# Aquatic Invasive Species Vector Risk Assessments:

## *Recreational vessels as vectors for non-native marine species in California*

Final Report July 2012


Submitted to the California Ocean Science Trust
Funded by the California Ocean Protection Council

By:

The Aquatic Bioinvasion Research & Policy Institute

*A Partnership between Portland State University & the Smithsonian Environmental Research Center*

Gail Ashton, Chela Zabin, Ian Davidson & Greg Ruiz

Smithsonian Environmental Research Center

Portland State University

## Table of Contents


**1. Executive Summary** .......... **2**

**2. Introduction** .......... **5**

2.1. The Recreational Vessel Vector .......... 6

2.2. History of the Vector .......... 8

**3. Aims** .......... **8**

**4. Methods** .......... **9**

4.1. Invasion History .......... 9

4.2. Contemporary Vector Operation in California .......... 12

**5. Results** .......... **14**

5.1. Invasion History .......... 14

Invasion History Key Findings .......... 24

5.2. Contemporary Vector Operation in California .......... 25

Contemporary Vector Key Findings .......... 40

**6. Discussion** .......... **41**

6.1. Invasion History & Impacts .......... 41

6.2. Current Patterns and Processes of Vector Operations .......... 42

6.3. Management Review and Recommendations .......... 43

6.4. Critical data gaps .......... 52

6.5. Key Management Recommendations for California .......... 52

**7. Acknowledgements** .......... **53**

**8. References** .......... **54**

## 1. Executive Summary

### Background

The introduction of non-indigenous species (NIS) is recognized around the world as a threat to biodiversity, ecosystem services and human health. California is a hotspot for the introduction of marine NIS in North America as well as globally. The number of new marine invasions detected per decade has increased dramatically over the past century in California and also in other regions. In response, management of the vectors of introduction has been advancing as the most effective and efficient mechanism to curtail this increase. To date, most vector management has focused on commercial vessels, which are important and active vectors of marine NIS transfers. In this regard, California has been a global leader in developing and implementing management actions to curb both ballast water and hull fouling modes of introduction by commercial shipping. Despite this progress, other vectors also exist, creating additional opportunity for the introduction and spread of marine NIS. The state is now seeking further information about these vectors, including how the vectors operate, the likelihood of past and future introductions, and identification of opportunities for successful interventions. Here, we characterize the current state of knowledge about recreational boating as a vector in California, including additional information from other regions.

### Aim

To characterize the operation and potential importance of recreational vessels as vectors for NIS introduction and coastwise spread in California.

### Approach

We used historical records of NIS introductions in California, along with records of biofouling organisms associated with the hulls and underwater surfaces of recreational boats from global studies, to assess the state of knowledge and historic importance of recreational vessel hull fouling. Further, we collected real-time data on vessel behavior and fouling communities to assess the contemporary and likely future role of recreational vessels in the spread of NIS in California. Finally, we reviewed briefly some potential management actions that could reduce the role of recreational vessels as vectors of NIS.

### Findings

Available data indicate that recreational vessels have been an important and potent vector for the spread of NIS in California, as well as other regions around the world, and this continues to be the case today. The opportunities for spread result from the large number of vessels in the state, their movements among bays, and also the biofouling (nonindigenous) organisms associated with the underwater surfaces of vessels. Approximately 800,000 – 900,000 recreational boats were registered in California in recent years (2008- 2010). Questionnaire responses during the present study, and results from previous studies, indicate that 20-50% of these vessels travel outside of their home port or bay (depending on study and home bay). Among transient vessels examined by in-water field surveys during this study (n=49), 86% had fouling species present on their hulls, 26% had hundreds of individual fouling organisms, and another25% had more than a thousand individuals organisms present. On average, 16 species were identified from transient vessel fouling communities; 29% of the species identified were considered non-native in California; including 3 species that have not been recorded from California (or the West Coast).

There is a global shortage of studies on the impact of marine NIS which limits understanding of the true extent of ecological and economic consequences of invasions due to hull fouling (as well as other vectors). Of the few studies that were available, most demonstrated a significant impact. Further research on impacts is warranted and critical in setting priorities for management response (eradication or control), in order to focus such efforts on high-impact species of concern.

Overall, when considering the number of recreational vessel movements and associated biofouling organisms documented on transient vessels in California, it is evident that recreational boats (a) transfer a large number of non-native organisms throughout California and (b) contribute to the spread of NIS into and through the state. Given that many of these NIS may cause impacts in the introduced habitat, the potential consequences of continued introduction and spread are extensive.

Whereas commercial vessels (and other vectors) may often be a source of initial introductions into the state, recreational vessels are likely to be especially important in facilitating coastwise spread of invasions. California receives approximately 5,000-6,000 commercial vessel arrivals each year to commercial ports, arriving mostly from overseas and outside the state. In contrast, we estimate arrivals of recreational vessels are at least two orders of magnitude greater, mostly from within the state, providing a high level of connectivity.

Importantly, small vessels can access harbors, bays, estuaries and coastlines that are inaccessible to commercial vessels, including remote areas where other vectors (aquaculture, and the trade in ornamental species, live bait and live seafood) can be rare. It is often not possible to partition the source of biofouling invasions among recreational, commercial, and fishing vessels. However, the invasion of small bays (without commercial vessel traffic) underscores the likely overall importance of non-commercial vessel transfers to marine invasions in the state; critically, the absolute number of species transfers by recreational vessels is expected to be greater in large bays, where more recreational vessels arrive, even if the exact role of commercial versus recreational vessels for particular invasions is not clear.

## Recommendations

There are currently no guidelines or regulations in California that aim to manage (reduce) the risk of marine species transfers associated with recreational vessels. In addition, there is only limited information on movement patterns and associated biota for these vessels in the state. The current approach to managing invasion risks for recreational vessels, which consists solely of efforts to educate boaters by agencies such as California Sea Grant, and the multi-agency Clean Marinas program, which focuses mostly on reducing chemical pollution,  is in sharp contrast to that for commercial ships. This disparity exists at both the state and national levels.

We recommend a lead agency be given the authority and resources to evaluate, advance, and assess efficacy of management strategies to reduce species transfers by recreational vessels operating in California waters.  This could include voluntary management practices, education and outreach campaigns, and incentive programs.  In addition to attempts to increase voluntary efforts, regulations targeting high-risk vessels at key control points might be considered, following the Hazard Analysis and Critical Control Point (HACCP) approach.  This may be especially effective for foreign arrivals, as a reporting and inspection mechanism already exists through Customs and Border Protection.  Examples of similar programs from Australia and New Zealand may provide useful models for California.

## 2. Introduction

The introduction of non-indigenous species (NIS) is recognized globally as a threat to biodiversity, ecosystem services and human health (Mack et al. 2000, Carlton 2001, Millennium Ecosystem Assessment 2005, Charles & Dukes 2007). California is a hotspot for the introduction of NIS (Cohen & Carlton 1998; Ruiz et al. 2011b) on the west coast of North America, nationally, and globally. The high numbers of NIS in California represent a potential threat to the health, resilience and productivity of coastal and ocean ecosystems. In 2010, the National Ocean's Economics Program valued both California's 'coastal economy' and 'ocean economy' at more than $2 trillion (www.oceaneconomics.org). This value includes industries (aquaculture, fisheries, tourism, and other businesses) and wages accrued from the ocean or coastal environments, but excludes services that are harder to put a value on, including recreation and health benefits (Kite-Powell et al. 2008), protection of coastal communities from storms and floods, and climate regulation (Doney et al. 2009). The Californian Ocean Protection Act (2004) states that: "California's coastal and ocean resources are critical to the State's environmental and economic security, and integral to the State's high quality of life and culture".

The number of recognized marine NIS has increased dramatically in recent decades around the globe (Ruiz et al. 2000; Hewitt et al. 2004), and this trend is likely to continue in the absence of management efforts, if the rates and magnitude of species transfers among regions expand with increasing globalization. While invasion management places a premium on prevention of invasions, as the most cost-effective and desirable approach (Wittenberg & Cock 2005), most efforts have focused historically on species-by-species management instead of a broader-based approach to manage the vectors (transfer mechanisms). Increasingly, scientists and governments are realizing that a vector approach allows the prevention of introductions across many species groups, can be applied globally, and once in place should continue to prevent the spread of NIS with minimal changes necessary (Ruiz & Carlton 2003). However, vector management requires information about how the vector operates, the likelihood of introductions via the vector, and identification of opportunities for successful intervention (management strategies). To guide the allocation of resources, an assessment of the relative risk of the vector, compared to other vectors is necessary.

Since early studies of marine NIS were published, commercial shipping has been recognized as a major vector for the spread of marine species (Carlton 1985, Cohen & Carlton 1995). California state agencies have been among global leaders driving guidelines and regulations to manage both the ballast water and hull fouling subvectors of the commercial shipping vector. The Ocean Science Trust has recognized at least six additional vectors that are potentially important to the introduction and spread of NIS on the coast of California: aquaculture, trade in ornamental species, fishing vessels, live bait trade, live seafood trade and recreational vessels. None of these vectors have been the target of focused management actions in California to date. In this report, we provide a review of the current knowledge recreational vessels as vectors for coastal marine organisms, both globally and in California, and present new data characterizing the contemporary risk of introductions associated with recreational vessel transport in California.

## 2.1. The Recreational Vessel Vector

Hull fouling is the principal method for the introduction of NIS associated with recreational boats and the focus or this study. For recreational vessels, species can also (a) become entangled on anchors, lines, boat bumpers, and other gear, (b) be carried among fishing/diving gear, and (c) become entrained in water in intakes and other such locations. While these are likely relatively low-level occurrences compared with hull fouling, relatively little information is available at the present time to characterize them.

Hull fouling involves the attachment of organisms to the submerged surfaces of a marine vessel. Fouling opportunities on recreational vessels, typically less than 50ft length, differ from those associated with commercial vessels in a number of ways (Table 1). Recreational vessels are frequently berthed or moored for long periods in sheltered marinas and bays (Floerl 2002). These habitats are conducive for the development of fouling communities, which are likely to spread onto the vessel hulls (Floerl & Inglis 2003). This contrasts with commercial vessels, which are routinely in port for a relatively short period of time (typically <24hrs) and spend most of their time traveling between multiple ports (Davidson et al 2009). However, the wetted surface area of a recreational boat is much less than that of a commercial vessel, and the size and intricacy of recessed niche areas (propellers, thrusters, sea chests), where the highest diversities and densities of fouling species often occur, is also greatly reduced. Sailing vessels are generally slower moving than commercial vessels, which might retain some species that could be sloughed off at the higher speeds traveled by motor-powered recreational boats and commercial vessels. The distances traveled by commercial vessels also tend to be much greater; thus commercial vessels are likely more important in moving species between coasts, compared with small boats, which may play a far greater role in moving species within a region. In addition, recreational vessels can access sheltered and shallow harbors that are inaccessible to larger commercial vessels, potentially allowing transfers to locations far away from major international ports.

**Table 1. Comparison of factors that influence the hull fouling communities on commercial and recreational vessels.**

| | Commercial vessels | Recreational vessels |
|---|---|---|
| **Factors determining destinations:** | Supply & demand | Variable:<br>Tourism/lack thereof<br>Distance/proximity<br>Cost |
| **Typically:** | Major Ports | Marinas/Harbors/Other |
| **Schedule:** | Efficient & Economical | Relaxed |
| **In-port duration:** | Short | Long/short |
| **Speed:** | Fast | Slow/fast |
| **Voyages:** | Long-distance | Long/Short |
| **Dry-docking:** | 2-5yrs, regulated | Ad-hoc |
| **Lay-ups:** | Infrequent | Frequent |
| **Monitoring (Data sources)** | USCG/NBIC/ CBP/Lloyd's | State Licensing |

California is a hot-spot of recreational vessel activity because of its substantial coastline, attractive climate and position at the border with Mexico and access to and from more southern destinations. Approximately 900,000 recreational vessels registered in the state of California from 2008-2009, and the number dropped to about 810,000 in 2010. Within the US, California is second only to Florida in numbers of registered boats (www.uscgboating.org). The number of NIS recorded from California is also high (Ruiz et al. 2011b). While most NIS are recorded from bays with commercial shipping activity (Wasson et al. 2001, Ruiz et al. 2009), there are many smaller bays and inlets which are inaccessible to commercial vessels, but frequently visited by recreational vessels. The flora and fauna of these waters is less well studied, therefore the true extent of NIS may not be realized (although see deRivera et al. 2005).

Hull fouling of recreational vessels is a nuisance to vessel operations, creating drag, blocking intakes and affecting antifouling efficiency. To minimize these negative effects, recreational vessel owners usually employ some means to prevent or delay the growth of fouling species. Techniques include keeping the vessel out of water when not in use, keeping the vessel in an in-water containment device (e.g. a skirt or boat-bag), or using an anti-foulants on the hull. Anti-fouling paint is the most common anti-fouling method, but other approaches are also used (e.g., applying zinc strips, using sonic devices and making the hull from a fouling-resistant material). Unfortunately, over time, all of these mechanisms are likely to fail, increasing the likelihood that recreational boats will transport species (both native and non-native species) to new locations.

## 2.2. History of the Vector

Since the 1960s, California has been recognized as a hotspot for introductions of marine nonindigenous species (Carlton 1979; Cohen & Carlton 1998). New records of marine NIS have continued to increase through time (Cohen & Carlton 1995, 1998; Ruiz et al. 2000) and the current known number of established marine NIS in California is greater than 257 (Ruiz et al. 2011b). This is twice the number described in Washington (n=94) and much greater than described for Oregon (n=75), British Columbia (n=62) and Alaska (n=10) (Ruiz et al. 2011b). The historic succession of NIS records indicates that California is an important point of entry for many marine NIS to the west coast of North America, with 79% of all new NIS on the coast being recorded first in California (Ruiz et al. 2011b).

It is often difficult to assign species introductions to specific vectors, because (a) the introduction event is rarely observed and (b) multiple vectors are often possible for dispersal of a given species. For marine and estuarine species described in California, a previous analysis attributed only 44% of introductions to a single vector, based on life history characteristics, location of introductions and time of introduction (Ruiz et al. 2011b); for the remaining NIS, multiple vectors were considered possible for the introduction to California. Vessels have been a dominant vector for introductions in California, both through ballast water and hull fouling (Fofonoff et al. 2003). More than 60% of marine NIS in California may have been introduced via hull fouling, with the vector solely responsible for 18% of introductions, and as one of several possible vectors for an additional 42% of introductions (Ruiz et al. 2011b).

# 3. Aims

We aim to characterize the operation and potential importance of recreational vessels as vectors of NIS to and along the coastline of California. Our definition of recreational vessels follows that of the Deparment of Motor Vehicles, i.e., every sail-powered vessel over eight feet in length and every motor-driven vessel (regardless of length). The class excludes commercial vessels that must be documented by the U.S. Coast Guard, and those vessels propelled solely by oar or paddle. Smaller craft such as kayaks, canoes, paddleboards and jet skis can potentially transfer species, but tend to 1) not travel long distances and 2) be removed from the water between uses, diminishing the build-up of fouling. We limit our study to operations in marine waters (bays, estuaries and nearshore waters), and focus exclusively on hull fouling as the potential vector.

We used historical records of NIS introductions in California, along with records of hull fouling of recreational boats from global studies to assess the state of knowledge and historic importance of recreational vessel hull fouling. Further, we collected real-time data on vessel behavior and fouling communities to assess the contemporary and likely future role of recreational vessels to the spread of NIS in California. Finally, we assessed management actions that could be used to reduce the role of recreational vessels as vectors of NIS.

# 4. Methods

## 4.1. Invasion History

### *4.1.1. Fouling species associated with recreational boats globally*

We surveyed the peer-reviewed and gray literature for documentation of species attached to or otherwise transported by recreational vessels. For the peer-reviewed literature we used the search terms “invasi*” AND “boat*”, “non-native” AND “boat*” and “fouling” AND “boat” for all years in BIOSIS. We gathered additional literature using references contained in these papers. Many such species are reported only incidentally in the literature, and are thus not likely to come up in such a search. We gathered additional papers and unpublished reports (gray literature) from references in the literature, from personal knowledge and from discussions with colleagues. We also corresponded with authors for further information not detailed in the published literature. Most studies did not distinguish between recreational and fishing vessels, so we included all records of species from small boats.

Species or taxa were entered into a database along with the location and date where they were found. When available, we also recorded life stage found, whether they were on resident, visiting, recreational or fishing boats. For this analysis, we did not attempt to determine whether the reported species were native or non-native to the region in which they were found, as we wished to simply assess diversity reported on vessels. Taxa were entered into a database and organized into higher taxonomic groups. We used three internet sites to assist with these classifications: AlgaeBase, Integrated Taxonomic Information System, and the World Register of Marine Species. Where there was disagreement between these systems, we used AlgaeBase as the authority for the algae, and for invertebrates Abbott et al.1997 (tunicates) and Carlton (2007). Higher-level taxonomic classification was based on Pearse et al. (1987).

### *4.1.2. Records and patterns of fouling species introductions in California*

A subset of the National Exotic Marine and Estuarine Species Information System (NEMESIS) was used to assess historic records of marine NIS in California. NEMESIS has been developed internally at the Smithsonian Environmental Research Center (SERC) as a resource for information on non-native (or exotic) species that occur in coastal marine waters of the United States. The database lists reported species (based on standardized literature searches), their current population status (i.e., whether established or not), as well as when, where, and the putative vector(s) associated with each invasion event; it also summarizes key information on the biology, ecology, and known impacts of each taxa listed. Vector classifications for each species in NEMESIS were based on species characteristics and the operation of a vector within a bay (See Appendix 1 for details). Characteristics of fouling species include: broadcast spawning; ability to attach to a surface or build a tube for shelter; filter feeding; and a tolerance of medium-energy environments. We used the species-vector designations assigned by SERC, as recorded in the database. Within the database, ‘fouling’ was a single vector, and it was not possible to distinguish between fouling of recreational, commercial or fishing vessels as vectors, except for small bays where commercial vessels were absent.

Previously, all records of NIS in California had been scrutinized and their location more accurately mapped at a watershed level by SERC. These California records were extracted into a project database. We made several further amendments to the database prior to analyses, and the data were evaluated in a number of ways. San Pablo Bay (SPB) is not distinct from San Francisco Bay (SFB) in terms of its recreational boat traffic (all traffic must pass through SFB to reach SPB). A comparison between species recorded by NEMESIS as present in SPB and SFB showed that there were no species present in SPB that were not recorded previously in SFB. For these reasons, the data for SPB were not included in analyses. Monterey Bay includes three independent marina systems: Monterey Harbor, Elkhorn Slough (including Moss Landing Harbor) and Santa Cruz Small Craft Harbor. These were treated as independent bays in our analyses; additional research was used to determing species presence in each system and the appropriate date of first record.

To examine patterns of spread of NIS over time and space, we analyzed the NEMESIS data in several ways. The decadal rate of new NIS records for California was calculated for (a) all NIS, (b) those NIS with fouling as a potential vector, and (c) those NIS with fouling as a sole vector. To compare the strength of the fouling vector to non-fouling vectors in a spatial analysis among bays, we used three vector divisions (fouling as a sole vector; fouling possible; fouling not a vector) of NIS and compared the relative contribution of each vector division among 42 different bays along the coastline of California. The number of recreational vessel berths in a bay (determined using internet searches and telephoning marinas) was compared to the number of fouling species recorded in the bay using Spearman's rank correlation.

To assess the importance of different bays as introduction entry points for the state through time, the species were divided by the decade and location of the $1^{st}$ record within the state, and the decade of $1^{st}$ record within each bay.

Several analyses were implemented to assess trends of spread in California. Date of first record in a bay was used to link the bays in sequential introduction events and estimate the strength of the connection between bay pairs. Because of the recognized importance of San Francisco Bay as an entry point for NIS to the state (Ruiz et al. 2011b) it was used as a focal point to assess where species spread after being recorded in SFB. Similar analyses were performed for San Diego and Humboldt Bay to look for patterns of northern and southern spread, respectively. Species presence data were used to create a resemblance matrix of the bays using Bray Curtis similarity indices, interpreted using cluster analysis in Primer6.

### *4.1.3. Impacts of fouling-mediated invaders*

We searched the peer-reviewed scientific literature for crustacean impacts studies on the NEMESIS list for non-native species established in California. Algae and molluscs were reviewed by UC Davis (UCD). These three broad taxonomic groups make up a significant portion (>50 %) of the non-native species in California.

Both SERC and UCD used the following approach for these searches, entering results into an identical database. Searches were carried out between November 2011- March 2012 (molluscs and algae) and February- April 2012 (crustaceans).

We used the following search terms in BIOSIS:

> Topic= (Adventive OR Alien* OR Bioinvasi* OR Biosecur* OR Exotic* OR Foreign OR Introduc* OR Incursion* OR Invad* OR Invasi* OR Nonendemic* OR Nonendemic* OR Non indigenous OR Nonindigenous OR Nonnative* OR Nuisance* OR Pest* OR Pest) AND
>
> Topic= (species name in quotes, e.g. "*Ficopomatus enigmaticus*") AND Timespan=1926-2011.

Searches were also carried out using synonyms for the current species name. We used WoRMS (World Registry of Marine Species) for lists of synonyms. We performed an initial sort by reading through the returned titles (>95% of papers for most species were not relevant). We sorted secondarily by reviewing abstracts and obtaining articles. Data from the relevant impact studies were extracted, and papers were retained for potential further review and analysis.

## 4.2. Contemporary Vector Operation in California

### *4.2.1. Vessel traffic: volume and travel patterns*

There is no single source of information on small-vessel traffic for California. All vessels arriving to California from outside of the US must register with Customs and Border Protection (CBP). Registration details include the last port of call, next port of call, and ship characteristics (e.g., type, length). A Freedom Of Information Act (FOIA) request was sent to CBP, asking for all records concerning arrivals of small vessels to California. The request included all arrivals in 2009 and 2010, by date and arrival port.

To study vessel flux at a local scale, eight key marinas along the California coast were used as study marinas. The marinas were selected (a) to cover the length of the state, (b) for their importance as a destination for transient vessels within a bay, and (c) for the availability of transient vessel data (the latter information was established during preliminary conversations with a much larger number of marinas). Study marinas were: the Police Dock, San Diego; Santa Barbara Harbor; Monterey Harbor; Pillar Point Harbor, Half Moon Bay; South Beach Harbor and Pier 39 Marina, San Francisco Bay; Spud Point Marina, Bodega Bay; and Humboldt Bay Harbor. Data from Monterey, Pillar Point, South Beach and Spud Point had been collected previously; the additional marinas were asked to provide records of transient vessel arrivals with all confidential information removed. Most marinas were able to provide this information in an electronic data file; for San Diego and Humboldt it was necessary to enter the data from paper records.

At least one year of data between 2007 and 2011 was available and collected from each marina. Data included a vessel identifier (registration number and/or vessel name), date of arrival, date of departure, vessel type, the vessel owner's home state and zip code (country if outside of the US). Typically these data are collected from visiting boat owners upon payment for use of a berth, and thus should be a very accurate record of visitors staying one night or more. Where possible, vessel type was used to isolate recreational motor and sail vessels from other transient vessels (including fishing, patrol and research vessels). Unfortunately vessel type was not provided reliably across marinas; for example, Spud Point Marina in particular is a marina that is recognized as important for fishing vessels, but transient boat records did not include vessel type.

These data were used to assess trends in the seasonal arrival of vessels, frequency of vessel arrivals from different source locations, duration of stays, and the number of times vessels visited any given marina within the time period of the data. Vessel identifiers were different among marinas and could not be used to track vessels through California.

#### *4.2.2. Boater habits: travel and hull maintenance*

An online survey was developed, reviewed and approved by Smithsonian Institution, and used to collect information on boater habits (http://tinyurl.com/SERCsurvey). There were 3 categories of questions based on those used in previous studies in California and globally: 1) vessel information (type, length and home marina), 2) hull maintenance practices, and 3) vessel use. The online version was advertised widely and did not require the questionnaire to be mailed out or returned by mail (saving costs and resources). The survey was advertised in mail outs from several of the study marinas, on sailing club social networks on the internet, and on the website of 'Latitude 38', a popular West Coast sailing magazine.

