Aquatic Invasive Species Vector Risk Assessments:
Live Saltwater Bait and the Introduction of Non-native Species into California

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Introduction

A variety of live marine or estuarine organisms are sold in California as saltwater fishing bait including fish, polychaete worms, true shrimp, ghost and mud shrimp, mole crabs and mussels. Some of these are harvested and used locally; some may be harvested in one part of the state and sold and utilized in another; and some live bait organisms come from other states or countries. Some of these bait organisms may carry parasites; some are shipped in seaweeds, salt water, or other media that may inadvertently transport other live organisms. We know from previous work that as a result of this trade certain bait, parasite or "hitchhiking" species have been released into California coastal waters and a few have become established.

The overall goal of this project is to assemble, summarize and analyze the information needed to assess the risk of the trade in live saltwater bait introducing and establishing or spreading non-native species in California waters. To that end, we investigated the history, scale and scope of the live bait trade, including determining past trends and possible future directions; identified traded and hitchhiker species; estimated the numbers sold, utilized and/or released into coastal waters; and identified organisms that were likely introduced and established by the bait trade in the past.

Previous Studies

Unlike the large number of studies that have been conducted on ballast water and vessel fouling, there has been very little assessment of the live saltwater bait trade as an invasion vector. Early references to this trade as an invasion vector can be found in Carlton (1975) and Carlton's Ph.D. thesis (1979, at pp. 99 & 361), which discuss transport in the seaweed (mainly *Ascophyllum nodosum*) packing for baitworms (the pileworm *Alitta virens* (formerly *Nereis virens*) and the bloodworm *Glycera dibranchiata*) from New England as a possible vector for the release of the Atlantic periwinkle *Littorina littorea* in Trinidad Bay and Newport Bay, California. Human's (1971) suggestion that the Atlantic oyster drill *Urosalpinx cinerea*, discovered in Newport Bay in 1969, “may have been introduced with purchase fish bait” may refer to the same trade in New England baitworms. Dawson and Foster (1982) similarly stated that *Codium fragile* subsp. *fragile* was introduced to San Francisco Bay as packing material for marine baitworms.[1] Carlton (1979, 1992a) lists several species (referred to here as "hitchhiking" species) that he found in the seaweed packing for Maine baitworms sold in Newport Bay. Cohen and Carlton (1995 at p. 164) and Carlton and Cohen (2007) again reviewed this mechanism, and noted several species that could have been introduced into San Francisco Bay as hitchhikers in bait. Lau's (1995) undergraduate project on these baitworms imported to the San Francisco Bay Area provided the first quantitative

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[1] Another relatively early reference is Randall's (1987) suggestion that the goldspot herring *Herklotsichthys quadrimaculatus* was introduced to Kaneohe Bay in Hawaii in the 1970s as discarded bait. However, the specific mechanism he describes—the capture of this species in the Marshall Islands for use as a bait by a vessel chartered by the National Marine Fisheries Service for exploratory fishing, and its subsequent release in Hawaiian waters by the same vessel—is not part of the bait trade.

sampling of their hitchhiking species. Lau also conducted a small number of angler surveys regarding the use and ultimate disposition of the worms and seaweed. Cohen *et al.* (2001) sampled baitworm shipments and conducted an extensive phone survey of bait retailers in the San Francisco Bay area and interviews of baitworm shippers in Maine to estimate the scale of the trade and the numbers and species of organisms imported and released. They concluded that this vector releases tons of seaweed and several tens of thousands of individuals of various New England invertebrate into San Francisco Bay each year. Hackman's (2002) undergraduate project sampled baitworm shipments in the Bay and Delta area and verified survival of the two New England baitworm species for three days in central California seawater.

Mullady *et al.* (2000) meanwhile looked for microorganisms in shipments arriving in Maryland or Virginia of a large nereid worm, *Namalycastis rhodochorde*, which had recently begun to be imported from Vietnam and sold as bait under the trade names "nuclear worm" (on the East Coast) or "magic cord" (on the West Coast), and found multiple species of *Vibrio* bacteria along with diatoms, ciliates, flagellates, amoebae and nematodes. Wallace (2003) briefly reviewed the trade in nuclear worms. Weigle (2002, and Weigle *et al.* 2005), as part of a study of non-shipping vectors of bioinvasions, conducted a survey of bait dealers in New England to assess the species and quantities of live saltwater bait organisms imported to New England from outside the region, and to understand some aspects of the holding and handling of these species. Pernet *et al.* (2008) examined ghost shrimp *Neotrypaea californiensis* shipped to southern California from Washington and Oregon for sale as bait, in order to quantify the abundance in these shipments of a ghost shrimp parasite that is not native to southern California. They also analyzed two mitochondrial DNA markers to assess the risk of homogenizing existing genetic variation in *N. californiensis*, which they found to be low.

Yarish *et al.* (2009) and Haska *et al.* (2011) reported on hitchhiker species in the *Ascophyllum nodosum* used as packing for the pileworm *Alitta virens* harvested in Maine and sold in Connecticut and New York in 2007-2008. In addition to identifying a variety of invertebrates and detecting two harmful algal species by DNA analysis, incubation of the packing material yielded a large number of macroalgal and microalgal species that were otherwise not detected. Passarelli's (2010) Masters' thesis reported on a mail survey of California bait shops conducted in 2008-2009 and estimated the numbers of five bait species imported into the state; assessed the transport of parasites on *N. californiensis* imported into the state as bait: and tested and found that three species transported by the live bait trade (the baitworms *Glycera dibranchiata* and *Perinereis aibuhitensis*, and the common ghost shrimp parasite *Ione cornuta*) can survive for at least five days in southern California water temperatures.

Several studies have identified the trade in the baitworms *A. virens* and *G. dibranchiata* as a possible or probable vector responsible for particular species arriving in California from the Atlantic Ocean. Carlton (1975, 1979, 1992), Cohen and Carlton (1995), Cohen *et al.* (2001), Carlton and Cohen (2007) and Chang *et al.* (2011) reported several occurrences of the periwinkle *Littorina littorea* in San Francisco Bay and single occurrences in Trinidad Bay and Newport Bay, suggesting that they were probably due, in part, to the bait trade. Dawson and Foster (1982) stated that *Codium fragile* subsp. *fragile* a Japanese seaweed that became established in the Atlantic Ocean in the late 1800s, was introduced into San Francisco Bay *as* the packing material for live marine baitworms from New England, though other than this statement there's no evidence that *Codium* was ever used as packing material for these worms. Cohen *et al.* (2001) discussed the evidence for *C. f. fragiie* having been introduced *in* the *A. nodosum* packing. Carlton and Scanlon (1985) suggested that *C. f. fragile* had been introduced into Virginia waters in the packing for Maine baitworms. Carlton (1992b) suggested that a single live specimen of the clam *Mercenaria mercenaria* found in Mission Bay might have been from discarded bait (though he didn't say whether he meant discarded *as* bait, carried by an angler from an established population of *M. mercenaria* in Alamitos Bay, or *with* baitworms, transported from the Atlantic). Cohen *et al.* (1995), Cohen and Carlton (1995) and Cohen *et al.* (2001) discussed the evidence indicating that the European green crab *Carcinus maenas* was likely introduced to the Pacific Coast in these baitworm shipments. Similarly Cohen and Carlton (1995), Carlton and Cohen (1998, 2007), Cohen *et al.* (2001) and Brown (2004) reported the appearance of the Atlantic rough periwinkle *Littorina saxatilis* in San Francisco Bay, distributed in small populations adjacent to popular fishing spots or boat launching sites, and concluded that it was probably introduced with baitworms from Maine. Cohen and Carlton (1995) also suggested that the seaweed *Aglaothamnion tenuissimum* (formerly *Callithamnion byssoides*) could have arrived in San Francisco Bay via by this trade. Finally, Krauss *et al.* (1971), Zaneveld and Willis (1974) and Orris (1980) reported the periodic presence of unestablished and unattached clumps of *Ascophyllum nodosum* in Chesapeake Bay, Silva (1979) and Josselyn and West (1986) reported the same for San Francisco Bay, and Schneider and Searles (1991) for North Carolina, in each case attributing these to transport with baitworms. Miller *et al.* (2004) reported the discovery and removal of a small, vegetatively reproducing, possibly established population of *A. nodosum* at a site in southwestern San Francisco Bay, suggesting introduction as either bait or seafood packing. Similarly, Ribera and Boudouresque (1995, citing Sancholle 1988) reported that the seaweed *Fucus spiralis* had been introduced from Atlantic France into the Mediterranean as packing material for bait.

Sherfy and Thompson (2000, 2001) and Thompson & Alam (2005) reported on their efforts to characterize the import trade of live saltwater bait into the United States through examination of U.S. Customs data for 1997-2000, for insight into the potential for this trade to introduce exotic species. They were able to obtain only limited, general data, due to the categories used to classify import goods and the limited reporting of quantities. Weigle (2002) and Weigle *et al.* (2005) surveyed Massachusetts bait shops located within 160 km of the coast and found that, compared to other activities surveyed (seafood, aquarium, aquaculture, research/education), bait shops imported the fewest species but the 2nd largest number of live or fresh (dead but not frozen or processed) marine organisms from outside of New England, were the most likely to receive these organisms packed in seaweed and the 2nd most likely to observe hitchhiker organisms in the shipments, and were the most likely to discharge untreated holding tank water into a water body (though not necessarily into salt water). Weigle (2007) conducted a similar survey in Maine and found that the bait dealers that responded to the survey imported some fresh organisms but no live organisms from outside of New England. One respondent estimated that he exported over 3 million live pileworms and bloodworms each year to Europe, the Pacific coast and the southern Atlantic coast.

Methods

Definitions, Classifications and Scope

We identified the saltwater species sold as live bait in California, and for each species compiled the information needed to assess:

- its native range
- the locations where it is harvested
- the regions where it is sold in California
- the quantities imported and sold
- shipping and packing media used (e.g. seaweed, seawater), and means of disposal for these
- holding procedures
- hitchhiker species
- prior invasion history in California.

We classified species as native, non-native or cryptogenic. These are explicitly place-contingent terms. A species is classified as native in reference to its presence within its native range,[2] and classified as non-native when referring to its presence or potential presence elsewhere. Cryptogenic is applied to species in reference to locations where the evidence is insufficient to determine whether they are native or non-native. These classifications include no implication regarding the behavior or impact of the species.

We assessed species classifications (native/non-native/cryptogenic), population status (whether established, failed, etc.), and possible/probable vector by a weight-of-the evidence approach, rather than other types of approaches (received wisdom, scoring system, correspondence with criteria, etc.) as described in Cohen (2004).

This study's focus is the risk of species invasions in California resulting from the commercial trade in live saltwater bait species in California. Thus we look at introduction pathways that involve, at some stage, a legal commercial transaction with a buyer of live saltwater bait located in California. Our primary interest was in bait species harvested or grown outside of California and transported into the state, but we also compiled and analyze some data on species harvested or grown within the state. We organized the within-state data by dividing the coastal and Delta counties of California

[2] There have been some minor differences among researchers in how they define native. For example, are species that were transplanted to a new location by aboriginal humans native or non-native? While we define these to be non-native, it makes no difference to the present work, as there are no known aboriginal introductions of marine species to California. Laws, regulations or government reports have sometimes defined native in terms of political boundaries, for political or jurisdictional reasons. For scientific or technical assessments, this is generally not appropriate.

into North, Bay, Delta, Central and South regions (Appendix A). For transfers within the state, risk was considered at the level of introductions between two bioregions divided at Point Conception (as had been agreed at a planning workshop in order to promote consistency between reports); that is, we did not consider the risk of introductions between California sites when both the source and release sites are located north of Point Conception, or when both are located south of Point Conception.

This study does not address live bait species imported illegally or non-commercially into the state, bait intended for sale frozen or "fresh" (dead and chilled), or the transport and sale of freshwater bait species.

Data Sources

Existing Databases with Trade Data

Two federal databases and one State of California database appeared to have the potential to provide information on the importation of live saltwater bait species into California. Sherfy and Thompson (2000, 2001) and Thompson & Alam (2005) reported on efforts to use information in U.S. Customs data to characterize the bait trade. These data are classified by import categories known as Harmonized Tariff Codes (HTC). The HTCs that these authors considered most relevant to the live bait trade apparently may include both marine and freshwater species ("Worms, Live"), artificial as well as live bait ("Bait, Other than Worms"), and seafood and other non-bait organisms along with bait organisms ("Aquatic Invertebrates" and "Fish, Live, Not Otherwise Specified or Included"), which limits the usefulness of the data for our current purposes. Nevertheless, we acquired and analyzed Customs data for relevant HTCs (or as they are now called, Harmonized Tariff Schedule (HTS) Categories) from 1989 (the first year for which data are available) to 2010 (the last full year available) from the online Interactive Tariff and Trade DataWeb provided by the International Trade Commission (http://dataweb.usitc.gov), which provides monthly data on value imported, quantity imported, country of origin and port of entry by HTS category. By sorting the data by country of origin and port of entry, and utilizing what we'd learned from surveys and other sources about the timing and origin of bait imports, we attempted to tease out whatever useful information we could.

A second potential source of information is the record of declarations that importers must file with the U.S. Fish and Wildlife Service in order to bring any wildlife into the United States. Wildlife is broadly defined as any living or dead wild animal, its parts, and any products made from it, including mammals, birds, reptiles, amphibians and fish, as well as invertebrates such as insects, crustaceans, arthropods, molluscs and coelenterates (www.fws.gov/le/ImpExp/CommWildlifeImportExport.htm). This definition would appear to include all live saltwater bait species, including baitworms, even though annelids are not specifically mentioned. The import declaration (Form 3-177) must include the animal's common and scientific names, the quantity and value being imported, the country where the animal was taken from the wild or where it was born, the country where the exporter is located, and a 3-letter description code; the relevant description code for live bait is LIV (Live Specimen). The information from these declarations is recorded in the USFWS/Office of Law Enforcement's Law Enforcement Management Information System (LEMIS). The data are organized by 4-, 3- or 2-letter species codes referring to species, genera or higher taxa, respectively, which are apparently assigned by USFWS based on the species name listed on the declaration. Eliot Crafton provided us with a LEMIS data set of live animal imports into California, obtained from USFWS through a FOIA request, which we searched for information on imports of live saltwater bait species.

California Fish and Game regulations require a permit for the importation of live aquatic plants or animals into California that are intended to be placed in California waters, including live bait (CDFG 2011; California Fish and Game Code §2271; California Administrative Code, Title 14, §236). Rachel Fontana provided us with a set of import data for 2004-2011 that she had obtained from Kirsten Ramey at CDFG, which we examined for bait species.

Existing Databases with Species Data

There are a substantial number of extant databases and data sets on non-native species. They differ in their scope, completeness, format, level of documentation, quality, public availability, etc. Many of them include data fields that classify species as native, non-native or cryptogenic (or similar categories), classify species as established or not, list the vector or vectors that introduced or might have introduced or probably introduced the species, list the species' native and/or source regions, list the dates of the species' arrival or initial collection, etc. Each entry in each of these fields represents a judgment by the individuals that compiled the database. There are a variety of approaches to making these judgments, as discussed in Cohen (2004), and each of these approaches may be applied with greater or lesser care and skill—some commonly-cited databases, in fact, appear to have very high error rates.[3] Given the ongoing rate of invasion, and our developing knowledge about past invasions, each of these databases is necessarily also a work in progress.

Rather than rely on any one database, we attempted to review all the available data, from these databases, from published literature and from other sources, in order to compile the relevant information to make the classification judgments needed for the tasks addressed here. The NEMESIS/California database, which was made available to

[3] California's Marine Invasive Species Program (MISP), charged by the California Legislature with the task of monitoring for non-native species in the state's coastal waters, has produced several reports and a database (CANOD, the California Aquatic Non-native Organism Database) that appear to have consistently high error rates. For example, a sampling of the data tables in the 2002 report to the Legislature on the coastal and estuarine waters of the state found error rates above 50% (including both identification and classification errors), and a review of the fundamental findings of the 2006 report on the open waters of the state found an error rate of 85%. Similarly, a review of the California/NEMESIS database found that for 59% of the species and 80% of the introductions for which Discarded Bait was listed as a possible vector, and for 100% of the species and introductions for which Discarded Seafood was listed as a possible vector, the listing was either an error or is inconsistent with the rest of the vector listings (see Appendix F in this study and in Cohen 2012).

us and the other research teams through a special arrangement with OST, lists "Discarded Bait" as a possible vector for 74 introductions into California bays involving 22 species. We considered the evidence for each of these being introduced by the commercial trade in live saltwater bait species in California.

Survey of California Bait Dealers

Following the methods of Cohen *et al.* (2001), Weigle (2002, 2007) and Weigle *et al.* (2005), in Sept.-Nov. 2011 we used local trade directories (online yellow pages), online databases and information acquired through Internet searches and personal contacts to compile as complete a list as possible (with addresses and phone numbers) of bait and tackle shops and bait dealers in California's coastal and Delta counties[4], including retail bait shops, bait receivers and bait wholesalers/distributors. In late Sept. to early Dec. 2011 we screened the list via telephone calls to narrow it as far as possible to dealers in live saltwater bait that are currently in business. If a telephone number was disconnected with no new number, or we were unsuccessful in contacting a business after attempts on five different days, we searched the Internet under the business name for evidence that it was out of business or for alternate telephone numbers. If an alternate number was found, contact was again attempted up to five times. Although the primary purpose of these screening calls was to focus the survey list for the mail survey, if a business confirmed that it sold live saltwater bait we asked and recorded which species it sold. Thus the screening calls essentially constituted an independent survey, which we used to extend and check the responses from the mail survey.

The final survey list included businesses in four categories:

- Retail bait and tackle shops that had been contacted and confirmed that they sold live saltwater bait species (we also obtained information on which species they sold).

- Businesses that were known or believed to be live bait receivers, based on phone contact, online information, or other sources. Bait receivers sell locally-caught live marine baitfish that are held in submersed cages suspended from anchored barges or docks in coastal waters, with the sales being entirely (from barges) or primarily (from docks) to boats.

- Businesses that were known or believed to be wholesalers (including grass shrimp harvesters) that provide live saltwater bait to California bait shops, based on phone contact, online information, or other sources.

