://quickfacts.census.gov/qfd/index.html

Table A.5 Summary of boat ownership and activity patterns in Coastal California, by region. Data are from the California Department of Boating and Waterways (2002).

Region	% of population that owns ≥1 boat	# of boats per region	Mean # of trips	Mean # of days on the water	% of boats stored in the water	Occupancy of marina berths in region	Occupancy of marina moorings in region
North Coast (1)	5%	34,945	20	42	10%	79%	87%
San Francisco Bay (2)	2.45%	154,975	25	45	20%	91%	95%
Central Coast (3)	3.3%	29,835	23	39	13%	82%	56%
South Coast (4)	1.8%	243,326	20	48	17%	94%	74%
San Diego (5)	2.4%	67,534	22	42	21%	98%	81%

Facility participation in the surveys varied between 71% for Regions 1 and 5 to 93 % for Region 2 (83% and 85% for regions 3 and 4 respectively). Only 5% of the boating facilities occur in Region 1 although it contains the greatest shoreline area. The North Coast Region (1) has a high proportion of boat ownership compared to other California regions (5% compared to 2.45%, 3.3%, 1.8% and 2.4% for regions 2-4 respectively). The high rate of ownership in Region 1 may be explained by the greater proportion of boats registered for fisheries or other commercial use.

In 2000, boaters took an average of 20-25 trips and spent between 39 days (annual average, Region 3) and 48 days (Region 4) on the water (42, 45 and 42 days for regions 1, 2 and 4, respectively). From all regions, most boaters (43%-55%) travel less than 100 miles from home to go boating (data on the distance of trips taken aboard vessels was not collected). More boaters in the South Coast Region (4) traveled more than 100 miles from their home to go boating, but most spent less than 5 days at this distance (this again may be an artifact of both coastal and inland geography in the region). For all regions, 25-45% of boaters spent 1-5 days at locations more than 100 miles from their home. Between 12% (Region 1) and 21% (Region 2) spent more than 5 days at locations more than 100 miles from home (Figure A.4).

Across all regions, most vessels were less than 16 feet in length. Frequency decreased with length, with very few vessels (<0.05%) being longer than 65 feet (Figure A.3). Most boaters kept their boats on their own property (66-78%) and primarily launch their boats from ramps (79-

84%). The most common storage for vessels is on a trailer with only 10-21% of boaters storing their vessels in the water. More than 50% of the marinas offering guest berths in regions 2, 3 and 4 turned away transient vessels. Space for transient vessels was even less available in Region 5 where more than 80% of facilities reported turning away vessels, while 77% of facilities in Region 1 reported no instances of turning away boaters.

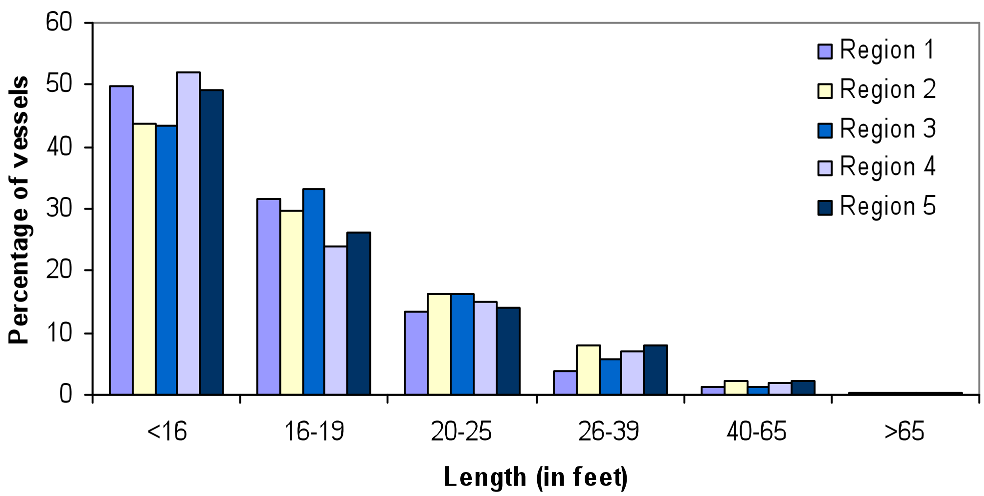

Figure A.1 Length of vessels reported from California regions 1-5.

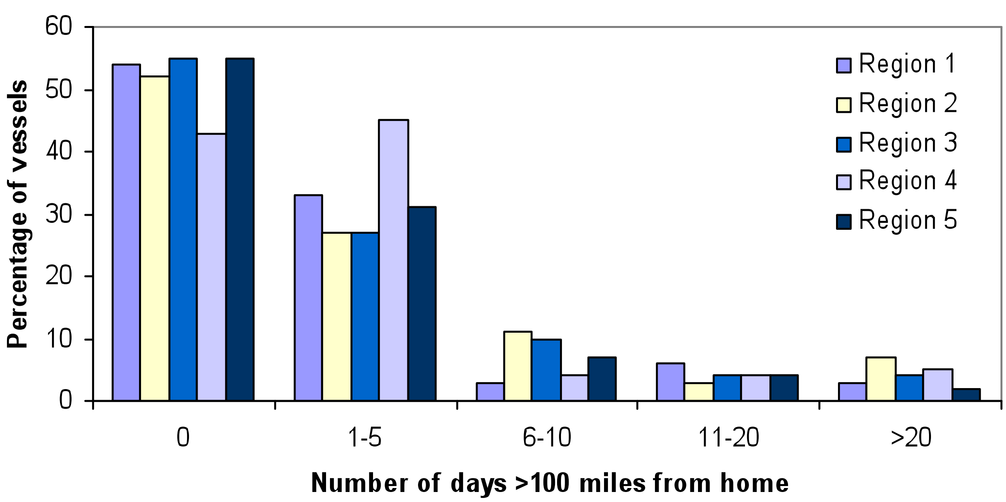

Figure A.2. Time spent boating more than 100 miles from a vessel owner's home, California regions 1-5.

Five of the top ten waterways used by boaters in Region 1were marine systems, with three to four of the top ten waterways in the other regions being marine systems. For Region 1, Lake Sonoma was ranked first followed by the Pacific Ocean (2nd), Humboldt Bay (3rd) Bodega Bay (7th) and Tomales Bay and San Francisco Bay ranked equally at ninth. For Region 2, San Francisco Bay ranked first, followed by the Sacramento-San Joaquin Delta (2nd), San Pablo Bay (7th), and the Pacific Ocean (9th). For Region 3, Lake Nacimiento was ranked first, followed by Monterey Bay (2nd), the Pacific Ocean (4th), Morro Bay (6th) and Moss Landing (9th). For Region 4, the Pacific Ocean ranked first, followed by the Channel Islands Harbor (6th), and Marina del Ray (10th). For Region 5, San Diego Bay ranked first, followed by Mission Bay (2nd), the Pacific Ocean (4th), and Oceanside Harbor (6th).

Oregon

The Oregon State Marine Board commissions a triennial survey of boating activities describing the use patterns of Oregon boaters; the most recent reports the results of a 2007 survey (Oregon State Marine Board 2008), which are summarized below.

Approximately 5% of Oregon's population (189,503 individuals) own at least one boat, with the majority of the boat-use days located on freshwater (~85%). Nearly one-third reported their boat was unused in the previous year. The "typical" Oregon boater spends 24.4 days on the water, many took overnight trips. The majority of recreational boats are trailered to and from the water, and most boaters have high site fidelity, returning to the same water-body 80% of the time. The majority of boating activity, 73%, occurs from May through September, and 63% of boaters reported fishing as their primary activity. The majority of registered Oregon boats were between 16 and 19 feet (~33,000), followed by 12 to 15 feet (~26,000), 20 to 27 feet (~15,000), and <12 feet (~12,000).

Boaters reporting activities in saltwater use coastal bays nearly twice as much as the Pacific Ocean, 9% and 5% respectively, which equates to 223,956 use days in bays and 125,355 use days in the ocean. Tillamook Bay is by far the most used bay (30%), followed by Coos Bay (17%), Yaquina Bay (15%), Winchester Bay (11%), Nehalem Bay (9%), Colquille Bay (8%), Rogue River Bay (6%), and Netarts Bay (4%). Since 2004, Tillamook Bay has seen a 31% increase in boating, while boating in Nehalem Bay has increased by 3.5%. Boating has decreased in Winchester Bay (-0.1%), Coos Bay (-0.5%), and Yaquina Bay (-18.5%). Boating in the Pacific Ocean is reportedly down as well (-4.0%).