We compared the responses in the current study to three earlier studies. Davidson et al. (2008 and 2010) used a written questionnaire similar to the current one to survey 221 boaters in 14 marinas in San Francisco Bay. Zabin et al. 2011 revised the questionnaire slightly and surveyed 394 boaters in three additional San Francisco Bay marinas (selected because they had active sailing communities) and at three nearby small coastal harbors (Spud Point in Bodega Bay, Pillar Point in Half Moon Bay, and Monterey Harbor in Monterey).

#### *4.2.3. Biofouling communities on transient boat hulls*

The contemporary flux of fouling species arriving to California on recreational vessel hulls was assessed by in-water sampling of transient vessels. Santa Barbara Harbor and the San Diego Police Dock were selected as focal marinas for these surveys, as we had previously sampled vessels in San Francisco Bay and Monterey (Zabin et al. 2011) and suspected fouling communities and travel patterns to differ between regions in the state. All transient vessels arriving within a one-week period (repeated two times at San Diego) were interviewed using the questionnaire described above, and asked whether the owner would permit us to do an in-water survey using SCUBA. When permission was granted (~95% of vessels), 2-3 divers completed an in-water survey of the vessel hull. The survey involved taking pictures of all underwater hull surfaces, concentrating on niche areas and locations where hull fouling was present; notes were made to document the extent of fouling for the whole vessel. In addition, all fouling species were collected when possible (a sub-sample focusing on collected organisms that appeared to be different based on morphology was taken on the few vessels where fouling was extensive). Samples were initially sorted into morpho-taxa, or morphologically distinctive organisms, shortly after collection and preserved for further processing to species level (or lowest taxonomic level possible). Certain groups were sent to expert taxonomists for identification or confirmation.

Using the photographs and notes, whole-vessel abundance estimates were described as one of six abundance categories. The categories were based on a log-scale estimate of abundance ranging from 1-10 organisms to >100,000 organisms (individuals or colonies). A seventh category of zero biota was also included. Images of all niche areas were used to measure percent cover of biofouling per niche area. Five photo-quadrats of hull surfaces were selected at random to generate a measure of percent cover of the hull. Hull quadrat images were processed using a point-count method of 100 dots superimposed on the image.

## 5. Results

### 5.1. Invasion History

#### *5.1.1. Fouling species associated with recreational boats globally*

Few studies have been done that focus on the species transported by recreational vessels, and most that do exist only as reports to funding agencies. Many more reports of single species collected from boats are likely to exist, but they are buried in the taxonomic and other literature and many were not exposed during the literature search. Conversely we found numerous papers that suggested yachts as a transport mechanism but did not document fouling extent or species composition directly. We found 23 papers or reports recording 455 marine or brackish water organisms collected from small vessels from 12 countries (including resident and transient vessels; Appendix 2, species list plus references). As a group, fouling species represent a broad spectrum of life forms and trophic levels, including both sessile (attached) and mobile taxa. In some cases, organisms were identified to species level, in other cases descriptive terms such as “green macroalgae” or “fish” were used. Conservatively, this would appear to represent 243 distinct animal, protist, and plant species or taxa in 15 phyla (Fig. 1).

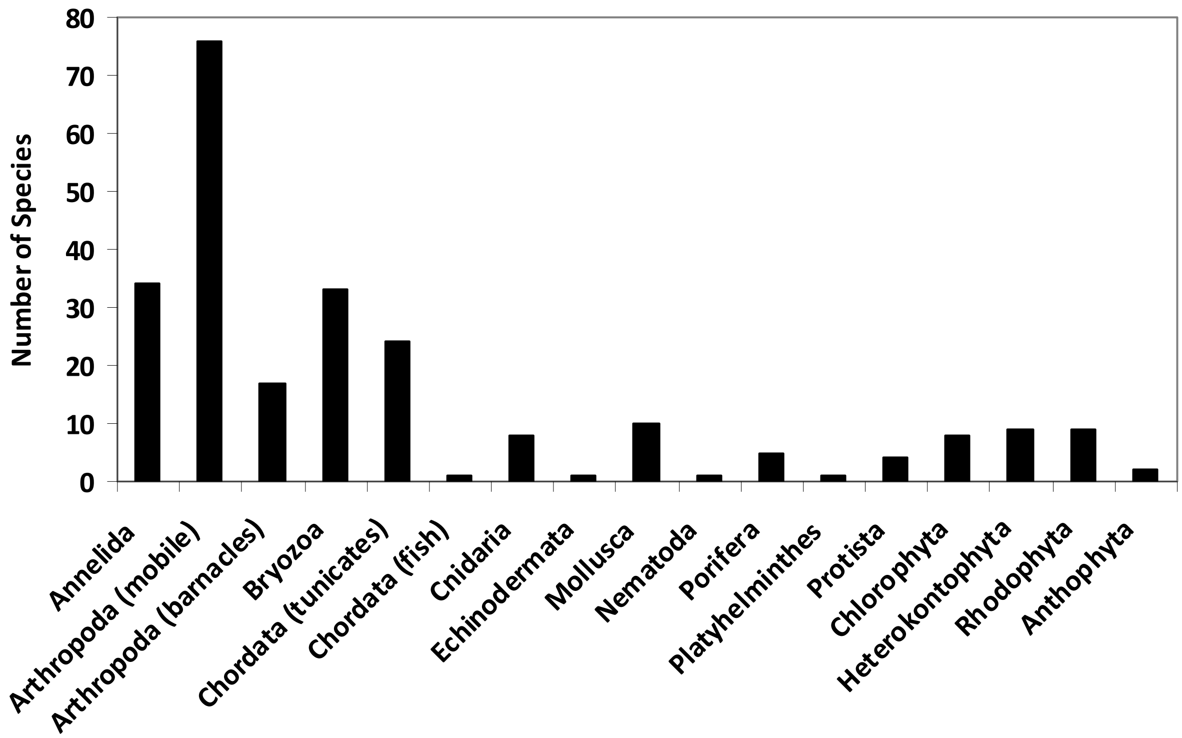



**Figure 1. The number of species by broader taxonomic group reported from small vessels.**

Mobile arthropods were by far the largest taxonomic group, with at least 76 distinct taxa reported. Over half of these species were amphipods, with smaller numbers of isopods, decapods (exclusively crabs) and copepods. Annelids, nearly all polychaetes, made up the second largest group, with 34 distinct taxa. There were 33 bryozoan species and 24 tunicates. Barnacles made up a significant group with 17 species reported. The three higher taxonomic groups of algae combined represented about 24 distinct taxa.

The most-reported taxon was a foliose form of the green alga *Ulva*, which was recorded six times. The arborescent bryozoan *Bugula neritina* was reported 5 times. Each of these may actually represent multiple species, as *B. neritina* is now recognized as a species complex, and there are several species of *Ulva* (which now also includes species formerly in the genus *Enteromorpha*). The tunicates *Botrylloides violaceus, Botryllus schlosseri* and *Diplosoma listerianum,* the barnacle *Amphibalanus amphitrite,* and the bryozoan *Watersipora subtorquata* were each reported four times.

There are several possibilities for biases other than an organism's ability to attach to and travel on boats that could lead to differences in the number of taxa per phylum in this literature, including geographic location where studies were done, taxonomic expertise and interest, and the number of species in the phylum. Eight of the studies were done in North America, and 7 in Europe, with most of the remainder in Australia/New Zealand or Hawaii (Table 2). Most of the researchers also have taxonomic expertise in invertebrate groups rather than in algae.

No reports evaluated the condition of the species reported from hulls, although some noted the presence of gravid individuals, eggs, larvae, and juveniles, indicating that at least some of the species present were capable of reproducing and dispersing into the local environment.

**Table 2. Location and year of publication of studies reporting fouling species from small vessels.**

| Continent | Geographic region | Year of study(s) |
|---|---|---|
| **Europe** | Belgium | 2002 |
| | France | 2008 |
| | Netherlands | 2001 |
| | Ireland | 2006, 2007 |
| | Italy | 2006 |
| **North America** | SE Alaska | 2010 |
| | British Columbia | 2011 |
| | California | 2009, 2010, 2011 |
| | Hawaii | 2004, 2009 |
| | Prince Edward Island | 2009 |
| **South America** | Brazil | 2007 |
| | Curacao | 2007 |
| **Australasia** | Australia | 2005 |
| | New Zealand | 2002 |

### *5.1.2. Records and patterns of fouling species introductions in California*

The project-specific database confirms that invasions in California have continued to increase over the last decade (Fig. 2). Sixty new NIS were recorded in the 1990s and the total number for the 2000s (for which data is incomplete) is likely higher. Fouling species are an important contributor to these numbers, both for species with fouling as a sole vector (13% of species), and as one of multiple vectors (51%; Fig. 2). The relative contribution of fouling species to the total pool of NIS in California has remained similar over the last 100 years.

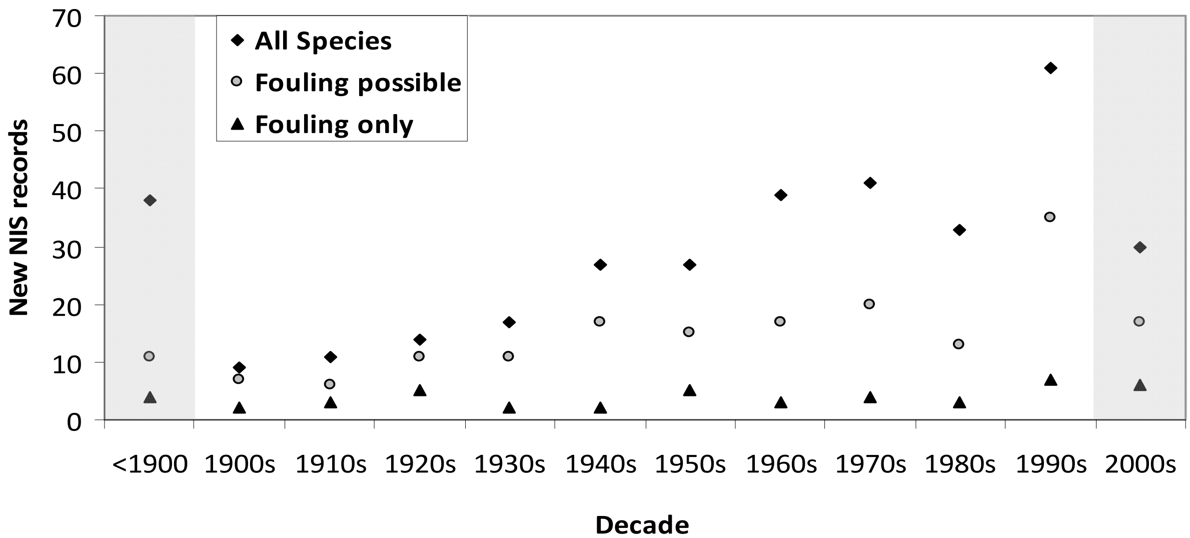



**Figure 2. Decadal rate of marine NIS records for California. Species are separated into those with fouling as the only possible vector (triangles) those with fouling as one of several possible vectors (circles) and all NIS (diamonds). Shaded areas indicate a time interval different from 10 years (all years prior to 1900; 2000-2006).**

San Francisco is an obvious outlier in California (and for the whole West Coast) in terms of both marine NIS and those with fouling as a vector (Fig. 3). There are records of at least 274 marine NIS in San Francisco Bay: 172 of these have fouling as a potential vector, 66 have fouling as a sole vector. The bays with the next highest numbers of marine NIS include the commercial shipping bays of Humboldt, Calleguas (Port Hueneme), San Pedro (Los Angeles-Long Beach) and San Diego; and those with a history of bivalve imports, e.g., Tomales Bay and Elkhorn Slough. Regardless of whether species have fouling as a potential vector, the most NIS have been recorded from bays with multiple vector opportunities. Mission and Santa Monica are the only two bays without a history of commercial shipping or bivalve culture, but with more than 50 NIS. Less than 50 NIS have been recorded in each of the other bays, where recreational boating is considered the dominant potential vector.

The number of fouling NIS recorded in a bay is significantly correlated to the number of recreational berths available in that bay (Spearman's $r$<0.001 for both fouling-only and fouling-possible species; Fig. 4). However, most bays with large numbers of berths also contain commercial shipping ports, including San Francisco, San Pedro and San Diego bays. Thus, there are several factors that likely covary with the number of recreational berths, including the number of commercial shipping vessel arrivals and ballast water discharge, human population, shoreline development, etc. It is difficult-to-impossible to discern between the relative importances of these factors, in particular the relative importance of commercial versus recreational vessels as a vector for fouling species.

For the past 100 years, most first records of NIS with fouling as a possible vector for the state have been in four bays: San Diego, San Pedro, San Francisco, and Humboldt (Fig. 5). This distinction is less apparent when subsequent records are considered (Fig. 6). Years in which high numbers of species new to a bay are reported (as opposed to a new record for the whole state) reflect survey efforts, e.g., surveys by Wasson et al. (2001) in Elkhorn Slough, Boyd et al. (2002) in Humboldt Bay and Fairey et al. (2002) and Needles (2007) in Morro Bay.

The additional analyses failed to reveal any clear or significant trends in introduction sequence or species similarity between bays. Only the summary of these extensive analyses will be described here:

- Neighboring bays did not share the most species, nor were records of the same species in close succession.
- When using San Francisco as a point source, more species were not shared with bays that were close, and the pattern of decade of record did not suggest that the species had spread to neighboring bays first (i.e., no evidence of gradual spread to bays at increasing distances from San Francisco).
- There was no clear pattern of sequential introductions in geographical direction, i.e., either from north and south of the state or from San Francisco Bay (SFB) as a point source. When looking at progressive introductions from the north and south, San Francisco was somewhat distinguished in that most species did not spread north or south without being recorded in SFB, but the trend was distorted by the biased sequence of introduction records (influenced by dates of surveys).
- Few species were shared between bays in the far north and south of the state, but similarity indices did not group the bays by geographic region, presence of alternative vector, or any other factor that could be determined.

There was no correlation between the number of bays in which a species has been found and the number of vectors that could be responsible for its distribution (e.g. *Watersipora subtorquata* has been introduced to 19 bays by fouling; *Codium fragile* ssp *fragile* is only in San Francisco Bay, but has 5 potential responsible vectors).

San Francisco had by far the largest number of species that have not been introduced elsewhere in the state (137 of 175 species only reported from one bay, including those now extinct or failed introductions). Humboldt Bay had the next highest number of unique species (n=8) followed by San Pedro (n=6) San Diego (n=5) and Tomales Bay (n=4).

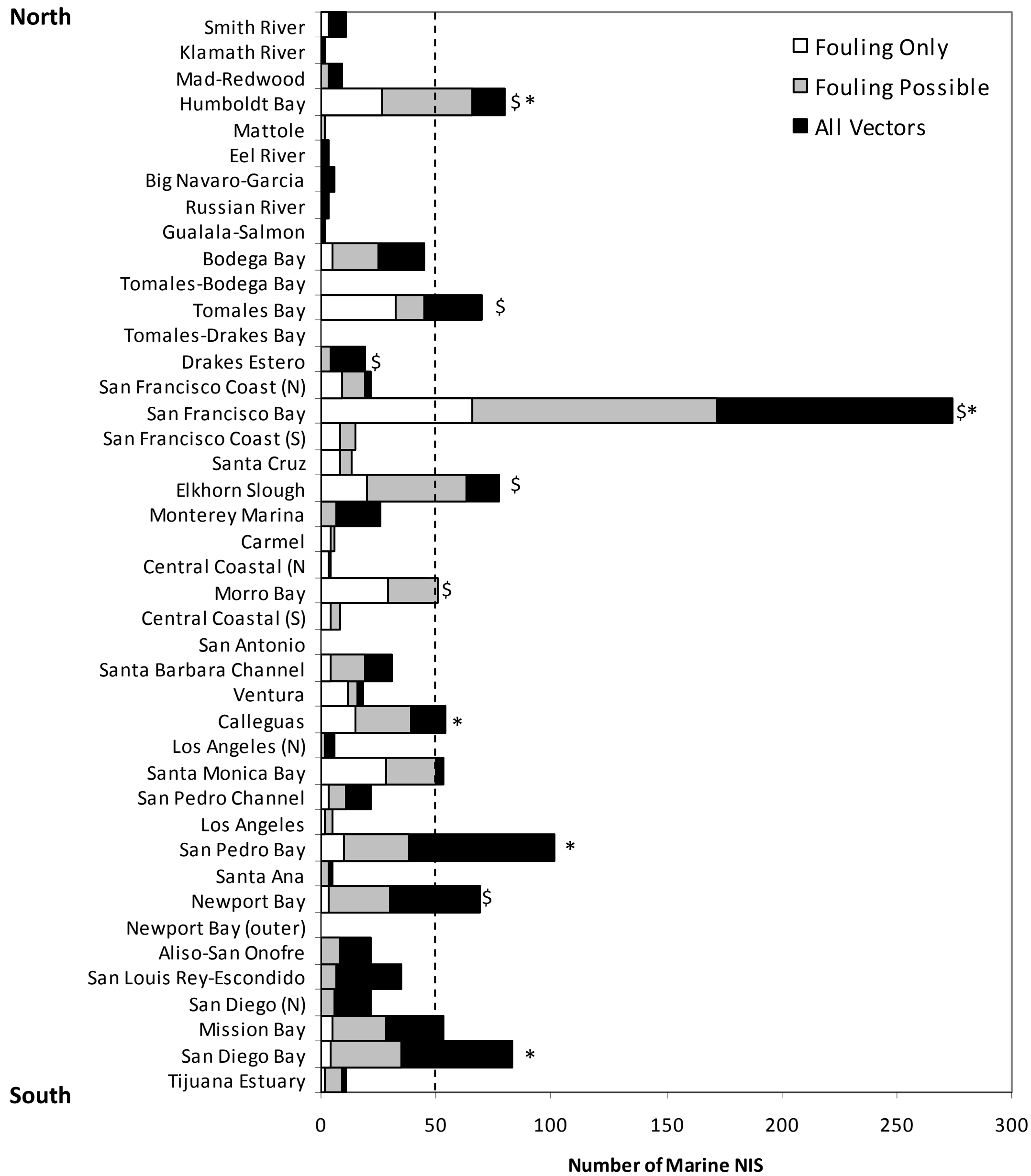



**Figure 3. Spatial distribution of marine NIS among California bays (arranged north to south from top to bottom). Species with fouling as a sole vector (white), fouling as one of several vectors (grey) and those with vectors not including fouling (black) are shown separately. *indicate bays with busy commercial ports; $ indicate bays with a history of bivalve imports for aquaculture. Dashed line indicates 50 NIS, referred to in the text.**

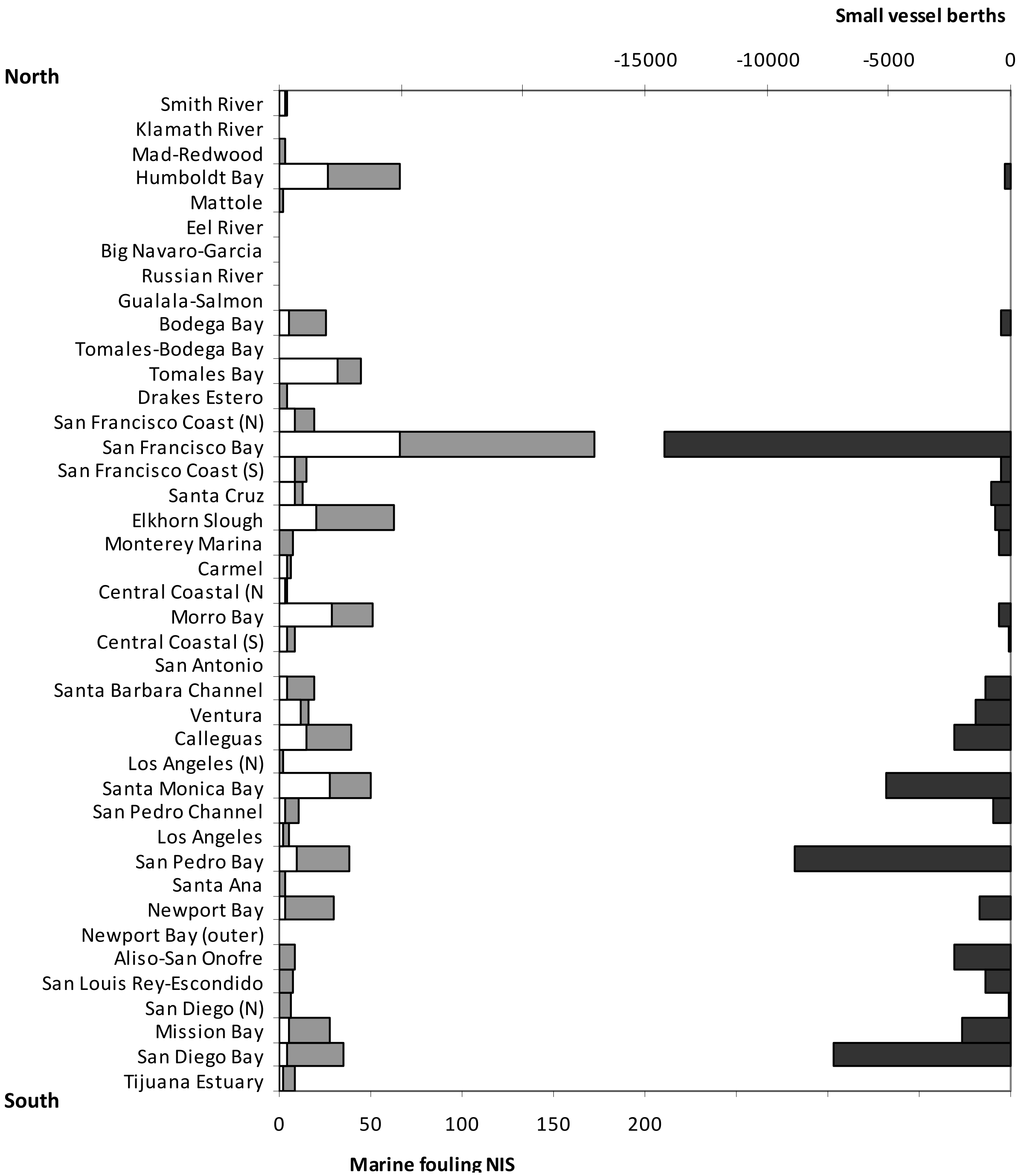



**Figure 4. Distribution of marine NIS with fouling as a sole (white) or possible vector (grey) among California bays. The numbers of small vessel berths in the bay are shown on the right axes. Bays are arranged north to south from top to bottom.**