- Businesses that we were unable to contact and also were unable to confirm by other means (primarily by searching for information on the Internet) that they were either out of business or that they did not sell live saltwater bait. Thus, these comprised a residue of businesses that appeared on our initial compilation of bait

[4] This included 40% of California's counties and covered about 24% of the state (Appendix A), with the coastal counties extending to about 15-60 miles from the coast.

and tackle shops or bait dealers that *might* sell live saltwater bait that we were unable to contact or find relevant information on despite substantial effort.

We prepared a survey booklet (Appendix B) and other survey materials (Appendix C) and in Mar. and Apr. 20012 conducted a mail survey of the businesses in all four categories using Dillman's Total Design Method (Dillman 1978; Salant & Dillman 1994). Survey questions addressed the types and quantities of live saltwater bait species sold, the source regions, whether the species are farmed or wild-caught, the shipping and packing materials, the disposal methods for packing materials and for water from shipments or holding tanks, and the geographic region and proximity of facilities to coastal waters. The survey was conducted via the following steps:

- A first-class letter containing a cover letter, a survey booklet and a stamped return envelope was sent to the survey list.

- One week later a reminder postcard was sent to the survey list minus any responses received up to that point.

- Two weeks after the postcard was mailed a second letter consisting of a new cover letter, a replacement survey booklet and a stamped return envelope was sent to the survey list minus any responses received up to that point.

- Three-and-a-half weeks after the second letter was send, a third letter consisting of a new cover letter, a replacement survey booklet and a stamped return envelope was sent to the survey list minus any responses received up to that point.

- When letters or cards were returned undelivered, we searched for the business name on the Internet to look for an alternate address; if found, we sent new letters, surveys and cards to the alternate address.

- A log was kept of letters and cards mailed, letters and cards returned, letters and cards re-mailed to alternate addresses, and responses received, as well as any responses received by telephone or email, in order to adjust and correct the list for the next mailing and to track response rates.

- Responses were entered into a spreadsheet as they were received. When necessary, businesses were called to clarify responses or to obtain more complete responses. When the person contacted was amenable, we also used these calls to obtain further information on the history of and trends in bait imports and sales.

In the data sheets, bait species identified by variable trade or common names in the responses were converted to scientific names and standard common names. Quantities reported in pounds or boxes were converted to numbers of organisms using estimates based on discussions with bait dealers or other information. The summary sheets were formatted to automatically calculate summary data.

Site Visits and Examination of Bait Species

We further investigated the types of live saltwater bait species sold in California by visiting bait shops in the San Francisco Bay Area and Los Angeles/Orange County area. On these visits we identified ourselves as researchers and, to the extent that there was interest, described the focus of our study. We identified live bait species by gross visual examination in the store or, where necessary, by purchase and examination or dissection in the laboratory. We searched for hitchhiker species by (1) examination of baitworm packing material in the store when this was possible (non-quantitative sampling), sometimes using a microscope in the store; and (2) by purchasing baitworms for quantitative samples of the packing seaweed and associated hitchhiker species sold with bait. Hitchhiker species were identified by examination under a microscope and dissection as needed in the laboratory. A small number of baitworms were dissected and examined for parasites. All organisms were identified using standard morphological keys (e.g. Smith 1964; Gosner 1971; Kozloff 1987; Pollock 1998; Carlton 2007); other relevant taxonomic literature; information or images from the Internet; and consultation with taxonomic experts. All hitchhiker specimens that we collected were preserved and will be deposited with the California Academy of Sciences.

When possible we engaged the proprietors or salespeople in conversation regarding species in the store and species that were sold by the store at other times, source regions, quantities, trends, etc. In these conversations, we identified ourselves as researchers and described the focus of our study. On a few site visits we were assisted by an interpreter fluent in Cantonese.

Live Bait Online

We searched online for live saltwater bait available retail, and for new live saltwater baits (not currently available in California), offered for international sale. We recorded species, number of companies offering, source areas and whether from wild harvest or cultivation.

<u>Analyses</u>

We tabulated the results from the examination of trade databases, telephone screening calls, mail survey and site visits and used linear extrapolations as needed to estimate the number of businesses selling live saltwater bait in California's coastal and Delta counties, the species and quantities sold, and other relevant characteristics of the trade. We assembled a list of hitchhiker species identified by our and others' examinations of live saltwater bait shipments and packages of bait sold. We assembled information on the native ranges and invasion histories of these bait and selected hitchhiker species.

We assessed whether the live bait species are environmentally suited to California's coastal waters by comparing the extent to which the faunal zone(s) as defined in Ekman (1953) of their source areas and of their native and invaded ranges matched California's, using the classification scheme outlined in Table 1. The boundaries of

Ekman's faunal zones are described in Appendix D; California lies entirely within Ekman's Cold Temperate Shelf Faunal Zone (CTSFZ).

Table 1. Classification of the environmental suitability to California's coastal waters. See text and Appendix D for explanation.

Does the importation source area fall within the CTSFZ?

- If yes, then California's coastal waters are Suitable.
- If no, does the species' range (including native and invaded range) fall at least partly within the CTSFZ?
    - If yes, then California's coastal waters are Possibly Suitable.
    - If no, then California's coastal waters are Not Suitable.

Results

<u>The California Trade in Live Saltwater Fishing Bait</u>

Results from Trade Data

We examined U.S. Customs data on the ITC's Interactive Tariff and Trade DataWeb for 1989-2010 for categories of imports that could include live saltwater bait. Initial review at the level of U.S. and California imports suggested that it would be challenging to extract useful information from these data since categories that could include live saltwater bait also included and were likely dominated by other import goods, such as earthworms, live freshwater bait, artificial bait, and other live aquatic organisms imported for food, ornament or other purposes. We decided to examined the data at finer scales by country of origin and port of entry to see whether we could track the imports of live saltwater bait that, from other sources, we knew had occurred. These were:

- Substantial regular imports into California, primarily southern California, of the lugworm *Perinereis aibuhitensis* from South Korea since at least 2004 to the present, with imports reportedly having started by 1972 (Passarelli 2010; B. Pernet, CSU, pers. comm.; L. Harris, LACMNH, pers. comm.; our survey and site visit data, discussed below).
- Imports into California of the "nuclear worm" *Namalycastis rhodochorde* from Vietnam, perhaps sporadic and small volumes, over a period from at least from 1994 to 2009, with a report of shipments arriving through the Port of San Francisco in August 2001 (Cohen *et al.* 2001; Thompson and Alam 2005; Glassby *et al.* 2007; Passarelli 2010; B. Pernet, CSU, pers. comm.; L. Harris, LACMNH, pers. comm.).
- Imports into the mid-Atlantic region of the U.S. of the "nuclear worm" from Vietnam, over a period from at least 1998 to 2005, with San Francisco reportedly the port of entry in 2002 (Mullady *et al.* 1999; Ringle 2002; Associated Press 2005).

We searched for all imports from South Korea or Vietnam through any U.S. port in the Category "Worms, Live" (HTS #106005020 for 1989-2001, when the code schedule was amended, and HTS #106900010 from 2002 to 2010). Table 2 shows the results for import value; no quantity data were available. Over the 22 years these total $19,059 worth of worms imported from South Korea to California, $14,387 from Vietnam to California, and $29,474 from Vietnam to the Mid-Atlantic States. There were no other reports of live worm imports from these two countries to any port in the U.S. These import locations (southern California for worms from South Korea; southern California, the San Francisco Bay Area and the Mid-Atlantic Region for worms from Vietnam) and their timing (during summer) strongly suggest that they are records of the lugworm and the nuclear worm. However, the records are impressively deficient, as there should be reports of annual imports of these worms for a substantial part of the record. Even the 2001 shipments through San Francisco reported by Thompson and Alam (2005), based on inspections by USFWS staff, are not recorded. Either the vast majority of shipments of these worms were undeclared, or they were classified under inappropriate HTS categories (assuming that all live worms should be classified as "Worms, Live").

The wholesale prices for lugworms listed online in 2011 by exporters in China[5] ranged from $22 to $49/kg, and lugworms that we purchased in Southern California in 2011 averaged 301 worms/kg. Using the midpoint value for the wholesale price, the values in

Table 2. Value of all reported imports to the U.S. of "Worms, Live" from South Korea and Vietnam in 1989-2010, from the ITC's Interactive Tariff and Trade DataWeb (http://dataweb.usitc.gov).

From	To	Date	Value
South Korea	Los Angeles, CA	Jun 2006	$2,625
		Jul 2006	$6,738
		Aug 2006	$7,473
		Jun 2010	$2,223
Vietnam	San Francisco, CA	Jul 1995	$1,920
Vietnam	Los Angeles, CA	May 2002	$2,078
		Jun 2002	$2,072
		Jul 2002	$4,145
		Aug 2002	$4,172
Vietnam	Norfolk, VA	Jul 2003	$14,195
		Aug 2003	$2,860
		Jun 2004	$2,835
		Jul 2004	$2,835
Vietnam	Washington, DC	Jul 2003	$6,749

[5] We found no wholesale price listings for lugworms from South Korea, and we are not sure if the lugworm listed from China is the same species the lugworm exported from South Korea. However, all wholesale prices that we found for Asian polychaetes fell within the $22-49/kg range, so this seems a reasonable basis for estimating the wholesale price for South Korean lugworms.

Table 2 for worms shipped from Korea to California thus correspond to about 160,000 lugworms (Table 3). The sole wholesale price that we found online for nuclear worms from Vietnam was $1.20 per 50-gram box. Assuming two worms per box (the typical sales unit in southern California—B. Pernet, pers. comm.), the values in Table 2 for worms shipped from Vietnam to California correspond to about 24,000 nuclear worms. If we assume that the values reported in the Customs data reflect all the shipments of those worms in those months when there are records, and that the worms are typically imported for three summer months each year at the mean monthly rate indicated by the Customs data, then about 120,000 lugworms and 14,000 nuclear worms are imported into California each year (Table 3).

Table 3. Estimated numbers of lugworms and nuclear worms imported annually. See text for explanation.

Worm	Imported into	Months reported	Value reported	Corresponding # of worms	Estimated annual import
Lugworm	California	4	$19,059	161,600	120,000
Nuclear worm	California	5	$14,387	23,980	14,000
Nuclear worm	Mid-Atlantic states	5	$29,474	49,120	29,000

We examined the imported wildlife data set and the list of USFWS Species Codes that Eliot Crafton obtained from USFWS. The species codes include several annelids, including two saltwater bait species, the pileworm *Alitta virens* (as *Nereis virens*) and the bloodworm *Glycera dibranchiata*, but do not have codes for two species that we know have been imported into California from outside of the U.S., the lugworm *Perinereis aibuhitensis* and the nuclear worm *Namalycastis rhodochorde*. Nor is there a code for "other annelids". These foreign worm species would therefore have to be listed under one of the generic "other invertebrate" categories, which could of course contain a wide variety of other species. Thus we could not see a way to extract any useful information regarding live bait imports from this dataset.

California law and California Fish and Game regulations require anyone importing live aquatic animals to be placed into California waters to obtain a permit from CDFG. Although the regulations specifically mention marine annelid worms and other common marine bait species (California Administrative Code, Title 14, §236(c)(6)(B)-(G)), inquiries in previous years had found that the permit requirement was not enforced for marine bait, and that no data on live marine bait imports had been collected (Cohen *et al.* 2001; Pernet *et al.* 2008). The data set of permits for 2004-2011 that we examined contained no marine bait species. On renewed inquiries, we found the situation appeared to be unchanged: no applications have been made to import live bait since at least 2009, no permits have been issued in that time, and there are no data on live bait imports going back at least to 2004 (K. Ramey, CDFG, and J. Moore, CDFG, pers. comm.).

Results from Survey

We assembled a list of 590 businesses by combining the businesses listed as coastal or Delta bait and tackle stores in one online database and three online directories. We winnowed this down to an initial list of 509 businesses that appeared to be non-duplicate bait and tackle stores within the study area. Based on the screening calls, we eliminated 389 businesses that were confirmed to be out of business or whose telephones were disconnected and no alternate numbers were found after searching on the Internet; or that were not in a fishing-related business (for example, a few hunting stores and equestrian tackle stores were erroneously included in the online directories under "Bait and Tackle Stores"); or were in a fishing-related business but did not sell bait, or did not sell live bait, or sold only freshwater live bait. This left us with a list of 74 businesses that had confirmed that they sold live saltwater bait (including a few bait receivers and bait wholesalers/distributors), and 46 businesses that we were unable to contact after five attempts (Table 4). We added the names of seven bait receivers and wholesalers that we learned about from the Internet or other sources, resulting in a mail survey list of 127 businesses.

Table 4. Initial list of bait and tackle shops and screening results.

Businesses reported as bait and tackle stores in California's coastal and Delta counties in four online databases or directories:	590
Minus duplicates (same business listed under different or variant names) and businesses actually located outside of California's coastal and Delta counties:	509
After screening calls:	
Confirmed to be out of business; or disconnected number and no alternate number found by Internet search; or not in a fishing-related business:	84
Does not sell organic bait (sells or manufactures artificial bait or fishing tackle or other fishing-related equipment or services);	164
Sells only dead/frozen/processed bait (freshwater or saltwater):	64
Sells live bait, but only freshwater species:	77
Sells live bait, including saltwater species (included on mail survey list):	74
Not able to contact after five attempts on initial and any alternate telephone numbers (included on mail survey list):	46

Table 5 breaks down the screening results by coastal region. Overall, 15% of the 510 distinct businesses that initially appeared to be bait and tackle stores within the coastal and Delta counties reported that they sold live saltwater bait, in response to the screening questions; 24% of the 510, including businesses we were unable to contact, were included in the mail survey list. These proportions varied across the coastal regions, with a range of 0-25% responding that they sold live saltwater bait, and 6-35% included in the mail survey list. The highest proportions were in the Bay and Delta regions. The lower proportions in southern California appear to be due in large part to the presence in southern California of a large number of manufacturers and distributors of artificial lures and fishing tackle.

Table 5. Breakdown by region of screening results.

Business category	Northern	Bay	Delta	Central	Southern	All
Not in business, out of business, or disconnected	4	31	11	3	35	84
Does not sell organic bait	3	38	7	6	110	164
Does not sell live bait	6	12	1	10	35	64
Sells live bait, but only freshwater	2	16	12	3	44	77
Sells live saltwater bait, wholesale only	0	4	0	0	0	4
Sells live saltwater bait, retail	0	33	11	2	24	70
Not able to contact	1	15	6	4	20	46
Total	16	149	48	28	268	509
Percent of total that sell live saltwater bait	0%	25%	23%	7%	9%	15%
Percent of total included on the mail survey list	6%	32%	35%	21%	16%	23%
Estimated number that sell live saltwater bait, retail	0	38	13	2	26	79

These data can be used to estimate the total number of shops that sell live saltwater bait in each region, by assuming that the proportion of the businesses in each region that sell such bait is the same for the listed businesses that had apparently live phone lines but that we were unable to contact as it is for the businesses that we contacted. The results are shown in the last row of Table 5, with an estimated total of 79 shops in the coastal and Delta counties that sell live saltwater bait (and since presumably no or few stores in inland counties sell live saltwater bait, this would be the same as or close to an estimate for the whole state).

It is likely, however, that the assumption used in the estimate is incorrect, in that a substantial portion of the businesses that did not answer their phones may be out of business (data from the mail survey, discussed below, supports this). In that case the estimate should be considered an upper bound estimate, with the actual number of business that reported that they sell live saltwater bait serving as a lower bound estimate. Thus, we estimate from the screening data that there are between 70 and 79 businesses in California that sell live saltwater bait retail, including bait shops and bait receivers.

In addition to refining the mail survey list, the screening calls obtained information on which saltwater bait species were sold. These data are summarized in Table 6, broken down by coastal region. Several geographic patterns are worth noting. Virtually all of the bait is sold in the more urbanized Bay/Delta and Southern California regions. The grass shrimp and the estuarine baitfish—staghorn sculpin (called "bullhead"), longjaw mudsuckers and shiner surfperch ("shiners")—are sold only in the Bay/Delta region. From our observations and conversations with anglers, bait sellers and bait harvesters and from the fisheries literature, as far as we know all four of these species are harvested for commercial sale only in San Francisco Bay, and thus appear to be harvested and used locally. Anchovies and sardines, which are harvested in coastal waters in California, are the main fish species sold as live bait in southern California, with only limited sales in the Bay Area. Pileworms, which are harvested in Maine, are primarily sold in the Bay/Delta area, with no reported sales in southern California. Bloodworms, also harvested in Maine, are sold by more shops in the Bay/Delta area than in southern California. Lugworms, on the other hand, which are harvested in South Korea, are primarily sold in southern California, with only a few shops selling them in the Bay/Delta area.

Table 6. Number of retail businesses selling live saltwater bait species in each region, based on the responses to screening calls.

Common name	Northern	Bay	Delta	Central	Southern	All
Pileworms	0	30	10	2	0	42
Bloodworms	0	8	7	1	5	21
Lugworms	0	1	2	0	13	16
Grass Shrimp	0	14	3	0	0	17
Ghost Shrimp	0	6	4	1	5	16
Mud Shrimp	0	0	2	0	0	2
Sand Crabs	0	0	0	0	1	1
Mussels	0	0	0	0	1	1
Longjaw mudsuckers	0	5	7	0	0	12
Staghorn sculpin	0	7	2	0	0	9
Shiner surfperch	0	2	0	0	0	2
Northern anchovies	0	1	0	0	5	6
Pacific sardines	0	0	0	0	5	5
Unidentified Fish	0	1	0	0	0	1

Table 7 shows the breakdown of the businesses that we mailed surveys to. From the responses and returned letters, we learned that some of these were no longer in business, and that a few were duplicate listings. In other cases where we received one or more of the survey letters and reminder card in return mail marked "Return to Sender/Not Deliverable/Unable to Forward," we considered the intended recipient to no longer be in business. We assumed that the reminder were open for business. Table 8 showed the breakdown of the surveyed businesses that we assumed were open for business, and Table 9 the businesses that responded to the survey. In Table 10 we show the response rate for selected categories (the number that responded divided by the number assumed to be open), where the numbers surveyed were large enough for the response rates to be meaningful. The overall response rate of 44% can be compared to the response rate of 36% in a previous mail survey of saltwater bait sellers (Weigle 2002; Weigle *et al.* 2005). The response rate of 48% from sellers of live saltwater bait that had been confirmed by prior screening can be compared to the 39% response rate in Passarelli (2010), who sent surveys only to live saltwater bait sellers confirmed by prior screening.