Changes in boat use are reported for six of the coastal counties. Since 2004, Tillamook, Clatsop and Curry counties have experienced an increase in boating, 19.4%, 11.1%, and 4.2% respectively. Coos, Lane, Douglas, and Lincoln have experienced declines in boating, -16.5%, -21.9%, -23.2%, and -24.0% respectively. The proportion of these changes attributed to those using marine waters, as opposed to freshwater, is unclear. Although it can be inferred that a large proportion of boating activity is marine in counties that rank high for sailing (Clatsop, Tillamook, Lincoln, Lane and Coos Counties), these counties also contain large, high-use coastal lakes where sailing is also popular.

Washington

The Washington State Recreation and Conservation Office commissioned a boater needs assessment to determine the needs of Washington boaters and aid in prioritizing resources (Responsive Management 2007). The assessment surveyed boating service providers, registered boat owners, and the general public.

An estimated 5% to 6% of Washington residents own a boat. With a population of nearly 6 million, there are between 294,706 and 353,647 boats in the state. The vast majority of boaters (75%) own a motor boat, 19% own a hand powered boat other than a kayak or canoe, 14% own a kayak, 12% own a canoe, 8% own a sailboat, and 5% own a personal watercraft. Counties along the eastern Puget Sound (e.g., San Juan, Snohomish, King, Pierce, Kitsap, and Thurston) had the highest number of registered boat owners. King County had the highest level of use among all boat types.

The majority (62%) of Washington boaters stayed within their county of residence when boating. Respondents preferred boating in King County the most (14.8%), followed by Pierce (7.0%), San Juan (5.7%), and Snohomish (5.6%). Twenty-five percent of respondents reported the body of water that they most boated in was the Puget Sound, which is consistent with the expected patterns based on reported preferences and counties of residence. Nearly half of boaters (46%) said they spent less than 10 days on the water in the last year, while 23% spent more than 30 days on the water. Sightseeing was the primary activity reported in both the Puget Sound and outer coast.

Movements within and between states

Commercial Fisheries

Commercial fishing vessels may be a vector for spreading fouling organisms from their homeports to locations where they offload their catch (landings) or where they dock while fishing away from home. We were unable to find any information in our literature review on the movements of commercial fishing vessels within or between states. Data provided by the Pacific States Marine Fisheries Commission for vessels fishing in California, Oregon and Washington are analyzed in Section 1.

Recreational Boating

Unlike the commercial fishing industry, which must report landings where catch is offloaded, there are no requirements for domestic recreational boaters to report or document their movements[4]. Other than the state-by-state boating reports that focused on identifying high use in-state waters cited above, we were unable to find any documents that characterize the movements of recreational vessels along the West Coast (but see Davidson et al. 2010). Data collected by individual harbors are analyzed in Section 2.

Hull Maintenance Practices

Typical antifouling practices include biocide coatings (including ablative coatings), fouling release coatings, and manual cleaning. Biocides prevent settlement of marine organisms by steadily releasing a toxic agent. Tributyltin (TBT), a tin-based product, was in use from 1976 until a global ban on TBT paint application in 2003 (Showalter and Savarese 2004). While TBT was extremely effective in preventing biofouling, it was banned because it causes abnormalities in marine organisms, including malformations and development of imposex or intersex (Coray and Bard 2007). Other heavy metals including lead, arsenic, mercury and their organic derivatives have also been used historically but are now banned due to toxicity (Showalter and Savarese 2004).

Ablative coatings are designed to peel and release biocide over time, releasing fouling organisms along with the coating. The first ablative coatings were patented in 1977 and are usually copper based (Chambers et al. 2006). Copper has long been recognized as an effective

[4] International arrivals are required to report their homeport however this data is not submitted or maintained in any database (actually may be kept by US Customs, but they would not release it to us without a FOIA request) but must be researched at each marina that berths an international vessel.

agent against biofouling and has been in use since the 1600s; however, environmental contamination by these paints has resulted in restrictive use of copper-based antifouling paints in recent years (Showalter and Savarese 2004). Leaching of copper from vessel hulls is the primary source of contamination, although inputs from hull cleaning activities and non-point source pollution also occur (Schiff et al. 2004). Coatings are typically applied once a year or every other year, depending on manufacturer recommendations.

Non-toxic substitutes and alternatives have been proposed to minimize contamination from chemical substances and non-native species introductions (Chambers et al. 2006, Stupak et al. 2003). Silicone, ceramic-epoxy and epoxy-based coatings show some promise for use as a long-term replacement for copper-based paints (Chambers et al. 2006). Benzoates and tannins from chestnut, mimosa and quebracho have also been explored in laboratory and small-scale field trials but the broad-scale application of these products is unknown (Stupak et al. 2003). Suggested alternatives to eliminate the need for antifouling paint include boatlifts and boat baths. These methods prevent biofouling settlement on hulls at berths by taking the vessel out of the water or surrounding it with tarp material and using freshwater or chlorination within the water bath. The primary shortcomings of non-toxic substitutes and alternatives are expense, maintenance and level of upkeep, and frequency of applications.

Manual cleaning methods include hull scraping or scrubbing on land, on a grid, or in the slip. When cleaning in the slip, hull cleaning may be accomplished by a diver or from the dock with scrapers and brushes. Frequency of cleaning depends on the individual owner preference and level of fouling. The Clean Marinas Program, described below, prohibits manual cleaning in the water in certified marinas to prevent the release of fouling organisms from other locations and the introduction of invasive species.

Clean Marinas is a nationwide pollution prevention program that provides certification to marinas that implement best management practices (BMPs) to protect the environment and reduce hazardous waste. While this program is not targeted at invasive species detection and management, some of the practices to reduce antifouling paint discharge to the water, if implemented properly, may also help to reduce the risk of invasive species introductions. Examples of these BMPs include:

- Restrict or prohibit sanding and scraping boats that are in the water to the greatest extent practicable.
- Conduct sanding and scraping away from the waters edge in a designated indoor or upland area.
- Vacuum or sweep debris and dispose non-hazardous material in a covered solid waste receptacle immediately following maintenance activity.
- Use dustless or vacuum sanders for all sanding activities.

Associated Biota

Large, commercial vessels have been the focus of vessel fouling research; however, recreational and fishing vessels have recently gained the attention of researchers and managers as potential vectors for non-native species (Minchin et al. 2006). Only a few studies have specifically examined the actual movements and transfer of non-native species by recreational and small fishing vessels (Mineur et al. 2008, Darbyson et al. 2009a). Rather, most studies infer species movements and transfer by evaluating patterns of species occurrence relative to human activity, retrospectively assigning biofouling vectors to established non-native species (Wasson et al. 2001, Mineur et al. 2008).

The greatest body of research on the role of small vessels in the transport of aquatic invasive species has been conducted in Australia and New Zealand (Floerl and Inglis 2003, Floerl and Inglis 2005a,b, Floerl et al. 2009). Not surprisingly, the volume of traffic at a marina was found to be a good explanatory variable for numbers of established non-native species (Floerl et al. 2009). The condition of antifouling paint and hull material was also important in preventing the establishment of invasive species (Floerl et al. 2005b). Enclosed marinas were found to increase propagule pressure to hulls and other hard surfaces and the development of fouling assemblages by retaining propagules (Floerl and Inglis 2003).

We focused our literature review on research that examined vessel hulls for fouling species as opposed to inferring from fouling plate studies because differences in substrate can influence fouling community composition (Hewitt et al. 2008). Six papers were identified through our literature review that conducted original work observing and quantifying fouling organisms on recreational vessels (Godwin et al. 2004, Floerl and Inglis 2005a, Ashton et al. 2006, Mineur et al. 2008, Darbyson et al. 2009a, Davidson et al. 2010). A seventh paper summarized the results of several papers examining the role of small craft and the spread of exotic species (Minchin et al. 2006). More than 100 taxa, including algae, vascular plants, vertebrates and many phyla of invertebrates, were observed on recreational vessels, primarily in temperate regions (Appendix C).