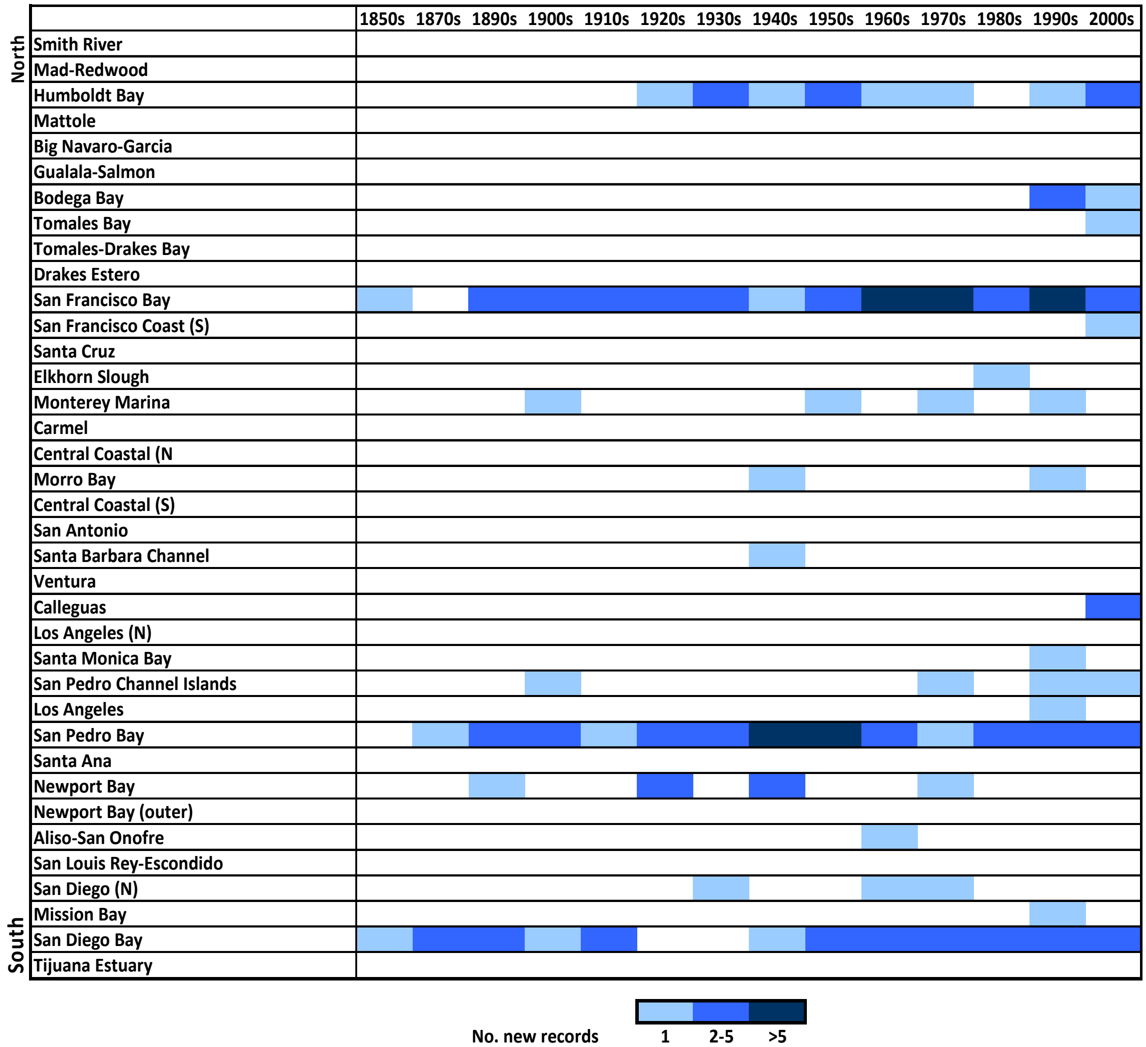



**Figure 5. Location and date of first records of marine NIS in California with fouling as a possible vector. Bays arranged north to south.**

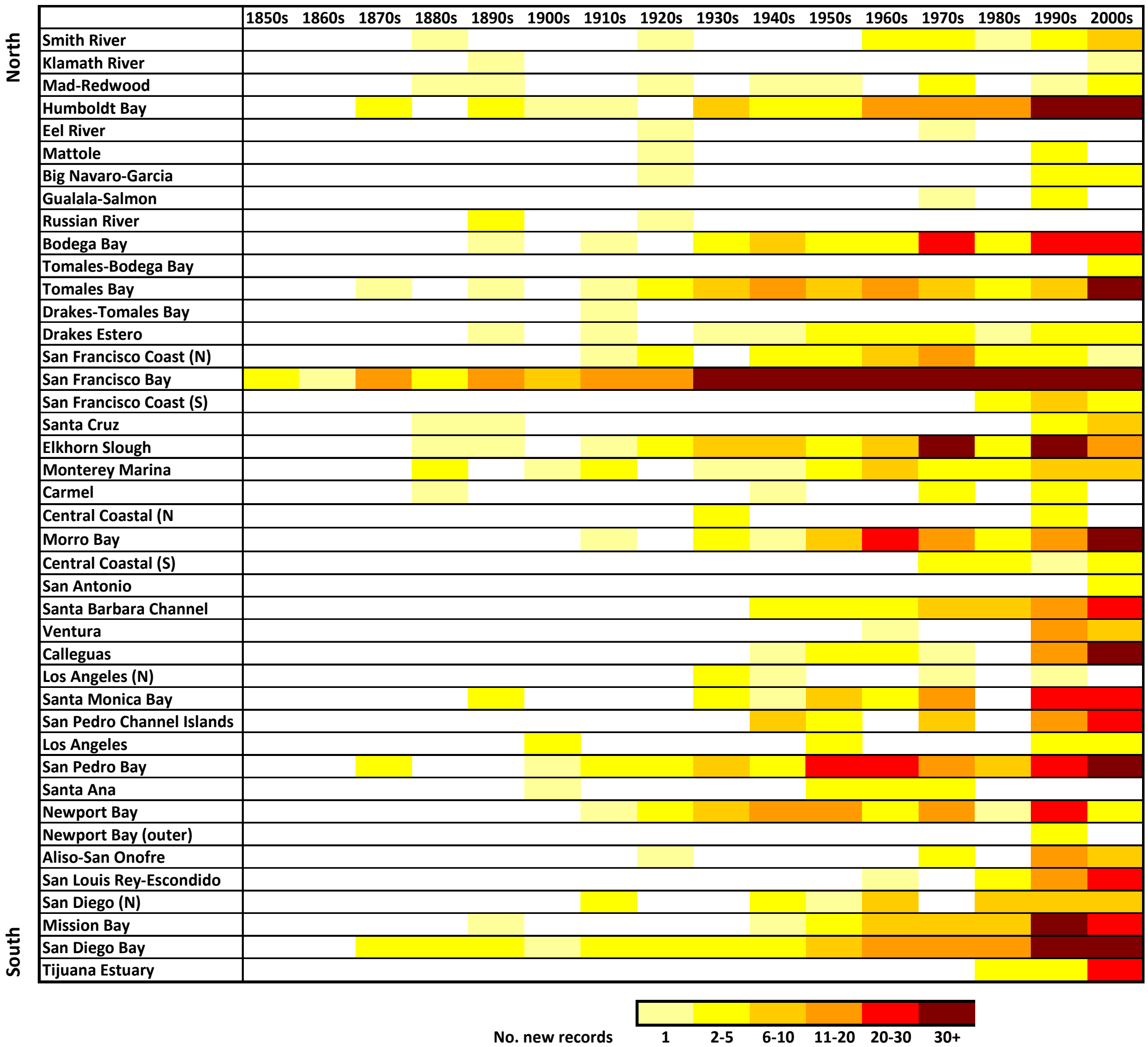



**Figure 6. Location and decade of first records of fouling marine NIS with fouling as a possible vector within each bay (species may have been described elsewhere in CA previously).**

*5.1.3. Impacts of fouling-mediated invaders*

Literature searches using BIOSIS were completed for 94 fouling species and their synonyms, including 53 crustaceans, 22 molluscs and 20 algae (Appendix 6, the latter two groups provided by UCD). All data were reported under the current species name (synonyms are listed in Appendix 6). BIOSIS returned titles for 68 species, but on further review of the abstracts and articles only 134 papers concerning 22 species were considered relevant. The 22 species included 7 algae, 9 crustacea and 6 molluscs. The earliest study retrieved was published in 1926 (Miller 1926) but almost 60% of the impact studies (n=80) were published in the last 5 years, since 2006.

The number of relevant papers per species ranged from 1 to 30 (30 for the alga *Sargassum muticum*). Other species with a large number of such papers include the alga *Codium fragile* ssp *fragile* (n=25), the European green crab *Carcinus maenas* (n=24) and the shipworm *Teredo bartschi* (n=17).

One-third (34%) of impact papers described studies completed in the USA, and one third of these (10% of the total) were conducted in California (n=14). Over half of all studies described impacts of non-native species on native species (56%). Impacts to native communities (12%) ecosystem processes (7%) and the whole community (native/non-native not specified, 5%) were also commonly studied. Almost half of the studies (48%) were based on experimental analyses, including field and laboratory experiments. The remaining studies were mostly mensurative (40%, measuring impacts with no manipulation), or observational (11%).

Studies of the impact of NIS vary greatly across species and study. For example, the impacts of *Sargassum muticum*, the fouling species for which the greatest number of studies were retrieved, were first studied in 1982 in California (Ambrose & Nelson, 1982). This is almost 40 years after the first observation of the alga outside its native range in British Columbia in 1944 (Wallentinus, 1999). Impact studies have been reported from several coastlines in Europe (including the Atlantic and the North Sea) and both coasts of North America. The articles range from describing a single impact on a single species or community (e.g., Ambrose & Nelson, 1982), to those on abundance, species richness, diversity, evenness and composition of multiple different components of the community (e.g., mobile epifauna, sessile epifauna, epibiota, Harries et al. 2007). Most studies on the impacts of *Sargassum muticum* were of impacts on native species populations, but include studies of biogeochemistry, physical habitat and native species response (e.g. a behavioral or physiological response).

The impacts of a second species, *Teredo navalis*, a wood-boring bivalve, were first recorded by Miller (1926). The study was of the economic impact of the species on structures in California. No other relevant impact studies of this species were found.

The 14 studies of fouling species impacts recorded from California include 7 species (*Sargassum muticum, Batillaria attramentaria, Musculista senhousia, Mytilus galloprovincialis, Teredo navalis, Carcinus maenas* and *Sphaeroma quoyanum*). The studies span the coast between Bodega Bay and San Diego Bay, including San Francisco Bay, Bolinas Lagoon and Santa Catalina Island. The lag between a species being described in California, and the first impact study being published varied between 10 years (*C. maenas*) and 103 years (*S. quoyanum*); the mean lag was 41 years. The impacted entities include native species (most studies), ecosystem processes, community and the economy. Papers describe both experimental and mensurative studies, in both field and lab settings. Most studies reported statistical analyses to demonstrate the significance of any effects. Most papers (87%, n=26) demonstrated a significant impact on the studied entity.

### *5.1.4. Invasions History Key Findings*

- The number of NIS recorded in California has continued to increase in recent time.
- Importantly, 64% of NIS recorded in California to date may have been introduced by hull fouling (of all vessel types).
- Bays with high numbers of recreational boats also have high numbers of NIS but the trend is confounded by other factors, including multiple vectors acting in these bays, high human population density and large areas of man-made substrates.
- In California, San Francisco is an outlier in terms of high numbers of marine NIS, fouling NIS, and NIS not recorded elsewhere in the state.
- A global literature search revealed only 23 papers of biofouling organisms on small vessels, recording 455 marine and brackish water organisms collected from these vessels sampled in 12 different countries.
- There is also a global paucity of data concerning the impact of marine NIS, making it difficult to evaluate impacts associated with hull fouling or other vectors.
- Of the studies available on the impacts of biofouling NIS, 87% reported a significant impact, and 56% of all studies were of impacts on native species.

## 5.2. Contemporary vector operation in California

### *5.2.1. Vessel traffic: volume and travel patterns*

In response to the FOIA request to Customs and Border Protection (CBP), we received one page of summary data (Appendix 2). These data indicate that from 2009-2010, 2183 vessels arrived in California from foreign last ports of call. Arrivals followed a seasonal pattern, being most frequent from March to June with a secondary, smaller increase in October (Fig. 7). San Diego was the most common port of registration for these vessels (Fig. 8). No information regarding the country of registration or last port of call of foreign vessels was provided.

On comparison with figures received independently from Long Beach and Monterey, it was determined that the summary data did not include all arrivals. A further request for the raw data was met with a proposition of receiving 24,000 pages of raw data sheets, but most of the information would be blacked-out under the Federal Privacy Act. Information concerning small vessels is not collected in an automated or electronic method by CBP, therefore digital versions of this data were not available. We did not pursue the FOIA request further and thus remain limited in our understanding of foreign vessel arrivals to California. We also learned anecdotally, in conversations with local boaters, that many do not report to CBP when re-entering the US (e.g., returning from Mexico) because the procedure is too time-consuming, and there may also be little-to-no risk of being caught or reprimanded.

We collected data on 9758 transient vessel arrivals from eight marinas. Data included date of arrival, duration of visit, vessel type and owner's city and/or ZIP code. Recreational boating activity in California was greatest during the summer season between May and September (Fig. 9). This peak was evident both in the number of transient vessels arriving to marinas and the number of boats making local trips (authors' pers. obs.). Far fewer transient vessels arrive between December and March. The seasonal trend is common to all study marinas (Appendix 3), although the summer increase was less apparent at San Diego Police Dock, where the number of arrivals remained high throughout the year. The reason for the year-round transient boat arrivals at San Diego is not known, but important factors may include: a southern latitude with less climate variation than central and northern California and the proximity to the Mexican border, which makes it a popular stop for vessels on longer-distance voyages which do not follow the seasons in the same way as vessels on shorter-distance voyages.

None of the study marinas asked for the homeport of transient vessels during registration. We used the registered home address as a coarse proxy for the homeport of the vessel. The relative importance of different source regions was common across marinas (Appendix 4) thus source regions for all marinas are shown collectively in Figure 10. Home address was not always recorded so homeport could not be inferred for approximately 11% of transient vessels (Fig. 10). The majority of boats were from West Coast states and British Columbia (79%; Fig. 10), indicating a strong coast-wise voyage trend for transient vessels in California. In particular, more than 70% of vessels were on voyages from home locations within California (although they may have visited other locations on the voyage, e.g., Mexico).

For home addresses listed in Central Canada, Central USA, Atlantic USA and the Caribbean (Fig. 10), it was impossible to determine the vessel's homeport and arrival route. Vessels may have been sailed, trailered, or kept at a location remote from the home address. Vessels from Nevada and Arizona make up approximately 50% of vessels from 'Central USA' states. For vessels from Asia, Europe and Australia, the registration data accompanying the home address (e.g., vessel license number, Customs and Border Protection certificate) suggested that the vessels had sailed from the listed home country. Vessels from these sources make up less than 1% of the total number of transient vessel records to the study marinas.

Transient vessels usually stay in marinas for a short period of time (67% of vessels stayed 1-2 days); the southern and more outer coast harbors of San Diego, Santa Barbara and Monterey had more vessels staying for longer than a week when compared to marinas in San Francisco Bay. Pillar Point (Half Moon Bay) and Humboldt Harbor had a higher number of vessels that stayed for over three weeks compared to other marinas, that number was still low relative to those staying for 1 day. Most vessels (>60% at all marinas) only registered at any given marina once in the time period for which we have records. An additional 10-20% visited a marina 2-3 times and a small percentage (0-5%) visited more than 10 times.

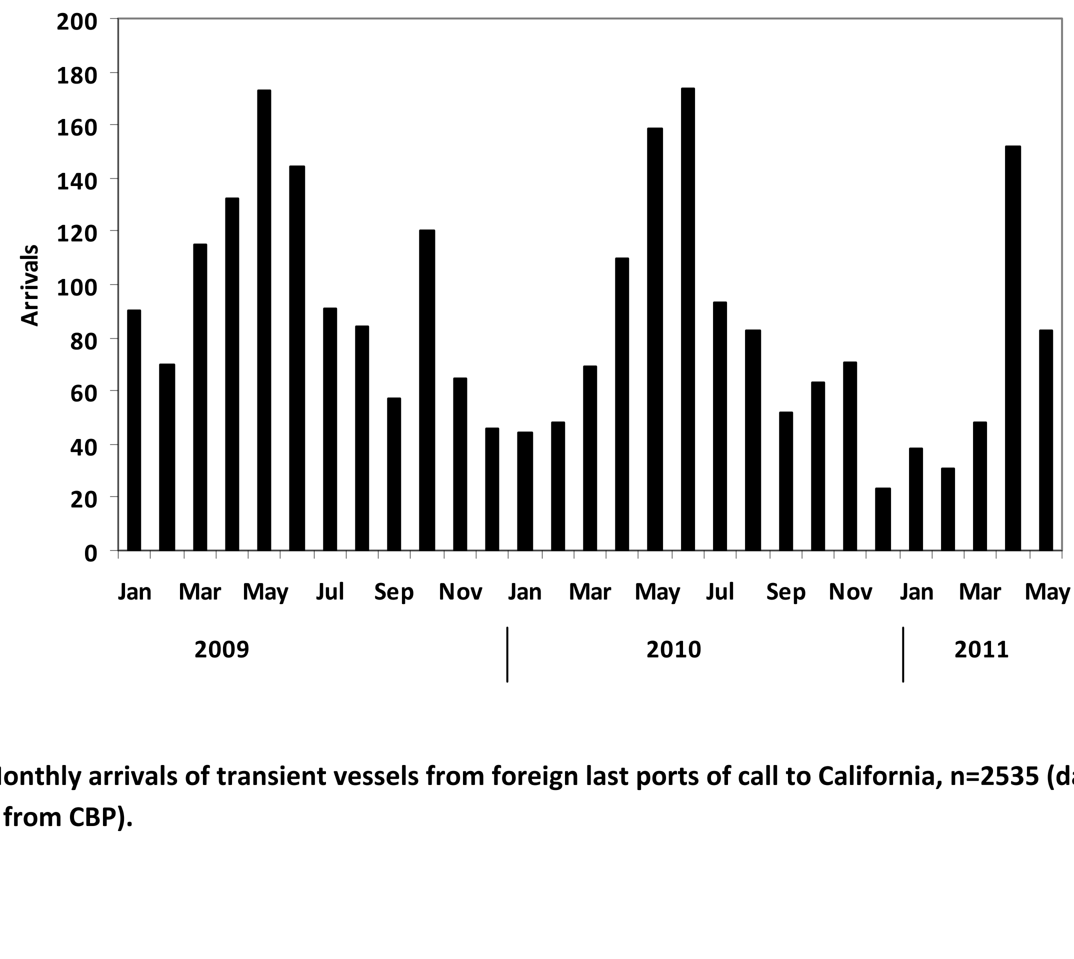



**Fig 7. Monthly arrivals of transient vessels from foreign last ports of call to California, n=2535 (data from CBP).**

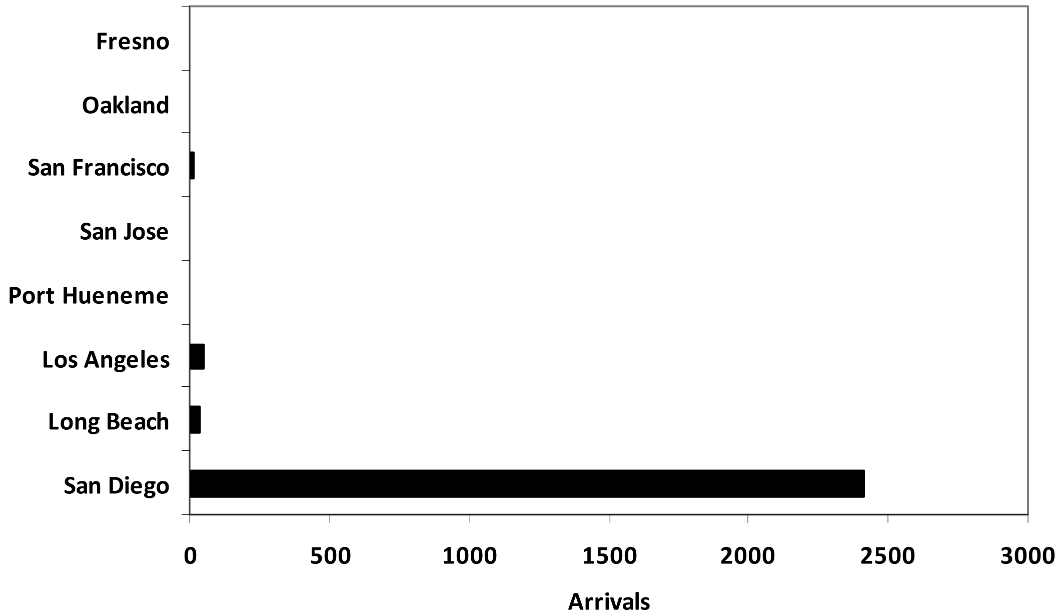



**Fig 8. Port of registration for transient vessels from foreign last ports of call to California, n=2535 (data from CBP).**

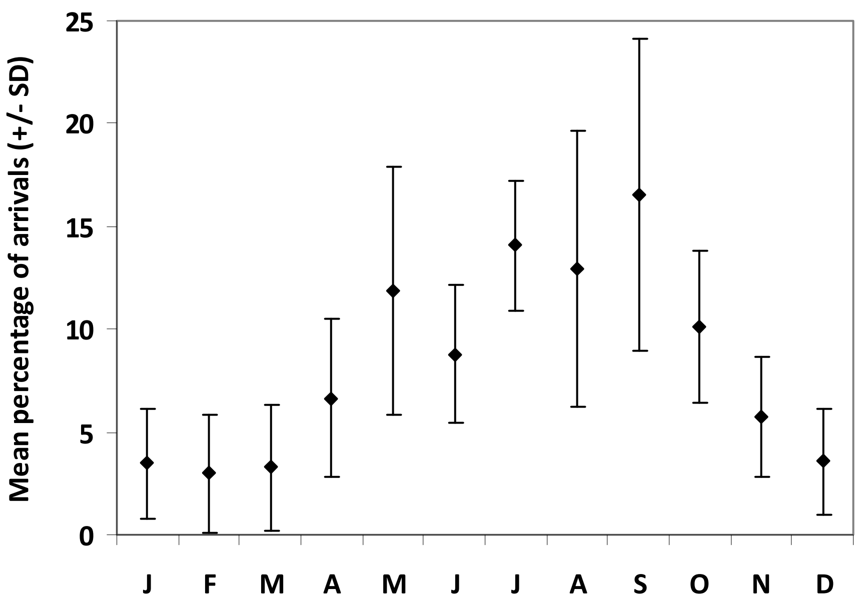



**Fig 9. Variation in monthly arrivals of transient vessels to marinas along the California coastline. Data are average (+/- SD) monthly percentages of a single year's total arrivals, from the eight study marinas (n=6961).**

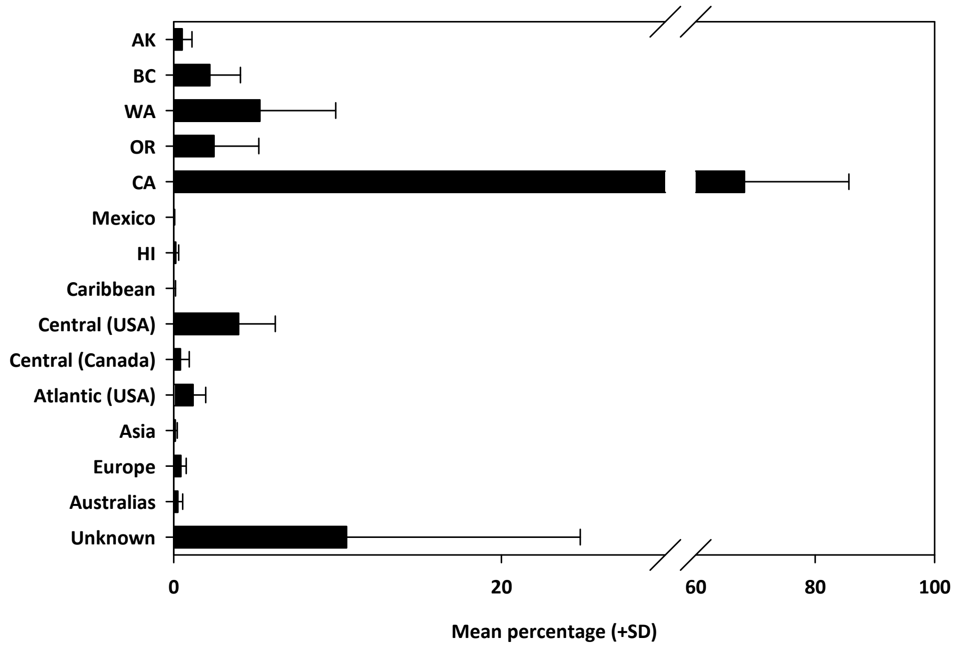



**Fig 10. Location of home addresses listed by transient vessels arriving to all marinas on the Californian coastline. Data are the mean percentage of vessel arrivals from seven study marinas (+ SD; n=9758).**

## *5.2.2. Boater habits: travel and hull maintenance*

### 5.2.2.1 Boat use

Of the 349 boaters who responded to our survey, 78% were sailboat owners, 19% owned a motorboat, 2% categorized their boats as "other," and 2% were fishermen. Just under half of the respondents were from San Francisco Bay (169); 44 respondents were from elsewhere in Central California, and the remaining 136 were from Southern California (south of Santa Barbara). We had no response from boaters north of San Francisco Bay.