In comparing Table 8 to Table 7, note that the portion of the businesses on the mail survey list that were found to be invalid, closed or presumably closed (and thus not include in Table 8) was much greater for the businesses classed as “not able to contact with screening calls” (46% of the 46 businesses counted in Table 7 were deleted from the count in Table 8), than for the contacted businesses that stated that they sold live saltwater bait (only 5% of those in Table 7 were not included in Table 8). This supports the idea, stated above in regard to the estimates of the total number of live saltwater bait sellers developed from the screening calls, that a substantial portion of the businesses that did not answer their phones were out of business, and thus those estimates should be considered to be upper bound estimates.

Table 7. Number of businesses on the mail survey list, broken down by region and by business category based on the screening calls.

Business category	Northern	Bay	Delta	Central	Southern	All
Sales of live saltwater bait, retail	0	32	11	2	21	66
Sales of live saltwater bait, wholesale only	1	5	2	0	0	8
Bait receiver	0	2	0	0	5	7
Not able to contact with screening calls	1	15	6	4	20	46
Total	2	54	19	6	46	127

Table 8. Number of businesses on the mail survey list assumed to be open, broken down by region and by business category based on the screening calls.

Business category	Northern	Bay	Delta	Central	Southern	All
Sales of live saltwater bait, retail	0	31	10	2	20	63
Sales of live saltwater bait, wholesale only	0	3	1	0	0	4
Bait receiver	0	1	0	0	3	4
Not able to contact with screening calls	0	12	3	1	9	25
Total	0	47	14	3	32	96

Table 9. Number of responses, broken down by region and by business category based on the screening calls.

Business category	Northern	Bay	Delta	Central	Southern	All
Sales of live saltwater bait, retail	0	13	4	1	12	30
Sales of live saltwater bait, wholesale only	0	1	0	0	0	1
Bait receiver	0	1	0	0	1	2
Not able to contact with screening calls	0	5	1	0	3	9
Total	0	20	5	1	16	42

Table 10. Response rate for selected categories, broken down by region and by business category based on the screening calls.

Business category	Bay	Delta	Southern	All regions
Sales of live saltwater bait, retail	42%	40%	60%	48%
Not able to contact with screening calls	42%	33%	33%	36%
Total, including wholesalers and bait receivers	43%	36%	50%	44%

Of the 42 respondents to the survey, 28 (68%) reported that they sell live saltwater bait. When we compared individual responses we found that seven businesses that had said on the prescreening calls that they sell one or more live saltwater bait species, reported that they don't sell live saltwater bait on the mail survey. If these seven are counted, then 83% of the mail survey respondents sell live saltwater bait. This suggests that the responses to the mail survey may substantially under-report some aspects of bait sales.

Most of the respondents are located in the Bay (48%), Southern (38%) or Delta (12%) regions, and all that reported selling live saltwater bait are in the Bay (54%), Southern (36%) or Delta (11%) regions (Table 12 below, last two rows). This is similar to the results from the screening calls, where most of those that reported selling live saltwater bait are in the Bay (49%), Southern (33%) or Delta (15%) regions (Table 3, fourth row). Forty-four percent of those that reported selling live saltwater bait are located within 500 feet of a salt or brackish water body.

The survey responses reported 12 species of live saltwater bait (Table 11), and provided a total of 70 records (respondent x species) of bait species sold. The most commonly reported baits were, in order, pileworms, ghost shrimp, bloodworms and grass shrimp (Table 12). This is similar to the results from the screening calls, except that lugworms were also one of the most common baits in those responses (Table 6): the rank order for the most common baits from the screening calls is: pileworms, bloodworms, grass shrimp, then ghost shrimp and lugworms tied. The geographic patterns from the mail survey are also similar to those from the screening calls (Table 6): all of the grass shrimp, mudsuckers, sculpin, surfperch and midshipmen, which are all harvested in the Bay, are all sold in the Bay and Delta regions; all of the pileworm sales are in the Bay/Delta regions, all of the lugworm sales are in southern California, and bloodworms are sold in both the Bay/Delta and southern California regions. Ghost shrimp are reported primarily in the Bay and Delta regions (the screening calls split these more evenly with southern California). There are only a couple of reports of mussels; as in the screening calls, these are all in southern California. The screening calls reported anchovies and sardines to be sold mainly in southern California, and to be the main baitfish there. The reports of these fish from the mail survey are too few (one report of anchovies, none of sardines) to reveal a pattern.

Table 11. Mail survey. Reported species, number of retail sellers, source type, and number of individuals sold. Number sold is the total from all respondents that provided quantity information for that species. Quantities reported in pounds or boxes were converted to numbers of organisms using estimates based on our sampling and discussions with bait dealers.

Common name	Scientific name	Number of sellers	Wild-caught	Farmed	Approximate number sold each year
Pileworms	*Alitta virens*	13	10	2	248,150
Bloodworms	*Glycera dibranchiata*	11	10	1	184,900
Lugworms	*Perinereis aibuhitensis*	5	4	0	6,740
Grass shrimp	*Crangon franciscorum**	9	9	0	7,253,050
Ghost shrimp	*Neotrypaea californiensis*	12	10	1	258,720
Mud shrimp	*Upogebia pugettensis*	2	2	0	13,200
Mussels	*Mytilus* sp.**	2	0	1	24,000
Longjaw mudsucker	*Gillichthys mirabilis****	6	6	0	71,600
Staghorn sculpin	*Leptocottus armatus*	4	4	0	85,970
Shiner surfperch	*Cymatogaster aggregata*	4	3	1	41,300
Plainfin midshipmen	*Porichthys notatus*	1	1	0	43,200
Northern anchovies	*Engraulis mordax*	1	1	0	500,000

* The grass shrimp bait harvest in California (also referred to as the bay shrimp fishery) consists primarily of *Crangon franciscorum* and secondarily of *C. nigricauda*, with some *Palaemon macrodactylus* or *C. nigromaculata* occasionally mixed in (Reilly *et al.* 2001).

** Based on reported source areas in southern California these are probably *Mytilus galloprovincialis*, but could include some *Mytilus trossulus* or hybrids.

*** We recorded all references to “mudsuckers” as Longjaw mudsuckers (*Gillichthys mirabilis*), although one bait shop owner said that the term mudsuckers could refer to either Longjaw mudsuckers or Yellowfin gobies (*Acanthogobius flavimanus*).

Table 12. Mail survey. Number of retail businesses reporting the sale of live saltwater bait species in each region.

Common name	Northern	Bay	Delta	Central	Southern	All
Pileworms	0	10	3	0	0	13
Bloodworms	0	4	3	0	4	11
Lugworms	0	0	0	0	5	5
Grass shrimp	0	7	2	0	0	9
Ghost shrimp	0	7	3	0	2	12
Mud shrimp	0	2	0	0	0	2
Mussels	0	0	0	0	2	2
Longjaw mudsuckers	0	4	2	0	0	6
Staghorn sculpin	0	4	0	0	0	4
Shiner surfperch	0	3	1	0	0	4
Plainfin midshipmen	0	1	0	0	0	1
Northern anchovies	0	1	0	0	0	1
# of respondents	0	19	5	1	16	41
# selling live saltwater bait	0	14	3	0	10	27

The respondents' understanding of whether their bait is harvested from the wild or is farmed (Table 11) generally agrees with our understanding; as far as we are aware, all of these live baits except possibly the mussels are harvested from the wild. We believe that the five other responses that identify various baits as farmed (pileworms, bloodworms, ghost shrimp and shiner surfperch) are incorrect. Similarly, most of the responses agree with our understanding of where these baits are harvested. Based on the literature and our discussions with Maine bait dealers and fishery managers, pileworms and bloodworms are all imported into California from the East Coast, all or nearly all from Maine, primarily from the Boothbay Harbor area. Many of the bait dealers are located in Wiscasset, on the shore of Boothbay Harbor, and they usually or always ship the worms through Logan Airport in Boston. Twenty-one out of 22 responses are consistent with this (Table 13); we believe that the single response reporting bloodworms from northern California is an error. Most of the other responses for other baits listed in Table 13 are also consistent with our understanding of their sources (given that the respondents' answers regarding the location of their businesses indicates that several of them used "Northern California" to refer to the Bay Area, despite a map in the survey booklet showing the area north of Cape Mendocino as Northern California). Lugworms come from South Korea, grass shrimp, mudsuckers, sculpin, surfperch and midshipmen are harvested in San Francisco Bay, and ghost shrimp are imported from Washington and Oregon. There is an active mud shrimp fishery in Oregon, though landings have declined dramatically and in recent years very small landings in Tillamook Bay make it unlikely that it is a source of exports to California (Oregon Department of Fish and Wildlife landings records, provided by J. Chapman).

Table 13. Mail survey. Reported source regions of species sold.

Common name	Reported source region (number of respondents reporting)
Pileworms	Eastern US (2); Northeastern US (1); Maine (7); Wiscasset (1); Boston (1)
Bloodworms	Eastern US (2); Maine (7); Northern CA (1)
Lugworms	Asia (1); South Korea (4)
Grass shrimp	CA (2); Northern CA (1); Central CA (3); SF Bay (2)
Ghost shrimp	WA (5); Seattle (1); WA, OR (2); OR (3)
Mud shrimp	OR, mostly Tillamook Bay (1); Northern CA (1)
Mussels	CA (1); Southern CA (1)
Longjaw mudsuckers	CA (1); Northern CA (1); Central CA (1); SF Bay (2)
Staghorn sculpin	Northern CA (1); Central CA (1); SF Bay (1)
Shiner surfperch	Central CA (1); SF Bay (1)
Plainfin midshipmen	No answer (1)
Northern anchovies	Central CA (1)

All of the responses stated that pileworms and bloodworms arrive packed in seaweed (Table 14), which is consistent with the literature and our observations. Four (of 13) respondents reported transferring pileworms out of the seaweed and into seawater, maintaining them in seawater (where they are believed to survive better than in seaweed), and putting them back into the *Ascophyllum* seaweed when selling them to customers; one respondent reported giving pileworms to customers in seawater. All responses indicated that any seaweed that isn't given to customers is disposed of in the trash.

Lugworms are typically shipped from South Korea in small styrofoam boxes containing a loose material that looks like (and presumably is) vermiculite, with 6 or 12 worms to a box. Responses that described the lugworm packing material as "sawdust and nutrients in small waterproof box" and as "wood/paper material - small pieces" apparently refer to vermiculite. Typically the lugworms are kept in the vermiculite and sold to customers in the boxes that they arrive in.[6]

Ghost shrimp usually arrive from Washington or Oregon in seawater, but one respondent reported receiving them in saw dust and another reported that the shipper recently changed from shipping them in seawater to shipping them in pine shavings, to reduce the package weight. That respondent keeps them and sells them in the pine shavings, with survival times similar to those in seawater.

Other species arrive in seawater, or not packed with anything.

[6] Vermiculite is a natural clay mineral. Given its use as a medium for holding worms, it's interesting that the word comes from the Latin verb *vermiculare*, meaning "to breed worms", because of the way vermiculite expands and exfoliates when heated.

Table 14. Mail survey. Reported packing/shipping material that bait arrives in.

Common name	Sea-weed	Seawater	None	Other, or multiple answers	
Pileworms	13	0	0	0	
Bloodworms	11	0	0	0	
Lugworms	0	0	0	3	sawdust (1); wood/paper pieces (1); vermiculite (1)
Grass shrimp	0	5	2	0	
Ghost shrimp	0	8	0	2	sawdust (1) seawater, pine shavings (1)
Mud shrimp	0	2	0	0	
Mussels	0	0	1	0	
Longjaw mudsucker	0	6	0	0	
Staghorn sculpin	0	4	0	0	
Shiner surfperch	0	3	1	0	
Plainfin midshipmen	0	1	0	0	
Northern anchovies	0	0	1	0	
Total	24	29	5	5	

Half of the respondents reported that they sometimes hold saltwater bait species in tanks of seawater. The most commonly reported method of disposing of the tank water is down a drain to a municipal wastewater treatment system (3.5 responses), or into a water body without filtration or treatment (3 responses). In two of the latter cases, the respondent also stated that the business was located within 500 feet of a salt or brackish water body. Next most common was disposal down a storm drain (2 responses) and disposal into a water body after the respondent filtered or treated it (2 responses) (none of these reported a location within 500 feet of salt/brackish water). Other disposal practices included draining it into a septic tank and draining onto the ground.

Results from Site Visits

We conducted 63 site visits to 34 bait shops in the Bay/Delta and Los Angeles areas (Table 15). On these visits we observed what bait species were present and asked about species that were sold but not available on that day. The geographic patterns in these data are similar to those in the data from the screening calls and mail survey (compare Table 15 to Tables 6 and 12). Every bait shop we visited in the Bay and Delta area sold pileworms; none of the shops that we visited in southern California did. Lugworms showed the reverse pattern, carried by 82% of the shops in southern California and by none of the Bay or Delta shops. Grass shrimp, mudsuckers and sculpin are sold only in the Bay or Delta region. Mussels are not common, and are sold only in southern California. Ghost shrimp and bloodworms are found in all three regions, with the bloodworms mainly in the north.

Table 15. Number of shops in which live saltwater bait species were observed on site visits.

Common name	Bay	Delta	Southern	Total
Pileworms	19	4	0	23
Bloodworms	5	3	1	9
Lugworms	0	0	9	9
Mussels	0	0	3	3
Grass shrimp	8	1	0	9
Ghost shrimp	2	1	2	5
Longjaw mudsuckers	0	2	0	2
Staghorn sculpin	3	0	0	3
Assorted Fish	1	0	0	1
Number of site visits	46	6	11	63
Number of businesses	19	4	11	34

Thirteen shops that carried pileworms or bloodworms held the worms in the seaweed that they were shipped in, but eight transferred them to seawater. Only two of these 21 shops said they sold worms to customers in seaweed, 16 (including all that transferred worms to seawater) said they never did, and three said they sold them in seaweed only on the rare occasions when the customer requested it. They typically gave the worms to the customers in cardboard boxes, plastic bags or styrofoam cups. One bait seller said he sometimes puts ice in the bag with the worms. Of 19 shops that reported on how they disposed of unused seaweed, all stated that they put it in the trash.

While the data from the screening calls, mail survey and site visits are generally consistent, there are some notable discrepancies where the same bait shop gave different answers to the same questions. The likely sources of error differ depending on the method of survey: written (mail survey), by telephone (screening calls) or face-to-face (site visits). Errors due to miscommunication—a respondent understanding a question to mean something other than what the survey designer intended, or providing an answer that the surveyor misunderstands—are likeliest in written surveys, where there's no opportunity for the participants to perceive and correct misunderstandings, and least likely in face-to-face surveys. Incomplete surveys due to "item nonresponse" (skipping some questions) or "early termination" (ending the survey before getting to all questions) are also likeliest in written surveys and least likely in face-to-face surveys. Finally, the problem of a respondent giving answers that he thinks will make the surveyor think well of him rather than accurate answers, known as "social desirability bias," is greatest with face-to-face surveys and least with mail surveys, where the respondent is largely anonymous (Dillman 1978).

These differences guide us in interpreting discrepancies between the three survey methods used in this study. For example, in the mail surveys 94% of the shops that sold pileworms or bloodworms reported that they sold these worms to customers packed in seaweed, but during site visits only 10% of the bait sellers said they sold these worms in seaweed. The site visit data seem reliable to us, based as they are on conversations where the bait sellers often provided corroborating detail and where we checked any statements that seemed inconsistent; while some of the mail survey respondents appeared to misunderstand the questions about seaweed handling. In our 1997 telephone survey, 87% of the shops selling pileworms or bloodworms said they routinely sold them to customers packed in seaweed; and Lau (1995) reported that all four bait shops that she interviewed sold their baitworms in seaweed. If we accept the site visit data, there has been a substantial shift over the past 15 years toward bait shops selling these worms without seaweed.

As noted earlier, seven shops that reported in the screening calls that they sell live saltwater bait reported on the mail survey that they did not. In four of these shops, we observed live saltwater bait during site visits. In another nine shops that reported on the mail survey that they sold some live saltwater bait species, additional species were reported during screening calls or were observed during site visits. The latter is an issue of early termination, as is expected on mail surveys. By combining data from the three methods, we can obtain a more complete picture of bait sales (Table 16). With this, and the mail survey's data on the numbers of organisms sold provided by individual sellers (Table 11), we estimate the total number of shops selling different bait species in California and the annual numbers sold. The method is shown in Appendix E, and the estimates are in Tables 17 and 18.

Table 16. Reported number of retail businesses selling live saltwater bait species in each region, combining data from the screening calls, mail survey and site visits.

Common name	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	31	11	2	0	44
Bloodworms	0	11	8	1	6	26
Lugworms	0	1	2	0	13	16
Grass shrimp	0	17	4	0	0	21
Ghost shrimp	0	12	5	1	6	24
Mud shrimp	0	2	2	0	0	4
Mussels	0	0	0	0	4	4
Sand crabs	0	0	0	0	1	1
Longjaw mudsucker	0	8	8	0	0	16
Staghorn sculpin	0	9	2	0	0	11
Shiner surfperch	0	3	1	0	0	4
Plainfin midshipmen	0	1	0	0	0	1
Northern anchovies	0	1	0	0	4	5
Pacific sardines	0	0	0	0	4	4
Live saltwater bait	0	34	12	2	24	72

Table 17. Estimated number of retail businesses selling live saltwater bait species in each region.

Common name	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	31–35	11–12	2	0	44–49
Bloodworms	0	11–12	8–9	1	6–7	26–29
Lugworms	0	1	2	0	13–14	16–17
Grass shrimp	0	17–19	4	0	0	21–23
Ghost shrimp	0	12–13	5	1	6–7	24–26
Mud shrimp	0	2	2	0	0	4
Mussels	0	0	0	0	4	4
Sand crabs	0	0	0	0	1	1
Longjaw mudsucker	0	8–9	8–9	0	0	16–18
Staghorn sculpin	0	9–10	2	0	0	11–12
Shiner surfperch	0	3	1	0	0	4
Plainfin midshipmen	0	1	0	0	0	1
Northern anchovies	0	1	0	0	4	5
Pacific sardines	0	0	0	0	4	4
Live saltwater bait	0	34–38	12–13	2	24–26	72–79

Table 18. Estimated number of live saltwater bait organisms sold (thousands), by species and region.