Over 290 non-native species are considered to be established in marine and estuarine waters of the North Pacific Ocean, from northern California to British Columbia (Ruiz et al. in press). Moreover, a large fraction of these species include hull fouling as a potential vector, for the initial introduction and subsequent spread along this coastline.

Discussion

The major invasion pathways for marine species on the West Coast are shipping and shellfish aquaculture (Wonham and Carlton 2005, Ruiz et al. in press). Recreational and fishing vessels clearly provide an opportunity for transferring introduced species from commercial ports to non-commercial ports and protected bays and estuaries throughout the region (Wasson et al. 2001). Recreational vessels appear to have relatively high site fidelity on the West Coast, thus a relatively low percentage of boaters could be considered high-risk vectors. However, these patterns may not hold everywhere. In eastern Prince Edward Island, Darbyson et al. (2009a and 2009b) found that a high proportion of recreational boaters, nearly half, were docked at a harbor outside of their homeport, which is very different from the patterns reported for California, Oregon and Washington (California Department of Boating and Waterways 2002, Oregon State Marine Board 2008, LeClair et al. 2009). Even with a low percentage of US West Coast boaters traveling between bays, when those percentages are converted to individual vessels there is a high number of potential introduction events (e.g., for California, at least 2% of vessels spend more than 20 days more than 100 miles from home, but that 2% represents more than 12,000 vessels). Those originating from busy ports with commercial shipping traffic are more likely to be exposed to non-native species, but this may not increase the spread or secondary infestations expected from recreational and fishing vessels (Floerl et al. 2009).

Boats that are used frequently or for long distance voyages tend to be better maintained than boats used infrequently or only for short distance voyages (Minchin et al. 2006, Mineur et al. 2008, but see Davidson et al. 2008b and this report Section 2). Therefore the greatest risk posed by recreational boaters generally comes from infrequent boaters who berth their boats in a marina (rather than trailer them) and travel only short distances to adjacent ports or harbors (Minchin et al. 2006).

Without more detailed information about the travel patterns and hull maintenance of small boats, it is not possible to determine the probability of species transfer posed by these boats. According to one published study, most boats are generally kept clean and use antifouling paint, and boat owners appear to have a high awareness of non-native species introductions, indicating the importance and effectiveness of education and outreach programs (Darbyson 2009a); other studies indicate that many boats are heavily fouled, although many of these are not active, e.g., Floerl et al. 2005a, Ashton et al. 2006, Davidson et al. 2008b, 2010).

For both commercial and noncommercial vessels alike, significant gaps include quantitative data about:

- the biota associated with vessel types, locations and routes;
- the number, flux (movement), and hull husbandry practices;
- the effect of hull-husbandry on biotic assemblages;
- the survival of organisms during transit and exposure to environmental changes;
- the likelihood or risk of establishment upon arrival to a new area following transit
- the transfer of invasive species via fishing gear, bait wells, and sea chests

Appendix B. Relevant References and Abstracts

Darbyson, EA, A Locke, JM Hanson and JHM Willison. 2009. Marine boating habits and the potential for spread of invasive species in the Gulf of St Lawrence. *Aquatic Invasions* 4:87-94.

Abstract. The potential for boating to disperse the clubbed tunicate *Styela clava* Herdman, 1881 and green crab *Carcinus maenas*(Linnaeus, 1758) in the southern Gulf of St. Lawrence was investigated using interviews with recreational and commercial boaters in eastern Prince Edward Island (PEI). Boaters were asked how long their boat had been at the present location; the primary use of the boat; if anchors, sounding equipment or fishing gear were used; whether any organisms were attached to these items when retrieved; and the fate of those organisms. Bilge water and hull scrapings from the vessels contained 31 and 47 taxa, respectively. Recreational boats, nearly half of which were docked outside their home estuary, were a more likely vector of dispersal than commercial fishing boats that tended to return to the same port each night. Northeastern Nova Scotia and the southern coast of PEI were most at risk for the spread of clubbed tunicate, while green crab could be transported to PEI and eastern New Brunswick. The Magdalen Islands, Quebec, were also predicted as a site to which green crabs could spread, and thefirst green crabs were detected there two years after our study.

Darbyson, EA, JM Hanson, A Locke and JHM Willison. 2009. Survival of European green crab (*Carcinus maenus* L.) exposed to simulated overland and boating-vector transport conditions. *Journal of Shellfish Research* 28:377-382.

Abstract. Juveniles and adults hitch-hiking in fishing gear, recreational vessels, and fisheries and aquaculture products are believed to be important vectors of local dispersal of invasive European green crab (*Carcinus maenus* L.). Assessing the distance green crab might spread by hitch hiking requires an estimate of survival time under typical transport conditions. An exposure experiment (stocking density 62 crabs/[m.sup.2]) was conducted in fish crates containing: just crabs (no water, no cover), dry rope, damp eelgrass (Zostera marina L.), seawater (1.5 cm deep), rope + seawater, or eelgrass + seawater. At mean air temperature of 24°C, almost no crabs died during the first 48 h, 50% of crabs stocked alone or with dry rope survived 68 h (none survived five days), 50% of crabs in eelgrass or eelgrass + seawater survived 90-100 h, and > 80% of crabs in sea water or rope + seawater survived the full five days. The second experiment (just crabs, sea water, and rope + seawater) used three stocking levels (84, 168, and 251 crabs/ [m.sup.2]) and ran for seven days. Stocking density did not have a significant effect on survival. At mean air temperature of 29°C, 50% of crabs fully exposed to air survived 60 h (almost none survived seven days), whereas about 60% of crabs survived to seven days when seawater or seawater + rope were present. The survival of green crab for several days out of water under severe summer conditions would allow them to be carried on boats to any point in Atlantic Canada, or almost anywhere on the eastern seaboard on trailered boats. This could result in further northward dispersal and the introduction of "northern" genetic material into previously colonized southern portions of the range, potentially increasing over wintering survival.

Davenport J and JA Davenport. 2006. The impact of tourism and personal leisure transport on coastal environments: A review. *Estuarine Coastal and Shelf Science* 67:20-292.

Abstract. Coastal tourism started in the 19th Century and has increased in non-linear fashion ever since, stimulated by a combination of developments in transport technology and rising prosperity. Initially, mainly national in character, the introduction of roll-on, roll-off ferries and inexpensive air transport caused an exponential 28-fold rise in international tourism between 1950 and the start of the 21st Century. This review considers the impact of tourism at two levels: (1) that created by the sheer numbers of tourists and their demands (‘mass tourism and transport’) and (2) that resulting from individual, often novel, forms of transport (‘personal leisure transport’). Under (1), the consequences of the construction of coastal resorts and roads, marinas and jetties for habitat fragmentation and reduced biodiversity are described. Next, the effects of large cruise ships (now some 250 in number) are considered, particularly in relation to unregulated pollution and the delivery of substantial numbers of tourists to remote destinations. Thirdly, the literature related to disturbance caused by intertidal trampling by tourists on rocky/sandy shores is reviewed, followed by a section devoted to the unappreciated effects of beach ‘cleaning’ (i.e. removal of natural strandlines as well as litter) that is practiced throughout the world's sandy beach resorts. Finally, the potentially positive area of coastal ecotourism is considered, but evidence is assembled to highlight the problems associated with too high a demand. Under (2), the impact of a range of personal leisure transport modes is considered. These range from relatively innocuous pursuits (e.g. swimming, surfing, sailboarding and dinghy sailing), to an extremely popular sport (SCUBA diving) that is marketed for its environmentally-friendly nature, yet causes measurable deterioration in the world's coral ecosystems despite good management practices. The impact of motorboats is considered, particularly in the context of transmission of non-native species, while the highly polluting and disturbing technology of ‘personal watercraft’ is evaluated. Finally, the uncontrolled emergence of new ‘extreme sports’ (e.g. ‘coasteering’, kitesurfing) is identified as a future problem.

Davidson, I., C. Zabin, A. Chang, M. Sytsma, G. Ruiz. 2008. Characterizing the risk of species transfers on recreational boats in marine systems via hull fouling: a pilot study. Report submitted to the US Fish & Wildlife Service, 38 pp.