Three hundred sixteen boaters reported making a total of 8,320 trips in the past year. Of these, 81% of trips were made in the boaters' home bays (6,708); the remaining 20% were overnight stays away from home bays for one or more nights (1,612).

On average, the 291 boaters who reported having made at least one trip in their home bay made just slightly fewer than 2 trips a month (23.1 trips a year, SE+/- 1.45). Forty-two percent of boaters made fewer than 12 trips a year; 68% made 24 or fewer (Fig. 11). Some boaters, however, made many trips: 11% made between 49-100 trips; only a few individuals reported more than 100 trips in a year. Reported boat usage was slightly lower than one earlier report (55% of boaters making 24 or fewer trips a year, Davidson et al. 2008, SF Bay boaters only); but slightly higher than another (76% making 20 or more trips a year, Zabin et al. 2011, boaters from SF Bay and small nearby coastal harbors), see Table 3.

Fifty-four percent of boaters (162) also reported having made trips outside of their home bays in the last year, with each boater on average making 11.4 such trips (SE+/- 1.33). This percentage is higher than two previous studies in the SF Bay area, which found that the vast majority of boaters stayed exclusively in their home bays (Table 3, 24% of boaters traveled outside home bay, Davidson et al. 2010, SF Bay only; 19%, Zabin et al. 2011, boaters from SF Bay and nearby coastal bays). It is possible that the online survey method attracted a slightly different and more active group of boaters than the mail-out, mail back surveys used in our previous work. In the present study, 36% of SF Bay boaters reported leaving the bay. The inclusion of Southern California boaters, who appear to be more active, also increased the overall average. Seventy-one percent of boaters who reported making trips outside of their home bays made fewer than 12 a year; 90% of boaters made 24 or fewer (Fig. 12). Only a few individuals reported more than 50 such trips.

The majority of trips away from home were for less than three days (62% of all reported trips), and most trips (97%) were less than one week long (Fig .12). However, several boaters reported trips of a month or longer. The most frequently reported trip duration was one day (24%); more boaters reported single-day trips in our two previous studies (Table 3).

**Table 3. A comparison of key metrics between the present study and two earlier studies.**

| Metric | This study | Davidson et al. 2008 | Zabin et al. 2011 |
|---|---|---|---|
| **% of boaters using boats more than 2 times a month** | 32% | 46% | 24% |
| **% of boaters who travel outside home bay** | 54% | 24% | 19% |
| **Most frequently reported trip duration** | 1 day (24%) | 1 day (51%) | 1 day (48%) |

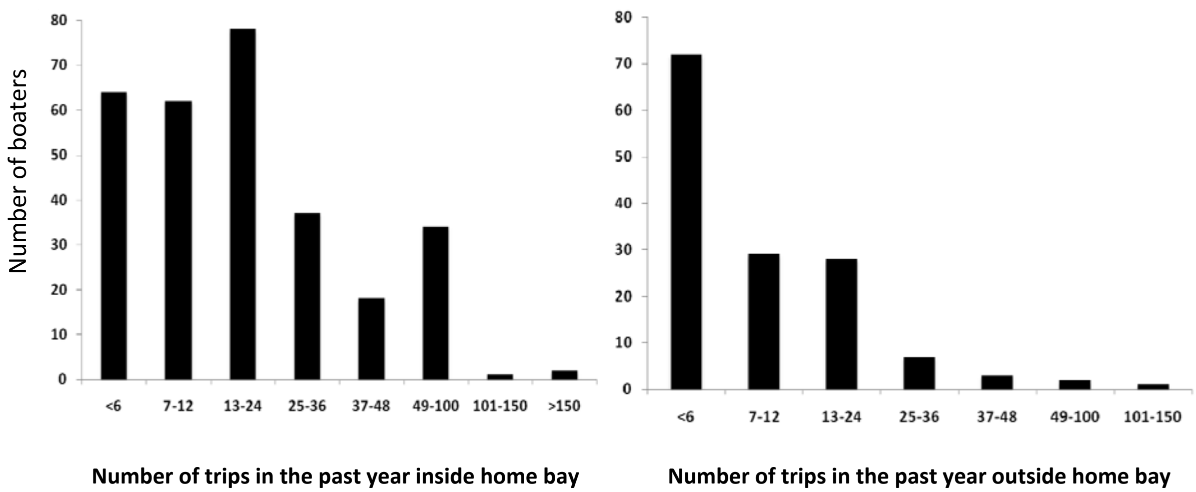



**Figure 11. Number of trips made in the past year by boaters inside their home bays (left) and outside their home bays (right). Data from boater questionnaires**

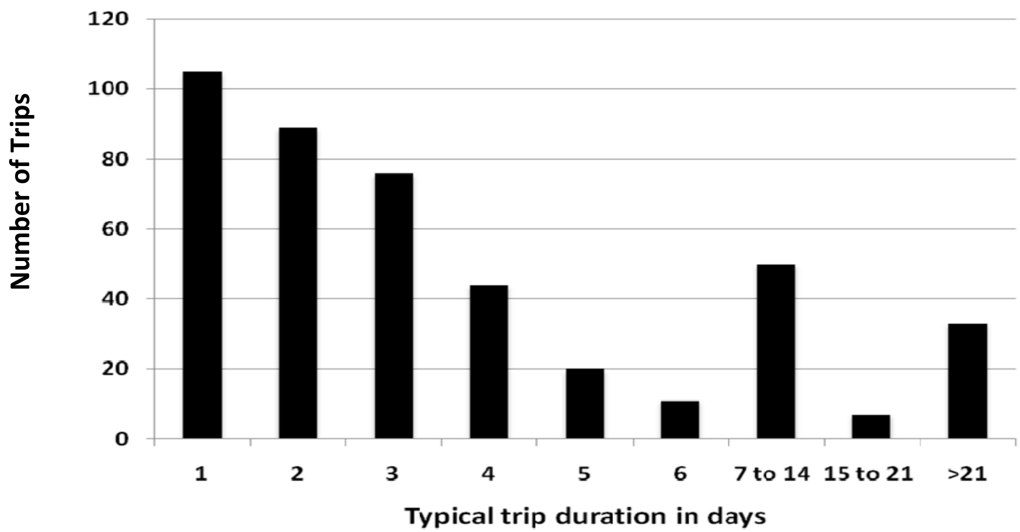



**Figure 12. Duration of trips outside the home bay of reported by boaters in the past year months. Data from boater questionnaires.**

### 5.2.2.2. Voyage patterns

Boat owners provided destination information on 8,230 trips. 81% of these trips were made in respondent's home bays. The Channel Islands were by far the top destination for traveling boaters from most bays from Santa Barbara south; 410 trips were reported there in the past year, compared to 63 trips made to Mexico and Newport Bay, which were tied for the second-most visited destination (Table 4). San Francisco Coastal South (which includes Half Moon Bay) and San Pedro were the third most frequented harbors with 37 visits each. San Diego Bay was also highly visited; 32 trips were reported, making it the fourth most-visited bay.

With the exception of the popularity of the Channel Islands, as a general pattern, more trips were made to bays near a boater's homeport. This pattern is more pronounced when the number of boats making trips rather than the number of trips are considered (Table 5). For example, the very high number of trips from Calleguas to Newport Bay disappears when boats rather than trips are considered, indicating that a single boat was making all of those trips. However, there was a striking and surprising exception to this pattern: boaters from San Francisco made as many trips to Mexico as did boaters from San Diego, with twice as many boats from San Francisco as from San Diego making this trip.

Our previous work (Davidson et al. 2008, 2010; Zabin et al. 2011) indicated that Half Moon Bay is the top overnight destination of San Francisco boaters, as does this study. However, our earlier surveys indicated that points immediately north (Drakes Estero, Tomales and Bodega Bays) and in Monterey Bay (Santa Cruz and Monterey) were the second-most visited locations. Trips from San Francisco to Mexico were rarely reported.

**Table 4. The number of trips reported by boaters from 15 home bays (left column) to various West Coast locations (rows). Blue highlighted cells are trips within a boater's home bay. The red to yellow gradient indicates the most to least number of trips between pairs of locations. Data are from boater questionnaires.**

| Home | Mexico | San Diego | Mission Bay | San Louis Rey-Escondido | Aliso-San Onofre | Newport Bay | San Pedro | Santa Monica Bay | Calleguas | Ventura | Channel Islands | Santa Barbara | Central Coastal | Monterey | Morro Bay | Santa Cruz | San Francisco Coastal South | San Francisco | Farallon Islands | Bodega Bay | Drakes Estero | Tomales Bay | Tomales-Drakes Bay coastal | Gualala-Salmon | WA | Canada | HI | Trans-Pacific | (blank) | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Diego | 26 | 598 | 16 | 7 | 1 | 5 | | 5 | | 3 | 38 | | 1 | | | | | | | | | | | | | | | | | 700 |
| Mission Bay | | | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | 30 |
| Aliso-San Onofre | 7 | 11 | | 3 | 252 | 22 | 11 | | | | 45 | 2 | | | | | | 1 | | | | | | | | | 1 | | | 355 |
| Newport Bay | | | | | 8 | 154 | 7 | | | | 43 | | | | | | | | | | | | | | | | | | | 212 |
| San Pedro | 2 | 2 | | | | 4 | 178 | 9 | | 1 | 67 | 4 | | | | 4 | | 1 | | | | | | | | | | | | 272 |
| Santa Monica Bay | | 2 | | 2 | 3 | 5 | 8 | 454 | | | 87 | | | | | | | 7 | | | | | | | | | | | | 568 |
| Calleguas | 1 | 1 | | | 2 | 25 | | | 212 | | | | | | | | | | | | | | | | | | | | | 241 |
| Ventura | | 1 | | | | | | | | 126 | 30 | | | | | | | 6 | | | | | | | | | | | | 163 |
| Channel Islands | | | | | | 1 | | | | | 11 | | | | | | | | | | | | | | | | | | | 12 |
| Santa Barbara | | | | | | | 1 | 1 | | 2 | 83 | 537 | | | | | | 2 | | | | | | | | | | | 9 | 635 |
| Central Coastal | | | | | | | | | | | | | 132 | | | | | | | | | | | | | | | | | 136 |
| Morro Bay | | | | | | | | | | 1 | | | | 2 | 51 | 3 | 1 | | | | | | | | | | | 3 | | 61 |
| Santa Cruz | | | | | | | | | | | | | | 6 | 6 | 329 | 2 | 4 | | | | | | | | | | | | 347 |
| San Francisco Coastal South | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| San Francisco | 26 | 15 | | | 4 | 1 | 10 | 4 | 2 | 1 | 17 | 1 | 2 | 8 | 5 | 11 | 34 | 4299 | 9 | 5 | 8 | 7 | 2 | 1 | 1 | 4 | 3 | | 39 | 4519 |
| Total local | | 598 | 30 | | 252 | 154 | 178 | 454 | 212 | 126 | | 537 | 132 | | 51 | 329 | | 4299 | | | | | | | | | | | | 7352 |
| Total transient | 63 | 32 | 16 | 12 | 18 | 63 | 37 | 19 | 2 | 8 | 410 | 7 | 3 | 16 | 11 | 18 | 37 | 21 | 9 | 5 | 8 | 7 | 2 | 1 | 1 | 4 | 4 | 3 | 48 | 885 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8237 |

**Table 5. The number of boats making trips from 15 home bays (left column) to various West Coast locations (rows). Blue highlighted cells are trips within a boater's home bay. The red to yellow gradient indicates the most to least number of trips between pairs of locations. Data are from boater questionnaires.**

| Home | Mexico | San Diego | Mission Bay | San Louis Rey-Escondido | Aliso-San Onofre | Newport Bay | San Pedro | Santa Monica Bay | Calleguas | Ventura | Channel Islands | Santa Barbara | Central Coastal | Monterey | Morro Bay | Santa Cruz | San Francisco Coastal South | San Francisco | Farallon Is | Bodega Bay | Drakes Estero | Tomales Bay | Tomales-Drakes Bay North Coastal | Gualala-Salmon | WA | Canada | HI | Trans-Pacific | (blank) | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Diego | 9 | 37 | 6 | 3 | 1 | 3 | | 1 | | 1 | 13 | | 1 | | | | | | | | | | | | | | | | | 75 |
| Mission Bay | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Aliso-San Onofre | 3 | 4 | | 2 | 16 | 7 | 4 | | | | 12 | 1 | | | | | | 1 | | | | | | | | | 1 | | | 51 |
| Newport Bay | | | | | 2 | 8 | 3 | | | | 7 | | | | | | | | | | | | | | | | | | | 20 |
| San Pedro | 2 | 1 | | | | 3 | 15 | 3 | | 1 | 20 | 3 | | | | 2 | | 1 | | | | | | | | | | | | 51 |
| Santa Monica Bay | | 2 | | 1 | 2 | 1 | 2 | 20 | | | 12 | | | | | | | 2 | | | | | | | | | | | | 42 |
| Calleguas | 1 | 1 | | | 1 | 1 | | | 3 | | | | | | | | | | | | | | | | | | | | | 7 |
| Ventura | | 1 | | | | | | | | 4 | 8 | | | | | | | 1 | | | | | | | | | | | | 14 |
| Channel Islands | | | | | | 1 | | | | | 3 | | | | | | | | | | | | | | | | | | | 4 |
| Santa Barbara | | | | | | | 1 | 1 | | 2 | 23 | 36 | | | | | | 1 | | | | | | | | | | | 2 | 66 |
| Central Coastal | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | | | 3 |
| Morro Bay | | | | | | | | | | 1 | | | | 1 | 6 | 1 | 1 | | | | | | | | | | | 1 | | 11 |
| Santa Cruz | | | | | | | | | | | | | | 2 | 2 | 4 | 1 | 1 | | | | | | | | | | | | 10 |
| San Francisco Coastal South | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| San Francisco | 18 | 9 | | | 2 | 1 | 1 | 3 | 2 | 1 | 9 | 1 | 1 | 6 | 4 | 7 | 21 | 278 | 5 | 3 | 7 | 3 | 2 | 1 | 1 | 4 | 3 | | 7 | 400 |
| Total Local | | 37 | 1 | | 16 | 8 | 15 | 20 | 3 | 4 | 3 | 36 | 3 | | 6 | 4 | | 278 | | | | | | | | | | | | 756 |
| Total Transient | 34 | 18 | 6 | 6 | 8 | 17 | 11 | 8 | 2 | 6 | 104 | 5 | 2 | 9 | 6 | 10 | 2 | 7 | 5 | 3 | 7 | 3 | 2 | 1 | 1 | 4 | 4 | 1 | 4 | |

### 5.2.2.3. Hull maintenance

Two hundred ninety-two boaters responded to questions about their hull maintenance practices. Of these, 38% of boaters reported having applied anti-fouling paint within the past 12 months. A nearly equal percentage, 35%, had hull paint older than 2 years. Mean paint age was 23 months, SE +/-2.21.

Sixty percent of boaters who answered questions about paint type reported using copper based paints, while <2% used Teflon or silicone-based paints. Sixty individuals reported using hard paint compared to 70 who checked “ablative” or “self-polishing”. Ablative (or self-polishing) paints work by sloughing off while the boat is underway. However, on average, boaters who reported using this type of paint did not travel more frequently than boaters who reported using a hard paint: users of ablative paint made 28 trips per year, (SE +/-3.91, mean includes 5 who did not travel); users of hard paint made 29.7 trips a year (SE +/-3.21, mean includes 12 who did not travel).

Two hundred forty-nine boaters answered questions about cleaning their hulls in between haul-outs: 48% of boaters had cleaned their boats within the past month and 66% had cleaned in the past 2 months; mean time since last cleaning was 2.2 months, SE +/-0.22. In-water cleaning was by far the preferred method (86% cleaned in this way). About 40% of respondents used a professional cleaning service (Fig. 13). Manual cleaning using brushes was the most commonly reported cleaning method.

Forty-two percent of boaters had cleaned OR painted in the past month (of 325 boaters who answered one or both of these questions); 66% had done so in the past 2 months, and 87% had done so within the past year. Mean time since last cleaning or painting was 5.9 months, SE +/-0.81.

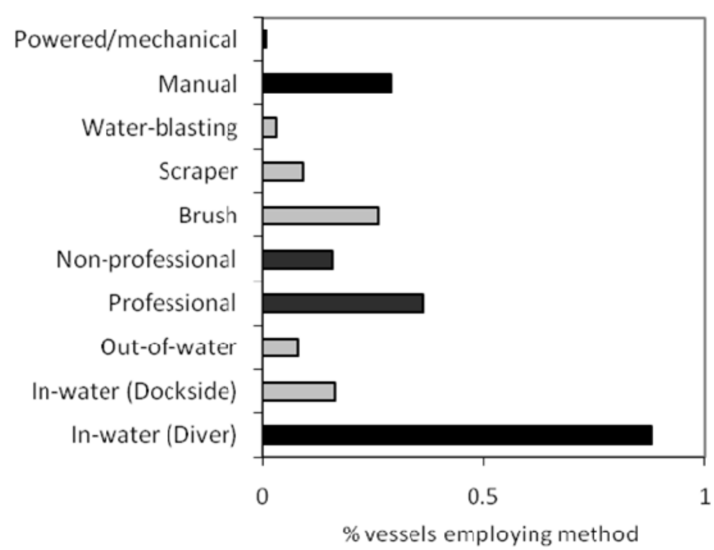



**Figure 13. Hull cleaning methods employed by boat owners responding to the questionnaire.**

There was no difference in mean paint age between Central California and Southern California boaters (Southern California = Santa Barbara and south, split based on differences in mean water temperature). In Southern California, mean paint age was 23.7 months (SE +/-2.1); it was 23.6 months (SE +/-2.1) in Central California. However, Southern California boaters cleaned more frequently (time since last cleaning in Southern California was 1.38 months (SE +/-0.15) vs. Central California, where it was 2.90 (SE +/-0.40). This difference is statistically significant ($T = -3.57$ $P < 0.0005$, df =156). Time since last cleaning or painting was also shorter (Southern California mean 2.64 month (SE +/-0.54) vs. Central California mean 8.6 (SE +/-1.4), and this difference was statistically significant ($T = -3.98$, $P < 0.0005$, df =222). This may reflect different rates of growth, possibly varying with temperature.

All maintenance intervals reported by Central California boaters in the current study were shorter than two earlier reports. Davidson et al. (2010) found that mean paint age across 14 San Francisco marinas was 27 months (SE +/-2.22), time since last cleaning was 3.1 months (SE +/-0.82), and time since most recent painting or cleaning (whichever is less) was 8.7 months (SE +/-1.16). Zabin et al. (2011) who surveyed boaters from San Francisco Bay and nearby three small coastal locations, also found average paint age, time since last cleaning and time since painting or cleaning to be higher: 23.2 (SE +/-1.22), 4.9 (SE +/-0.65)and 9.6 (SE +/-0.91) months respectively. Again, this may indicate that the online survey reached a different and perhaps more active boater demographic.

### *5.2.3. Biofouling on transient boat hulls*

We sampled 49 transient recreational vessels in-water using SCUBA during 2011 and 2012. Twelve were sampled in Santa Barbara Harbor and 37 in San Diego (at the Police Dock).

#### 5.2.3.1. Biofouling composition

In the field, an average of 16 morpho-species were identified per vessel, with numbers ranging from 0 to 72 (Fig. 14). Bryozoans, pericarids (e.g., isopods, amphipods) and ascidians were the most frequently sampled taxonomic groups (Fig. 15); polychaetes and cirripeds (barnacles) were also common among samples.

SERC staff identified bryozoans, cirripeds, and ascidians to species (or genus in some cases). The algae, hydroids, pericarids, decapods, and polychaetes were sent to taxonomic experts for identification. A list of species identified from recreational boat hulls in this study is shown in Appendix 5 (n=169). 39% of species identified were native to California; 26% were non-native but have been described from the coast previously; 27% could only be identified to genus (juveniles or lacking taxonomic characters to identify fully) and other members of that genus are known to be present in California; the biogeography of 12 species (7%) is undetermined and these species were described as cryptogenic. Species of note are shown in Table 6. We recorded the bryozoan *Hippoporina indica,* which has not been identified from the west coast of North America previously (L. McCann pers comm.); members of the polychaete genus *Branchiomma* have only recently (since 2008) been described from the West Coast, in California, and a new species of this genus is noted here (*Branchiomma* sp. 2 Harris; the taxonomy of this genus needs revision thus no species names are provided, L. Harris, pers comm.). A second polychaete, *Syllis* sp. 37 Harris, exhibits a novel combination of pigment pattern and morphological features and appears to be new to the area. Other species that are of interest include the ascidian *Botrylloides perspicuum* and polychaete *Pileolaria tiarata* which have only been described from Southern California to date. A small blade of *Undaria pinnatifida,* a large kelp that has invaded numerous locations in California, and around the world, was also found on a boat hull in San Diego, a location in which it is not yet reported to be established. A red alga, *Dasya sessilis,* which has invaded serveral European countries in association with aquaculture practices (Hughey et al. 2009) and has been demonstrated to decrease native algal diversity (Williams and Smith 2007), was also recorded. In California, this species is known only from Southern California.