Common name	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	640–720	230–250	41	0	910–1,000
Bloodworms	0	200–220	150–170	18	110–130	480–540
Lugworms	0	3	7	0	40–50	54–57
Grass shrimp	0	18,000–20,000	4,100	0	0	22,000–24,000
Ghost shrimp	0	350–370	144	29	170–200	690–750
Mud shrimp	0	13	13	0	0	26
Mussels	0	0	0	0	96	96
Sand crabs	–	–	–	–	–	–
Longjaw mudsucker	0	120–130	120–130	0	0	230–260
Staghorn sculpin	0	190–220	43	0	0	240–260
Shiner surfperch	0	41	14	0	0	55
Plainfin midshipmen	0	43	0	0	0	43
Northern anchovies	0	500	0	0	2,000	2,500
Pacific sardines	–	–	–	–	–	–
Live saltwater bait	0	20,000–22,000	4,900	89	2,400–2,500	27,000–29,000

A few cautions about the estimated quantities in Table 18 are in order. For most of the species for which we produced estimates, we have quantity data from at least a quarter of the estimated sellers of that species in the state. But for lugworms and anchovies we have quantity data from only two (12%) and only one (20%) of the estimated sellers of those species, respectively. This fact raises the uncertainty of those estimates.

For some bait species—sand crabs and Pacific sardines—we had reports of sellers from the screening calls but no reports from sellers and no quantity data from the mail survey, and for other species—especially market squid (*Loligo opalescens*)—we had no data from either source. For these species, we could not estimate regional and total quantities. The bait fishery for sand crabs is apparently tiny (Herbinson and Larson (2001) report an average annual statewide catch of 22 lbs. since 1997, or about 5,000 crabs), and only one bait shop reported carrying them. But anchovies, sardines and squid are all very important live bait species in southern California (these species are sold live by bait receivers, which are more numerous in southern California than elsewhere in the state), and since we either have no or highly uncertain estimates for these species, the overall quantity of bait organisms estimated for southern California is highly uncertain and probably a substantial underestimate.

Table 19 shows recent landings for some relevant species. The geographic patterns largely conform to the patterns shown by the screening calls, mail survey and site visits (Tables 6, 12 and 15, and combined in Table 16). At least 99% of the grass shrimp, longjaw mudsuckers, staghorn sculpin and shiner surfperch are landed in the Bay region, and our data show these species being sold only in the Bay and Delta area (Table 16). Most of the yellowfin goby and plainfin midshipman landings are in the Bay region, though a significant fraction is reported from the southern and central regions. Our surveys provided little information on these two species, though both are harvested for bait from San Francisco Bay and sold as bait in the Bay and Delta regions (Brittan 1970; Cohen and Carlton 1995). Landings in southern and central California may be for bait or possibly for human consumption (yellowfin goby is a valued seafood species in Japan—Eschmeyer *et al.* 1983). At least 99% of the mussel and sand crab landings are in southern California, and our surveys and site visits reported these in bait shops only in southern California. Bait landings constitute only a very minor part of the landings for anchovies, sardines and squid, most of which is landed for human consumption, so the landings data are not necessarily a good indicator of the distribution of bait landings; however the large proportion of the landings that are in southern California and the very small proportion that are in the Bay region (<1%) are consistent with our understanding of where these bait are sold. Note that there are no reported landings of ghost shrimp or mud shrimp in California; this is consistent with the survey reports that these are imported from Washington and Oregon.

The landings data can be converted to estimated annual numbers of bait organisms landed and compared to our estimates, based on survey data, of the annual numbers sold (Table 20). The grass shrimp estimates match pretty well, but for the other species reported landings are substantially less than the estimated number sold for bait. The sales estimates could be high: some of them are based on very few reports of quantities sold by individual sellers, and these individual estimates are somewhat uncertain. On the other hand, it's possible that landings of these bait species are under-reported (this seems likely, for example, for sand crabs: one pound of landings reported over five years).

Table 19. Mean annual commercial landings of bait species in California in 2006-2010 (includes landings for human consumption as well as landings for bait). Source: www.dfg.ca.gov/marine/fishing.asp.

Common name	Pounds/year				
	Northern	Bay	Central	Southern	Total
Grass shrimp	459	52,104	30	0	52,593
Longjaw mudsucker	0	140	0	0	140
Yellowfin goby	0	239	0	172	411
Staghorn sculpin	8	3,432	12	2	3,454
Shiner surfperch	0	34	0	0	34
Plainfin midshipmen	0	82	18	45	145
Mussels	10	0	0	762	772
Sand crab	0	0	0	0.2	0.2
Northern anchovies	0	46,368	12,883,878	5,217,602	18,147,848
Pacific sardines	2	658,657	47,240,044	65,230,312	113,129,015
Market squid	911	396,390	9,347,053	148,997,154	158,741,508

Table 20. Estimated annual number of bait organisms landed and sold in California.

Common name	Organisms per pound*	Estimated number of organisms landed	Estimated number of organisms sold as bait (Table 18)
Grass shrimp	350	18,400,000	22,000,000–24,000,000
Longjaw mudsucker	24	3,400	230,000–260,000
Yellowfin goby	24	9,900	–
Staghorn sculpin	24	82,900	240,000–260,000
Shiner surfperch	24	800	55,000
Plainfin midshipmen	24	3,500	43,000
Mussels	22.5	17,400	96,000

* K. Fraser pers. comm. and our measurements (grass shrimp); K. Fraser pers. comm. (estuarine fish); http://newenglandlobster.net (mussels).

Online Sales—Retail

We searched the Internet for sites offering live saltwater bait for retail sale and shipment to California, using appropriate search terms and combinations. We found three businesses offering eight species (pileworms, bloodworms, a clam, crab, shrimp and three fish) from three locations (New Brunswick, Maine and Florida) (Table 21). Two of the businesses ship worms in seaweed (which looks like *Ascophyllum nodosum* in the online photographs), while the third ships them in seawater, guaranteeing survival for two weeks. The prices charged for small quantities of the worms, including shipping, are about 1.5-2 times higher than the average prices charged at bait shops in the Bay Area. (A fourth business offered pileworms and bloodworms for sale to the East Coast only.)

Table 21. Live saltwater bait available online for retail sale and shipment to California.

Common name	Species	Source region	Shipped in:
Pileworms	*Alitta virens*	Maine	Seawater
Pileworms	*Alitta virens*	New Brunswick	Seaweed
Bloodworms	*Glycera dibranchiata*	Maine	Seawater
Bloodworms	*Glycera dibranchiata*	New Brunswick	Seaweed
Bloodworms	*Glycera dibranchiata*	Florida	Seaweed
Quahog	*Mercenaria campechiensis*	Florida	?
Sand crab	*Emerita analoga*	Florida	?
marine bait shrimp	?	Florida	?
Bullhead minnow	*Fundulus grandis*	Florida	Seawater
Florida flagfish	*Jordanella floridae*	Florida	Seawater
Green sailfin mollies	*Poecilia velifera*	Florida	Seawater

Online Sales—Wholesale

We searched the internet for live saltwater baitworms available from foreign wholesalers, and found 31 companies in China (mainly in Jiangsu and Shandong provinces), Japan, South Korea, Singapore and Vietnam that offer farmed or wild-harvested live saltwater baitworms for delivery anywhere in the world. Table 22 reports those species that were identified by scientific name. Most worms were not, and we don't know whether the scientific names given are reliable. Nonetheless, it's clear that there is an active industry in Asia harvesting or producing several species of baitworms in at least three phyla for the international market. There are additional producers and harvesters of saltwater baitworms in Europe and Australia, though we did not find them marketed online. We expect that at some point some of these worms will turn up for sale in California bait shops, unless management actions prevent it.

Table 22. Live baitworm species available from foreign wholesalers marketing online. Scientific names are listed as given in the wholesalers' online descriptions. Source country is the source of the worm, if identified; otherwise, it is the country where the wholesaler is located.

Taxon group	Scientific name	Source countries
Annelida: Polychaeta	*Arenicola* sp.	China, Vietnam
Annelida: Polychaeta	*Diopatra bilobata*	China
Annelida: Polychaeta	*Glycera* sp.	China
Annelida: Polychaeta	*Marphysa sanguinea*	China, South Korea
Annelida: Polychaeta	*Marphysa* sp.	Vietnam
Annelida: Polychaeta	*Nereis oxypoda marenzeller*	China
Annelida: Polychaeta	*Nereis virens*	China
Annelida: Polychaeta	*Perinereis aibuhitensis*	China, South Korea
Annelida: Polychaeta	*Perinereis nuntia vallata*	China
Annelida: Polychaeta	Unidentified polychaete worms	China, South Korea, Japan, Vietnam
Sipuncula	*Sipunculus nudus*	China, Vietnam
Echiura	*Urechis unicinctus*	China

Live Bait Species

Table 23 lists all the live saltwater bait species for which we found evidence of commercial sale in California in recent years, based on screening calls, surveys, site visits, the scientific and fisheries literature, information from the Internet and discussions with bait dealers and resource agency staff. These are divided into four groups based on whether the harvest area for the California trade is inside or outside of California, and whether they are native or not. The first three groups (native to and/or harvested from outside of California) are considered further in the sections on Establishment Potential and Risk. The last group is not. These are species that both native to California and whose source regions for the California bait trade are within California. The evidence from our surveys, landings data and the literature indicate that these species are always or nearly always harvested and sold locally. There is no evidence that these species are ever harvested in one part of California and transferred alive for sale as bait to a distant part of California. Thus, the risk of trade in these species causing an invasion between California bioregions divided at Point Conception seems very low.

A few other marine species are reported in the literature as being used for bait in California, including Pacific herring (*Clupea pallasii*), white croaker (*Genyonemus lineatus*), Pacific butterfish (*Peprilus simillimus*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), queenfish (*Seriphus politus*) and Pacific tomcod (*Microgadus proximus*) (Maxwell 1974; Smith 1979). We found no evidence that these species have been sold as live bait in recent years, but if they are they are probably harvested and sold through bait receivers and used locally.

Table 23. Live saltwater bait species sold in California in recent years.

Common or trade name(s)	Scientific name	Main or sole source region
<u>Non-California Source; Not California Native</u>		
Bloodworm	*Glycera dibranchiata*	Maine
Pileworm, Sandworm	*Alitta virens*	Maine
Lugworm, Green worm	*Perinereis aibuhitensis*	South Korea
Nuclear worm, Magic cord	*Namalycastis rhodochorde*	Vietnam
<u>Non-California Source; California Native</u>		
Ghost shrimp	*Neotrypaea californiensis*	Washington, Oregon
Mud shrimp	*Upogebia pugettensis*	Oregon
<u>California Source; Not California Native</u>		
Mussel	*Mytilus* sp., probably *galloprovincialis*	Southern California
Grass shrimp, Korean shrimp	*Palaemon macrodactylus**	SF Bay
Yellowfin goby	*Acanthogobius flavimanus*	SF Bay & Southern Calif.
<u>California Source; California Native</u>		
Grass shrimp, Bay shrimp	*Crangon franciscorum**	SF Bay
Grass shrimp, Bay shrimp	*Crangon nigricauda**	SF Bay
Grass shrimp, Bay shrimp	*Crangon nigromaculata**	SF Bay
Sand crab, Mole crab	*Emerita analoga*	Southern California
Longjaw mudsucker	*Gillichthys mirabilis*	SF Bay
Staghorn sculpin, Bullhead	*Leptocottus armatus*	SF Bay
Shiner surfperch, Shiner perch	*Cymatogaster aggregata*	SF Bay
Plainfin midshipman	*Porichthys notatus*	California
Northern anchovy	*Engraulis mordax*	California
Pacific sardine	*Sardinops sagax*	California
Market squid	*Loligo opalescens*	California

* The *Crangon* species and *Palaemon macrodactylus* are sold together as “grass shrimp.”

<u>Hitchhiker Organisms</u>

Table 24 lists hitchhiker species that have been detected in commercial bait shipments received in California, from this and previous studies. Four microbial species, two seaweeds in addition to the *Ascophyllum* used for packing material (and not counting species present only as pieces) and 30 invertebrates are reported in the packing for pileworms and bloodworms shipped from Maine. Several of these were also reported by researchers examining baitworm shipments received in Connecticut or New York or examining the seaweed packing at bait shipping operations in Maine, suggesting the frequency with which some of the species occur in these shipments. Three invertebrate species were found on ghost shrimp shipped from Washington or Oregon.

Table 24a. Hitchhiker species reported in live saltwater bait received in California: with pileworms *Alitta virens* or bloodworms *Glycera dibranchiata* from New England.

Taxon group	Scientific name	References and comments
Foraminifera	*Trochammina inflata*	Cohen *et al.* 2001
Foraminifera	unidentified sp., not *Trochammina*	Cohen *et al.* unpubl. data
Ascomycete	*Pleospora* sp.	Carlton (1979, 1992a)
Bacillariophyta	chain diatom	Cohen *et al.* 2001
Chlorophyta	unidentified epiphyte on *Littorina saxatilis*	Cohen *et al.* unpubl. data
Phaeophyta	*Ascophyllum nodosum*	Packing material for baitworms—numerous references.
Phaeophyta	*Elachistea fucicola*	Cohen *et al.* 2001
Phaeophyta	pieces of *Fucus spiralis*	Cohen *et al.* unpubl. data; pieces reported by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Phaeophyta	*Fucus vesiculosus*	Carlton (1979), implying that it is a significant part of the packing material; Carlton (1992a); a few pieces reported by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Plantae	pieces of *Zostera* sp.	Cohen *et al.* 2001
Plantae	pieces of *Spartina* sp.	Cohen *et al.* 2001; pieces reported by Yarish *et al.* 2009; Haska *et al.* 2011 in shipments received in CT/NY.
Nematoda	unidentified sp.	Cohen *et al.* 2001; also reported by Crawford 2001 at a bait-packing facility in ME.
Platyhelminthes	unidentified sp.	Cohen *et al.* 2001; Miller (1969) reported the presence of several flatworm species in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.
Oligochaeta	Enchytraeid sp.	Cohen *et al.* 2001; unidentified oligochaetes reported by Lau 1995 and by Crawford 2001 at a bait-packing facility in ME.
Polychaeta	Capitellid sp.	Cohen *et al.* 2001
Polychaeta	*Fabricia sabella*	Lau 1995; Cohen *et al.* 2001
Gastropoda	Hydrobiid sp.	Cohen *et al.* 2001; Yarish *et al.* 2009 and Haska *et al.* 2011 reported *Hydrobia* spp. in shipments received in CT/NY.
Gastropoda	*Lacuna vincta*	Cohen *et al.* 2001; also reported by Crawford 2001 at a bait-packing facility in ME.
Gastropoda	*Littorina littorea*	Carlton 1979, 1992a; Cohen *et al.* 2001; also reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME, by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY, and by Miller (1969) in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.
Gastropoda	*Littorina obtusata*	Carlton 1979, 1992a; Lau 1995; Cohen *et al.* 2001; Hackman 2002; also reported by Crawford 2001 and observed by A. Cohen at bait shipping operations in ME, by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY, and by Miller (1969) in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.

Taxon group	Scientific name	References and comments
Gastropoda	*Littorina saxatilis*	Carlton 1979, 1992a; Lau 1995; Cohen *et al.* 2001; Hackman 2002; also reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME, and Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Bivalvia	*Modiolis modiolis*	Cohen *et al.* 2001
Bivalvia	*Mytilus edulis*	Carlton 1979, 1992a; Lau 1995; Cohen *et al.* 2001; Hackman 2002; also reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME, and by Miller (1969) in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.
Bivalvia	unidentified clam	Cohen *et al.* 2001
Acarina	2 *Halacarus* spp.	Cohen *et al.* 2001; unidentified Halacarid spp. reported by Lau 1995, and by Crawford 2001 at a bait-packing facility in ME; *Halacarus* sp. and Trombdiid species reported by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Acarina	Cryptostigmatid? sp.	Cohen *et al.* 2001
Acarina	unidentified sp.	Cohen *et al.* 2001
Insecta	Chironomid sp. (larva)	Cohen *et al.* 2001; also reported by Crawford 2001 at a bait-packing facility in ME, and by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Insecta	Dipteran sp. (larva)	Cohen *et al.* 2001; also reported by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Insecta	Coleopteran sp.	Cohen *et al.* 2001
Ostracoda	unidentified sp.	Cohen *et al.* 2001; also reported by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Copepoda	2 Harpacticoid spp.	Lau 1995; Cohen *et al.* 2001; unidentified Harpacticoid spp. also reported by Crawford 2001 at a bait-packing facility in ME.
Copepoda	Cyclopoid? sp.	Cohen *et al.* 2001
Tanaidacea	unidentified sp.	Cohen *et al.* 2001
Isopoda	*Jaera marina*	Cohen *et al.* 2001; reported as *Idotea* sp. in Lau 1995; presumably were among the unidentified isopods reported in Carlton 1979, 1992a; reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME, and by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Amphipoda	*Hyale nilssoni*	Cohen *et al.* 2001; reported as *Hyale* sp. in Lau 1995; presumably were among the unidentified gammarid amphipods reported in Carlton 1979, 1992a; reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME, and by Yarish *et al.* 2009 and Haska *et al.* 2011 in shipments received in CT/NY.
Amphipoda	Talitrid? sp.	Cohen *et al.* unpubl. data

Taxon group	Scientific name	References and comments
Amphipoda	Gammarid sp.	Cohen *et al.* 2001; Hackman 2002; Miller (1969) reported several unidentified gammarid amphipods in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.
Decapoda	*Carcinus maenas*	Cohen *et al.* 2001; Hackman 2002; also reported by Crawford 2001 and observed by A. Cohen at bait-packing facilities in ME.

Table 24b. Hitchhiker species reported in live saltwater bait received in California: with ghost shrimp *Neotrypaea californiensis* from Washington or Oregon.