Abstract. With more than 175 aquatic nonindigenous species (NIS), San Francisco Bay has been described as the most invaded bay in North America. Hard-substratum benthic (fouling) organisms contribute much to the NIS richness of the system, and these species have arrived primarily as a result of shipping and aquaculture activity in the Bay over the centuries. A consequence of this diversity of marine fouling NIS is the potential for further spread by recreational boat traffic in the Bay Surprisingly, no assessment of the leisure craft vector has been carried out in the Bay until this study, which aimed to 1) assess the extent and composition of biofouling on boats’ submerged surfaces at a subset of the Bay’s marinas and 2) characterize boater behavior (hull maintenance and travel patterns) likely to affect the risk of invasive-species transfer There were significant differences among marinas in the extent and richness of biofouling on vessels. Boats at two sites strongly influenced by freshwater had lower levels of fouling but the non-native bryozoan, *Membranipora chesapeakensis*, was prominent on some vessels at one of these sites. All marinas had vessels ranging from less than 30% biofouling

cover on their hull surface to more than 90% cover and the prevalence of heavily fouled boats was higher in SF Bay than other sites reported in the literature. Several NIS, already established within SF Bay, were observed on vessel hulls, including the bryozoans *Bugula neritina* and *Watersipora* sp., the ascidians *Botrylloides violaceus, Styela clava* and *Ciona intestinalis,* the polychaete *Ficopomatus enigmaticus*, and the sponge *Clathria prolifera*. Respondents to a questionnaire (n = 221) revealed that a minority of vessels (16%) traveled to sites outside of SF Bay in the previous 12 months, however, and the most heavily used boats tended to have reduced biofouling extent. These findings suggest that the potential for NIS spread is high because of dense source populations of NIS in marinas, heavily fouled boat hulls, and high incidence of NIS on boats. However, realized vector activity is limited by 1) relatively low connectivity with marinas outside the Bay and 2) better maintenance practices among those vessels that travel to adjacent bays. More data are needed to better characterize recreational vessel movements in the area and in the NE Pacific generally. This preliminary study, and recent similar assessments from Europe and the Southern Hemisphere, suggests that the recreational boat-fouling vector probably behaves similarly to other maritime vectors (commercial ship fouling and ballast water) whereby most vessels have relatively few organisms but some high density vector events that occur occasionally (e.g. when a boat is sold) pose a significant risk of transferring species.

Davidson, I.C., C.J. Zabin, A.L. Chang, C.W. Brown, M.D. Sytsma, G.M. Ruiz. 2010. Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquatic Biology 11: 179-191.

With more than 200 aquatic nonindigenous species (NIS), San Francisco Bay (California, USA) is among the world's most invaded harbors. Hard-substratum benthic (biofouling) organisms, which dominate NIS richness, have arrived primarily as a result of shipping and aquaculture activity over past centuries. To date there has been no assessment of the leisure craft vector in the Bay. We aimed to characterize (1) biofouling on boats' submerged surfaces and (2) boater behavior likely to affect the risk of NIS transfers. We used an underwater pole-cam, specimen collections, and a boater questionnaire to quantify the extent and composition of biofouling on recreational boats and to eval- uate boater behavior at a subset of the Bay's marinas. Several NIS, already established within the Bay, were recorded from vessel hulls, including the bryozoans *Bugula neritina, Membranipora chesapeakensis* and *Watersipora* sp., the ascidians *Botrylloides violaceus, Styela clava* and *Ciona intestinalis*, the polychaete *Ficopomatus enigmaticus,* and the sponge *Clathria prolifera*. Only 16% of questionnaire respondents had traveled to sites outside the Bay in the previous 12 mo. Frequency of hull painting and cleaning varied substantially, but we did not find strong patterns of biofouling extent associated with hull husbandry or boat usage. The potential for within-Bay and coastwise regional spread of NIS is high, and recreational boats probably interact in close proximity to other vectors (e.g. commercial ships), causing a ratchet effect of vector events; however, there remains a gap in understanding the levels and condition of biofouling on transient boats. Transient vessels from San Francisco Bay and other West Coast sites should be the focus of future studies to evaluate the extent to which organisms are being transferred among bays and how vector management could be applied to prevent NIS transfers and impacts.

Floerl O and GJ Inglis. 2003. Boat harbor design can exacerbate hull fouling. *Austral Ecology* 28:116-127.

Abstract. Hull fouling is a major cost for owners of small vessels and an important pathway for the spread of non-indigenous aquatic species. The extent of fouling depends on a hull's susceptibility to recruitment by aquatic organisms and the local availability of competent planktonic propagules ('propagule pressure'). Management strategies have typically been concerned with increasing resistance of the hull to recruitment through the use of toxic paints. Here we tested the hypothesis that fouling is influenced by the design of the harbour in which the boat is moored. We compared recruitment of sessile invertebrates to available surfaces in two types of recreational boat harbours: marinas that were partially enclosed by a permanent breakwall, and marinas that lacked breakwalls. Recruitment in the marinas was compared to coastal reference sites that were not used for mooring. At each location, recruitment tiles were deployed for 4 weeks on four separate occasions over a period of 2 years. Measurements of current velocities and spatial patterns of water flow at each location showed that permanent breakwalls created complex patterns of circulation that retained water within the marina basin for up to 12 h d-1 Despite large regional and temporal variability in fouling over time, most organisms recruited in greatest numbers to surfaces in partially enclosed marinas, and were often several orders of magnitude more abundant in the enclosed marinas than in unenclosed marinas or coastal reference locations. Harbour design has an important influence on the rate at which fouling organisms recruit to available surfaces within marinas. Entrainment of water in enclosed marinas may limit the dispersal of planktonic propagules by advective currents but effectively increases propagule pressure to available surfaces, including resident boat hulls. This is likely to accelerate the development of hull-fouling assemblages and increase the chances of transport of non-indigenous species that establish populations in the harbour basin.

Floerl O and GJ Inglis. 2005. Potential for the introduction and spread of marine pests by private yachts. *Proceedings of a Workshop on Current Issues and Potential Management Strategies: Hull fouling as a Mechanism for Marine Invasive Species Introductions.* February 12-13, 2003. Honolulu, HI.

Abstract. Recreational boating is a booming industry worldwide, and movements of domestic and international yachts constitute the majority of inshore vessel movements in many coastal countries. Hull fouling on private ocean-going yachts has been implicated as a vector in the introduction and secondary spread of a number of aquatic nonindigenous species (NIS). Despite this, there are no existing quarantine procedures for international yachts to prevent the introduction of fouling organisms into native marine systems. The development of predictive tools that allow quarantine officials to efficiently discriminate low-risk vessels from those that may pose a risk to marine biosecurity would help reduce the number of propagules that reach native environments and, therefore, the number of marine NIS that may establish and become spread.

Floerl O and GJ Inglis. 2005. Starting the invasion pathway: the interaction between source populations and human transport vectors. *Biological Invasions* 7:589-606.

Abstract. Human transport hubs, such as shipping ports, airports and mail centers are important foci for the spread of non-indigenous species. High relative abundance in a transport hub has been proposed as a correlate of invasion success, since abundant species are thought more likely to colonize vectors and to be transported more frequently. We here evaluate the relative importance of vector characteristics and local source assemblages in determining the pool of species that is transported by hull fouling on recreational boats. We compared the resident fouling communities of three recreational boat harbors in Australia with the assemblages on the hulls of boats that travel between them. We used data on the recent travel and maintenance history of the boats to evaluate correlates of transport probability and the potential for intra-coastal spread of fouling organisms. Invertebrate assemblages on heavily fouled vessels reflected the composition of biotic assemblages within the marina in which they were moored, but by itself, relative abundance in the source port was not a reliable predictor of transport probability. More important was the age of the antifouling paint on the vessels' hulls, which acted selectively on some groups of organisms. Movements of vessels were characterized by "*fidelity*" (vessels remaining close to homeport) interspersed with "*promiscuity*" (vessels traveling to a diverse pool of destinations). In an infested harbor, measures taken to increase the resistance of vectors to colonization by the invader should be effective in slowing the rate of spread to other locations, by decreasing the overall frequency of transport.