**Table 6. Non-indigenous species of note collected from recreational boat hulls during in-water surveys.**

| Species | Comments |
|---|---|
| *Botrylloides perspiccum* | Only recorded from Southern California to date. |
| *Pileolaria tiarata* | Only recorded from Southern California to date. |
| *Undaria pinnatifida* | Found on a boat hull in San Diego, a location where it is not yet reported to be established. |
| *Dasya sessilis* | Only recorded from Southern California to date. |
| *Brachiomma* sp. 1 Harris | Only described from the West Coast, in California, since 2008 |
| *Brachiomma* sp. 2 Harris | New record for the West Coast (may be a new species) |
| *Syllis* sp. 37 Harris | Exhibits new coloration and appears to be new to the area. |
| *Hippoporina indica* | Not yet recorded from the west coast of North America |

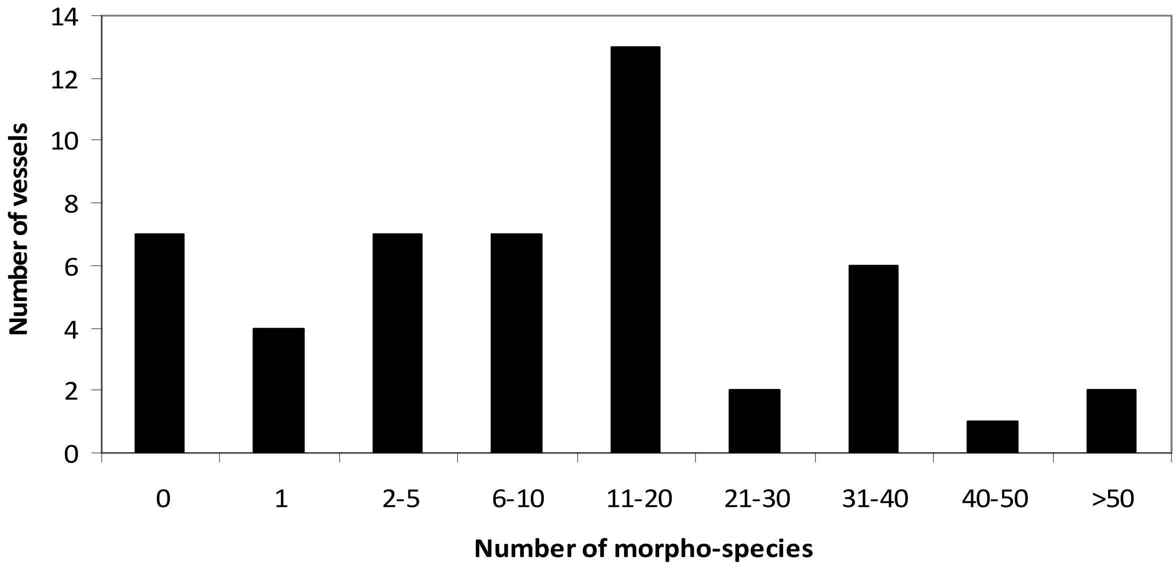



**Figure 14. Morpho-species identified from recreational vessel hulls in the field (initial IDs are not always congruent with final taxonomic IDs). Number of vessels =49.**

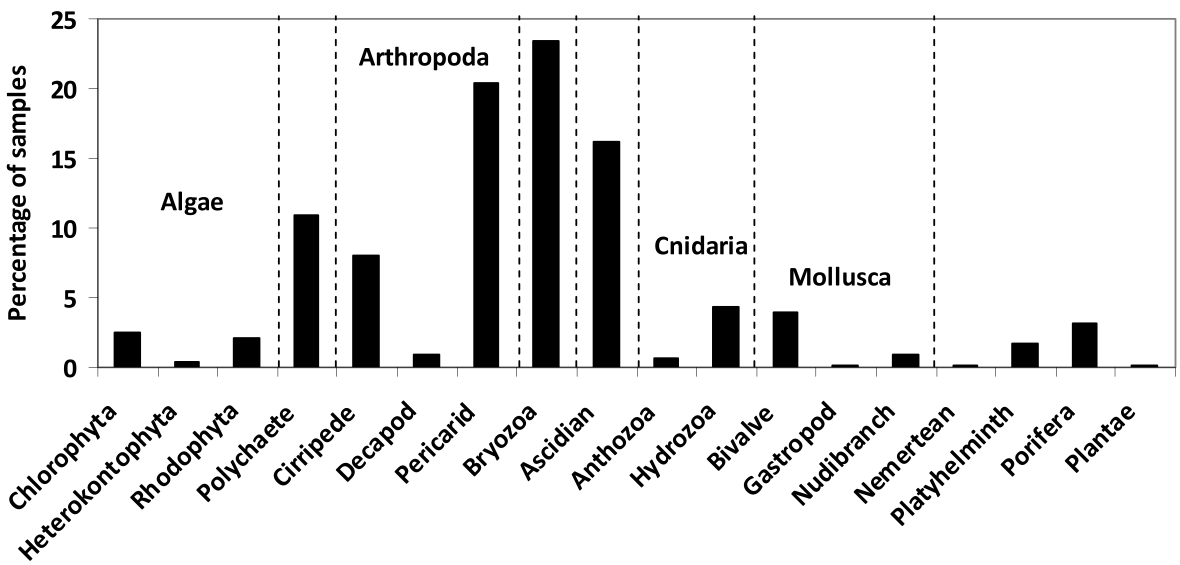



**Figure 15. Taxonomic diversity of samples collected from recreational vessel hulls in Santa Barbara and San Diego. Number of samples = 718.Higher taxonomic groupings are indicated by dashed lines.**

### 5.2.3.2. Biofouling extent

A minority of 14% of transient vessels sampled during this project had no detectable macro-fauna or macro-algae (Fig. 16). Using categorical abundance estimates, we found that 22% of vessels had only isolated individuals on their submerged surfaces, while a further 12% had between eleven and 100 organisms. The most common extent category recorded comprised of boats with between 101 and 1000 organisms (26.5% of vessels). Nearly 25% of transient vessels sampled had more than 1000 organisms, especially the vessels at the upper end of the distribution that had hundreds of thousands of individuals and colonies (Fig. 17). These extensive biofouling assemblages are more often associated with resident or laid up vessels (authors' personal observations), but we observed five vessels with over 10,000 organisms each, suggesting that a significant minority of vessels transport very large quantities of biota from harbor to harbor on their coastal journeys.

As recorded in ours and others' previous studies, biofouling tended to occur more often on niche areas of vessels rather than hull surfaces. This was certainly true for vessels that were recorded in the lower abundance categories (1-10, 11-100, 101-1000 organisms; Fig. 18). Vessels in the higher abundance categories, however, tended to have fouling on both hull and non-hull surfaces. On the most heavily fouled vessels, there was an increase in the average percent cover of fouling on hulls, but also a wide variability in fouling on hulls (Fig. 18), reflecting the patchy nature of fouling cover on laminar surfaces of heavily fouled boats.

For 46 of the 49 sampled vessels, we had corresponding questionnaire data with responses on antifouling paint age. Antifouling paint had been applied within three years of sampling for a majority of vessels (87%). There was a significant correlation between antifouling paint age and abundance of fouling organisms on hulls ($r=0.521$, $p<0.001$; Fig. 19). There was also a majority of vessel operators reporting some maintenance activity (hull cleaning or paint application) within 12 months of sampling (90%), but the correlation between biofouling extent and duration since last maintenance was not significant ($r=0.265$, $p>0.05$).

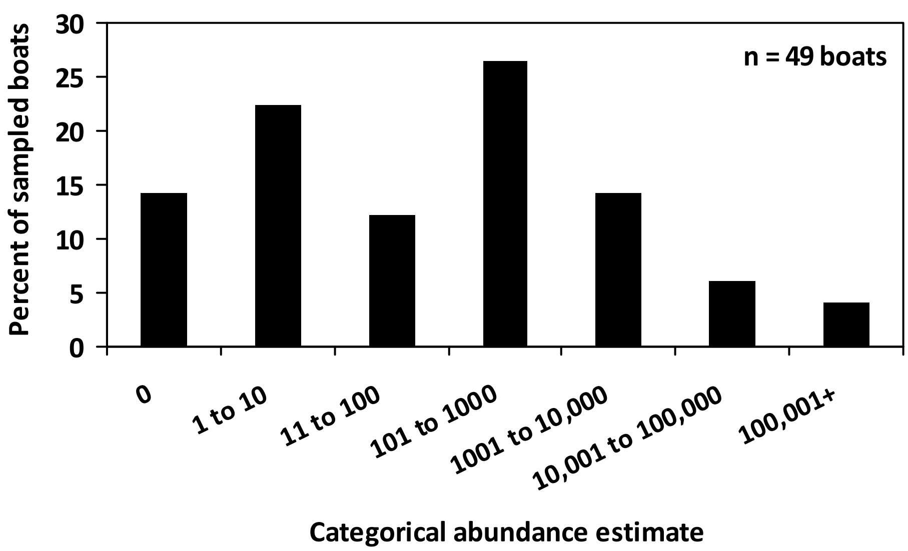



**Figure 16. Frequency of transient vessels with different biota abundance categories. This plot shows the proportion of sampled boats that were assigned to one of seven abundance categories. Underwater observations and subsequent assessments of images were used to assign each boat into a log-scale category of organism abundance.**

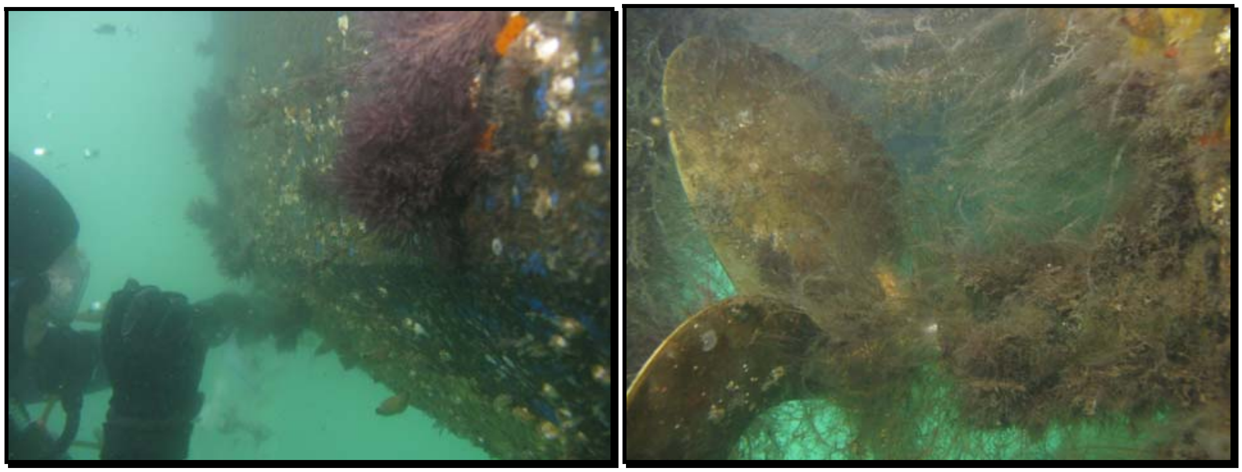


**Figure 17. Biofouling observed during SCUBA surveys of two transient recreational vessels surveyed in San Diego.**

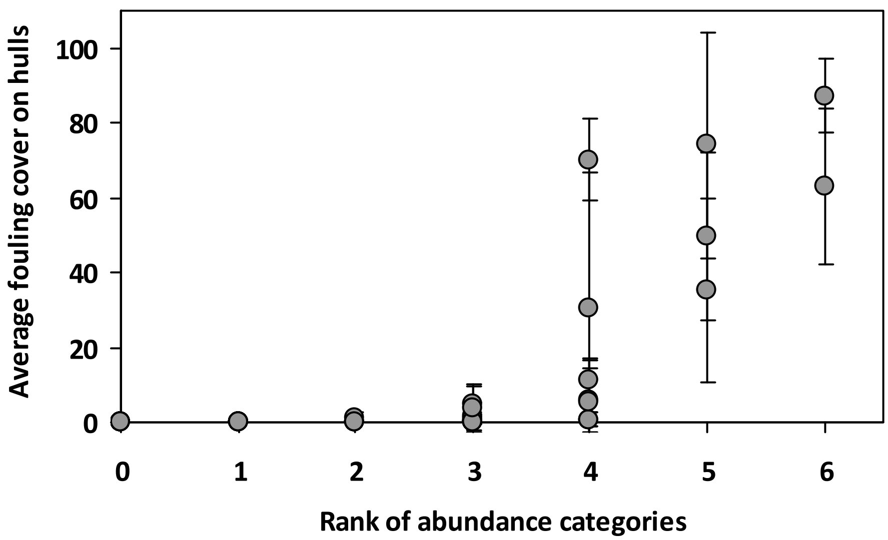



**Figure 18. Comparison of biofouling percent cover on hulls with whole vessel biofouling extent. The categories of fouling abundance correspond to the seven categories outlined in Fig. 17 (where rank 1 corresponds to abundance 1 to 10, rank 2 to abundance of 10 to 100, and so on). The percent over of biofouling on hulls tends to increase on extensively fouled vessels, but variation in cover also increases.**

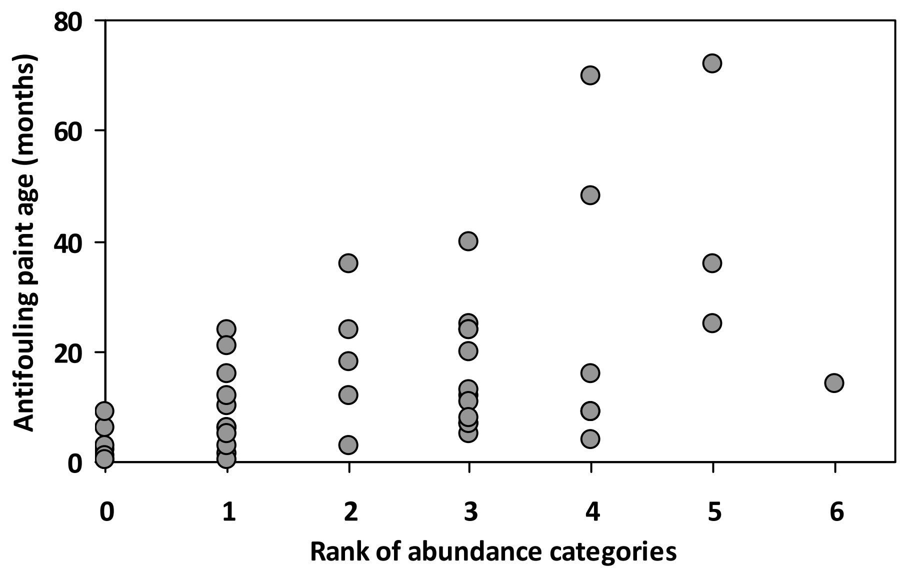



**Figure 19. Comparison of biofouling abundance with reported age of antifouling paint. The categories of fouling abundance correspond to the seven categories outlined in Fig. 17 (where rank 1 corresponds to abundance 1 to 10 and so on). There was a significant correlation between paint age and extent of fouling (see text).**

### *5.2.4. Contemporary Vector Key Findings*

- There is no central data resource concerning the movements of recreational boats in California. Available data suggest that more than 1000 vessels arrive to the state from foreign last ports of call annually; arrivals of vessels from US ports may be 100 times greater.
- More than 70% of transient vessels arriving to focal marinas in our study were from home ports in California.
- Although our surveys indicated ~81% of vessel trips remain within the boaters' home bay, 54% of boaters reported traveling outside of their home bay in the last 12 months.
- The Channel Islands were the top destination for transient voyages; other trips were commonly to bays near a boater's homeport, with popular destinations including Mexico, Newport Bay, Half Moon Bay and San Pedro.
- In our survey, 42% of boaters had cleaned or painted their boat in the past month (87% within the past year), but this may be a sign of the diligence (bias) of those responding to the questionnaire rather than the general trend.
- Among transient vessels sampled during this project, only 14% were clean of macro-fouling. On most vessels, we detected 100s of macro-fouling organisms, and 25% had more than 1000 of these organisms present.
- Biofouling was most common in niche areas.
- Almost 1/3 of species collected from hulls were considered non-native to California, including new records for California and the West Coast.

## 6. Discussion

Recreational vessels have been an important and potent vector for the spread of NIS in California, as well as other regions around the world, and this continues to be the case today. Boating continues to be one of the most popular forms of recreation in California, with nearly one million vessels registered for use in the state during recent years (2008-2010). Many of these vessels travel among embayments with biofouling (nonindigenous) organisms associated with the underwater surfaces of vessels, expanding the opportunities for dispersal of organisms. Left unchanged, the current operation of this vector will result in increasing the spread and impacts of marine NIS in California over time; this human-mediated dispersal increases impacts because (a) the geographic footprint of infested areas will increase through time, (b) some subset of NIS will have significant ecological or economic effects, and (c) the cumulative impact is the product of per-capita effects X area affected (Parker et al. 1999).

### 6.1. Invasion History & Impacts

Despite the magnitude of recreational boating, and its role in the spread of NIS, the global knowledge of this vector's activity and associated NIS remains surprisingly limited. We found only 23 studies of recreational boat fouling communities which describe species abundance and composition. Many of these were limited in taxonomic scope and most did not distinguish between native and non-native species recorded, whether the boats sampled were active, residents or visitors, or whether the boats were yachts vs. smaller fishing vessels that might be kept in marinas. The studies were also geographically restricted. Nonetheless, the available information documents over 400 species present on these vessels, and this is clearly a gross underestimate of the actual species diversity in motion.

Primary introductions to California from outside the state are generally recorded from bays with commercial shipping and or a history of aquaculture activity. Secondary spread likely occurs by numerous vectors; unfortunately the resolution of dates of arrival and number of potential vectors does not allow us to determine the relative importance of recreational boating.

Confounding the study of recreational hull fouling is the difficulty in isolating transport via recreational boats from that of commercial or fishing vessels. Bays where commercial vessel access would be excluded (due to channel depth or width) have rarely been surveyed for marine NIS. Exceptions to this in California include a study of Elkhorn Slough (where oyster culture could have been a major vector historically; Wasson et al. 2001) and a study of National Marine Sanctuaries and National Estuarine Research Reserves (deRivera et al. 2005). Both of these studies found high numbers (≤50) of NIS in habitats where commercial vessels are generally not active (arrivals for dredging, construction and in some locations fishing vessel activity can not be excluded). The studies and the NEMESIS data as a whole suggest that recreational boats have been an important vector in the historical spread of NIS in California.

Only 7 species have been the subject of impact studies in California. Most of these (86%, n=26) demonstrated a significant impact. The low number of studies highlights our limited knowledge of marine NIS impacts generally (Ruiz et al. 1999; Ruiz et al. 2011a) and specifically those impacts on

California ecosystems.  This should be a research priority within the state, to better establish the true extent of ecological and economic impacts of marine NIS.  Moreover, knowledge about impacts associated with current and future invaders may also be useful in setting priorities for management response (eradication or control) for particular high-impact species of concern.

## 6.2. Current Patterns and Processes of Vector Operations

Boating continues to be one of the most popular forms of recreation in California, with almost a million vessels registered annually, operating in both marine and freshwater.  It remains difficult to estimate the proportion of these vessels in coastal marine and estuarine waters of the state.  Of those operating in marine waters, available data suggest that 20% of boaters make trips outside of their home bay, with high levels of connectivity between large international and small regional harbors.  Considerable numbers of boaters from Oregon and Washington also visit the state.  In addition, approximately 1000 foreign vessels a year arrived to California during 2009-2011.  Thus, the potential for the continued spread of NIS in the state is considerable.

Among California boaters, the Channel Islands, which are located within the Channel Islands National Marine Sanctuary, were particularly popular.  There are two recreational boat marinas on Santa Cruz Island, and many more bays where boats stay at anchor overnight.  We do not know of any surveys for marine NIS or marine fouling communities in general from the Channel Islands; however non-native algal species are present outside of the marina settings there (KA Miller, personal communication).  Given the high value places on these natural ecosystems, marine surveys of fouling communities, boating structures, and nearby natural communities in the Channel Islands in these locations are highly recommended.

The high number of vessels traveling to Mexico from both San Francisco and San Diego is also particularly interesting.  Only limited information exists for marine NIS from the Pacific coast of Mexico (e.g., Okolodkov et al. 2007; CONABIO 2010), and this is a serious gap in knowledge for both California and the whole West Coast across all vectors (including commercial shipping).  Other bays that were identified as popular destinations among recreational boaters include Half Moon Bay, Newport Bay, San Pedro, Monterey Bay and bays immediately north of San Francisco.

Most recreational boats carried some biofouling. Thirty percent of the species we identified were non-native.  The bryozoan *Hippoporina indica*, polychaetes *Baranchiomma* sp. 2 Harris and *Syllis* sp. 37 Harris are all new records for California and suggest that these species are capable of being transported by recreational boats and may become established here (identification from a boat hull does not confirm establishment).  *Botrylloides perspicuum* and *Pileolaria tiarata* have only been reported from Southern California, and recreational boating may be responsible for their future spread within the state.

It's clear that hull husbandry practices vary greatly among vessels and that these affect the associated biofouling assemblages.  Age of antifouling paint, but not most recent hull cleaning, was correlated with the extent of fouling communities on a ship's hull.  This is likely because not all hull cleaning methods are equally effective, while a haul-out and new paint application is almost guaranteed to reset the fouling community back to zero. Unfortunately, 27% of boaters reported having painted their hulls 12-24 months previously and 35% had hull paint older than 2 years (suggesting hundreds to thousands of fouling organisms may be present). Probably the least effective cleaning treatment is the use of a scrubbing brush from above water, when only the surface line of algal fouling may be removed, and none of the commonly fouled niche areas will be affected. The most effective cleaning treatments include mooring in freshwater for a long period (>4 weeks) to kill all marine fouling organisms, and cleaning by professional divers.

## 6.3. Management Review and Recommendations

There are currently no comprehensive management strategies in place in California. It is clearly in the vessel owner's interest (particularly those who travel far and/or frequently) to maintain a clean hull, increasing vessel performance (including speed, fuel-efficiency, and mechanical operation). A review of current approaches to reduce hull fouling is provided in Table 7. However, the motivation for maintenance will vary among owners. In our surveys, we found hull fouling organisms on 86% of transient vessels surveyed, including dense aggregations on more than 25% of vessels.

Management options could be considered to reduce transfers of organisms on vessel hulls, independent (or in addition) to those aimed at vessel performance. When considering management options, it is important to evaluate costs, benefits, and efficacy of potential strategies, recognizing that the vector in this case is a recreational activity; in particular, care must be taken in order not to impede the enjoyment of boating (which also generates a significant contribution to the state's economy ($17 billion in 2007; DFG 2008), and public support for the maintenance and enhancement of coastal environments. Management strategies should also take the opportunity to address the whole array of vectors associated with recreational boating, including those vessels operating in freshwater and the alternative transport mechanisms described in the introduction (e.g. fishing gears, water intakes, anchors).

**Table 7. Available strategies for reducing recreational vessel hull fouling. The table shows the methods, benefits and issues related to applications of tools to disrupt a biofouling vector transfer by recreational vessels.**

| Action | Method | Benefits | Issues |
|---|---|---|---|
| **Prevent species colonization** | Keep the boat on a hoist or stored on land | - Separating the vessel from the water is the most effective preventative measure | - Expense<br>- Inconvenience<br>- Not available for all boat types |
| | Use a skirt or container around vessel at berth (e.g. boat bath) | - Relatively simple tool<br>- Allows for vessels to remain in water (more convenient than above)<br>- Skirt also remains in water for convenient replacement after voyages | - Expense<br>- Inconvenience<br>- This treatment is more effective if freshwater or chlorine is used inside the bath, but this has other environmental implications and is prohibited in most locations<br>- If not maintained, the skirts become fouled on the outside, adding to the maintenance burden |
| | Maintain a pristine antifouling coating with toxic agents (including niche areas) | - Antifouling paint is the most commonly available prevention option making it readily available<br>- Convenience | - Expense<br>- Maintenance burden (re-applications may be necessary)<br>- Interim measures are usually required (in-water cleaning)<br>- Requires regular vessel usage because stationary periods can compromise efficacy<br>- Toxicity issues (e.g. copper) conflict with other environmental management |
| **Prevent species transfer after colonization has occurred** | Use a non-toxic foul-release coating | - Prevents pollution<br>- Does not conflict with other environmental regulations<br>- Convenience | - Expense<br>- Maintenance burden (re-applications)<br>- Interim measures required (soft scrubs)<br>- Partial efficacy may contribute to NIS spread (if dislodgement doesn't occur soon after departure) |
| | Clean hull in-water by owner | - Straightforward<br>- Inexpensive | - Application rigor varies widely<br>- Niche areas often ignored<br>- Awareness/training usually needed to improve efficacy<br>- Usually less effective than professional service |

| | | | |
|---|---|---|---|
| | | | - Releases species/propagules into the environment<br>- Must be done regularly (clean-before-you-go) to ensure propagule release does not include transferred biota |
| | Clean hull in-water by professional service | - Convenience<br>- Usually more effective than amateur cleaning | - Expense<br>- Application rigor generally better than amateur cleaning but still varies<br>- Niche areas not always targeted<br>- Releases species/propagules into the environment<br>- Must be done regularly (clean-before-you-go) to ensure propagule release does not include transferred biota |
| | Clean hull out-of-water (by owner or professionally) | - Can be effective if conducted properly<br>- Allows for other maintenance issues to be attended to (e.g. paint touch-ups) | - Expensive<br>- Shoreline cleaning (by trailer or hoist) must also include a containment strategy<br>- Dry docks must treat all solid and liquid effluent (treatment or land-fill) |

### *6.3.1. Global management review*

While multiple studies globally have recommended management of recreational boats as a vector for marine NIS (e.g. Davidson et al. 2010; Clarke Murray et al. 2011; Zabin et al. 2011), we know of no regulations which have been implemented or enforced at the national level in the US to prevent the spread of marine NIS with recreational vessels (although regulations do exist for target freshwater species including the zebra mussel, *Dreissena polymorpha*). Two countries which have made a focused effort to address the recreational boating vector are Australia and New Zealand, which both have identified a single governmental body responsible for the management of this vector. By requiring advanced notification by vessels arriving from overseas, both countries have provided scope for intervention of recreational boats arriving to the country should they pose a biosecurity threat.

The Australian Quarantine and Inspection Service (AQIS) requires foreign vessels arriving to a marina to register their anticipated arrival 12-96 hrs prior to their estimated arrival (www.daff.gov.au/aqis, accessed April 2012). On arrival, a vessel may be inspected for assessment of biofouling risks. Since 2005, AQIS has also been conducting a voluntary biofouling management regime for overseas vessels. The recommendations include (DAFF 2011):

"•application of an effective anti-fouling coating suited to the operation of the vessel
•inspecting, and if necessary, cleaning your vessel including niche areas (including but not

limited to internal seawater systems, sea chests, rudder stock and propeller shafts), anchors, chains and other ancillary gear immediately prior to arrival in Australia
•once inspected and cleaned at an overseas port, departing immediately and travelling directly to Australia to minimise re-contamination
•maintaining a voyage and biofouling maintenance log and other documentation that supports any biofouling mitigation activities undertaken."