Taxon group	Scientific name	Reference
Nematoda	*Ascarophis*? sp.	Passarelli 2010
Copepoda	*Clausidium vancouverense*	Pernet *et al.* 2008; Passarelli 2010
Isopoda	*Ione cornuta*	Pernet *et al.* 2008; Passarelli 2010

Table 25 lists additional species (not listed in Table 24) found by researchers examining shipments received elsewhere of species of bait that are imported into California. Mullady *et al.*'s (2000) study identified *Vibrio cholerae*, the bacterium that causes cholera, and other small organisms shipped with nuclear worms, *Namalycastis rhodochorde*, from Vietnam purchased in Maryland or Virginia (Table 25a). These organisms were found either on the worms or in the packing material. Yarish *et al.* 2009 and Haska *et al.* 2011 reported a large number of algae and other organisms found in or on the seaweed *Ascophyllum nodosum* used as packing for pileworms from Maine purchased at bait shops in Connecticut or New York, or on pieces of seaweed (*Fucus* spp.) or cordgrass (*Spartina* sp.) mixed in with the *Ascophyllum*. On one occasion (out of 75 sampling events) pileworms were not available, and they purchased bloodworms packed in *Ascophyllum* instead. Twenty-seven microbial species were identified to at least family level by (a) microscopic examination, (b) PCR amplification to test for seven harmful species of dinoflagellates and diatoms, and (c) 18S rDNA sequencing of subsamples from two sampling events matched against GenBank sequences (Table 25b). The identified species included two species targeted by PCR, the dinoflagellate *Alexandrium fundyense* and the diatom *Pseudonitzschia multiseries*. Many of the clones from the two sequenced subsamples had no matches in GenBank, and based upon >2% sequence difference included a total of 24 unique taxa in one subsample and 49 unique taxa in the other, with the total diversity in the latter probably being significantly greater based on the shape of the cumulative taxa curve. Thirteen species of macroalgal epiphytes were identified (Table 25c), all but one of them (the green seaweed *Cladophora ruchingeri*) requiring incubation in enriched media for 10 days or longer for detection and identification. Eleven invertebrate species were identified that have not been identified from baitworm shipments in California (Table 25d), although two of them may have been collected there (an oligochaete identified in the California work only to genus, and a snail identified only to family), and Crawford (2001) reported two of the invertebrates in *Ascophyllum* examined at a Maine bait-packing facility. Table

Table 25a. Hitchhiker species reported in shipments of nuclear worms *Namalycastis rhodochorde* received in Maryland or Virginia (Mullady *et al.* 2000).

Taxon group	Scientific name
Bacteria	*Vibrio cholerae*, 2 serotypes
Bacteria	*Vibrio* spp., not *cholerae*
?	at least 7 genera of amoebae
?	flagellates
Ciliophora	ciliates
Bacillariophyta	diatoms
Nematoda	nematodes

Table 25b. Additional hitchhiker species reported in shipments of pileworms *Alitta virens*, not listed in Table 24: microbial species in shipments received in Connecticut or New York (Yarish *et al.* 2009; Haska *et al.* 2011).

Taxon group	Scientific name	Detection and identification
Chromista	*Pteridomonas* sp.	By DNA sequencing with match to Genbank.
Apicomplexa	Eimeriidae	By DNA sequencing with match to Genbank.
Ciliophora	*Aspidisca sp.*	By DNA sequencing with match to Genbank.
Ciliophora	*Diophrys* sp.	By DNA sequencing with match to Genbank.
Ciliophora	*Euplotes* sp.	By DNA sequencing with match to Genbank.
Ciliophora	*Holosticha* sp.	By DNA sequencing with match to Genbank.
Sarcodina	*Hartmannella* sp.	By DNA sequencing with match to Genbank.
Sarcodina	*Platyamoeba* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Bacillaria* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Caloneis* sp.	By microscope.
Bacillariophyta	*Chaetoceros* sp.	By microscope.
Bacillariophyta	*Cocconeis* sp.	By microscope.
Bacillariophyta	*Cylindrotheca* sp.	By microscope.
Bacillariophyta	*Fragilaria* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Melosira* sp.	By microscope.
Bacillariophyta	*Navicula* sp.	By microscope & DNA sequencing with match to Genbank.
Bacillariophyta	*Neofragilaria* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Nitzschia* sp.	By microscope & DNA sequencing with match to Genbank.
Bacillariophyta	*Odontella* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Pseudonitzschia multiseries*	By targeted PCR.
Bacillariophyta	*Skeletonema costatum*	By DNA sequencing with match to Genbank.
Bacillariophyta	*Tabularia* sp.	By DNA sequencing with match to Genbank.
Bacillariophyta	*Thalassiosira* sp.	By microscope & DNA sequencing with match to Genbank.
Pyrrophycophyta	*Alexandrium fundyense*	By targeted PCR.
Pyrrophycophyta	*Peridinium* sp.	By DNA sequencing with match to Genbank.
Craspedophyta	*Monosiga* sp.	By DNA sequencing with match to Genbank.
Chrysophyta	*Paraphysomonas* sp.	By DNA sequencing with match to Genbank.

Table 25c. Additional hitchhiker species reported in shipments of pileworms *Alitta virens*, not listed in Table 24: macroalgae in shipments received in Connecticut or New York (Yarish *et al.* 2009; Haska *et al.* 2011).

Taxon group	Scientific name
Chlorophyta	*Chaetomorpha linum, Cladophora ruchingeri, Percursaria percursa, Rhizoclonium tortuosum, Ulothrix flacca, Ulva clathrata, U. compressa, U. flexuosa, U. intestinalis, U. prolifera*
Phaeophyta	*Ectocarpus siliculosus, Myrionema corunnae, Pilayella littoralis*

Table 25d. Additional hitchhiker species reported in shipments of pileworms *Alitta virens*, not listed in Table 24: invertebrates in shipments received in Connecticut or New York (Yarish *et al.* 2009; Haska *et al.* 2011).

Taxon group	Scientific name	Comments
Polychaeta	*Enchytraeus albidus*	Cohen *et al.* 2001 reported an Enchytraeid species.
Polychaeta	*Spirorbis spirillum*	Miller (1969) reported *Spirorbis* sp. in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S.
Gastropoda	*Hydrobia* spp.	Cohen *et al.* 2001 reported a Hydrobiid species.
Bivalvia	*Gemma gemma*	
Bivalvia	*Mercenaria mercenaria*	
Bivalvia	*Mya arenaria*	Also reported by Crawford 2001 at a bait-packing facility in ME; Cohen *et al.* 2001 reported *M. arenaria* shell fragments in shipments received in CA.
Copepoda	*Tigriopsis* sp.	
Amphipoda	*Eulimnogammarus obtusatus*	Crawford 2001 reported "*Microdeutopus obtusatus*" observed at a bait-packing facility in ME, which probably refers to this species (formerly *Marinogammarus obtusatus*). *Microdeutopus obtusatus* is a European species.
Amphipoda	*Jassa falcata*	Also reported by Crawford 2001 at a bait-packing facility in ME.
Amphipoda	*Caprella penantis*	

Table 25e. Hitchhiker species detected in direct shipments of mud shrimp *Upogebia pugettensis* received in Connecticut (Chapman *et al.* 2012, citing J. Carlton).

Taxon group	Scientific name	Comments
Isopoda	*Orthione griffenis*	On 100% of the mud shrimp in one shipment.
?	?	7 other species.

25e shows a parasitic bopyrid parasite found on mud shrimp shipped from Oregon to Connecticut. Several other species were found on the mud shrimp and on other bait shipments examined, but the data have not yet been published (J. Carlton, pers. comm.).

Table 26. Additional hitchhiker species reported in the packing materials for pileworms *Alitta virens* and bloodworms *Glycera dibranchiata*, not listed in Tables 24 or 25: invertebrates reported in a bait-packing facility in ME (Crawford 2001).

Taxon group	Scientific name	Comments
Trematoda	unidentified sp.	
Nemertea	unidentified sp.	
Gastropoda	*Hydrobia minuta*	Cohen *et al.* 2001 reported a Hydrobiid species, and Yarish *et al.* 2009 and Haska *et al.* 2011 reported *Hydrobia* spp.
Gastropoda	*Ilyanassa trivittata*	As *Nassarius trivittatus.*
Gastropoda	*"Onchidoris bisuturalis"*	May refer to *Odostomia bisuturalis* or to *Onchidoris bilamellata.*
Gastropoda	*"Spirorbis planorbis"*	May refer to *Spirorbis spirorbis*; Yarish *et al.* 2009 and Haska *et al.* 2011 reported *Spirorbis spirillum.*
Gastropoda	*Nucella lapillus*	As *Thais lapillus.*
Entognatha	Collembola sp.	
Insecta	Tabanid sp.	Cohen *et al.* 2001, Yarish *et al.* 2009 and Haska *et al.* 2011 reported a Dipteran species.
Mysidacea	unidentified sp.	
Isopoda	*Idotea phosphorea*	
Amphipoda	*Ampithoe rubricata*	
Amphipoda	*Corophium* spp.	
Amphipoda	*"Diastylis thea"*	*Diastylis* is a cumacean genus; this may refer to the amphipod *Dexamine thea*.
Amphipoda	*"Gammarus angulosus"*	May refer to *Gammarellus angulosus*; *Gammarus angulosus* is a European species.
Amphipoda	*Gammarus oceanicus*	
Amphipoda	*"Microdeutopus finmarchicus"*	May refer to *Gammarus* (=*Marinogammarus*) *finmarchicus.*
Amphipoda	*Orchestia* spp.	Cohen *et al.* 2001 reported a Talitrid species.

Table 26 lists additional species (not listed in Tables 24 or 25) reported by Crawford (2001) from examination of the *Ascophyllum* used to pack baitworms at a packing facility in ME. Because of the limited taxonomic resources available to Crawford, and because the specimens were not kept (S. Crawford, pers. comm.), we feel that these records need to be verified by independent collection.

Table 27 shows additional species reported in *Ascophyllum nodosum* used as packing for shipments of live marine organisms, in this case live Atlantic lobsters *Homarus americanus* shipped from the northeastern U.S. to San Francisco. Although these data may serve as an indication of the ability of these species to survive cross-country transport in *Ascophyllum* packing, it is uncertain whether they should necessarily be taken as evidence of what can be expected in baitworm packing, since the seaweed used to pack lobsters is likely collected from different regions than is the seaweed used to pack baitworms, and may therefore have associated with it a somewhat different suite of organisms.

Table 27. Additional hitchhiker species reported in *Ascophyllum* packing materials (not listed in Tables 24-26): invertebrates reported in *A. nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S. (Miller 1969).

Taxon group	Scientific name	Abundance in shipments
Porifera	*Leucosolenia* sp.	Not common
Cnidaria	*Campanularia flexuosa*	Common
Cnidaria	*Clava leptostyla*	Common
Cnidaria	*Gonothyraea loveni*	Not common
Cnidaria	*Obelia* sp.	Not common
Cnidaria	*Sertularia pumila*	Common
Cnidaria	*Tubularia* sp.	Not common
Platyhelminthes	*Monoophorum* sp.	Common
Platyhelminthes	*Monocoelis* sp.	Common
Gastropoda	*Mitrella lunata*	Common
Cirripedia	*Balanus amphitrite niveus*	Not common
Amphipoda	*Ampelisca* sp.	Common
Echinodermata	*Asteria forbesi*	Not common
Bryozoa	*Bowerbankia* sp.	Common
Bryozoa	*Flustrellidra* sp.	Common
Bryozoa	*Bugula* sp.	Not common

Despite the long list of species found on or among *Ascophyllum nodosum* used as packing material for shipping live bait and seafood (Tables 24a, 25b-d, 26 and 27), further examinations are likely to find additional hitchhiker species. Table 28, for example, lists one fungus and 38 seaweeds reported on *Ascophyllum nodosum* in the northwestern Atlantic, but so far only six of these have been found by the investigations of *Ascophyllum* packing. Similarly, many of the known parasites and epibiota of the other bait species, as well as parasites and epibiota of the various hitchhiker species that have been found in bait shipments, are likely to be discovered in future studies of bait shipments.

Table 28. Epiphytes reported on *Ascophyllum nodosum* in the northwestern Atlantic). In packing: **CA** – found in baitworm shipments received in California (Cohen *et al.* 2001); **CT/NY** – found in baitworm shipments received in Connecticut or New York (Yarish *et al.* 2009; Haska *et al.* 2011).

Group	Species	In packing	Comments
Ascomycete	*Mycophysias ascophylli*		=*Mycosphaerella ascophylli*. Moe 1997; Deckert & Garbary 2005a,b; Garbary *et al.* 2005
Chlorophyta	*Blidingia minima*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Chaetomorpha picquotiana*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Cladophora prolifera*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Cladophora sericea*		Haska *et al.* 2011 (in UNH herbarium)

Group	Species	In packing	Comments
Chlorophyta	*Codium fragile tomentosoides*		Carlton and Scanlon 1985
Chlorophyta	*Epicladia flustrae*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Monostroma fuscum*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Rhizoclonium riparium*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Rhizoclonium tortuosum*	**CT/NY**	Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Spongomorpha arcta*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulothrix flacca*	**CT/NY**	Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulothrix speciosa*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulva clathrata*	**CT/NY**	Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulva lactuca*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulva linza*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulva prolifera*	**CT/NY**	Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Ulvaria oxysperma*		Haska *et al.* 2011 (in UNH herbarium)
Chlorophyta	*Urospora penicilliformis*		Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Elachista fucicola*	**CA**	Deckert & Garbary 2005b; Longtin & Scrosati 2009; Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Fucus muscoides*		Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Fucus vesiculosus*		Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Pylaiella littoralis*	**CT/NY**	Longtin & Scrosati 2009; Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Sphacelaria*		Haska *et al.* 2011 (in UNH herbarium)
Phaeophyta	*Spongonema tomentosum*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Audouinella membranacea*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Aglaothamnion tenuissimum*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Ceramium rubrum*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Ceramium strictum*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Choreocolax polysiphoniae*		Parasitic on *Polysiphonia fastigata*. Lee 2008; Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Dasya baillouviana*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Erythrotrichia ciliaris*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Neosiphonia harveyi*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Polysiphonia denudata*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Polisiphonia fastigiata*		Lee 2008.
Rhodophyta	*Porphyra umbilicalis*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Ptilota serrata*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Stylonema alsidii*		Haska *et al.* 2011 (in UNH herbarium)
Rhodophyta	*Vertebrata lanosa*		=*Polysiphonia lanosa*. Deckert & Garbary 2005a; Garbary *et al.* 2005; Longtin & Scrosati 2009; Haska *et al.* 2011 (in UNH herbarium)

Past Invasions

We reviewed the scientific literature and the available databases for non-native species established in California that we judged were possibly or probably introduced in association with the live saltwater bait trade. We determined that eight species meet these criteria (Table 29).

The online National Introduced Marine Pest Information System (NIMPIS) database defines the Discarded Bait vector with the following example: "It is possible that two species of prawn that are introduced into San Francisco Bay, were originally imported for sale as bait or human food. The dumping of organisms from vessels or release from shore may have led to the establishment in the wild." There are two exotic Palaemonid species established in the San Francisco Bay/Delta estuary, the Siberian prawn *Exopalaemon modestus*, a freshwater species first collected in the Delta in 2000, and the Korean shrimp *Palaemon macrodactylus*, first collected in San Francisco Bay in 1957. As neither of them was sold as bait in California before these dates (though *P. macrodactylus* is now an incidental catch in the local grass shrimp bait fishery), there doesn't appear to be any mechanism by which the bait trade could have introduced them.

The NEMESIS/California database includes 22 species and 74 introductions (introductions of a species to a distinct coastal water system in California) that list Discarded Bait as a possible vector. Seven of these species, involving 12 introductions, appear to us to be possible or probable introductions via the live saltwater bait trade; these are included in Table 29 and discussed below in the vector diagnoses (which also includes one species and introduction, *Polysiphonia denudata* introduced into San Francisco Bay, for which Discarded Bait is not listed as a possible vector in the NEMESIS/California database). Another two species that are not established in California (Littorina littorea) probably arrived, at least in part, via the bait trade. The reasons for not counting the rest as bait trade introductions are discussed in Appendix F.

Determining which vector or vectors to assign to an introduction involves making a distinction between transport scenarios that appear probable enough to be counted as a possible vector for that introduction, and scenarios that seem so improbable as to not warrant assignment as a possible vector. A vector assignment should be based on evidence, and the logic underlying the assignment should be explained (Cohen 2004). The explanations for our vector assignments are provided in the vector diagnoses for the eight species listed in Table 29.

Table 29. Non-native species established in California that possibly or probably arrived via the trade in live saltwater bait. (See vector diagnoses below.)

Species	First records in California bays	Records in bait shipments or bait packing material
Codium fragile subsp. *fragile*	San Francisco Bay (1973)	No
Aglaothamnion tenuissimum	San Francisco Bay (1978-1983)	No
Polysiphonia denudata	San Francisco Bay (1978-1983, but possibly observed in 1963-64 or 1975)	No
Maritrema arenaria	San Francisco Bay (2003)	No
Microphallus similis	San Francisco Bay (2003)	No
Microphallus pygmaeus group	San Francisco Bay (2003)	No
Littorina saxatilis	San Francisco Bay (1993)	Cohen *et al.* 2001; Crawford 2001; Hackman 2002; Yarish *et al.* 2009; Haska *et al.* 2011
Carcinus maenas	Estero Americano (1989), San Francisco Bay (1989-90), Bolinas Lagoon (1993), Drakes Estero (1993), Tomales Bay (1993), Bodega Bay (1993), Elkhorn Slough (1994), Humboldt Bay (1995), Morro Bay (1998, but not established)	Cohen *et al.* 2001; Crawford 2001; Hackman 2002

Vector Diagnoses of Established Species that were Possibly or Probably Introduced via the Live Saltwater Bait Trade

• *Codium fragile* subsp*. fragile* (=*Codium fragile* subsp*. tomentosoides*) (Dead Man's Fingers, Oyster Thief, Sputnick Weed)

Dawson and Foster (1982) and Cohen *et al.* (2001) discuss the importation of New England baitworms as a vector for introducing this species into San Francisco Bay and the NEMESIS/California database lists Discarded Bait as a vector along with Fouling Community, Oyster Accidental, Ballast Water and Fisheries Accidental (not Oyster).