Floerl, O, GJ Inglis and HM Marsh. 2005. Selectivity in vector management: an investigation of the effectiveness of measures used to prevent transport of non-indigenous species. *Biological Invasions* 7:459-475.

Abstract. Measures taken to control the spread of non-indigenous species by human vectors may act selectively by providing effective protection against some (but not all) species. Toxic 'antifouling paints' are used by boat owners to prevent the development of ' fouling assemblages ' on the hulls of their boats, which reduce vessel speed and maneuverability. By reducing fouling, these paints also prevent transport of non-indigenous species. Using experimental surfaces mimicking boat hulls, we evaluated the effectiveness and selectivity of (1) antifouling paints, and (2) manual, in-water hull cleaning for preventing the transport of marine sessile invertebrates by recreational vessels. Different types of antifouling paints provided effective protection only against barnacles and bivalves. Other fouling taxa occurred on experimental surfaces after a period of only 2 months. Manual hull cleaning did not remove fouling completely, and even enhanced the risk of subsequent recruitment by some fouling organisms. Up to six times more individuals and colonies recruited to boat surfaces from which the existing fouling organisms had been removed manually than to surfaces that had been sterilized or contained intact fouling assemblages. Bivalves, colonial and solitary ascidians, encrusting bryozoans, hydroids, tubiculous polychaetes, and sponges consistently recruited in greatest abundance to manually cleaned surfaces. Individual taxa responded in complex, but predictable ways to the biogenic cues left by manual cleaning, so that different suites of organisms colonized surfaces that had originally contained fouling assemblages of local or non-local origin. Our study shows that widely adopted measures to control the spread of non-indigenous species by human vectors are often highly selective and, while effective for some taxa, do not prevent the transport of others.

Godwin, LS. 2003. Hull fouling of maritime vessels as a pathway for marine species invasions to the Hawaiian Islands. *Biofouling* 19:123-131.

Abstract. The natural barriers to species invasions that exist in isolated marine environments such as Hawaii are overcome by anthropogenic influences on the dispersal patterns of marine organisms. This creates a situation where the marine habitats of the Hawaiian Archipelago are more readily exposed to marine non-indigenous species. A case study of a particular anthropogenic dispersal mode, maritime vessel hull fouling, is reviewed. This mode has effects on altered environments, such as harbors, as well as unaltered coastal habitats. Hull fouling of commercial maritime vessels is documented as a transport vector, and an inter-island dispersal mechanism for marine non-indigenous species to the main Hawaiian Islands.

Herborg, LM, P O'Hara and TW Therriault. 2009. Forecasting the potential distribution of the invasive tunicate *Didemnum vexillum*. *Journal of Applied Ecology* 26:64-72.

Abstract. Invasive species are a major threat to global biodiversity and their introduction can have significant economic consequences. The invasive tunicate *Didemnum vexillum* is a notorious invader with significant negative impacts on cultured shellfish and natural benthic communities, including commercially important ones. We conducted an expert survey, identifying the five most important transport vectors for *D. vexillum* along the west coast of North America. We determined the spatially explicit vector density for all vectors in order to identify introduction hotspots. Additionally, we developed an environmental niche model based on 46 occurrence points and nine environmental variables to identify areas suitable for *D. vexillum*. Spatial distribution of the most important transport vectors (slow-moving vessels, aquaculture, fishing vessels, small vessels, and large commercial vessels) identified several hotspots with high vector densities. These proved to be a very good predictor of current *D. vexillum* occurrence in British Columbia (BC). Ecological niche modelling (Genetic Algorithm for Rule-set Prediction) predicted suitable environments in southern BC, parts of central BC and along the east coast of the Queen Charlotte Islands. Independent validation of the model based on the current distribution in BC indicated good predictive accuracy. Additional analytical steps confirmed that no environmental variable dominated the predictions and we identified ranges of environmental conditions predicted suitable by the model. We identified areas of high establishment probability for *D. vexillum* by combining the vector model and environmental niche model. Parts of central BC, the west coast of Vancouver Island and the Strait of Georgia are areas where *D. vexillum* is most likely to establish. Synthesis and applications. Spatially explicit predictions of the potential distribution of biological invaders are crucial for informing risk assessments, development of management strategies, and resource allocation. While most studies only focus on one step in the invasion process, we successfully combined the likelihood of introduction and establishment. Results from this study are informing the canadian risk assessment of invasive tunicates, guiding current monitoring efforts, and providing a basis for potential intervention/mediation measures.

Minchin, D, O Floerl, D Savini and A Occhipinti-Ambrogi. 2006. Small craft and the spread of exotic species. In: Davenport J and JL Davenport (eds.). *The Ecology of Transportation: Managing Mobility for the Environment*, pp. 99-118. Springer Link, The Netherlands.

Abstract. Over the past centuries, an increasing number of marine non-indigenous species (NIS) have been recorded from urban and port environments worldwide (Cohen & Carlton 1988; Cranfield et al. 1998; Hewitt et al. 1999; Coles et al. 1999; Godwin 2003). This spread has for many species been attributed to shipping. Ships are capable of spreading exotic species in ballast water (taken on board to provide stability at sea) or attached to submerged hull surfaces (hull fouling). Worldwide, more than 2,000 different species have been identified from hull fouling assemblages (Visscher 1927; Allen 1953; Skerman 1960; Gollasch 2002). Despite a likely decline in the rate of species transfers on ship hulls through the development of modern toxic ‘antifouling paints’, NIS continue to be transported on the hulls of domestic and international vessels (Rainer 1995; Ruiz et al. 1997; Coutts 1999).

Despite the large numbers of private and commercial small craft in coastal locations worldwide, managers so far have focused almost exclusively on large ships as vectors. The role of small craft in the transport of NIS has only recently become acknowledged and has only been investigated in a few studies (James & Hayden 2000; Floerl 2002; Floerl et al. in press a). In freshwater environments, private small craft are known to facilitate the spread of both aquatic invertebrates and plants. Trailered overland boat traffic between rivers and lakes is the main means by which recreational vessels spread the zebra mussel (*Dreissena polymorpha*) and some exotic macrophytes through New Zealand, the US and Ireland (Johnstone et al. 1985; Minchin et al. 2006). Transport of these taxa occurs primarily by entanglement of fragments or individuals snagged in fishing gear, anchor chains and boat trailers. In contrast, transport of marine organisms on small craft is mainly by attachment (fouling) to submerged parts of the hull. In many countries, organotin-based, highly effective antifouling paints have not been permitted on vessels <25m in length since themid-1980s due to impacts of tributyl tin (TBT) on aquaculture production (Champ & Lowenstein 1987). Small craft owners have had to rely on the less effective copper based products.

Yachts, motorised craft and small commercial vessels are normally held at marinas or on moorings in sheltered bays, estuaries, lakes and rivers. These environments have suitable conditions for establishment and the subsequent spread of fouling organisms. Marinas provide a wide and extensive range of hard surfaces for attachment that include breakwaters, pontoons and pilings. A typical marina holds 100-1,000 small craft and many are idle for extensive periods (weeks to months) and some are poorly maintained (Floerl 2002). This contrasts with large ships normally in port for hours to days (Coutts 1999). Many common fouling organisms can survive transport on vessel hulls for considerable distances (Allen 1953; Crisp 1958;Carlton & Hodder 1995; Gollasch & Riemann-Zuerneck 1996; Apte et al. 2000).

In this chapter, we examine hull fouling on small craft as a transportation vector for NIS in widely dispersed regions including temperate and tropical environments. We provide summaries of NIS incursions associated with small craft movements, outline factors that make small craft susceptible to fouling, document a recent general increase in the abundance of small craft and associated industries, discuss the likely dispersal routes of NIS by small craft and make recommendations for managing the risks of small craft fouling and NIS transportation.

Hewitt, CL, ML Campbell and B Schaffelke. 2007. Introductions of seaweeds: accidental transfer pathways and mechanisms. *Botanica Marina* 50:326-337.