The Australian Government anticipated moving towards mandatory risk-based biofouling management requirements for all overseas vessels. These have not been implemented to date, but would be consistent with the above recommendations. In-water inspections of vessels not meeting these recommendations would be a component of the regulations.

In New Zealand, the Ministry of Agriculture and Forestry, Biosecurity New Zealand division (MAFBNZ) is responsible for preventing the importation of unwanted pests and diseases and for controlling, managing or eradicating them should they arrive (MAFBNZ 2010). Arrivals from overseas can only arrive to designated ports (unless an alternative arrival port is approved) and advance notice of the arrival is required 48 hrs in advance. The following are recommended by MAFBNZ:

"•**Clean hull**: Before departing your last port bound for New Zealand – clean your hull, keel and hull fittings of fouling. Wash out places where marine organisms are able to live such as water inlets and outlets, anchor wells and cockpit areas (any places where seawater is retained). Ensure your antifouling paint is in good condition and effective.
•**Clean on arrival:** if you have not cleaned before departure: If you have been unable to access cleaning facilities prior to your departure for New Zealand, have your vessel cleaned within four days of arrival, particularly if you plan to stay for more than two weeks. Your Biosecurity Inspector will be able to direct you to local haulout facilities (which contain and treat discharges) at your place of arrival.
•**Do not beach:** Do not clean your hull by beaching your vessel or by cleaning it in the water unless the fouling present is no more than a slime layer.
•**Disposal:** Put fouling or removed sediment material into a container and dispose of it on land (ie in marina or port rubbish bins). Do not discharge such material into the sea or coast. "

Once again, inspection of a vessel thought to pose a severe biosecurity risk may be enforced.

We know of only one study that assessed the management of both foreign and local vessels for a local region, a study of recreational boats in Nelson Harbor, New Zealand (Piola & Forrest 2009). The report recommended a combination of approaches:

1. A fouling regime that includes antifouling application every 12 months, with the use of a sticker to display compliance

2. Regular surface and in-water vessel inspections

3. Ensure resources necessary for cleaning vessels (in- or out-of- water) are available to boat owners

4. Consider implementing a fee for failure to comply with the point 1 above (or general failure to maintain a good hull condition) to fund points 2 & 3. Alternatively, marina fees could be increased to fund points 2 & 3.

In Nelson, the City Council and Nelson Marina Manager would be responsible for overseeing (or enforcing) the above measures. It was also hoped that similar approaches would be implemented at the regional and national scale.

### *6.3.2. California Management Review*

There is no coordinated management of recreational vessel hull fouling in California. No agency has sufficient jurisdiction, authority, and funding to adequately manage the movement of marine NIS in association with recreational vessels. Unlike commercial ships, recreational boats are not subject to regulations governing activities that might transfer non-native species (other than a few freshwater species as mentioned above). Previous actions have been largely sporadic and motivated by multiple agencies/groups within the state, including efforts to 'Stop Aquatic Hitchikers' by the ANS Task Force (protectyourwaters.net/) and various awareness campaign projects supported by agencies including California Department of Boating and Waterways, U.S. Fish & Wildlife service and California Sea Grant to increase awareness of the issue (e.g., UCSGEP-SD 2006) and several responses to the discovery of the non-native kelp, *Undaria pinnatifida*, identified in Californian marinas (Lonhart and Bunzel 2009; Zabin et al. 2009);.

In the California Aquatic Invasive Species Management Plan (2008), the Department of Boating and Waterways (DBW) was charged with managing the recreational boating vector of AIS in California, although, it was noted that "there is not funding and staff for a comprehensive program". To this end, DBW leads the California Clean Boating Network – a collaboration of government, business, boating and academic organizations working to increase and improve clean boating education efforts, including invasive species education, across the state. Responsibility for boat maintenance therefore falls on individual boat owners, who may currently not know or care about the issue of non-native species and measures they could take to prevent species transfers.

### *6.3.3. Management options for California*

In California, less than 1% of transient vessel arrivals by recreational vessels are from overseas (i.e., other than coastwise traffic). Most transient boat arrivals from outside the State arrive from other regions of the West Coast (78% including British Columbia and Mexico). However, the vast majority of vessel traffic is intrastate, and 70% of the transits are by California vessels. While it is perhaps easy to imagine the US CBP requiring foreign vessels to register in advance of their arrival to allow assessment of the risk of marine NIS introductions, especially as a reporting system exists, it is more challenging to implement similar management actions for all domestic and California boaters. Yet, management of foreign vessels would reach a very small fraction of transient vessels, and management actions for domestic and local vessels are likely to have the greatest potential to impede the spread of marine NIS within the state by recreational vessels.

There is currently limited-to-no coordination or authority among California state agencies to practically manage this vector. With adequate dedicated funding and authority, DBW would be the obvious agency to lead and coordinate management efforts. Through the California Clean Boating Network, channels of communication between management agencies, marina operators and boaters should already be in place.

Several options for managing the recreational vessel vector at the state level are presented in Table 8; the options are listed in order of resources necessary for implementation. It would be particularly useful to assess the efficacy of previously implemented education efforts, outreach campaigns and incentive programs. This would allow an assessment of whether future efforts should support similar actions, or if more assertive madatory actions, including at least the threat of penalties, are needed. Coordination of such actions among west coast states would be advantageous.

One option for funding management strategies is for marinas to collect a small fee from resident and visiting boaters to contribute towards NIS prevention strategies. The fee could also be added to the cost of vessel registration with the DMV, although it should be noted that boat owners may prefer to document their vessel with USCG than pay the increased fee to register with the state, and this method does not add any responsibility to vessels from out-of-state.

A high priority for the state should be to target high-risk vessels (i.e., those with high levels of biofouling and those that may be likely to carry particular high-impact species of concern), focusing on key control points; this could utilize the Hazard Analysis and Critical Control Point (HACCP) approach, which is becoming the standard for aquatic invasive species management (Gonzalez & Johnson 2007). Key control points would be those marinas receiving high numbers of foreign and transient vessels.

**Table 8. Strategies for statewide management of recreational vessel biofouling. The table describes a range of measures that could be adopted, from the least to the most resource intensive (top to bottom) which also gives an indication of the likely time horizon of the strategy (immediate actions at the top).**

| Item | Actions | Outcomes |
|---|---|---|
| **Retain the status quo** | - Do nothing | - Potential conflict with stakeholders concerned at the lack of action on vector management<br>- No conflict with recreational boaters or marina owners<br>- Unintended consequences avoided (e.g. additional copper pollution)<br>- Recreational vessel influence on spread of NISremains unchanged<br>- The 'do nothing' option is not static and the per capita effect of NIS × Area affected will expand dramatically over time |
| **Conduct outreach to recreational boaters (without evaluation of effectiveness)** | - Attempt to increase awareness of AIS and vector issues among recreational boaters and professionals working with boat owners (e.g., marina staff and professional divers) | - Can be scaled to suit budget and resource availability<br>- May provide very favorable cost-benefit outcome<br>- The effects of outreach will be largely unknowable<br>- Recreational vessel influence on AIS spread may decline |
| **Conduct outreach to recreational boaters with scientific evaluation of effectiveness** | - Attempt to increase awareness of AIS and vector issues AND determine efficacy/behavior changes | - Can be scaled to suit budget and resource availability<br>- May provide very favorable cost-benefit outcome<br>- The effects of outreach will be assessed with before and after polling to determine efficacy<br>- Efficacy measures can be used in adaptive strategy and to inform future policy directions<br>- Higher chance (than above) for beneficial effect on AIS transfers |

| | | |
|---|---|---|
| **Propose voluntary guidelines on a statewide basis** | - Create and promote best management practices to boaters and commercial divers from marina locations<br><br>- Add guidelines regarding vector management to materials issued by the state DMV<br><br>- Guidelines provided to foreign vessels by CBP | - May be inexpensive<br>- Linking voluntary guidelines to other permitting interactions may enhance vector management<br>- Additional monitoring required to determine efficacy<br>- Recreational vessel influence on NIS spread may decline |
| **Propose mandatory rules governing vector management** | - Create regulation and enforcement mechanism for vector management of recreational vessels<br><br>- Could be implemented at the marina level using resident and visiting boater contracts<br><br>- Alternatively, implement at the state level using DMV registration mechanism<br><br>- State agent with legal authority necessary to ensure enforcement<br><br>- CBP responsible for monitoring arrivals of foreign vessels | - A model of state vector management already exists in the state that can be mimicked (SLC rules for commercial vessels)<br>- Marinas, the DMV or DBW would need to adopt responsibility for governance of the recreational vessel vector<br>- Highest likelihood of effective vector management<br>- High and continuous expense<br>- High possibility of conflict with boaters and marina owners<br>- Possibility of unintended consequences (e.g. copper pollution or inappropriate use of foul-release coatings) |

As suggested in Table 8, management actions could be implemented at various levels from individual marinas to statewide regulation. We recommend further exploration of the various approaches and suggest that the following options should be among the ideas explored.

- Inspection of a boat's underwater surfaces for fouling species could be a requirement of the purchase of a boat (other than a new boat that has not been stored in water). The inspection would need to be carried out by a qualified individual aware of best management practices for NIS. The inspection might trigger an in-water cleaning or haul out depending on percent cover of fouling and/or the presence of key species.
- Marinas could include a clause in their resident-boater contract that requires regular cleaning of the vessel by a professional diver.

- Following the model in place in New Zealand, Customs inspectors could require paperwork documenting hull cleaning of vessels arriving from foreign ports, including those home ported in another country, and US vessels that have been docked in foreign ports for more than a few days. Agents could be trained to carry out visual inspections of vessels deemed to be high risk (determination based a risk assessment model, which would need to be developed). The inspection might trigger an in-water cleaning or haul out depending on percent cover of fouling and/or the presence of key species.
- Similarly, marina staff could require hull-cleaning documentation and/or do a visual inspection of visiting boats intending to stay at guest berths. The inspection might trigger an in-water cleaning or haul out depending on percent cover of fouling and/or the presence of key species; or boats could be turned away if highly fouled.
- The development of legal authority for a state's agent (i.e. CDFG or DBW) under certain circumstances to quarantine or otherwise restrict the movement of a boat known to be carrying high-risk species. While there are regulations governing the intentional import and release of non-native species for aquaculture and research purposes, there are no rules that restrict the movement of vessels fouled with non-native species. The current lack of any such authority hampers attempts to eradicate and control invasions.

Regardless of the management strategy adopted (or the current scenario of no coordinated management), detection and monitoring of marinas and harbors should also be implemented. This can indicate whether the program is working (to reduce invasions), providing a mechanism for adapative management (Ruiz & Carlton 2003). In addition, detection would also allow for response(s) to new incursions, especially focused on target species of concern. After prevention, early detection is an essential part of a comprehensive strategy for NIS management. Small populations of organisms that are not widely dispersed and/or have not undergone reproduction are more easily eradicated than those that have become established and widespread (Myers et al. 2000; Lodge et al. 2006). Research indicates that harbors with high levels of boater activity (connectivity to other marinas) are at the highest risk for both receiving and exporting NIS (Floerl et al. 2009). These areas ought to be prioritized for frequent monitoring. Considering the evidence of the influence of San Francisco Bay as the entry point for non-native species to the state, many of which subsequently spread to other locations both in the state and along the West Coast (Ruiz et al. 2011b), marinas in the Bay ought to be among the priority locations for monitoring efforts. More specifically, marinas in the central portion of the bay ought to receive top priority, as they have more oceanic conditions and would presumably support species that are likely to survive coastal travel. A thorough examination of the travel patterns of recreational boats could help determine other priority bays and marinas. Based on our data, for example, we recommend focusing on the Channel Islands as an important location for monitoring efforts.

## 6.4. Critical data gaps

Currently, our ability to fully understand and quantitatively evaluate the strength of this vector is hindered by, among other things: 1) the lack of any coordinated data gathering of recreational boat traffic, especially movements among embayments in California, 2) a lack of centralization of data that are gathered, and 3) improved information on biotic content of vessels associated with specific regions and management practices. Information on travel patterns of vessels is important to evaluating the strength of the vector, predicting where new invaders might turn up, and focusing education/prevention activities. Further studies of factors influencing the fouling biota associated with recreational vessels both locally and globally are also necessary, as not all vessels and locations pose equal risks, and such information would allow for a more focused, agile, and effective strategy in abating risks.

We recommend an exploration of the feasibility of standardizing the data collected by marina staff from visiting boats. Such data should at a minimum include home port, last port of call, next port of call, length of stay at a marina. Additional key (and streamlined) information on husbandry practices would be invaluable. Ideally, a standardized format would be used. Data could be reported to a central location for use in analysis; boater's confidential information could be removed before doing so. By making the system automated and centralized, it should cause minimal inconvenience beyond the registration process at most marinas. Towards this end, as of January 2012, the CBP has implemented a web-based 'Small Vessel Reporting System'. This will allow national participants to expeditiously report their arrivals from foreign ports. The impact of this system is not yet known, but if boaters comply, the system should improve our future understanding of vessel movements from foreign ports into California.

## 6.5. Key Management Recommendations for California

In summary, our recommendations for the state are as follows:

1) Provide the authority and funding for a lead agency to implement a management strategy, which is urgently needed to prevent the introduction and spread of NIS by recreational vessels.
2) Create a centralized resource to collect data concerning recreational vessel habits and meet the data gaps identified above.
3) Assess the efficacy of previously implemented education efforts, outreach campaigns and incentive programs and the need for mandatory regulation and enforcement.
4) Evaluate available options, including the costs and benefits of these within the context of California's jurisdictions and interests.
5) Sustain and advance efforts to detect NIS and evaluate impacts, to better guide management resource decisions.
6) Implement a coordinated management approach on a state-wide, as well as regional, basis.
7) Assess the efficacy of adopted management strategies, on a continued basis, using adaptive management to adapt the program accordingly.

## 7. Acknowledgements

We would like to thank Chris Brown, Dale Calder, Jeff Cordell, Leslie Harris, Linda McCann and Kathy Ann Miller for specimen identifications. Chris Brown also provided field assistance and discussion of the project. Contemporary data were all collected with the assistance of harbor masters and staff at the study marinas: Pillar Point, Pier 39, Santa Barbara Harbor, Monterey Harbor, San Diego Police Dock, Humboldt Bay Harbor, San Francisco Marina, South Beach Marina. Particular thanks go to Judy Neidert and Tim at San Diego Police dock, and Kathy Sangster and Mick Kronman at Santa Barbara Marina. Kim Holzer, Rachel Fontana and Eliot Crafton provided the impacts data (summarized in Appendices 7 and 8). P Fofonoff and B Steves for their development of NEMESIS and California Department of Fish and Game for data used to improve and create the California specific database used in this report.

## 8. References


Abbott DP, AT Newberry, KM Morris and G Lambert. 1997. *Reef and Shore Fauna of Hawaii Section 6B: Ascidians (Urochordata).* Bernice P. Bishop Museum Special Publication, Honolulu: 64 pp.

Ambrose RF and BV Nelson. 1982. Inhibition of giant kelp recruitment by an introduced brown alga. Botanica Marina 25: 265-267.

Boyd MJ, TJ Mulligan and FJ Shaughnessy. 2002. Nonindigenous Marine Species of Humboldt Bay, California. Appendix B in: Report to the Legislature: A Survey of Non-Indigenous Aquatic Species in the Coastal and Estuarine Waters of California, M.E. Ashe (ed.), California Department of Fish and Game, Office of Oil Spill Prevention and Response, Sacramento

California Ocean Protection Act. 2004. Division 26.5 of the California Public Resources Code. General Provisions Section 35500.

Carlton JT. 1979. History, biogeography, and ecology of the introduced marine and estuarine invertebrates of the Pacific Coast of North America. PhD dissertation, University of California, Davis, CA

Carlton JT. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanography and Marine Biology, an Annual Review 23:313-371.

Carlton JT. 2001. Introduced species in coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington VA.

Carlton JT ed. 2007. *The Light & Smith Manual: Intertidal Invertebrates of the California and Oregon Coast.* University of California Press, Berkeley: 1001 pp.

Charles, H., and J. S. Dukes. 2007. Impacts of invasive species on ecosystem services. Pages 217-237 in W. Nentwig, editor. Biological Invasions. Springer, Berlin.

Clarke Murray C, EA Pakhamov and T Thierriault. 2011. Recreational boating: a large unregulated vector transporting marine invasive species. Diversity and Distributions 17: 1161-1172.

CONABIO. 2010. Workshop: "Invasive Species and Other Drivers of Biodiversity Change in the Gulf of Mexico." September 2010.

Cohen AN and JT Carlton. 1995. Biological study of nonindigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and Delta. Report to US Fish and Wildlife Service, Washington, DC

Cohen AN and JT Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279:555–558

DAFF. 2011. Proposed Australian Biofouling Management Strategies Factsheet for Recreational Vessels. Prepared by the Australian Government, Department of Agriculture, Fisheries and Forestry.

(http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/biofouling/recreational-vessels; accessed April 2012)

Dafforn KA, TM Glasby EL Johnston. 2008. Differential effects of tributyltin and copper antifoulants on recruitment of non-indigenous species. Biofouling 24: 23-33.

Davidson I, C Zabin, A Chang, M Sytsma and 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 Sevice. 38p.

Davidson I, CW Brown, MD Sytsma and GM Ruiz. 2009. The role of containerships as transfer mechanisms of marine biofouling species. Biofouling 25: 645-655.

Davidson IC, CJ Zabin, AL Chang, CW Brown, MD Sytsma and GM Ruiz. 2010. Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquatic Biology 11:179-191.

Davidson IC and C Simkanin. 2011. The biology of Ballast water 25 years later. Biological Invasions, DOI 10.1007/s10530-011-0056-1

deRivera et al. 2005. Broad-Scale Non-indigenous Species Monitoring along the West Coast in National Marine Sanctuaries and National Estuarine Research Reserves

DFG. 2008. California Aquatic Invasive Species Management Plan. State of California Resources Agency, Department of Fish and Game. http://www.nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=3868

Doney SC, VJ Fabry, RA Feely and JA Kleypas. 2009. Ocean acidification: The other CO2 problem. Annual Review of Marine Science. 1: 169-192

Ewel JJ, DJ O'Dowd, J Bergelson, CC Daehler, CM D'Antonio, LD Gomez, DR Gordon, RJ Hobbs, A Holt, KR Hopper, CE Hughes, M Lahart, RRB Leakey, DH Lorence, SM Louda, AE Lugo, PB McEvoy, DM Richardson and P Vitousek, 1999. Deliberate introductions of species: research needs. BioScience 49: 619-630.

Fairey R, R Dunn, C Roberts, M Sigala, and J Oliver. 2002. Introduced Aquatic Species in California Coastal Waters, Final Report. California Department of Fish and Game.San Jose State University Foundation/Moss Landing Marine Laboratories.

Floerl O. 2002. Intracoastal spread of fouling organisms by recreational vessels. PhD Dissertation, James Cook University, Townsville. 293pp.

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

Floerl O. Inglis G, Dey K and A Smith. 2009. The importance of transport hubs in stepping-stone invasions. Journal of Applied Ecology 46: 37-45.

Fofonoff PW, GM Ruiz, B Steves and JT Carlton. 2003. In ships or on ships? Mechanisms of transfer and invasion for nonnative species to the coasts of North America. In: Ruiz GM and JT Carlton (eds) Invasive species: vectors and management. Island Press, Washington, DC, p 152–182

Gonzalez JA and LT Johnson. 2007 .Balancing recreational boating, invasive species prevention, and water quality protection. Proceedings of Coastal Zone 07. Portland, Oregon.

Harries DB, S Harrow, JR Wilson, JM Mair and DW Donnan. 2007. The establishment of the invasive alga *Sargassum muticum* on the west coast of Scotland: a preliminary assessment of community effects. Journal of Marine Biological Association of United Kingdom, 87:1057–1067

Hewitt CL, ML Campbell, RE Thresher, RB Martin, S Boyd, BF Cohen, DR Currie, MF Gomon, MJ Keough, JA Lewis, MM Lockett, N Mays, MA McArthur, TD O'Hara, GCB Poore, DJ Ross, MJ Storey, JE Watson and RS Wilson. 2004. Introduced and cryptogenic and species in Port Phillip Bay, Victoria, Australia. Marine Biology 144:183-202

Hughey JR, KA Miller and A Lyman. 2009. California. Madroño 56(4) 293-295.

Lodge DM, S Williams, HJ MacIsaac, KR Hayes, B Leung, S Reichard, RN Mack, PB Moyle, M Smith, DA Andow, JT Carlton and A McMichael. 2006. Biological Invasions: Recommendations for U.S. Policy and Management. Ecological Applications 16:2035–2054

Lonhart S and R Bunzel. 2009. Monterey Bay Undaria Removal Project. Final Report to NOAA Community-Based Restoration Program. 51pp (http://montereybay.noaa.gov/research/techreports/lonhart_bunzel_2009.pdf)

Kite-Powell H, L Fleming, L Backer, E Faustman, P Hoagland, A Tsuchiya, L Young, B Wilcox and R Gast. 2008. Linking the oceans to public health: current efforts and future directions. Environmental Health 7: S6.

Mack RN, D Simberloff, WM Lonsdale, H Evans, M Clout and F Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences and control. Ecological Applications 10:689-710

MAFBNZ. 2010. Requirements for Vessels Arriving in New Zealand; A MAF Biosecurity New Zealand (MAFBNZ) Standard prepared by the Biosecurity Standards Group. 17pp. http://www.biosecurity.govt.nz/files/regs/ships/vessel-standard-current.pdf

Meyerson LA and HA Mooney. 2007. Invasive alien species in an era of globalization. Frontiers in Ecology and the Environment 5: 199–208.

Millennium Ecosystem Assessment 2005. Ecosystems and human well-being: Synthesis. Island Press, Washington DC.

Miller R. 1926. Ecological relations of marine wood-boring organisms in San Francisco Bay. Ecology, 1:247-254.

Myers JH, Simberloff D, Kuris AM and JR Carey. 2000. Eradication revisited: dealing with exotic species. Trends in Ecology and Evolution, 15: 316-320.

Needles LA. 2007. Big Changes to a Small Bay: Exotic Species in the Morro Bay Fouling Community over Thirty Years. Master's Thesis, California Polytechnic State University, San Luis Obispo

Okolodkov YB, R Bastida-Zavala, AL Ibáñez, JW Chapman, E Suárez-Morales, F Pedroche, FJ Gutiérrez-Mendieta. 2007. Especies acuáticas no indígenas en México. Ciencia y Marinas 11:29-67.

Parker IM, D Simberloff, WM Lonsdale, K Goodell, M Wonham, PM Kareiva, MH Williamson, B Von Holle, PB Moyle, JE Byers and L Goldwasser. 1999. Impact: toward a framework for understanding the ecological effects of invaders. Biological Invasions 1: 3-19.

Pearse V, J Pearse, M Buchsbaum and R Buchsbaum. 1987. *Living Invertebrates.* Blackwell/Boxwood, Pacific Grove, CA: 848 pp.

Piola R and E Johnston. 2006. Differential resistance to extended copper exposure in four introduced bryozoans. Marine Ecology Progress Series 311: 103-114.

Piola R and B Forrest. 2009. Options for Managing Biosecurity Risks from Recreational Vessel Hubs. Prepared for Nelson City Council. Cawthron Report No. 1591. 45 pp.

Ruiz, GM, Fofonoff PF, Hines AH and ED Grosholz. 1999. Nonindigenous species as stressors in estuarine and marine communities: Assessing invasion impacts and interactions. Limnology and Oceanography, 44:950-972

Ruiz GM and JT Carlton. 2003. Invasion Vectors: A Conceptual Framework for Management. In: Ruiz GM and JT Carlton (eds) Invasive species: vectors and management. Island Press, Washington, DC, p 459-504.

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.

Ruiz G, A Freestone, P Fofonoff and C Simkanin. 2009. Habitat distribution and heterogeneity in marine invasion dynamics: the importance of hard substrate and artificial structure. In: Wahl M (ed) Marine hard bottom communities pp. 321–332.