The green seaweed *Codium fragile* subsp*. fragile* is native to Japan. It became established in Europe in the 1800s, and spread across the Atlantic to Long Island Sound by the late 1950s (probably as hull fouling, but possibly with transplanted European oysters) and reached Boothbay Harbor, Maine by 1964 (Coffin and Stickney 1967; Carlton and Scanlon 1985). It was collected in San Francisco Bay in 1973 (P. Silva, pers. comm.). Dawson and Foster (1982) reported that it was introduced as discards from its use as "packing material to ship live marine baitworms from New England to San Francisco Bay," but we have been unable to trace the evidence for that claim (M. Foster, pers. comm.; P. Silva, pers. comm.), nor have we found any indication that *Codium* was ever used as packing material for shipments of New England baitworms. While *Codium* has not been found in the *Ascophyllum* packing for shipments of live bait or seafood (Tables 24-27), it has been reported as an epiphyte on *Ascophyllum nodosum* (Carlton and Scanlon 1985) and entangled in *Ascophyllum* in Boothbay Harbor (Coffin and Stickney 1967). That, plus the timing of *C. f. fragile*'s discovery in San Francisco Bay (long after the commercial plantings of Atlantic oysters and the frequent arrival of heavily fouled, wood-hulled cargo vessels from the Atlantic in the late 1800s-early 1900s, but within a decade after the discovery of *C. f. fragile* in Boothbay Harbor and the initiation of regular baitworm shipments from there to the San Francisco Bay area), suggest that *C. f. fragile* may have been introduced to San Francisco Bay via the bait trade. Modern transport as hull fouling or in ballast water from Japan also seems possible, while modern transport as hull fouling or in ballast water from the Atlantic seems considerably less likely because of the lesser amount of ship traffic, longer distances and (for hull fouling) passage through the freshwater Panama Canal system on most voyages. Transport with the occasional experimental plantings of Atlantic oysters in San Francisco Bay, which continued through the 1970s, is also possible (*C. f. fragile* attaches to oysters; one of its common names is oyster thief, as it sometimes drifts away with an oyster). However, since these plantings were small and infrequent, this mechanism is unlikely.[7]

• *Aglaothamnion tenuissimum* (=*Callithamnion byssoides*)

Cohen and Carlton (1995) mention the importation of New England baitworms as a possible vector for introducing this species into San Francisco Bay and the NEMESIS/California database lists Discarded Bait as a vector along with Ballast Water, Fouling Community and Fisheries Accidental (not Oyster).

The red seaweed *Aglaothamnion tenuissimum* is native to the northwestern Atlantic from Nova Scotia to Florida (Taylor 1957). Silva (1979) did not report it in his review of San Francisco Bay seaweeds, but Josselyn and West (1985) found it attached to rocks throughout the bay between 1978 and 1983. *A. tenuissimum* has been collected as an epiphyte on *Ascophyllum nodosum* in the Gulf of Maine (Table 28; Haska *et al.* 2011). That, plus the timing of *A. tenuissimum*'s discovery in San Francisco Bay (long after the commercial plantings of Atlantic oysters and the frequent arrival of heavily fouled, wood-hulled cargo vessels from the Atlantic in the late 1800s-early 1900s, but soon after the initiation of regular baitworm shipments from New England to the San Francisco Bay area), suggest that it may have been introduced to San Francisco Bay via the bait trade. Although *Aglaothamnion* species have been reported as common fouling species (WHOI 1952), modern transport as hull fouling or in ballast water from the Atlantic seems relatively unlikely because of the infrequent ship traffic between the Atlantic and San Francisco Bay, the long distances involved and (for hull fouling) passage through the freshwater Panama Canal system on most voyages. Transport with the occasional experimental plantings of Atlantic oysters in San Francisco Bay, which continued

[7] Genetic analysis may shed light on all this, by determining whether the *C. f. tomentosoides* in San Francisco Bay came from Japan or from the Atlantic, and if from the Atlantic then whether it came from the Boothbay Harbor area. The latter determination may be possible as there is evidence that the *Codium* population in Boothbay Harbor, which was isolated from other Atlantic populations for at least 20 years, may be genetically distinct from them (Carlton and Scanlon 1985, citing Malinowski 1974).

through the 1970s, might also be also possible. However, since *A. tenuissimum* is not known as an oyster fouler, and because these experimental plantings were small and infrequent, this mechanism is very unlikely.

• *Polysiphonia denudata*

The NEMESIS/California database lists Discarded Bait as a vector for this species' introduction into San Pablo Bay (but not San Francisco Bay) along with Fouling (Commercial Shipping), Ballast Water, Fouling (Recreational Boats) and Discarded Seafood.

The red seaweed *Polysiphonia denudata* is native to the Atlantic coast from Prince Edward Island to Florida and the tropics, commonly occurring in tide pools and in shallow bays attached to rocks, shells and wharves (Taylor 1957). Silva (1979) did not report it in his review of San Francisco Bay seaweeds, but Josselyn and West (1985) reported it as a common drift or epiphytic algae throughout the bay between 1978 and 1983. They further suggest that decaying mats of seaweed observed in Palo Alto in the summer of 1975 may have been *P. denudata*. Carlton observed a sometimes abundant *Polysiphonia* that could have been *P. denudata* in Lake Merritt (a brackish lagoon connected to San Francisco Bay) in 1963-64 (Cohen and Carlton 1995). *P. denudata* has been collected as an epiphyte on *Ascophyllum nodosum* in the Gulf of Maine (Table 28; Haska *et al.* 2011). That, plus the timing of *P. denudata*'s discovery in San Francisco Bay (long after the commercial plantings of Atlantic oysters and the frequent arrival of heavily fouled, wood-hulled cargo vessels from the Atlantic in the late 1800s-early 1900s, but soon after the initiation of regular baitworm shipments from New England to the San Francisco Bay area), suggest that it may have been introduced to San Francisco Bay via the bait trade. Although *Polysiphonia* species are common foulers of artificial structures including ships (WHOI 1952; Fletcher *et al.* 1984), and some *Polysiphonia* species can tolerate copper- and mercury-based anti-fouling compounds (Weiss 1947), modern transport as hull fouling or in ballast water from the Atlantic seems relatively unlikely because of the infrequent ship traffic between the Atlantic and San Francisco Bay, the long distances involved and (for hull fouling) passage through the freshwater Panama Canal system on most voyages. Transport with the occasional experimental plantings of Atlantic oysters in San Francisco Bay, which continued through the 1970s, might also be also possible. However, since *P. denudata* is not known as an oyster fouler, and because these experimental plantings were small and infrequent, this mechanism is very unlikely.

• *Littorina saxatilis* (Rough Periwinkle)

Cohen and Carlton (1995), Carlton and Cohen (1998), Cohen *et al.* (2001) and Brown (2004) argue that this species was most likely introduced into San Francisco Bay with baitworms imported from Maine. The NEMESIS/California database lists Discarded Bait as a vector along with Fisheries Accidental (not Oyster).

The periwinkle *Littorina saxatilis* is native to the northeastern and northwestern Atlantic. Since 1993 it has been discovered at nine sites in San Francisco Bay (Carlton & Cohen 1998; Brown 2004). In most or all of these locations it occurs in populations that cover a small stretch of shore near a popular fishing spot, public boat-launching ramp or small-boat dock. In the Atlantic, *L. saxatilis* shows significant genetic variation even over short distances (Berger 1973); the populations in San Francisco Bay show little genetic variation, suggesting that they may derive from a single Atlantic location (Brown 2004). *L. saxatilis* has non-planktonic larvae and is thus an unlikely candidate for transport in ships' ballast water. It is, however, commonly reported (Table 24a) and often abundant in the *Ascophyllum* packing for baitworms shipped from Maine to California and other sites (Cohen *et al.* 2001; Hackman 2002). Once released, its non-planktonic larvae may give it an advantage in becoming established, by reducing larval dispersal and increasing the probability that adults will settle in close enough proximity to locate mates (Johannesson 1988; Carlton and Cohen 1998). These factors together suggest that *L. saxatilis* was most likely introduced via baitworm imports. Alternatively, it is possible that *L. saxatilis* could have been introduced in the *Ascophyllum nodosum* used to pack shipments of live lobsters from New England, even though it was not reported in the one published investigation of hitchhiker organisms in those shipments (Miller 1969). However, the relatively small amount of lobster-packing seaweed that would end up in the waters of San Francisco Bay and the association of *L. saxatilis* with fishing spots, boat ramps and boat docks in the bay make introduction with baitworms far more likely.

• *Maritrema arenaria*, *Microphallus similis* and *Microphallus pygmaeus* group

The NEMESIS/California database lists Discarded Bait as the sole possible vector for these species' introduction into San Francisco Bay.

These three trematode flatworm parasites were found in the snail *Littorina saxatilis* collected in San Francisco Bay in 2003 and identified by A. Blakeslee (NEMESIS/California database). They are all apparently native to the North Atlantic[8] where *L. saxatilis* serves as a first intermediate host for all three trematodes, *Littorina obtusata* serves as a first intermediate host for the two *Microphallus* species, and the crab *Carcinus maenas* is the second intermediate host of *Microphallus similis* (Stunkard 1957; James 1968; Pohley 1976; McCarthy *et al.* 2002). *Microphallus pygmaeus* was found once in *Littorina littorea*, which did not appear to be a normal host for it (Pohley 1976). Shore birds or water birds (turnstones, gulls, terns or ducks) are the final hosts of these trematodes (Hadley and Castle 1940, Stunkard 1957; Hutton 1964; James 1968; Bustnes and Galaktionov 1999).

It seems most likely that these trematodes arrived in San Francisco Bay either in *Littorina saxatilis* or (for the *Microphallus* species) in *Littorina obtusata* that were transported in the *Ascophyllum* packing of baitworms from Maine; both these snails

[8] Although there are a few records of *M. pygmaeus* and *M. similis* identified morphologically in Washington state or British Colombia (Ching 1962, 1965; Ching *et al.* 2000), the vast preponderance of records for these species are in the North Atlantic, and these West Coast records probably represent distinct species.

were very abundant in the baitworm packing arriving in San Francisco Bay in the 1990s (Lau 1995; Cohen *et al.* 2001). *Microphallus similis* could also have arrived in *C. maenas* transported in baitworm packing, though *Carcinus* was much less abundant in baitworm packing than the snails. *Microphallus pygmaeus* could possibly have arrived in *Littorina littorea* carried in baitworm packing or imported into California as live seafood (Cohen 2012), though the rare occurrence of *M. pygmaeus* in *L. littorea* makes this unlikely. Transport into California in the trematodes' other identified intermediate hosts (various snail and barnacle species) also seems unlikely since there is no mechanism regularly transporting these other species from the Atlantic Ocean to the northeastern Pacific. Transport into California in migrating bird hosts seems highly unlikely, as these coastal birds migrate along north-south flyways, and not east-west across the North American continent.

• *Carcinus maenas* (Green Crab)

Cohen *et al.* (1995), Ruiz and Grosholz (1995), Cohen and Carlton (1995), Carlton and Cohen (2003) discuss the introduction and spread of this species, including its possible introduction in the seaweed packing for baitworms imported from Maine. The NEMESIS/California database lists Discarded Bait as a possible vector for introduction to seven locations (Humboldt Bay, Bodega Harbor, Tomales Bay, Drakes Estero, Bolinas Lagoon, San Francisco Bay, Elkhorn Slough and Morro Bay), along with 1-4 other possible vectors.

Carcinus maenas, the European green crab, was introduced to the northwestern Atlantic by the early 19th century, to southern Australia by 1900, and to South Africa by 1983. A single large crab was collected in the Estero Americano, near Bodega, in 1989. It was found in San Francisco Bay in 1989-90, in Bolinas Lagoon, Drakes Estero, Tomales Bay and Bodega Harbor in 1993, in Elkhorn Slough in 1994, in Humboldt Bay in 1995 and in Morro Bay in 1998. It was also collected in southern Oregon in 1997, in Washington in 1998 and in British Columbia in 1999. A variety of possible vectors for its initial introduction into California are reviewed in detail in Cohen *et al.* (1995) and Carlton and Cohen (2003). It has been collected in shipments of Maine baitworms examined in California (Cohen *et al.* 2001; Hackman 2002), and is very common in the intertidal *Ascophyllum nodosum* near Wiscasset, Maine and common in the *Ascophyllum* examined in bait-packing facilities in Maine (Crawford 2001; A. Cohen unpubl. data; 15 were collected in a random 250 g sample of the seaweed—S. Crawford, pers. comm.). Relative to the other possibilities, it seems likely that *C. maenas* was introduced to California in baitworm packing. However, it is unlikely that its extraordinarily rapid increase in range from an initial center somewhere in the San Francisco Bay area was accomplished by further introductions from the East Coast. Rather, these additional Pacific Coast locations were almost certainly reached from previously invaded Pacific Coast sites, either by dispersal of larvae and possibly adults in coastwise currents, or by that in combination with transport in oyster shipments between oyster-producing bays.

Review of Glycera dibranchiata

The bloodworm, *Glycera dibranchiata*, native to the western Atlantic, has frequently been reported as occurring on the Pacific Coast (*e.g.* Steinbeck and Ricketts 1941; Hartman 1950, 1968; Pettibone 1963; MacGinitie and MacGinitie 1968; Blake 1975; Creaser *et al.* 1983; Salazar-Vallejo and Lodoño-Mesa 2004; Blake and Ruff 2007), with a range often reported as Mazatlan to San Mateo County. These records have led to some speculation that *G. dibranchiata* might already have been introduced onto the Pacific Coast via the bait trade.

With assistance from Leslie Harris and James Carlton, we undertook a review of the status of *G. dibranchiata* on the Pacific Coast, including a literature review, a review of the major databases of benthic organisms in central and southern California, and an examination by Leslie Harris of all *G. dibranchiata* specimens in the Natural History Museum of Los Angeles County-Allan Hancock Foundation Polychaete Collection (LACM-AHF). A summary of all known Pacific Coast specimens resulting from this review is provided in Table 30. Other reported records from Newport Bay in California, from a few sites in Mexico and from Costa Rica were determined by Leslie Harris or others to be other species. There are no records of *G. dibranchiata* in the California Academy of Sciences Invertebrate Zoology Collection database, in the Department of Water Resources San Francisco Bay records (Heather Fuller, pers. comm.), in the U.S. Geological Survey's San Francisco Bay records (Susan Mccormick, pers. comm.), in the Southern California Coastal Water Research Project (SCCWRP) records (consisting of various surveys in the Southern California Bight area from 1977-2003) or in EPA's EMAP records of the 1999 and 2000 EMAP surveys).

Table 30. Records of the bloodworm, Glycera dibranchiata, on the Pacific Coast.

Country or State	Location, Date of Collection and Comments
Oregon	1 specimen "from Oregon" given to Olga Hartman by Irene McCulloch, 1949. Possibly the source for Rudy and Rudy (1979) reporting it "in our area."
California	1 specimen, Moss Beach, 1917. Probably the source of records referring to the range extending to central California or San Mateo County.
	1 specimen "collected...from southern California, presumably Mission Bay," 1929.
Mexico	Appear to be at least 20 specimens from numerous locations between Turtle Bay, Pacific coast of Baja California Sur (27°39'N, 114°51'W) and Bahia de Manzanillo, Colima (19°03'N, 104°18'W).
Panama	2 specimens from Panama

Leslie Harris determined, based on the LACM-AHF specimens, that the two California specimens and the one Oregon specimen are equal in size to the baitworms imported from the Atlantic Coast, while the Mexican worms are substantially smaller. There are also some morphological differences between the Mexican and the three northern worms. These differences could indicate that these are different species, but the morphological difference could possibly be size dependent; comparison with small specimens from the Atlantic, or DNA analysis could settle this question.

Overall, these data suggest that the *G. dibranchiata* records on the Pacific Coast consists mainly of an unnamed species with a normal northern range limit in Baja California, which is genetically and perhaps morphologically distinct from the true *G. dibranchiata* of the western Atlantic. The three larger specimens from California and Oregon may result from sporadic anthropogenic transport of *G. dibranchiata* from the Atlantic Coast. Though the Moss Beach specimen, at least, appears to have been collected from California waters, the collection information for the Oregon and Mission Bay specimens is vague. The 1949 Oregon specimen might, for example, be a worm taken from a very early bait shipment from the Atlantic Coast, rather than collected in California's coastal waters. In any event, it doesn't look like the live bait trade introduced *G. dibranchiata* to the Pacific Coast.

Environmental Suitability

We assessed the environmental suitability of the bait species that are not native to California or that are imported into California by comparing the faunal zone of their source areas and/or ranges to California's faunal zone (Table 1 and Appendix D). By this method, organisms with source areas within California are automatically classified as Suitable. The bait species with source areas in Oregon and Washington were also classified as Suitable (Table 30). The native ranges of the ghost shrimp and mud shrimp species imported from Washington or Oregon extend throughout California into Baja California (Table 31). While there's little difference in average summer (August) sea surface temperatures between Washington and California, average winter (February) sea surface temperatures in Oregon and Washington are 1-2°C lower than in Northern California and 4-5°C lower than in Southern California (Sverdrup *et al.* 1947), so California or some parts of it might not be suitable for hitchhiker species transported

Table 30. Suitability classifications of live saltwater bait species for California waters. (See methods section for explanation.)

Scientific name	Calif. Native?	Source Region	Suitability to CA waters
Alitta virens	No	Maine	Suitable?
Glycera dibranchiata	No	Maine	Suitable?
Perinereis aibuhitensis	No	South Korea	Suitable?
Namalycastis rhodochorde	No	Vietnam	Not Suitable
Mytilus galloprovincialis	No	southern California	Suitable
Neotrypaea californiensis	Yes	Washington, Oregon	Suitable
Upogebia pugettensis	Yes	Oregon	Suitable
Palaemon macrodactylus	No	SF Bay	Suitable
Acanthogobius flavimanus	No	SF Bay & southern California	Suitable

Table 31. Native and invaded ranges of live saltwater bait species.