Abstract. Macroalgae are a significant component of historic and modern invasions, with association to a wide variety of transport mechanisms. These transport mechanisms pose specific constraints on the ways by which species can be taken up, transported and released into a new environment. Currently operating transport mechanisms for marine macroalgae are either associations with intentional introductions (translocations for aquaculture, aquarium or live seafood trade) or accidental introductions (mainly as hull-fouling). A number of potential management options exist, including the development of international instruments and regional agreements. The development of treatment options for hull fouling, the most significant and poorly managed transport mechanism for macroalgae, is of urgent need. Our current ability to identify which species are likely to invade next is limited. However, an examination of the synergies between species' functional traits, transport constraints, and recipient community attributes will likely provide possible options in the future.

Hopkins, GA and BM Forrest. 2008. Management options for vessel hull fouling: An overview of risks posed by in-water cleaning. *ICES Journal of Marine Science* 65:811-815.

Abstract. Hull fouling has been identified as an important pathway for the spread of non-indigenous marine species. However, the management of associated biosecurity risks has proven challenging. Left unmanaged, a fouled vessel can pose a biosecurity risk through the detachment and dispersal of viable material, and through spawning by adult taxa upon arrival in a recipient port or region. These risks can be managed effectively through the removal of the vessel to land for defouling (e.g. dry-docking). However, alternative methods are needed for small (e.g. recreational) vessels, as well as for large vessels fouled outside their dry-docking schedule. Among the various treatment options, in-water cleaning is relatively common, although some countries have placed restrictions on this method because of perceived biosecurity risks. Here, we present a conceptual framework that identifies risks posed by in-water cleaning compared with alternatives, including no management. Decisions on the appropriate management option will be influenced by many factors, including the species present, the level of fouling, and the time a vessel spends in a recipient region. It is important that any regulatory changes regarding in-water defouling be supported by relevant research that quantifies the risks associated with the various management options.

McGee, S, R Piorkowski and GM Ruiz. 2006. Analysis of recent vessel arrivals and ballast water discharge in Alaska: Toward assessing ship mediated invasion risk. *Marine Pollution Bulletin* 52:1634-1645.

Abstract. Ships are a dominant vector for biological invasions through ballast water discharge (BWD) and hull fouling. Here, we provide a first comprehensive analysis of shipping in Alaska, summarizing (a) the number, type and origin of vessel arrivals to Alaska for 2003 and 2004, (b) the spatial and temporal variation in vessel traffic, and (c) the available data on ballast water discharge in order to prioritize locations for tracking biological invasions. Most arrivals were passenger vessels, followed by ferries and fishing vessels, all of which carried little ballast water. Regional and seasonal patterns in arrivals and BWD were unevenly distributed among vessel

types. The majority of vessels reporting BWD were from foreign ports, and most of this ballast was untreated. The largest volumes of ballast were from tankers at Valdez and Kenai Peninsula ports. Although Alaska has few documented invasions, opportunities for ship-mediated transfer now appear high and warrant further scrutiny.

Mineur, F, MP Johnson and CA Maggs. 2008. Macroalgal introductions by hull fouling on recreational vessels: Seaweeds and sailors. *Environmental Management* 42:667-676.

Abstract. Macroalgal invasions in coastal areas have been a growing concern during the past decade. The present study aimed to assess the role of hull fouling on recreational yachts as a vector for macroalgal introductions. Questionnaire and hull surveys were carried out in marinas in France and Spain. The questionnaires revealed that the majority of yacht owners are aware of seaweed introductions, usually undertake short range journeys, dry dock their boat at least once a year, and use antifouling paints. The hull survey showed that many in-service yachts were completely free of macroalgae. When present, fouling assemblages consisted mainly of one to two macroalgal species. The most commonly found species was the tolerant green seaweed *Ulva flexuosa*. Most of the other species found are also cosmopolitan and opportunistic. A few nonnative and potentially invasive Ceramiales (Rhodophyta) were found occasionally on in-service yachts. On the basis of the information gathered during interviews of yacht owners in the surveyed area, these occurrences are likely to be uncommon. However they can pose a significant risk of primary or secondary introductions of alien macroalgal species, especially in the light of the increase in yachting activities. With large numbers of recreational yachts and relatively rare occurrences of nonnative species on hulls, comprehensive screening programs do not seem justified or practical. The risks of transferring nonnative species may, however, be minimized by encouraging the behaviors that prevent fouling on hulls and by taking action against neglected boats before they can act as vectors.

Ruiz, GM, PW Fofonoff, JT Carlton, MJ Wonham and AH Hines. 2000. Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases. *Annual Review of Ecology and Systematics* 31:481-531.

Abstract. Biological invasions of marine habitats have been common, and many patterns emerge from the existing Literature. In North America, we identify 298 nonindigenous species (NIS) of invertebrates and algae that are established in marine and estuarine waters, generating many "apparent patterns" of invasion: (a) The rate of reported invasions has increased exponentially over the past 200 years; (b) Most NIS are crustaceans and molluscs while NIS in taxonomic groups dominated by small organisms are rare; (c) Most invasions have resulted from shipping; (d) More NIS are present along the Pacific coast than the Atlantic and Gulf coasts; (e) Native and source regions of NIS differ among coasts, corresponding to trade patterns. The validity of these apparent patterns remains to be tested, because strong bias exists in the data. Overall, the emergent patterns reflect interactive effects of propagule supply, invasion resistance, and sampling bias. Understanding the relative contribution of each component remains a major challenge for invasion ecology and requires standardized, quantitative measures in space and time that we now lack.

Wyatt, ASJ, CL Hewitt, DI Walker and TJ Ward. 2005. Marine introductions in the Shark Bay World Heritage property, Western Australia: a preliminary assessment. *Diversity and Distributions* 11:33-44.

Abstract. The presence and impacts of non-indigenous species (NIS) in marine areas of high conservation or World Heritage significance have rarely been examined. Case studies worldwide suggest that the potential exists for the introduction of NIS to significantly impact conservation values in regions conserved for the uniqueness and diversity of native assemblages. In this study, a preliminary investigation was conducted to provide information essential for managing marine introductions in the Shark Bay World Heritage Property. A focused fouling plate survey sampled a total of 112 encrusting taxa, of which 10 (11.2%) were classified as introduced and 10 others as cryptogenic. Eight introduced bryozoans: *Aetea anguina* (Linnaeus, 1758), *Bugula neritina* (Linnaeus, 1758), *Bugula stolonifera* Ryland, 1960, *Conopeum seurati* (Canu, 1928), *Savignyella lafontii* (Audouin, 1826), *Schizoporella errata* (Waters, 1878), *Watersipora subtorquata* (d'Orbigny, 1842) and *Zoobotryon verticellatum della* Chiaje, 1828; one tunicate, *Styela plicata* Lesueur, 1823; and an introduced hydroid, *Obelia dichotoma* (Linnaeus, 1758) were frequent, and in some cases dominant, components of encrusting communities. Of the 20 most frequently occurring species detected in the Bay, four were introduced and of the 20 species with highest average percent cover per plate, six were introduced. At one site, space occupation by NIS averaged 71.6% ± 7.4 of plate live cover. Space occupation by an individual NIS was as high as 62.4% of plate area (mean 7.82% ± 1.8). NIS were detected at sites lacking commercial traffic and ballast water discharge and isolated by distance and physical environment, suggesting that hull fouling of recreational craft may be the most important vector in the region. Seventy-five percent of NIS detected in Shark Bay are established in Australian ports to the south of Shark Bay, while 33% are established to the north, tentatively implicating temperate affinity NIS and the movement of vessels from Australian ports south of Shark Bay as a greater risk to the region.

Zabin, C.J., G.V. Ashton, C.W. Brown & G.M. Ruiz. 2009. Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. Aquatic Invasions 4 (3): 429-434.

Abstract. The kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae), a native of Japan, northern China, and Korea, is now established at multiple locations throughout the world, including the west coast of the United States and Mexico. In 2000, *U. pinnatifida* was first reported in the United States from Los Angeles Harbor, California. Within a year, it had also been found 500 km to the north, in Monterey Harbor, California. In 2002, this alga was reported from Ensenada, Mexico to Monterey, California, and no subsequent spread has been reported since this time. In May 2009, we discovered *U. pinnatifida* to the north, at two marinas in San Francisco Bay and the outer coastal harbor at Pillar Point, San Mateo County. All observed individuals were removed and measured. Based on size and reproductive status, it appears that multiple cohorts were present. Transfer on the hulls of recreational boats is suggested as the source of this recent range expansion in California. Given the large flux of both recreational and commercial boat traffic in San Francisco Bay, this may become an important source for further spread both along the coast and to other biogeographic regions.