Ruiz GM, PW Fofonoff, BP Steves and A Dahlstrom. 2011a. Marine Crustacean Invasions in North America: A Synthesis of Historical Records and Documented Impacts. In: Galil BS, PE Clark and JT Carlton (eds) In the Wrong Place- Alien Marine Crustaceans: Distribution, Biology and Impacts.pp215-250.

Ruiz GM, PW Fofonoff, BP Steves, SF Foss and SN Shiba. 2011b. Marine invasion history and vector analysis of California: A hotspot for western North America. Diversity and Distributions. 17:362–373.

Takata L, M Faulkner and S Gilmore. 2006. Commercial vessel fouling in California: Analysis, evaluation, and recommendations to reduce nonindigenous species release from the non-ballast water vector. Produced for the California State Legislature by the California State Lands Commission Marine Facilities Division. 76pp.

UCSGEP-SD. 2006. University of California Sea Grant Extension Program-San Diego Fact Sheet 06-1 March 2006: Managing Hull-Borne Invasive Species on California's Coastal Boats. http://www.rimeis.org/stakeholders/docs/transportation/hullborneAIS.pdf)

Wallentinus I. 1999. *Sargassum muticum*. In: Gollasch, S., Minchin, D., Rosenthal, H. & Voigt, M. (eds.): Exotics across the ocean. Case histories on introduced species: their general biology, distribution, range expansion and impact. Logos Verlag, Berlin.

Wasson K, CJ Zabin, L Bedinger, CM Diaz and JS Pearse. 2001. Biological invasions of estuaries without international shipping: the importance of intraregional transport. *Biological Conservation* 102(2):143-153

Williams SL and JE Smith. 2007. A global review of the distribution, taxonomy and impacts of introduced seaweeds. Annual Review of Ecology, Evolution and Systematics 38:327-359.

Wittenburg R and W Cock. 2005. Best practices for the prevention and management of invasive alien species. In: Mooney HA, RN Mack, JA McNeely, LE Neville, PJ Schei and JK Waage (eds). Invasive alien species. Island Press, Washington, D.C. p 209-232.

Zabin CJ, G Ashton, CW Brown and GM Ruiz. 2009. Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. Aquatic Invasions Volume 4: 429-434.

Zabin CJ, G Ashton, CW Brown, I Davidson, T Chestnut, R Draheim, MD Sytsma and GM Ruiz. 2011. Hull Fouling: Characterizing Magnitude and Risk of Species Transfers by Recreational and Fishing Vessels. Final report to the Pacific States Marine Fisheries Commission. 105 pp.

# Recreational Vessels as Vectors of Non-Native Marine Species in California

**Appendices**

**<u>July 2012</u>**

***Submitted to***

**Ocean Science Trust**

***Submitted by***


**G Ashton, C Zabin, I Davidson, G Ruiz**

Smithsonian Environmental Research Center

&

Portland State University

## Appendix 1

Characteristics used by P Fofonoff to define 'Fouling' species in NEMESIS

**Organism Characteristics**- Sessile or sedentary organisms firmly attached to a surface (algae, polyps, mussels, tunicates, etc), animals living within or on attached organisms, or in the matrix of the fouling community (isopods, amphipods, mobile polychaetes), wood-borers (gribbles, shipworms). Highly mobile organisms such as fishes, shrimps, and mysids are less likely, although transport of fish eggs in fouling is possible. Organisms transported in fouling tolerate oceanic conditions, including high salinity and fluctuating temperatures.

Many fouling organisms have long-lived planktonic life-stages (larvae, medusae) and so could be transported with roughly equal probability by ballast water or fouling. Historically, fouling would have been a major vector for California from the Gold Rush (and maybe earlier) to the present.

Sea chests were not treated separately. They do provide a potential mode of transport for larger and more active organisms that would not tolerate hydrodynamic stress or would be washed away in transit, but more study is needed to determine their importance.

Appendix 2 cont.d

**References for literature search biofouling taxa reported from small craft**

[1]Ashton G, Davidson I and G Ruiz.2010. History and biofouling of ships' hulls arriving to Ketchikan, Alaska: a case study. Final report submitted to Alaska Department of Fish and Game. 42 pp.

[2]Clarke Murray C, Pakhomov EA and TW Therriault.2011. Recreational boating: a large unregulated vector transporting marine invasive species. Diversity and Distributions:1-12.

[3]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.

[4]Davidson IC, CJ Zabin, AL Chang, CW Brown, MD Sytsma and GM Ruiz. 2010. Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquatic Biology 11:179-191.

[5]DeBlauwe H and Faasse M. 2001.Extension of the range of the bryozoans *Tricellariainopinata*and *Bugula simplex* in the North-East Atlantic Ocean (Bryozoa: Cheilostomatida).NederlandseFaunisticheMededelingen 14: 103-112.

[6]Farraperia CMR. 2011. The introduction of the bryozoan *Zoobotryonverticillatum* (Della Chiaje, 1822) in northeast of Brazil: a cause for concern. Biological Invasions (2011) 13:13-16.

[7]Floerl O. 2002. Intracoastal spread of fouling organisms by recreational vessels. PhD thesis, James Cook University, Townsville.

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

[9]Godwin LS, Eldredge LG and K Gaut. 2004. The assessment of hull fouling as a mechanism for the introduction and dispersal of marine alien species in the main Hawaiian Islands. Bishop Museum Technical Report No. 28. August 2004. 114 pp.

[10]Leonard J. 2009.Hull Fouling Surveys of Recreational Boats in Hawaii. Hawaii Department of Land and Natural Resources, Department of Aquatic Resources Report. 32 pp.

[11]Lougheed VL and RJ Stevenson. 2004. Exotic marine macroalga*(Enteromorphaflexuosa)* reaches bloom proportions in a coastal lake of Lake Michigan. Journal of Great Lakes Research 30(4): 538-544.

[12]Kerckhof F. 2002.Barnacles (Cirripedia, Balanomorpha) in Belgian waters, an overview of the species and recent evolutions, with emphasis on exotic species. Bulletin de l'Institut Royal Des Sciences Naturelles de Belgique, Biologies, 72-Supplement: 93-104.

[13]Meinesz A, Belsher T, Thibaut T, Antolic B, Mustapha KB, Boudouresque C-F, Chiaverini D, Cinelli F, Cottalorda J-M, Djellouli A, El Abed A, Orestano C, Grau AM, Ivesa L, Jaklin A, Langar H, Massuti-Pascual E, Peirano A, Tunesi L, de Vaugelas J, Zavodnik N and A Zuljevic. 2001. The introduced

green alga *Caulerpataxifolia* continues to spread in the Mediterranean. Biological Invasions 3: 201-210.

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

[15]Minchin D and Holmes JMC. 2007. The first record of *Caprellamutica*Schurin, 1935 (Crustacea: Amphipoda) from the East Coast of Ireland. The Irish Naturalists' Journal, 28 (8):321-323.

[6]Minchin D and Sides E. 2006. Appearance of a cryptogenic tunicate, a *Didemnum* sp. fouling marina pontoons and leisure craft in Ireland. Aquatic Invasions 1 (3):143-147.

[17]Mintz CT. 2001.Vessel hulls as a dispersal vector for coastal marine organisms.Bachelor's Thesis, Williams College, Williamstown, Ma.41pp

[18]Neves CS, Rocha RM, Bettini-Pitombo F and JJ Roper. 2007. Use of artificial substrata by introduced and cryptogenic marine species in Paranagua Bay, southern Brazil. Biofouling 23(5): 319-330.

[19]Savini D, Marchini A, Forni G and M Castellazzi. 2006. Touristic harbours and secondary spread of alien species. Biol. Mar. Medit (1):760-763.

[20]Zabin, CJ, Zardus J, Bettini-Pitombo F, Fread V and MG Hadfield. 2007. A tale of three seas: consistency of natural history traits in a Caribbean-Atlantic barnacle introduced to Hawaii, *Biological Invasions*: 9: 523-544.

[21]Zabin, CJ, Ashton GV, Brown CW &Ruiz GM. 2009.Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. Aquatic Invasions 4 (3): 429-434.

[22]Zabin CJ, Ashton G, Brown CW, Davidson I, Chestnut T, Draheim R, Sytsma MD and GM Ruiz. 2011. Hull Fouling: Characterizing Magnitude and Risk of Species Transfers by Recreational and Fishing Vessels. Final report to the Pacific States Marine Fisheries Commission. 105 pp.

<u>Appendix 3</u>

Data received from Customs and Border Protection in response to FOIA requests:

A table of ‘small’ vessels arriving by sea for the period of January 2009 to present; which have registered with U.S. Customs and Border Protection (CBP), specifically in the ports of San Diego, Eureka, Port Hueneme, Monterey, San Francisco, as well as all other ports of entry in California that deal with the arrivals of ‘small vessels’.

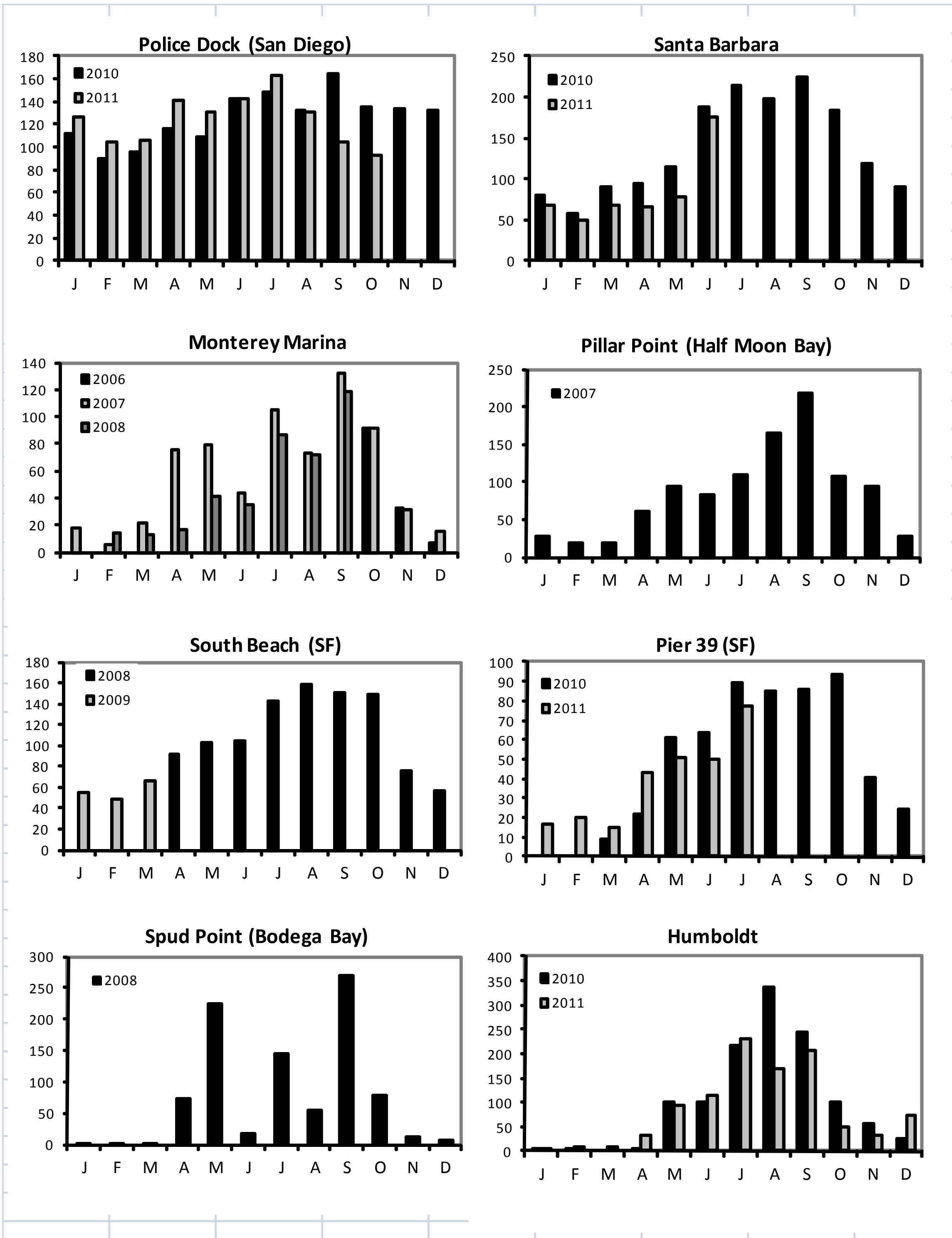
**Pleasure Boat Conveyance Arrivals: January 2009 to May 2011**

| Port Name | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jan | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| San Diego, CA | 86 | 66 | 113 | 128 | 164 | 134 | 87 | 71 | 46 | 111 | 61 | 42 | 44 | 45 | 68 | 107 | 158 | 170 | 90 | 78 | 49 | 60 | 67 | 22 | 38 | 31 | 47 | 150 | 80 | 2,413 |
| Los Angeles, CA | 3 | 2 | 1 | 1 | 3 | 5 | 1 | 3 | 4 | 5 | 3 | 4 | | 3 | 1 | 1 | 1 | 2 | | 2 | 2 | 1 | 3 | | | | 1 | | | 52 |
| Long Beach, CA | 1 | 1 | 1 | 2 | 4 | 4 | 2 | 7 | 2 | 3 | | | | | | 2 | | 2 | 1 | | | | | | | | | 2 | 3 | 37 |
| Port Hueneme, CA | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | | | | | | | 3 |
| San Francisco, CA | | | | | 2 | | 1 | 1 | 2 | | | | | | | | | | 1 | 1 | 1 | 2 | | 1 | | | | | | 12 |
| Oakland, CA | | | | 1 | | 1 | | 2 | 1 | 1 | | | | | | | | | 1 | 1 | | | | | | | | | | 8 |
| Eureka, CA | | | | | | 2 | | | 1 | | | | | | | | | | 2 | | 1 | 1 | | | | | | | | 7 |
| Fresno, CA | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | 1 |
| San Jose, CA | | 1 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | 2 |
| Total | 90 | 70 | 115 | 132 | 173 | 146 | 91 | 84 | 58 | 120 | 65 | 46 | 44 | 48 | 69 | 110 | 159 | 174 | 95 | 83 | 53 | 64 | 71 | 23 | 38 | 31 | 48 | 152 | 83 | 2,535 |

**Fishing Vessel Arrivals:**

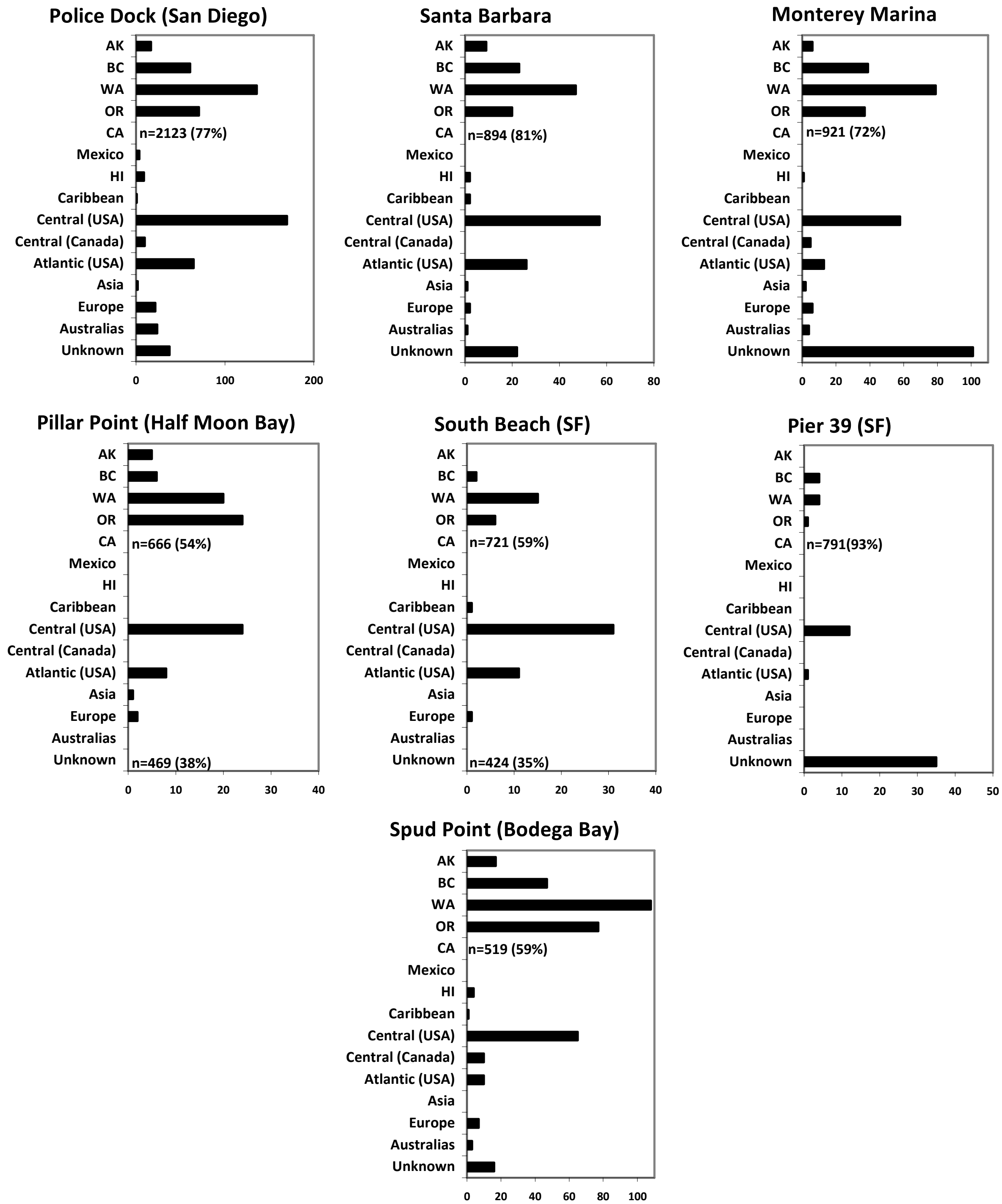
| Port Name | Total |
|---|---|
| San Diego, CA | 71 |
| Los Angeles, CA | 9 |
| Port Hueneme, CA | 3 |
| Oakland, CA | 10 |
| Eureka, CA | 2 |
| Total | 95 |

Appendix 4




**Monthly records of transient vessel arrivals to marinas along the California coastline. Shading is used to distinguish between different years (indicated by legends). Note different scales on the y-axes.**

Appendix 5




**Appendix Fig 2- Location of home addresses listed by transient vessels arriving to key marinas on the Californian coastline. Data are counts of vessels. Note different scales on the x-axes.**

<u>Appendix 6</u>

**List of species identified from recreational vessels. Numbers indicate number of vessels that the species was sampled from. Letters indicate status of the species in California: N- Native, I- Introduced, C- cryptogenic, G- could not be identified to species, but there are native members of this group. * indicates species not yet recorded from CA.**

**<u>Algae</u>**

1 N *Blidingia minima*
1 N *Chaetomorpha aerea*
1 I *Colpomenia peregrina*
1 N *Dasya sessillis*
1 I *Lomentaria hakodatensis*
1 N *Myriogramme spectabilis*
1 N *Polyneura latissima*
1 N *Polysiphonia pacifica*
1 N *Pterosiphonia dendroidea*
1 N *Pterothamnion pectinatum*
1 N *Ulva clathrata*
1 N *Ulva intestinalis*
3 G *Ulva* sp.
1 I *Undaria pinnatifida*

**<u>Ascidians</u>**

6 N *Ascidia ceratodes*
1 N *Ascidia paratropa*
1 G *Ascidia* sp.
2 I *Ascidia zara*
6 N *Botrylloides diegensis*
2 I *Botrylloides perspicuum*
3 G *Botrylloides* sp.
14 I *Botrylloides violaceus*
19 I *Botryllus schlosseri*
9 I *Ciona intestinalis*
1 I *Ciona savignyi*
1 I *Molgula* cf. *manhattensis*
1 I *Molgula ficus*
6 I *Molgula* sp.
1 G *Riterella* sp.
4 I *Styela clava*
10 I *Styela plicata*
8 G *Styela* sp.

**<u>Hydrozoans</u>**

3 N *Aglaophenia diegensis*
1 N *Amphisbetia furcata*
2 I *Bougainvillia muscus*
1 G *Bougainvilliidae (blank)*
3 N *Campanulinidae (blank)*
2 G *Clytia* sp.
1 G *Coryne* sp.
2 N *Ectopleura* sp.
1 N *Gonothyraea loveni*
5 N *Obelia dichotoma*
8 N *Obelia longissima*
1 N *Plumularia setacea*

**<u>Arthropods</u>**

1 G *Allorchestes* sp.
1 C *Ampithoe plumulosa*
1 G *Aoroides* sp. juvenile
1 N *Cancer gracilis*
11 N *Caprella californica*
10 C *Caprella equilibra*
3 N *Caprella kennerlyi*
15 I *Caprella mutica*
1 I *Caprella simia*
2 G *Corophiidae* juveniles
2 I *Elasmopus rapax*
9 C *Erichthonius brasiliensis*
2 C *Erichthonius* sp. juveniles
1 G Gammaridea juvenile
1 G Grapsidae
1 G Harpacticoida
7 I *Jassa marmorata*
11 N *Jassa slatteryi*
1 G *Jassa* sp. juveniles
1 N *Jassa staudei*
9 N *Laticorophium baconi*
1 G *Leucothoe* sp. *juveniles*
1 I *Leucothoe spinicarpa*
8 I *Monocorophium acherusicum*
1 I *Monocorophium insidiosum*
1 I *Monocorophium uenoi*
1 N *Pachycheles rudis*
14 N *Paracerceis sculpta*
11 N *Paranthura elegans*
1 N *Podocerus* cf. *cristatus*
2 N *Pugettia gracilis*
1 G Sphaeromatidae juveniles
1 G Stenothoidae, unidentified
2 G Xanthidae
8 N *Zeuxo normani*
7 G *Zeuxo* sp. juveniles

**Bryozoans**

| | | |
|---|---|---|
| 2 | G | *Diaperoforma* sp. |
| 13 | G | *Bowerbankia* sp. |
| 32 | I | *Bugula neritina* |
| 23 | I | *Bugula stolonifera* |
| 17 | N | *Celleporaria brunnea* |
| 1 | N | *Celleporella hyalina* |
| 1 | G | *Celleporella* sp. |
| 1 | G | *Celleporina* sp. |
| 1 | I | *Conopeum* cf. *tenuissimum* |
| 2 | G | *Conopeum* sp. |
| 1 | N | *Crisia* cf. *occidentalis* |
| 2 | G | *Crisia* sp. |
| 1 | G | *Crisidae* sp. |
| 3 | G | *Crisulipora* sp. |
| 14 | I | *Cryptosula pallasiana* |
| 1 | G | *Electra* cf. *crustulenta* |
| 2 | G | *Electra* sp. |
| 1 | I | *Hippoporina indica** |
| 3 | N | *Membranipora villosa* |
| 1 | N | *Microporella setiformis* |
| 4 | I | *Schizoporella japonica* |
| 2 | G | *Schizoporella* sp. |
| 2 | N | *Scrupocellaria bertholetti* |
| 8 | N | *Thalamoporella californica* |
| 2 | N | *Tricellaria occidentalis* |
| 1 | N | *Tubulipora* cf *pacifica* |
| 3 | I | *Watersipora arcuata* |
| 21 | I | *Watersipora subtorquata* |
| 5 | I | *Zooobotryon* sp. |

**Cirripeds**

| | | |
|---|---|---|
| 5 | I | *Amphibalanus amphitrite* |
| 8 | I | *Amphibalanus eburneus* |
| 5 | I | *Amphibalanus improvisus* |
| 1 | G | *Amphibalanus* (blank) |
| 11 | N | *Balanus crenatus* |
| 3 | N | *Balanus glandula* |
| 1 | G | *Balanus* sp. |
| 9 | N | *Balanus trigonus* |
| 1 | N | *Conchoderma auritum* |
| 1 | G | *Conchoderma* sp. |
| 1 | N | *Lepas anatifera* |
| 2 | N | *Lepas pacifica* |
| 2 | G | *Lepas* sp. |
| 3 | C | *Megabalanus cf tanagrae* |
| 3 | N | *Megabalanus coccopoma* |
| 1 | G | *Megabalanus* sp. |
| 1 | G | *Megabalanus* sp.A |
| 1 | G | *Megabalanus* sp.B |
| 2 | N | *Megabalanus tintinnabulum* |