Scientific name	Native Range	Invaded Range
Alitta virens	Labrador to Virginia; Iceland, Norway & White Sea to France	–
Glycera dibranchiata	Prince Edward Island to Texas and the West Indies	southern Brazil?
Perinereis aibuhitensis	China, South Korea	–
Namalycastis rhodochorde	Vietnam, Indonesia	–
Mytilus galloprovincialis	Mediterranean Sea	Mendocino County to San Diego, Atlantic Europe, South Africa, Japan, China, Australia, New Zealand
Neotrypaea californiensis	Southern Alaska to Punta Banda, Baja California	–
Upogebia pugettensis	Southern Alaska to San Quintin, Baja California	–
Palaemon macrodactylus	Japan, Korea, northern China	Washington to southern California, Rhode Island to New York, England, Germany to Spain, Black Sea, Argentina, Australia
Acanthogobius flavimanus	Japan, South Korea, China	Estero Americano to San Diego

with these baits. One parasite of the ghost shrimp *Neotrypaea californiensis*, the bopyrid isopod *Ione cornuta*, is fairly common on ghost shrimp imported into California (Pernet *et al.* 2008). Pernet *et al.* (2008) found, based on their sampling and other records, that *I. cornuta* is not native to and does not occur south of Point Conception. On the other hand *Orthione griffenis*, a bopyrid parasite of the mud shrimp *Upogebia pugettensis*, a species introduced from Japan, has been found throughout California to Punta Banda, Baja California (Chapman *et al.* 2012).

The Maine and South Korean source regions for three bait species lie in areas that Ekman considered to either be a part of the Cold Temperate Shelf Faunal Zone (CTSFZ) that California is in, or to be within a northern transitional zone. In both areas, summer temperatures are comparable to typical temperatures in the CTSFZ, but winter temperatures are substantially colder (Ekman 1953). Thus they are classified as questionably Suitable. The ranges of the worms from Maine extend far enough south that their species' range overlaps the temperature range of California; however, it's possible that the worms in the Maine source region could be genetically adapted to colder winter temperatures such that they would not be suited to the more southern parts of California. The range of the Korean worm *Perinereis aibuhitensis* isn't specified in the literature precisely enough to determine whether its temperature range overlaps California's.

The Vietnamese worm *Namalycastis rhodochorde* was only recently described and its range is still imperfectly known. However, the known portion of its range is well outside the CTSFZ, and seems unlikely to extend into it when fully known, so it is classified as Not Suitable for California's waters. This is supported by a comparison of water temperatures. The average summer sea surface temperatures in the coldest part of its known range are 11° warmer than the summer temperatures at California's southern border; while the average winter temperatures in the coldest part of its range are about 7° warmer than the winter temperatures at California's southern border.

Conclusions

From landings records and the data developed by our survey, corroborated by interviews of bait dealers, it appears that most of the live saltwater bait sold in California consists of native species, and that most of it is harvested and used locally within a region of the state. Thus, most of the saltwater live bait sold in central/northern California is grass shrimp, primarily native *Crangon* species, and nearly all of it is harvested in San Francisco Bay and sold in the Bay/Delta region (Tables 18 and 19). Anchovies and sardines, harvested from southern California waters, are probably the dominant live saltwater bait sold in southern California, though we lack data on these sales. The same is true of several other native bait species: sand crabs are harvested and sold in southern California; estuarine fish (longjaw mudsuckers, yellowfin gobies, staghorn sculpin, shiner surfperch and plainfin midshipmen) are primarily harvested in San Francisco Bay (some of it being incidental catch by the bait shrimp harvesters) and sold in the Bay region.

The same pattern of harvest and sale locally also appears to hold for the two established, non-native species that are sold as live bait. Mussels, primarily or entirely consisting of the Mediterranean mussel *Mytilus galloprovincialis*, are harvested and sold as bait almost entirely in southern California; the oriental shrimp *Palaemon macrodactylus* is caught in San Francisco Bay as an incidental part of the grass shrimp fishery and sold, according to the survey data, entirely within the Bay/Delta region.

There are however, a large number of pileworms and bloodworms imported from Maine (our estimates from the survey data put it at about 1.5 million worms annually (Table 18)) and possibly a large number of lugworms from Korea (our estimate is fairly small, but we suspect that it may be an underestimate). Environmental comparisons suggest that the lugworms may not be suited to warm southern California waters, so it may be fortunate that they are sold primarily in southern California. That may change, however. In a 1997 survey, we found no bait shops in the Bay/Delta area that sold lugworms (Cohen *et al.* 2001). In a 2009 survey, Passarelli (2010 and unpubl. data) found a single store in the Bay/Delta region that sold lugworms. In 2011-2012, we found three. Use of the Korean lugworm in cooler waters in central or northern California could pose a greater risk of establishment than its use in southern California waters.

The other imported worm, the nuclear worm from Vietnam, is classified as unsuited for California waters, since it comes from a much warmer part of the ocean. It may offer the least risk of any of the imported non-native species. If anthropogenic climate change raises the temperature of California's coastal waters, they could become more hospitable to this worm. However, since so little is known about the nuclear worm's environmental requirements or range (it was only recently described as a species, and has so far been reported in only two locations—Glassby *et al.* 2007), there is little to base an analysis on. The nuclear worm is not very commonly sold, and its use in California appears to be declining. In the 1997 survey, which only covered the Bay/Delta region, we identified three bait shops that had sold the nuclear worms up to 3 years earlier and 2 shops that were then selling it; Passarelli (2010 and unpubl. data) identified 4 shops that sold nuclear worms, only one of which was in the Bay/Delta region. In the most recent survey (2011-2012), we did not find a single shop in California that sells nuclear worms.

Ghost shrimp are imported from Washington and Oregon in large numbers, and mud shrimp from Oregon in small numbers that may yet get smaller: mud shrimp populations all along the U.S. Pacific Coast are collapsing (Chapman *et al.* 2012), and landings in Oregon have declined exponentially (J. Chapman, unpubl. data). Both of these bait species carry bopyrid isopod parasites that provide some reasons to be concerned, as well as reasons not to be. *Ione cornuta*, parasite on the ghost shrimp *N. californiensis*, is native to the coast but doesn't appear to occur south of Point Conception (Pernet *et al.* 2008). It is fairly common on ghost shrimp imported into California, and if introduced south of Point Conception, could infect the native ghost shrimp there. While *I. cornuta*'s impact on the ghost shrimp that now carry it appears to be slight, the southern California ghost shrimp are a naive host population, and may possibly lack appropriate defenses or responses so that the impacts of an *I. cornuta* infestation could be severe. On the other hand, *I. cornuta* is native and thus has had at least thousands of years to make its way down to, and become established in, southern California. That it has not done so suggests that something about the environment in southern California is preventing *I. cornuta* from spreading south. Further investigation is warranted.

Orthione griffenis is a Japanese bopyrid parasite that has infested mud shrimp along the North American Pacific Coast, where it was first discovered in 1988. It greatly reduces its host's ability to reproduce, and may have caused or contributed to the collapse of Pacific Coast *Upogebia* populations (Chapman *et al.* 2012). It has been found from Washington State to Carpinteria Marsh in southern California, near Santa Barbara. However, it is not known whether it has reached the possibly vulnerable populations of *Upogebia* on the Channel Islands, *Upogebia lepta* and *U. onychion*. Chapman *et al.* (2012) argue that adults removed from their holes cannot re-burrow, and that any released or escaped *Upogebia* will quickly die along with any parasites. If so, transporting adult *Upogebia* as bait may not risk spreading the parasite; however, its apparent devastating impact suggests that further investigation of the potential for transport is warranted.

The two Maine worms are imported in large numbers, and might or might not be suited to California waters. A much bigger concern is the seaweed packing for the worms, which carries a large complement of hitchhiker organisms. Eight of these appear to have been released from bait boxes into the environment, and have established populations. At least two others (*Ascophyllum* and *Littorina littorea*) have been released into the environment in California on multiple occasions. Some of these hitchhiker species have had major impacts in other invaded regions: *Littorina littorea*, for example, has altered salt marsh and soft-bottom habitats, and controlled algal composition; *Carcinus maenas* has decimated shellfish populations. Eight species established over approximately 40 years since regular baitworm imports began in the late 1960s or early 1970s suggests that an invasion rate of up to about two species a decade can be expected. The *Ascophyllum* packing and its numerous hitchhikers thus appear to be a greater threat than any of the bait species.

There are a few companies that offer live saltwater bait online for retail sale and shipment to California, including a few species not available in California bait shops. While the costs of shipping suggest that purchase of these baits by California anglers may be very limited, no data on such sales were available. There are many foreign companies offering a taxonomically diverse suite of live saltwater baitworms for wholesale purchase and shipment to the U.S. It seems likely that at some point California bait shops will offer some of these novel species for sale, unless regulations are implemented to restrict them.

California law currently requires importers to obtain a permit from CDFG before importing any live bait species (California Fish and Game Code §2271, and California Administrative Code, Title 14, §236), but as far as we have been able to determine CDFG has never enforced this requirement and the companies importing live marine bait into the state have never held import permits.[9] This law provides an obvious method for obtaining better information on the species, source regions and quantities of live saltwater bait being imported into the state, as well as a mechanism for managing current imports, possibly for managing online retail sales and shipments from out-of-state, and for monitoring and managing future imports of novel saltwater bait species from other parts of the world.

[9] We note that on at least two occasions companies applied for permission to import the Korean lugworm *Perinereis aibuhitensis*, which they were not granted. In 1998 a company applied to the California Department of Food and Agriculture, which didn't grant permission because marine organisms are not under its jurisdiction. In 2004 the Greensea Trading Company applied to the California Fish and Game Commission for "authorization to import and sell live seaworms (*Perinereis aibuhitensis*) for saltwater fishing bait," which the Commission denied (California Fish and Game Commission, August 26-27, 2004 Meeting Summary, Item 2; L. Harris, R. Watanabe, pers. comm.). The denial was apparently based on a review or risk assessement, which we have been unable to obtain. These requests and denials do not appear to have been communicated to the section of the Department of Fish and Game that implements the import permit requirement (T. Moore, K. Ramey, pers. comm.), nor do they appear to have affected imports of the Korean lugworm, which continue to this day.

Summary of Key Points

- Most of the live saltwater bait sold in California is harvested and sold locally, and thus poses little risk of introducing non-native species to new regions.

- However, there are four species of polychaete worms that are or have recently been imported from other coasts and sold live in California, and two thalassinid crustaceans (ghost shrimp and mud shrimp) that are imported from Washington or Oregon. These are the species of greatest concern.

- Probably the greatest demonstrated risk lies with the Atlantic seaweed that is used to pack two baitworm species imported from Maine. This seaweed packing carries a wide selection of intertidal organisms from the New England coast, including two species that invaded New England from Europe and had large, negative impacts on native species distributions, habitats and fisheries in New England. Some non-native species have become established in California as a result of this mechanism, many other organisms are transported by or available for transport by this mechanism, and further introductions are to be expected. Although an assessment of management options is outside the scope of this study, it is clear that several feasible options are available to reduce or eliminate this risk, including requiring distributors or retailers to remove and dispose of the packing seaweed before sale to customers, banning the use of seaweed as packing for imported worms, or banning the import and sale of these worms.

- Bopyrid parasites carried by thalassinid bait species have the potential to harm native thalassinids. Although it's not clear that bait shipments can be effective in introducing one of these parasites (*Orthione griffenis*), impacts by this parasite can be devastating, and further assessment of the risks from bopyrid parasites in the bait trade are fully warranted.

- Whatever the risks of the current mix of imported bait in California, bait species from other parts of the world, including from an Asian industry active in producing and promoting a variety of baitworm species for live export, are likely to be sold in California and to present new risks, unless management actions are taken to limit or prevent this.

- Existing California law requiring a permit from CDFG in order to import live bait provides a mechanism for monitoring and managing current and potential future imports of live saltwater bait species, if the state chooses to implement that law.

Additional Issues

Dead Fresh or Frozen Bait

Some bait is sold "fresh" (dead and chilled) or frozen. Dead fresh or frozen fish are capable of transporting viable viruses,[10] and fresh, dead bait organisms could transport live parasites or hitchhiking organisms. These issues are outside the scope of this study, which addresses live bait.

Harvest and Transport of Bait by Private Parties

Anglers may sometimes harvest bait in one bay or region and transport it live for use in another bay or region. Though the quantity of live bait transported between bays or regions by this activity is probably small, this could theoretically introduce bait or hitchhiker species to new locations. This issue is outside the scope of this study, which addresses the commercial trade in live saltwater bait.

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[10] The federal Lacey Act prohibits the importing of dead salmonid fish that have not been assayed for specified viral diseases and certified to be free of them. Recently, shipments of frozen fish from Great Lakes states were prohibited by some states because of the discovery of Viral Hemorrhagic Septicemia (VHS) in the Great Lakes.

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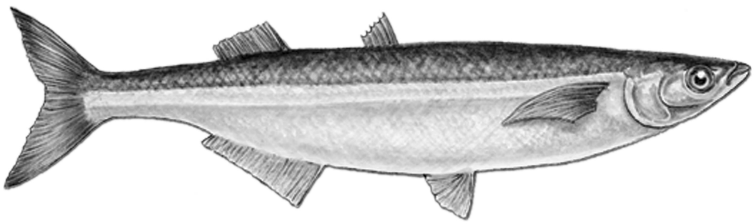
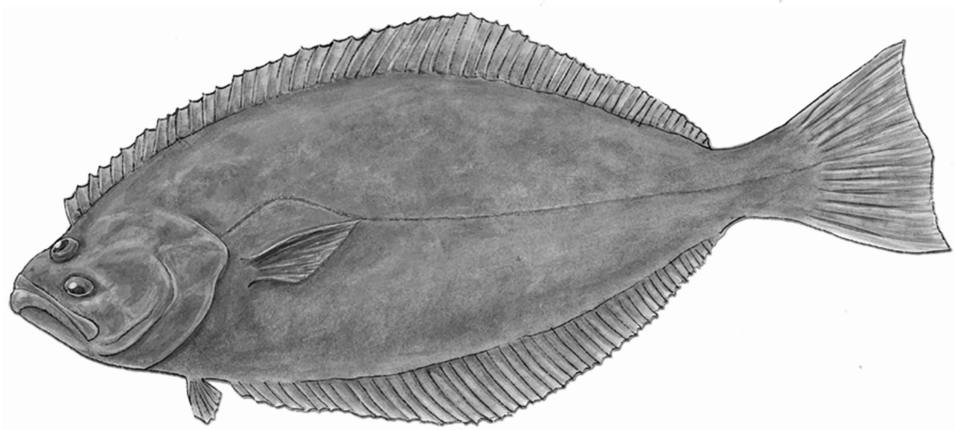
Appendix A. Coastal and Delta Counties Surveyed

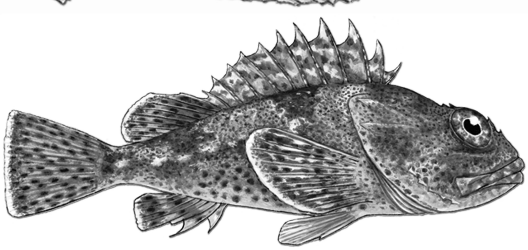
Region	County	Area (sq. mi.)
Northern	Del Norte	1,008
Northern	Humboldt	3,572
Northern	Mendocino	3,509
Bay	Sonoma	1,576
Bay	Marin	520
Bay	Napa	754
Bay	Solano	829
Bay	Contra Costa	720
Bay	Alameda	738
Bay	San Francisco	47
Bay	San Mateo	449
Bay	Santa Clara	1,291
Delta	Sacramento	966
Delta	San Joaquin	1,399
Delta	Yolo	1,013
Central	Santa Cruz	445
Central	Monterey	3,322
Central	San Luis Obispo	3,304
Southern	Santa Barbara	2,737
Southern	Ventura	1,845
Southern	Los Angeles	4,061
Southern	Orange	789
Southern	San Diego	4,200

Region	# of Counties	Area (sq. mi.)
Northern	3	8,089
Bay	9	6,924
Delta	3	3,378
Central	3	7,071
Southern	5	13,632
Coastal & Delta Counties	23	39,094
California	58	163,696

Live Saltwater Fishing Bait Sold in California







CRAB
5994 McBryde Avenue
Richmond, CA 94805-1164

Section 1

Q-1. Do you sell live saltwater bait? (*Circle one*)

1 YES *If yes ⇒ Please continue.*

2 NO *If no ⇒ Please return the survey in the envelope provided, so we know that you do not sell live saltwater bait.*

Q-2. Where is your store located? (*Circle one – see map on facing page*)

1 NORTHERN CALIFORNIA (North of Cape Mendocino)

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception)

3 SOUTHERN CALIFORNIA (South of Pt. Conception)

Q-3. Do you ever hold saltwater bait species in tanks of water? (*Circle one*)

1 YES *If yes ⇒ Go to Question 4.*

2 NO *If no ⇒ Go to Question 5.*

Q-4. How is the water discharged? (*Circle all that apply*)

1 INTO A WATER BODY WITHOUT FILTRATION OR TREATMENT

2 INTO A WATER BODY AFTER YOU FILTER OR TREAT IT

3 DOWN A DRAIN TO MUNICIPAL WASTEWATER TREATMENT

4 DOWN A STORM DRAIN

5 OTHER (*Please describe*) ____________________________________

6 DON'T KNOW

Q-5. Is your facility within 500 feet of a salt or brackish water body? (*Circle one*)

1 YES

2 NO

Section 2

Next, we would like to ask some questions about the bait species you sell. On the following pages, please fill out one page for each live saltwater bait species.

If you need additional pages, either photocopy one of the pages or contact us at 510-778-9201 or MarineCrab1@gmail.com.

Please provide your best estimate of quantities. Call or email us if you have any questions.