Appendix C. Some of the fouling organisms previously observed on recreational boat hulls

	Region	Source
Algae		
Antithamnionella spirographidis	France	Mineur et al. 2008
Bachelotia antillarum	France	Mineur et al. 2008
Bangiales	France	Mineur et al. 2008
Bryopsis plumose	Gulf of St Lawrence	Darbyson et al. 2009
Caulerpa taxifolia	Mediteranean Sea	In Michin et al. 2006
Ceramiales	France	Mineur et al. 2008
Ceramium sp.	Gulf of St Lawrence	Darbyson et al. 2009
Chlorophyta	France	Mineur et al. 2008
Ectocarpales	France	Mineur et al. 2008
Ectocarpus siliculosus	France	Mineur et al. 2008
Enteromorpha sp.	Gulf of St Lawrence	Darbyson et al. 2009
Erythropeltidales	France	Mineur et al. 2008
Erythrotrichia carnea	France	Mineur et al. 2008
Feldmannia irregularis	France	Mineur et al. 2008
Filamentous algae	Gulf of St Lawrence	Darbyson et al. 2009
Neosiphonia harveyi	France	Mineur et al. 2008
Polysiphonia brodiei	France	Mineur et al. 2008
Polysiphonia denudata	France	Mineur et al. 2008
Polysiphonia elongata	France	Mineur et al. 2008
Polysiphonia sp.	Gulf of St Lawrence	Darbyson et al. 2009
Polysiphonia sp.	France	Mineur et al. 2008
Polysiphonia subtilissima	France	Mineur et al. 2008
Porphyra leucosticta	France	Mineur et al. 2008
Rhodophyta	France	Mineur et al. 2008
Sargassum muticum	NE Atlantic, NE Pacific	In Michin et al. 2006
Stramenopiles	France	Mineur et al. 2008
Ulothrichales	France	Mineur et al. 2008
Ulothrix flacca	France	Mineur et al. 2008
Ulva compressa	France	Mineur et al. 2008
Ulva flexuosa	France	Mineur et al. 2008
Ulva linza	France	Mineur et al. 2008
Ulva prolifera	France	Mineur et al. 2008
Ulvales	France	Mineur et al. 2008
Undaria pinnatifida	New Zealand, Australia, N Europe, Argentina	In Michin et al. 2006
Unknown ectocarpalean	France	Mineur et al. 2008
Other algae	Gulf of St Lawrence	Darbyson et al. 2009
Vascular Plants:		
Zostera marina	Gulf of St Lawrence	Darbyson et al. 2009
Terrestrial plants	Gulf of St Lawrence	Darbyson et al. 2009

	Region	**Source**
Cnidaria:		
Aurelia aurita	Gulf of St Lawrence	Darbyson et al. 2009
Campanulariidae	Gulf of St Lawrence	Darbyson et al. 2009
Hydrozoa	Gulf of St Lawrence	Darbyson et al. 2009
Laomedea sp.	Gulf of St Lawrence	Darbyson et al. 2009
Medusozoa	Gulf of St Lawrence	Darbyson et al. 2009
Sertulariidae	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Cnidaria	Gulf of St Lawrence	Darbyson et al. 2009
Copepoda:		
Acartia hudsonica	Gulf of St Lawrence	Darbyson et al. 2009
Acartia sp.	Gulf of St Lawrence	Darbyson et al. 2009
Acartia tonsa	Gulf of St Lawrence	Darbyson et al. 2009
Calanoida	Gulf of St Lawrence	Darbyson et al. 2009
Calanus finmarchicus	Gulf of St Lawrence	Darbyson et al. 2009
Centropages hamatus	Gulf of St Lawrence	Darbyson et al. 2009
Copepoda nauplii	Gulf of St Lawrence	Darbyson et al. 2009
Eurytemora hirundoides	Gulf of St Lawrence	Darbyson et al. 2009
Eurytemora sp.	Gulf of St Lawrence	Darbyson et al. 2009
Harpacticoida	Gulf of St Lawrence	Darbyson et al. 2009
Oithona similis	Gulf of St Lawrence	Darbyson et al. 2009
Pseudocalanus minutus	Gulf of St Lawrence	Darbyson et al. 2009
Temora longicornis	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Copepoda	Gulf of St Lawrence	Darbyson et al. 2009
Other Crustacea:		
Ampithoe longimana	Gulf of St Lawrence	Darbyson et al. 2009
Calliopius laeviusculus	Gulf of St Lawrence	Darbyson et al. 2009
Cancer irroratus	Gulf of St Lawrence	Darbyson et al. 2009
Caprella scaura	N Adriatic Sea	In Michin et al. 2006
Caprellidea	Gulf of St Lawrence	Darbyson et al. 2009
Cirripedia	Gulf of St Lawrence	Darbyson et al. 2009
Cirripedia nauplii	Gulf of St Lawrence	Darbyson et al. 2009
Dyspanopeus sayi	Gulf of St Lawrence	Darbyson et al. 2009
Elminius modestus	N Europe	In Michin et al. 2006
Evadne nordmanni	Gulf of St Lawrence	Darbyson et al. 2009
Evadne sp.	Gulf of St Lawrence	Darbyson et al. 2009
Gammarus lawrencianus	Gulf of St Lawrence	Darbyson et al. 2009
Gammarus oceanicus	Gulf of St Lawrence	Darbyson et al. 2009
Hyperia sp.	Gulf of St Lawrence	Darbyson et al. 2009
Idotea sp. Juveniles	Gulf of St Lawrence	Darbyson et al. 2009
Ostracoda	Gulf of St Lawrence	Darbyson et al. 2009
Podon sp.	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Amphipoda	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Decapoda	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Isopoda	Gulf of St Lawrence	Darbyson et al. 2009

	Region	Source
Arachnida:		
Acaridae	Gulf of St Lawrence	Darbyson et al. 2009
Insecta:		
Chironomidae	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Insecta	Gulf of St Lawrence	Darbyson et al. 2009
Mollusca:		
Bivalvia	Gulf of St Lawrence	Darbyson et al. 2009
Bivalve veligers	Gulf of St Lawrence	Darbyson et al. 2009
Mytiloida	Gulf of St Lawrence	Darbyson et al. 2009
Mytilopsis sallei	Australia, India	In Michin et al. 2006
Perna viridis	Australia, Gulf of Mexico, Carribbean	In Michin et al. 2006
Unidentified Gastropoda	Gulf of St Lawrence	Darbyson et al. 2009
Polychaeta:		
Ampharete arctica	Gulf of St Lawrence	Darbyson et al. 2009
Cirratulidae	Gulf of St Lawrence	Darbyson et al. 2009
Ficopomatus enigmaticus	Europe, New Zealand, Australia	In Michin et al. 2006
Pectinariidae larva	Gulf of St Lawrence	Darbyson et al. 2009
Sigalionidae larvae	Gulf of St Lawrence	Darbyson et al. 2009
Spionidae larvae	Gulf of St Lawrence	Darbyson et al. 2009
Unidentified Polychaeta	Gulf of St Lawrence	Darbyson et al. 2009
Echinodermata:		
Echinodermata juvenile	Gulf of St Lawrence	Darbyson et al. 2009
Bryozoa:		
Bryozoa, unidentified	Gulf of St Lawrence	Darbyson et al. 2009
Bugula turrita	Gulf of St Lawrence	Darbyson et al. 2009
Tricellaria inopinata	N Europe	In Michin et al. 2006
Watersipora subtorquata	Australasia	In Michin et al. 2006
Vertebrata:		
Fish eggs	Gulf of St Lawrence	Darbyson et al. 2009
Gasterosteidae larvae	Gulf of St Lawrence	Darbyson et al. 2009
Other Taxa:	Gulf of St Lawrence	Darbyson et al. 2009
Foraminifera	Gulf of St Lawrence	Darbyson et al. 2009
Nematoda	Gulf of St Lawrence	Darbyson et al. 2009
Oligochaeta	Gulf of St Lawrence	Darbyson et al. 2009

Appendix D. Questionnaire sent to boaters.