**Polychaetes**

| | | |
|---|---|---|
| 5 | N | *Paleanotus bellis* |
| 1 | G | Cirratulidae |
| 1 | C | *Dorvillea moniloceras* |
| 1 | G | Nereididae |
| 2 | I | *Alitta succinea* |
| 1 | N | *Nereis latescens* |
| 1 | N | *Nereis mediator* |
| 1 | N | *Nereis vexillosa* |
| 6 | N | *Platynereis bicanaliculata* |
| 1 | N | *Eualia quadrioculata* |
| 3 | N | *Halosydna brevisetosa* |
| 1 | N | *Halosydna johnsoni* |
| 1 | C | *Harmathoe imbricata* complex |
| 1 | C | *Thormora johnstoni* |
| 1 | C | *Bispira* sp.7 Harris |
| *1* | I | *Branchiomma* sp. 1 |
| 3 | I | *Branchiomma* sp. 2 Harris |
| 1 | N | *Eudistylia polymorpha* |
| 1 | G | *Eudistylia* sp. |
| 1 | C | *Megalomma coloratum* |
| 2 | N | *Paradialychone ecaudata* |
| 4 | I | *Parasabella fullo* |
| 2 | N | *Pseudopotamilla ocellata* |
| 1 | G | Serpulidae |
| 2 | I | *Ficopomatus enigmaticus* |
| 1 | I | *Hydroides crucigera* |
| 1 | I | *Hydroides diramphus* |
| 9 | I | *Hydroides elegans* |
| 6 | N | *Hydroides gracilis* |
| 2 | G | *Hydroides* sp. |
| 9 | C | *Salmacina tribranchiata* |
| 1 | I | *Boccardiella hamata* |
| 2 | N | *Polydora narica* |
| 3 | G | Spirorbidae |
| 10 | N | *Pileolaria marginata* |
| 1 | N | *Pileolaria tiatara* |
| 3 | G | Autolytinae |
| 1 | C | *Syllis gracilis complex* |
| 2 | I | *Syllis* sp. 37 Harris |
| 2 | G | *Trypanosyllis* sp. |
| 1 | N | *Eupolymnia heterbranchia* |

## Appendix 7

**Results of BIOSIS searches for impact studies. Note that the number of Biosis Abstracts returned often includes duplicates and is unreliable. Only articles that could be sourced and assessed for relevance are included in the final column.**

| Taxonomic Group | Class | Species | BIOSIS Abstracts returned | Title suggests relevance | Article relevant |
|---|---|---|---|---|---|
| **Algae** | **Chlorophyta** | *Bryopsis hypnoides* | 2 | 2 | 0 |
| | | *Codium fragile ssp fragile* | 137 | 68 | 25 |
| | **Heterokontophyta** | *Cutleria cylindrica* | 1 | 0 | 0 |
| | | *Sargassum horneri* | 4 | 2 | 0 |
| | | *Sargassum muticum* | 132 | 71 | 30 |
| | | *Undaria pinnatifida* | 116 | 50 | 9 |
| | **Rhodophyta** | *Aglaothamnion tenuissimum* | 0 | 0 | 0 |
| | | *Antithamnion hubbsii* | 3 | 0 | 0 |
| | | *Antithamnion pectinatum* | 6 | 0 | 0 |
| | | *Caulacanthus ustulatus* | 8 | 0 | 0 |
| | | *Ceramium kondoi* | 1 | 0 | 0 |
| | | *Chondria arcuata* | 0 | 0 | 0 |
| | | *Dasya sessilis* | 4 | 1 | 1 |
| | | *Gracilaria vermiculophylla* | 34 | 14 | 6 |
| | | *Grateloupia lanceolata* | 6 | 0 | 0 |
| | | *Grateloupia turuturu* | 32 | 9 | 2 |
| | | *Lomentaria hakodatensis* | 5 | 1 | 0 |
| | | *Neosiphonia harveyi* | 18 | 4 | 2 |
| | | *Pikea yoshizakii* | 0 | 0 | 0 |
| | | *Polysiphonia denudata* | 1 | 0 | 0 |

| Taxonomic Group | Class | Species | BIOSIS Abstracts returned | Title suggests relevance | Article relevant |
|---|---|---|---|---|---|
| **Arthropoda** | **Amphipoda** | *Abludomelita rylovae* | 0 | 0 | 0 |
| | | *Ampelisca abdita* | 14 | 3 | 0 |
| | | *Ampithoe* | 9 | 4 | 0 |
| | | *Ampithoe longimana* | 3 | 0 | 0 |
| | | *Ampithoe valida* | 3 | 0 | 0 |
| | | *Aoroides secunda* | 0 | 0 | 0 |
| | | *Calliopiella sp.* | 0 | 0 | 0 |
| | | *Caprella drepanochir* | 0 | 0 | 0 |
| | | *Caprella mutica* | 42 | 11 | 2 |
| | | *Caprella scaura* | 7 | 1 | 1 |
| | | *Caprella simia* | 0 | 0 | 0 |
| | | *Chelura terebrans* | 1 | 0 | 0 |
| | | *Corophium heteroceratum* | 2 | 0 | 0 |
| | | *Eochelidium* | 0 | 0 | 0 |
| | | *Eochelidium miraculum* | 0 | 0 | 0 |
| | | *Grandidierella japonica* | 8 | 0 | 0 |
| | | *Incisocalliope derzhavini* | 0 | 0 | 0 |
| | | *Jassa marmorata* | 7 | 1 | 0 |
| | | *Melita nitida* | 9 | 4 | 0 |
| | | *Microdeutopus gryllotalpa* | 2 | 1 | 0 |
| | | *Monocorophium acherusicum* | 8 | 3 | 0 |
| | | *Monocorophium insidiosum* | 8 | 3 | 0 |
| | | *Monocorophiun uenoi* | 0 | 0 | 0 |
| | | *Paracorophium lucasi* | 2 | 1 | 0 |
| | | *Paradexamine* | 0 | 0 | 0 |
| | | *Stenothoe valida* | 0 | 0 | 0 |
| | **Cirripede** | *Amphibalanus albicostatus* | 4 | 2 | 0 |
| | | *Amphibalanus amphitrite* | 100 | 11 | 1 |
| | | *Amphibalanus eburneus* | 3 | 2 | 0 |
| | | *Amphibalanus improvisus* | 51 | 10 | 3 |
| | | *Amphibalanus reticulatus* | 18 | 2 | 0 |
| | | *Balanus trigonus* | 13 | 1 | 0 |
| | **Copepoda** | *Mytilicola orientalis* | 10 | 6 | 5 |
| | **Cumacean** | *Nippoleucon hinumensis* | 1 | 1 | 0 |

| Taxonomic Group | Class | Species | BIOSIS Abstracts returned | Title suggests relevance | Article relevant |
|---|---|---|---|---|---|
| **Crustacea** | **Decapoda** | *Carcinus maenas* | 394 | 149 | 24 |
| **cont.d** | | *Rhithropanopeus harrisii* | 74 | 13 | 3 |
| | **Isopoda** | *Caecijaera horvathi* | 0 | 0 | 0 |
| | | *Dynoides dentisinus* | 0 | 0 | 0 |
| | | *Eurylana arcuata* | 4 | 1 | 0 |
| | | *Iais californica* | 0 | 0 | 0 |
| | | *Ianiropsis serricaudis* | 0 | 0 | 0 |
| | | *Limnoria quadripunctata* | 3 | 0 | 0 |
| | | *Limnoria tripunctata* | 10 | 0 | 0 |
| | | *Paranthura japonica* | 2 | 1 | 0 |
| | | *Pseudosphaeroma sp.* | 1 | 1 | 0 |
| | | *Sphaeroma quoianum* | 14 | 4 | 2 |
| | | *Sphaeroma walkeri* | 10 | 0 | 0 |
| | | *Sphaeroma sp.* | 45 | 6 | 3 |
| | | *Synidotea laevidorsalis* | 11 | 8 | 0 |
| | | *Uromunna sp.* | 0 | 0 | 0 |
| | **Ostracoda** | *Aspidoconcha limnoriae* | 0 | 0 | 0 |
| | | *Redekea californica* | 0 | 0 | 0 |
| | **Tanaid** | *Sinelobus stanfordi* | 4 | 0 | 0 |

| Taxonomic Group | Class | Species | BIOSIS Abstracts returned | Title suggests relevance | Article relevant |
|---|---|---|---|---|---|
| **Mollusca** | **Bivalvia** | *Crassostrea gigas* | 415 | 42 | 12 |
| | | *Geukensia demissa* | 26 | 0 | 0 |
| | | *Ischadium recurvum* | 5 | 0 | 0 |
| | | *Lyrodus pedicellatus* | 6 | 0 | 0 |
| | | *Musculista senhousia* | 56 | 13 | 8 |
| | | *Mytilus galloprovincialis* | 278 | 62 | 17 |
| | | *Teredo bartschi* | 5 | 1 | 0 |
| | | *Teredo furcifera* | 5 | 0 | 0 |
| | | *Teredo navalis* | 16 | 7 | 1 |
| | **Gastropoda** | *Anteaeolidiella foulisi* | 0 | 0 | 0 |
| | | *Babakina festiva* | 0 | 0 | 0 |
| | | *Batillaria attramentaria* | 14 | 4 | 4 |
| | | *Catriona rickettsi* | 0 | 0 | 0 |
| | | *Crepidula convexa* | 5 | 4 | 0 |
| | | *Crepidula plana* | 1 | 1 | 0 |
| | | *Cuthona perca* | 1 | 0 | 0 |
| | | *Eubranchus misakiensis* | 0 | 0 | 0 |
| | | *Guildfordia yoka* | 0 | 0 | 0 |
| | | *Okenia plana* | 1 | 0 | 0 |
| | | *Potamopyrgus antipodarum* | 136 | 21 | 2 |
| | | *Sakuraeolis enosimensis* | 1 | 0 | 0 |
| | | *Tenellia adspersa* | 2 | 0 | 0 |

## Appendix 8

Synonyms listed in WoRMS (World Register of Marine Species; www.marinespecies.org) used as search terms in BIOSIS. Current recognized nomenclature is listed in bold, synonyms follow.

**Mollusca**

***Anadara ovalis:*** *Arca americana , Arca campechiensis, Arca canalicostata, Arca cayenensis, Arca costata, Arca declivis, Arca holmesii, Arca indica, Arca ovalis, Arca pariaensis, Arca pectinoides, Arca pexata, Arca semidentata, Lunarca ovalis*

***Anadara transvers****:a Anadara demiri, Arca amygdalum, Arca sulcosa, Arca transversa, Scapharca demiri*

***Anomia simplex:*** *Anomia acontes, Anomia glabra*

***Anteaeolidiella indica:*** *Anteaeolidiella foulisi, Aeolidiella indica, Aeolidiella takanosimensis, Aeolis foulisi, Anteaeolidiella indica*

***Arctica islandica:*** *Arctica vulgaris, Cyprina islandica, Pectunculus crassus, Venus buccardium, Venus ferröensis, Venus islandica, Venus pitar*

***Crassostrea gigas:*** *Crassostrea angulata, Crassostrea talienwhanensis, Dioeciostrea hispaniola, Gryphaea angulata, Lopha posjetica, Ostrea angulata, Ostrea complanata, Ostrea cymbaeformis, Ostrea gigas, Ostrea laperousii, Ostrea posjetica, Ostrea rostralis, Ostrea virginica var. lusitanica,*

***Crassostrea virginica:*** *Dioeciostrea americana, Ostrea borealis, Ostrea canadensis, Ostrea floridensis, Ostrea procyon, Ostrea reniformis, Ostrea rostrata, Ostrea triangularis, Ostrea virginiana, Ostrea virginica*

***Crepidula convexa:*** *Crepidula acuta, Crepidula glauca*

***Crepidula fornicate:*** *Crepidula riisei, Crepidula virginica, Crypta densata, Crypta nauturum, Patella fornicata*

***Crepidula plana****: Crepidula depressa, Crepidula lamina, Crepidula rhyssema*

***Eubranchus misakiensis****: Leostyletus misakiensis*

***Gemma gemma:*** *Cyrena purpurea, Gemma fretensis, Gemma tottenii, Parastarte concentrica, Venus gemma, Venus manhattensis*

***Geukensia demissa:*** *Brachidontes demissus, Brachydontes clava, Modiola plicatula, Modiola semicostata, Modiolus demissus, Mytilus demissa*

***Haminoea japonica****: Haminoea callidegenita*

***Ilyanassa obsolete****: Buccinum noveboracensis, Buccinum oliviforme, Nassa obsoleta,*

***Ischadium recurvum****: Mytilus carolinensis, Mytilus hamatus, Mytilus recurvum, Mytilus striatus*

***Littorina littorea:*** *Littorina armoricana, Littorina bartonensis, Littorina communis, Littorina parva, Littorina rudis, Littorina sphaeroidalis, Littorina vulgaris, Turbo bicarinatus, Turbo carinatus, Turbo elongatus, Turbo litoreus, Turbo littoreus, Turbo sulcatus, Turbo ustulatus, Turbo ventricosus*

***Littorina saxatilis****: Litorina groenlandica, Litorina incarnata, Litorina marmorata, Litorina sulcata, Littorina castanea, Littorina danieli, Littorina neglecta, Littorina nervillei, Littorina nigrolineata, Littorina palliata, Littorina rudis, Littorina saxoides, Littorina simplex, Littorina tenebrosa, Littorina zonaria, Nerita rustica, Turbo obligatus, Turbo rudis, Turbo rudissimus*

***Lyrodus pedicellatus****: Teredo arabica, Teredo calmani, Teredo chlorotica, Teredo dagmarae, Teredo diegensis, Teredo floridana, Teredo franziusi, Teredo hawaiensis, Teredo helleniusi, Teredo hibicola, Teredo honoluluensis, Teredo indica, Teredo kauiensis, Teredo lamyi, Teredo linaoana, Teredo lomensis, Teredo madrasensis, Teredo malaccana, Teredo midwayensis, Teredo nodosa, Teredo pedicellata, Teredo* *pertingens, Teredo pochhammeri, Teredo robsoni, Teredo samoaensis, Teredo siamensis, Teredo taiwanensis, Teredo tateyamensis, Teredo togoensis, Teredo townsendi, Teredo tristis, Teredo yatsui*

***Melanoides tuberculatus**: Melanoides tuberculata*

***Mercenaria mercenaria**: Mercenaria cancellata, Mercenaria fulgurans, Mercenaria rutila, Mercenaria violacea, Venus cyprinoides, Venus mercenaria, Venus notata, Venus obliqua, Venus praeparca, Venus submercenaria, Venus ziczac*

***Meretrix lusoria**: Cytherea formosa, Cytherea graphica, Meretrix virgatula, Venus lusoria*

***Musculista senhousia**: Arcuatula senhousia, Modiola aquarius, Modiola bellardiana, Modiola senhousia*

***Mya arenaria**: Mya acuta, Mya alba, Mya communis, Mya corpulenta, Mya declivis, Mya elongata, Mya hemphilli, Mya japonica, Mya lata, Mya oonogai, Mya subovata, Mya subtruncata, Sphenia ovoidea*

***Myosotella myosotis**: Ovatella myosotis*

***Mytilus galloprovincialis**: Mytilus dilatatus, Mytilus edulis diegensis, Mytilus edulis galloprovincialis, Mytilus edulis zhirmunskii, Mytilus flavus, Mytilus hesperianus, Mytilus lamarckianus, Mytilus orbicularis, Mytilus sagittatus, Mytilus succineus*

***Nuttallia obscurata**: Nuttallia solida, Psammobia olivacea, Soletellina obscurata*

***Ocinebrellus inornatus**: Ocenebra inornata, Murex crassus, Murex endermonis, Murex inornatus, Murex japonicus, Murex talienwhanensis, Pteropurpura inornata, Ocinebrellus inornata, Tritonium submuricatum, Fusus submuricatum, Trophon incompta*

***Okenia plana**: Okenia eolida, Doris eolida*

***Ostrea edulis**: Monoeciostrea europa, Ostrea adriatica, Ostrea boblayei, Ostrea corbuloides, Ostrea cristata, Ostrea cumana, Ostrea cyrnusi, Ostrea depressa, Ostrea exalbida, Ostrea hippopus, Ostrea lamellosa, Ostrea leonica, Ostrea parasitica, Ostrea rostrata, Ostrea saxatilis, Ostrea scaeva, Ostrea striatum, Ostrea sublamellosa, Ostrea taurica, Ostrea vulgare*

***Petricolaria pholadiformis**: Gastranella tumida, Petricola carolinensis, Petricola flagellata, Petricola fornicata, Petricola pholadiformis, Petricola rogersi*

***Philine japonica**: Philine orientalis, Philine argentata, Philine striatella*

***Philine orientalis**: Philine argentata, Philine striatella, Philine japonica*

***Potamopyrgus antipodarum**: Hydrobia jenkinsi, Paludestrina jenkinsi, Potamopyrgus jenkinsi*

***Tenellia adspersa:** Embletonia pallida, Eolis ventilabrum, Tenellia pallida, Tergipes adspersus*

***Teredo bartschi**: Teredo aegyptia, Teredo balatro, Teredo batilliformis, Teredo fragilis, Teredo grobbai, Teredo hiloensis, Teredo shawi*

***Teredo furcifera**: Teredo australasiatica, Teredo bensoni, Teredo furcata, Teredo furcillatus, Teredo krappei, Teredo laciniata, Teredo parksi*

***Teredo navalis**: Pholas teredo, Serpula teredo, Teredo austini, Teredo batavus, Teredo beachi, Teredo beaufortana, Teredo japonica, Teredo marina, Teredo morsei, Teredo novangliae, Teredo pocilliformis, Teredo sellii, Teredo sinensis, Teredo vulgaris*

***Urosalpinx cinerea**: Fusus cinereus, Urosalpinx follyensis*

***Venerupis philippinarum**: Paphia bifurcata, Ruditapes philippinarum, Tapes philippinarum, Tapes biradiata, Tapes denticulata, Tapes ducalis, Tapes indica, Tapes japonica, Tapes semidecussata, Tapes violascens, Venus philippinarum, Venus tessellata*

**Algae**

***Aglaothamnion tenuissimum:*** *Aglaothamnion byssoides, Callithamnion arachnoideum, Callithamnion arnottii, Callithamnion byssoides, Callithamnion furcellariae, Callithamnion hiemale, Callithamnion tenuissimum (Bonnemaison), Ceramium tenuissimum Bonnemaison*

***Antithamnion pectinatum:*** *Antithamnion nipponicum, Antithamnion applicitum, Antithamnion cristirhizoph,um, Callithamnion applicitum, Callithamnion pectinatum, Herpothamnion pectinatum, Ptilothamnion pectinatum*

***Ascophyllum nodosum:*** *Ascophylla laevigatum, Ascophyllum laevigatum, Ascophyllum mackayi, Ascophyllum mackayi f. robertsonii, Ch,daria sc,pioides, Fucodium nodosum, Fucus mackayi, Fucus nodosus, Fucus sc,pioides, Halicoccus nodosus, Halidrys siliquosa, Ozothallia nodosa, Ozothallia vulgaris*

***Caulacanthus ustulatus:*** *Caulacanthus divaricatus, Caulacanthus indicus, Caulacanthus okamurae, Caulacanthus spinellus, Fucus acicularis var. ustulatus, Gelidium ustulatum, Gigartina ustulata, Laurencia divaricata, Rhodomela spinella, Sphaerococcus ustulatus*

***Caulerpa taxifoli:****, Fucus taxifolius*

***Codium fragile ssp fragile:*** *Codium fragile fragile, Codium fragile capense, Codium fragile ssp tomentosoides*

***Gelidium vagum:*** *Gelidium grubbae*

***Gracilaria vermiculophylla****: Gracilaria asiatica, Gracilariopsis vermiculophylla*

***Grateloupia lanceolata****: Aeodes lanceolata, Pachymeniopsis lanceolata*

***Grateloupia turuturu:*** *Grateloupia d,yph,a*

***Lomentaria hakodatensis****: Lomentaria sinensis*

***Neosiphonia harveyi:*** *Polysiphonia argentinica, Polysiphonia havanensis var. insidiosa, Polysiphonia insidiosa, Polysiphonia nova-angliae, Polysiphonia harveyi*

***Polysiphonia denudate****: Hutchinsia biasolettoana, Hutchinsia variegata, Polysiphonia leptura, Polysiphonia variegata, Polysiphonia vidovichii*

***Sargassum horneri****: Sargassum h,neri, Fucus h,neri, Sargassum (Bactrophycus) h,neri, Sargassum spathulatum*

***Sargassum muticum*** *Sargassum kjellmanianum f. muticum*

***Undaria pinnatifida****: Alaria pinnatifida, Ulopteryx pinnatifida*

**Crustacea**

***Caprella mutica****: Caprella macho*

***Orientomysis aspera:*** *Acanthomysis aspera*

***Orientomysis hwanhaiensis****: Acanthomysis hwanhaiensis*

***Hyperacanthomysis longirostris:*** *Acanthomysis longirostris*

***Caecidotea racovitzai****: Asellus racovitzai*

***Amphibalanus Amphitrite:*** *Balanus amphitrite*

***Amphibalanus improvisus:*** *Balanus improvisus*

***Amphibalanus reticulates:*** *Balanus reticulatus*

***Carcinus maenas:*** *Cancer granarius, Cancer granulatus, Cancer maenas, Cancer pygmeus, Cancer rhomboidalis, Cancer viridis, Carcinus granulatus, Carcinus moenas, Megalopa montagui*

***Caprella scaura:*** *Caprella cornuta, Caprella nodosa*

***Chelura terebrans:*** *Chelura cambrica, Chelura nesaeoides, Chelura pontica, Chelura xylophaga*

***Eurylana arcuata:*** *Cirolana arcuata*

***Monocorophium acherusicum:*** *Corophium acherusicum*

***Monocorophium insidiosum:*** *Corophium insidiosum*

***Dynoides dentisinus:*** *Dynoidella conchicola, Dynoides conchicola*

***Synidotea laevidorsalis:*** *Edotia laevidorsalis*

***Amphibalanus albicostatus:*** *Fistulobalanus albicostatus*

***Upogebia affinis:*** *Gebia affinis*

***Eriocheir sinensis:*** *Grapsus nankin, Grapsus nankin*

***Iais californica:*** *Janiropsis californica*

***Exopalaemon modestus:*** *Leander czerniavskyi, Leander macrogenitus, Leander modestus*

***Exopalaemon carinicauda:*** *Leander longirostris, Palaemon carinicauda, Exopalaemon carinicauda*

***Lernaea cyprinacea:*** *Lernaea carassii, Lernaea elegans, Lernaea esocina, Lernaea ranae, Lernaea tentaculis, Lernaeocera cyprinacea, Lernaeocera gasterostei*

***Sinocalanus doerrii:*** *Limnocalanus sinensis doerrii*

***Microdeutopus gryllotalpa:*** *Microdeutopus bidens, Microdeutopus grandimana, Microdeutopus minax, Microdeutopus salenskii*

***Mytilicola orientalis:*** *Mytilicola ostreae*

***Transorchestia enigmatica:*** *Orchestia enigmatica*

***Rhithropanopeus harrisii:*** *Panopeus wurdemannii, Pilumnus harrisii*

***Pseudosphaeroma sp****.: Paradynamenopsis sp.*

***Callinectes sapidus:*** *Portunus diacantha*

***Stenothoe valida:*** *Probolium polyprion, Stenothoe assimilis, Stenothoe megacheles, Stenothoe ornata, Stenothoe polyprion*

***Eusarsiella zostericola:*** *Sarsiella tricostata, Sarsiella zostericola*

***Pseudodiaptomus forbesi:*** *Schmackeria forbesi*

***Corophium alienense:*** *Sinocorophium alienense*

***Corophium heteroceratum****: Sinocorophium heteroceratum*

***Sphaeroma quoianum****: Sphaeroma quoyanum*