Research Questionnaire
Biofouling and boat hull maintenance
www.clr.pdx.edu/fouling

Dear boat owner,

The Smithsonian Environmental Research Center and Portland State University are conducting a survey of boat owners regarding recreational and fishing boat movements and hull maintenance. We conduct marine ecology research, and for this project we are interested in biofouling organisms (marine animals and seaweed) that accumulate on the hulls of vessels. In particular, we would like to gather information on vessel maintenance and recent voyage histories to help us better understand the factors contributing to biofouling on boats. Fouling species are a nuisance to boat owners, harbors and the environment. The information we gather may help us to better understand how to deal with this problem. We have prepared six questions and would greatly appreciate your time in answering them. **Please return these surveys by April 20, 2009.**

Your participation is voluntary and you may remain anonymous if you choose. The purpose of this questionnaire is for research only and there is no risk attached to your participation. We do not require your name or contact details, however, you may provide them if you wish to be entered into a drawing for a $200 gift certificate toward West Marine.

We are also interested in surveying boat hulls using an underwater camera and divers in April and May 2009. Our surveys will be conducted in Central California on boats that are berthed. We use an underwater camera on a pole to video the submerged portions of your boat. Divers may remove fouling animals and algae from small patches on your boat, using flexible plastic tools only which will not damage hull paint. Your participation in hull surveys is entirely voluntary and you may withdraw at any time. You may also opt to have us use the camera only (no divers). Your attendance at surveys is not required but if you wish you can use this as an opportunity to view the underside of your boat and ask any questions you may have.

If you have any questions regarding the questionnaire please contact Chris Brown (browncw@si.edu) or Chela Zabin (zabinc@si.edu) or call (415) 435-7128. You may report problemswith this survey or direct questions in regard to your rights as a subject in this study to Karen Otiji, Office of Sponsored Projects, Smithsonian Institution, (202)633-7110. All reports or correspondence will be kept confidential. By completing the survey, you are granting the investigators permission to use your responses in the aggregate data collected for this study. Any personal information provided will be seen only by the researchers and destroyed at the completion of the project.

Yours sincerely,

Chris Brown and Chela Zabin, Smithsonian Environmental Research Center

Smithsonian Environmental Research Center & Portland State University

Research Questionnaire:
Hull maintenance and biofouling of recreational craft

AIM: To assess the factors contributing to fouling accumulation on vessel hulls

Dear vessel owner or operator: Please answer the following questions regarding your boat use and hull maintenance. Your contact informationis not required but if you wish to provide these details to be eligible for a prize drawing they will remain confidential. Each eligible questionnaire will be entered into a drawing for a **$200 gift voucher towards West Marine** if returned by **April 20, 2009**. All of the information collected is for research purposes only. Please return this form to the drop box at your marina, in the return envelope provided, or fax to (415) 435-7128. Please visit www.clr.pdx.edu/fouling if you would like to submit an electronic form and/or for more information on the project.

1.Today's Date: ____/____/____ (mm/dd/yy)

2.Type of craft: recreational sailboat/yacht recreational motorboat
fishing boat charter fishing boat
charter sailing________ other (specify) ______________________

3. Home marina______________________________

4. Please provide information on the hull maintenance techniques used on your boat.

(a)Antifouling paint.

Last paint application ___/___ (mm/yy)

Product (or product type) used: __________________ (Don't know)

(b)Manual hull cleaning (brushing, scrubbing, water-blasting, etc):

Have you manually cleaned your hull since paint was last applied?

Yes No

If yes, how often: __ times Most recent: ___/___ (mm/yy)

If yes, what method(s) did you use: _________________________________

If yes, where (check multiple boxes if applicable):

in-water at a marinaon a trailer at a slip

on a trailer at a garage/at your home Other (specify__________________)

SURVEY CONTINUES ON THE NEXT PAGE

5. Please provide some information on the use and movements of your boat during the past 12 months. Check multiple boxes if they apply and write on page margins if needed.

All of my trips were within my local bay, with no overnight stays

About how many trips: _____ trips

I traveled by boat to the following coastal locations:

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

I trailered my boat to the following coastal locations:

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

I trailered my boat to other locations (rivers, lakes, across country). Provide some details:

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

Location ________________________ No. of trips ____ Usual duration____________

6. We would like an opportunity to **assess biofouling on your vessel**. In late April and May, we intend to visit several marinas in Central California and use an underwater camera and divers to examine biofouling on boat hulls. Hull assessments with the camera take about 30 minutes to complete and your boat's hull will not be scraped or interfered with (visual examination only). If you opt to allow divers, we will collect fouling organisms from small patches on your hull using flexible, plastic tools only. You are not required to be present but are very welcome to view the footage of your vessel's hull and ask any questions you may have.

SURVEY CONTINUS ON THE NEXT PAGE

YES, I would like to participate and I will allow a camera and diver survey of my boat's hull. I am providing my contact details below for hull surveys and inclusion in the drawing.

YES, I would like to participate and I will allow a camera survey of my boat's hull (no divers). I am providing my contact details below for hull surveys and inclusion in the drawing.

NO, I do not wish to participate in the hull survey but I am providing my contact details below for inclusion in the prize drawing.

NO, I do not wish to participate and choose to remain anonymous. I understand that I will not be included in the prize drawing.

Name:

Contact information (email, phone):

Slip # (for those who checked YES on question 6):

SURVEY CONTINUS ON THE NEXT PAGE

Appendix E. Organisms found on sampled vessels from Monterey and South Beach

Each row represents a single vessel. Non-native species are shown in bold.

HARBOR	***Bugula neritina***	*Bugula calfornica*	*Bugula pacifica*	***Bugula stolonifera***	***Watersipora cf subtorquata***	*Celleporaria brunnea*	*Tricelleria occidentalis*	*Bowerbankia sp*	*Obelia sp.*	cf. Euphysora	***Ascidia zara***	*Ascidia ceratodes*	*Ascidia aspersa*	*Styela montereyensis*	*Molgula sp.*	***Botryllus violaceus***	***Botryllus schlosseri***	*Diplosoma sp.*	Mussels	Oyster (cf. Pododesmus)	Polyplacophoran	***Ficopomatus sp.***	Spirorbids	Serpulids	Polychaetes	Sabellids	*Balanus crenatus*	*Caprella sp.*	***Caprella mutica***	*Caprella californica*	*Caprella penantis*	Gammarids	*Algae*
Monterey	✓	✓			✓	✓		✓															✓						✓	✓	✓		
Monterey																													✓	✓			
Monterey					✓																									✓		✓	
Monterey																													✓	✓		✓	
Monterey	✓	✓			✓	✓							✓				✓						✓			✓			✓	✓			
Monterey					✓																								✓	✓		✓	
Monterey					✓	✓				✓																						✓	
Monterey					✓	✓																							✓			✓	
Monterey																														✓			
Monterey						✓													✓				✓					✓		✓			
Monterey					✓	✓																				✓						✓	
Monterey					✓	✓																								✓		✓	
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Monterey	✓																	✓	✓				✓				✓						
Monterey					✓	✓					✓								✓				✓										
Monterey																			✓	✓							✓		✓	✓		✓	
Monterey	✓	✓				✓						✓						✓					✓						✓	✓	✓	✓	
Monterey					✓																							✓					
Monterey	✓			✓	✓	✓										✓		✓				✓			✓		✓		✓	✓			
Monterey	✓					✓												✓											✓	✓			
Monterey	✓		✓					✓						✓	✓		✓										✓						
South Beach	✓		✓																								✓						

SURVEY CONTINUS ON THE NEXT PAGE

South Beach															✓
South Beach			✓			✓	✓	✓				✓			
South Beach										✓					
South Beach	✓				✓					✓	✓			✓	
South Beach	✓													✓	
South Beach	✓	✓			✓	✓						✓	✓	✓	
South Beach	✓	✓		✓		✓			✓	✓		✓	✓	✓	
South Beach	✓				✓					✓		✓			
South Beach	✓	✓		✓	✓					✓		✓		✓	
South Beach										✓					
South Beach	✓			✓						✓					
South Beach					✓					✓		✓			

<u>SURVEY CONTINUS ON THE NEXT PAGE</u>