Please fill out this page for one live saltwater bait species that you sell:

Q-6. Common or Trade Name of Bait Species: ______________________________

Q-7. Scientific Name, if known: ____

Q-8. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-9. Where is this species harvested or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page*)

____

Q-10. Approximate number sold each year: ________________________________

Q-11. What type of packing material does this bait arrive in? (*Circle all that apply*)

1 SEAWEED

2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Q-12. How is this packing material disposed of? (*Circle all that apply*)

1 TRASH PICKUP/LANDFILL

2 DISCARD IN A WATER BODY

3 DOWN SINK OR TOILET

4 INTO A STORM DRAIN (e.g. curbside)

4 GIVE TO CUSTOMERS WITH BAIT

5 OTHER (*Please describe*) ____

Q-13. What type of material is this bait held in, prior to sale? (*Circle all that apply*)

1 SEAWEED

2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Q-14. In what type of material is this bait sold to customers? (*Circle all that apply*)

1 IN SEAWEED

2 IN SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Please fill out this page for another live saltwater bait species that you sell:

Q-6. Common or Trade Name of Bait Species: ______________________________

Q-7. Scientific Name, if known: ____

Q-8. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-9. Where is this species harvested or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-10. Approximate number sold each year: ________________________________

Q-11. What type of packing material does this bait arrive in? (*Circle all that apply*)

1 SEAWEED

2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Q-12. How is this packing material disposed of? (*Circle all that apply*)

1 TRASH PICKUP/LANDFILL

2 DISCARD IN A WATER BODY

3 DOWN SINK OR TOILET

4 INTO A STORM DRAIN (e.g. curbside)

4 GIVE TO CUSTOMERS WITH BAIT

5 OTHER (*Please describe*) ____

Q-13. What type of material is this bait held in, prior to sale? (*Circle all that apply*)

1 SEAWEED

2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Q-14. In what type of material is this bait sold to customers? (*Circle all that apply*)

1 IN SEAWEED

2 IN SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

These pages are for additional live saltwater bait species:

Q-6. Common or Trade Name of Bait Species: ______________________________

Q-7. Scientific Name, if known: ____

Q-8. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-9. Where is this species harvested or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-10. Approximate number sold each year: ________________________________

Q-11. What type of packing material does this bait arrive in? (*Circle all that apply*)

1 SEAWEED

2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

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1 TRASH PICKUP/LANDFILL

2 DISCARD IN A WATER BODY

3 DOWN SINK OR TOILET

4 INTO A STORM DRAIN (e.g. curbside)

4 GIVE TO CUSTOMERS WITH BAIT

5 OTHER (*Please describe*) ____

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2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Q-14. In what type of material is this bait sold to customers? (*Circle all that apply*)

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2 IN SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

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Q-8. Type: (*Circle all that apply*)

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2 FARMED

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3 NO PACKING MATERIAL

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Q-12. How is this packing material disposed of? (*Circle all that apply*)

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4 GIVE TO CUSTOMERS WITH BAIT

5 OTHER (*Please describe*) ______________________________

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2 SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ______________________________

Q-14. In what type of material is this bait sold to customers? (*Circle all that apply*)

1 IN SEAWEED

2 IN SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ______________________________

These pages are for additional live saltwater bait species:

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Q-7. Scientific Name, if known: ____

Q-8. Type: (*Circle all that apply*)

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Q-9. Where is this species harvested or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

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2 SEA WATER

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4 OTHER (*Please describe*) ____

Q-12. How is this packing material disposed of? (*Circle all that apply*)

1 TRASH PICKUP/LANDFILL

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Q-8. Type: (*Circle all that apply*)

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Q-9. Where is this species harvested or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

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4 OTHER (*Please describe*) ____

Q-14. In what type of material is this bait sold to customers? (*Circle all that apply*)

1 IN SEAWEED

2 IN SEA WATER

3 NO PACKING MATERIAL

4 OTHER (*Please describe*) ____

Is there any other information you would like to tell us about live saltwater fishing bait in California? If so, please use this space for that purpose.

Also, any comments on this questionnaire or information you have that you think would help us to understand how non-native marine species are introduced into California would be appreciated.

Your responses are greatly appreciated.

If you would like a summary of results, please write "Results requested" on the back of the return envelope and print your name and your mail or email address below it (NOT on this questionnaire).

Mail the completed questionnaire in the envelope provided to:

CRAB, 5994 McBryde Avenue, Richmond CA 94805-1164

CRAB (Center for Research on Aquatic Bioinvasions)
5994 McBryde Avenue, Richmond CA 94805-1164
(510) 778-9201

Company (Bait)
Street Address
City State Zip

Non-native saltwater species have harmed recreational and commercial fisheries, wetlands and other coastal habitats, and posed risks to public health. On behalf of the California Ocean Protection Council (part of the state government), we're studying the role of ships, boats, aquaculture and the live seafood, bait and aquarium pet trades in transporting live saltwater animals. Our goal is to understand the possible pathways for introducing non-native animals or plants, and to assess the risk of their becoming established in California's marine waters.

Your company was randomly selected from a list of bait shops in the coastal counties of California, to participate in a short survey about live bait. I hope you can take a few minutes to complete the enclosed questionnaire in the next week, and return it in the pre-paid envelope. This survey is a critical part of our study.

Any information provided will be completely confidential. The questionnaire has an identification number only so that your company can be checked off the mailing list when your questionnaire is returned. Your company's name will never be placed on the questionnaire.

If you wish to receive a summary of the results, write "Results requested" on the back of the return envelope and print your name and your mail or email address below it. (Please do not put this information on the questionnaire itself.)

I would be happy to answer any questions that you might have. Please feel free to call or email me.

Thank you for your help.

Sincerely,

Andrew Cohen
Project Director
(510) 778-9201
MarineCrab1@gmail.com

Last week a questionnaire was mailed to you seeking your input on live saltwater bait species sold in California. Your company was selected at random from a list of bait shops in California's coastal counties.

If you have already completed the questionnaire and returned it to us please accept our sincere thanks. If not, please do so today. Because it was sent to a representative sample, it is extremely important that your response be included if the results are to accurately represent bait dealers.

If by some chance you did not receive the questionnaire, or it was misplaced, please call or email me right now and I will get another one in the mail to you today.

Sincerely,

Andrew Cohen, Project Director
(510) 778-9201
MarineCrab1@gmail.com

Center for Research on Aquatic Bioinvasions

CRAB
5994 McBryde Avenue
Richmond CA 94805-1164

Company (Bait)
Street Address
City State Zip

Center for Research on Aquatic Bioinvasions
CRAB
5994 McBryde Avenue
Richmond CA 94805-1164
(510) 778-9201

Company (Bait)
Street Address
City State Zip

Three weeks ago I wrote you asking for your help on a survey of California bait shops. As of today, we have not yet received your completed questionnaire.

Our research unit has undertaken this study to help California agencies understand the role of ships, boats, aquaculture and the live seafood, bait and aquarium trades in transporting live saltwater animals, and possible pathways for introducing non-native animals or plants.

I am writing to you again because of the importance of each questionnaire. Your company was randomly selected from a list of California bait shops that we assembled from a variety of sources. In order for the results to be truly representative, it is essential that each company in the sample return its questionnaire.

I want to assure you again that any information provided will be kept confidential. The identification number on the questionnaire is used only to check your company off on the mailing list—your company name will not appear on the questionnaire or in the results.

If you would like a copy of the results, please write "Results requested" on the back of the return envelope and print your mail or email address below it.

I'd be happy to answer any questions that you have. My direct phone line and email address are below.

Your help is greatly appreciated.

Sincerely,

Andrew Cohen
Project Director
(510) 778-9201
MarineCrab1@gmail.com

P.S. – A few respondents have asked when the results will be available. We expect to have them compiled by the end of next month.

Center for Research on Aquatic Bioinvasions
CRAB
5994 McBryde Avenue
Richmond CA 94805-1164
(510) 778-9201

Company (Bait)
Street Address
City State Zip

I am writing to you once again regarding our study of the California bait trade. As of the date of this writing, we have not yet received your completed questionnaire.

While the number of questionnaires that have been returned is encouraging, how accurately we will be able to describe the California live bait trade depends on you and the others who have not yet responded. Because the businesses randomly selected for this survey must stand as representatives for all bait sellers in the state, getting as complete a response as possible is critical. These results, in combination with parallel studies now being conducted, will assist California agencies in understanding the role of ships, boats, aquaculture and the live seafood, bait and aquarium trades in transporting live saltwater animals, and the possible pathways for introducing non-native animals or plants.

It is for these reasons that I am writing again to ask you to complete and return the questionnaire in the enclosed envelope. Depending on your responses, it may take no more than a few minutes to complete. I have enclosed a replacement questionnaire for your convenience.

I want to assure you that any information provided will be kept confidential. No bait shops will be identified in the survey report. If you would like a summary of the results, please write "Results requested" on the back of the return envelope and print your mail or email address below it.

Your contribution to the success of this study will be greatly appreciated.

Most Sincerely,

Andrew Cohen
Project Director
(510) 778-9201
MarineCrab1@gmail.com

Appendix D. Boundaries of the Shelf Faunal Zones and Faunal Regions.

Summarized from Ekman, S. 1953. Zoogeography of the Sea, Sidgwick & Jackson, Ltd., London. 417 pp.

NORTHERN HEMISPHERE: POLAR SHELF FAUNA (Ch. 8)

ATLANTIC-ARCTIC REGION (p165, 167)

- S limit on the European side in the Barent Sea between North Cape & Bear Island; considerably further S on the American side due to Labrador Current.
- The interior of the White Sea is a high-arctic relict region.

PACIFIC-ARCTIC REGION (p167, 169)

- On the American side, S limit is at the Bering Strait; on the Asian side, the Bering Sea, the sea around Kamchatka, the Okhotsk Sea and the northern Kurile Islands are arctic.

NORTHERN HEMISPHERE: COLD-TEMPERATE (BOREAL) SHELF FAUNA

North Atlantic Cold-Temperate (Boreal) Shelf Fauna (Ch. 6, p100)

EUROPEAN ATLANTIC REGION (p100-101)

- "The boreal region is bounded by intermediate zones with representatives from both the neighboring faunas." North Sea is centre of distribution. Southern intermediate zone lies to the SW of Great Britain & the NW of France (but p145 says the SW entrance to the English Channel is the S boundary of the boreal region). Subarctic (boreal-arctic) transitional zone formed by East Finmark, SW part of Barents Sea, shallow parts of White Sea, N & E Iceland, the most SW part of Greenland, & the submarine ridge between the Shetlands, Faroes & Iceland.

AMERICAN ATLANTIC REGION (p135-137)

- Approximate S boundary at Cape Hatteras, though transitional zone extends to Florida. N boundary difficult to define because of complex hydrology, but may vary seasonally or otherwise between Cape Cod and Newfoundland. Although Cape Cod was regarded by older American scientists (eg Packard & Verrill) as an important zoogeographical boundary, "this cannot, however, be correct." Many arctic-subarctic species have S limit at Cape Cod, but many boreal species extend further N and even have S breeding limit there (e. g. the cod). Great seasonal & vertical temperature differences: while May temperatures at Cape Cod (5 °C) compare to Arctic Circle off Norway, August temperatures (19°C) compare to southern Portugal; water at 50 m off Cape Cod is 4-5°C, comparable to southern Greenland. Region between Cape Cod & Cape Hatteras influenced by N water in winter and S water in summer. In summer at Cape Cod and in winter at Cape Hatteras temperatures may fluctuate 11-13°C in 2-5 days.

North Pacific Cold-Temperate (Boreal) Shelf Fauna (Ch. 7, p142)

American Pacific Region (p142-145, 151-152)

- From the middle of Baja California to S of the Yukon River estuary (62°N), or possibly further north to include Norton Sound and the eastern side of the Bering Sea as far as the Bering Strait (65°N). Temperature very uniform (ranging about 10-16°C) over this range, warmed by Kuroshio Current in N and cooled by upwelling in the S from southern Baja to about 45° N (about Cascade Head, OR). This is all essentially boreal, with little room for the development of a warm-temperate fauna.
- Some have subdivided this region (e. g. *Californian, Oregonian, Aleutian*, etc.), while others say it is too uniform to be subdivided. Schenk & Keen (1936, etc.), based on molluscs, distinguish a *Californian Province* reaching to N of Cape Mendocino (42°N), a *transitional zone* with a mixed fauna reaching to Seattle & Puget Sound (48°N), an *Aleutian Province* reaching to N of the Pribilofs (58°N), a second transitional zone reaching to the start of the Arctic zone (62°N).

Asian Region (p153-155)

- From about 36° N on ocean coast of Japan to S end of Okhotsk Sea. Hydrographically similar to American Atlantic Boreal region, with great vertical temperature differences.
- Fauna of the Sea of Japan may consist mainly of a seasonal mix of northern (boreal) and southern (subtropical) elements. Annual temperature range off the coast of Japan is 24° C.

NORTHERN HEMISPHERE: WARM-TEMPERATE SHELF FAUNA

Mediterranean-Atlantic Warm-Temperate Fauna (Ch. 5, p80-82)

- SW entrance of English Channel to possibly Cape Blanco (=Cap Blanc =Al Ra's al-Abyad) (21° N).
- *Mediterranean fauna* (p 80): "Straits of Gibraltar do not represent an important zoogeographical boundary and the Mediterranean is, therefore, not a distinct faunal unit but enters into a greater one which includes" Lusitanian and Mauretanian faunas; while SE Mediterranean may be subtropical fauna, possibly a Tethyan relict.
- *Lusitanian fauna* (p80-82): Straits of Gibraltar to N limit at SW entrance to English Channel.
- *Mauretanian fauna* (p56, 80, 82): Straits of Gibraltar to S probably at least as far as Cape Blanco; essentially subtropical but mixed, forming a transition to warmwater temperate fauna.
- Cape Verde Islands, Canaries, Madeira & Azores usually included in Mauretanian, but Cape Verdes seem clearly subtropical.

Sarmatic Fauna (Ch. 5, p91-98)

- Black Sea combines impoverished Mediterranean & Sarmatic fauna
- Azov and Caspian Seas have Sarmatic fauna.

Other Coasts of the Northern Hemisphere

- Appears to be little development of a distinct warm-temperate fauna. Instead, transitional zones exist between boreal and subtropical faunas: In Europe SW of the English Channel (treated as Lusitanian above and described as the intermediate zone bounding the European boreal region below); in NE Pacific from the middle of Baja California to Mexico-US border (treated as transitional subtropical fauna within the warm-water shelf fauna above, and as part of the cold-temperate shelf fauna below); and possibly on the ocean coast of Japan from Osaka Bay to E of Tokyo (p25).

WARM-WATER (TROPICAL & SUBTROPICAL) SHELF FAUNA

Indo-West Pacific Warm-Water Shelf Fauna (Ch. 2, p11)

- In the W, Red Sea to South Africa a little S of Durban. In the NE, roughly in the Korean Strait on the Asian mainland; further N on the NW coast of Japan; E of Tokyo on the ocean coast of Japan. In the E, the furthest outposts are Hawaii, Marquesas Islands, and Tuamotu (=Paumotu) archipelago. In the S, around Sydney on the E coast of Australia, and S of Shark's Bay on the W coast.
- "...said 'boundaries' are far from being sharply defined. They are, as in all similar cases, transitional and mixed zones rather than boundaries in the strict sense."
- *Indo-Malayan* region (p16-17): region is faunistic centre for IWPWWSF and faunistic centre of region is Malay Archipelago; NE boundary between northern Linshoten Islands and the rest of the Rui-Kiu Islands (=Ryukyu =Nansei-shoto); S boundary between Kei (=Kepulauan Kai) and Aru (=Kepulauan Aru) islands. (Döderlein (1927) designated the smaller Ambonesian region comprising "the Philippines, the Moluccas, the small Sunda Islands and Celebes.")
- *Central Pacific Islands except Hawaii* (p18): boundary with Indo-Malayan/Australia regions is unclear, may or may not coincide with the Andesitic line, the boundary of the "ancient continent," e. g. it's unclear whether Melanesia is in Central Pacific or tropical Australia regions.
- *Hawaiian Islands* (p19).
- *Subtropical Japan* (p22-3): subtropical Honshu fauna: N boundary on E coast is E of Tokyo at about 36° N, where warm Kurishio Current meets cold Oyashio (=Kuril) Current and bends eastward; N boundary on W Coast is further S but indistinct, at about the N part of Korea Strait. Tanaka (1931) based on fish placed boundary on E coast at Chosi (=Choshi) E of Tokyo, and on W coast at Hamada (35° N).
- *Tropical and Subtropical Australia* (p25-27): S limit on W coast at about 29° S, just including Abrolhos (=Houtman) Islands; S limit on E coast at 32-34° S, N of Sydney, or possibly reaching to Port Jackson in Sydney, plus Lord Howe Island. Divided by Clark (1946) and prior naturalists into: *Solanderian Province*, E and S of Torres Strait (essentially the Great Barrier Reef area); and *Dampierian Province*, W of Torres Strait.
- *Indian Ocean* (p27): "the rich Indo-Malayan fauna is distributed over a large part of the Indian Ocean but...the number of species constantly decreases as we proceed in a westerly direction."

Atlanto-East Pacific Warm-Water Shelf Fauna (Ch. 3, p30)

American Pacific Region (p38-39)

- N limit roughly at US-Mexico border, but "it is by no means clear-cut" (tropical zone comprises whole Bay of California but only southern tip of Lower California; further to the N a subtropical transitional fauna changes into a temperate fauna in the region of San Diego); S limit is off Pt. Aguja, Peru (6° S) or at Guayaquil Bay (3-4° S) on Peru-Ecuador border (between 3-6° S there is possibly a transitional zone with a subtropical fauna).
- Galapagos Islands have a tropical fauna (though not wholly, p209); Peruvian (Humboldt) Current turns W at bend in coast at Pt. Aguja.
- Warm-water fauna generally limited to upper 100 m throughout western America.
- Subregions (p45): *Gulf of Panama* (the term "Panamic Province," which is often applied to the whole American Pacific warmwater zone, may be better applied to this subregion); *California Gulf, Galapagos Islands*.

American Atlantic Region (p46-47)

- N to Cape Hatteras or a little S, including Bermuda (at 100-200 m depth some warm-water fauna spread further N in Gulf Stream, some temperate fauna spread further S in surface water near coast); S boundary less clear, but probably at Rio de Janeiro or a little S (40% of mollusks at mouth of La Plata River are West Indian species). (The whole sometimes called the "West Indian" fauna, p53.)
- Coral reefs & mangrove swamps stop at Rio de Janeiro (Cape Frio); coral reefs extend to Bermuda & southern tip of Florida.
- Too poorly known to divide into subregions with certainty (p53-54). Some authors regard the archipelago from Florida to Venezuela as the "Antillean" subregion; while Henderson (1920) regarded the American Atlantic warmwater region as Antillean based on scaphopods. Bermudas fauna is an impoverished branch of the Antilles fauna. Brazil may constitute a separate subregion. N part of Gulf of Mexico "occupies a special position...in possessing features which are" more temperate." The Stephensons (1950) found a zoogeographical boundary for intertidal fauna in N Florida, differentiating S Florida fauna from Florida-Cape Hatteras fauna (possibly based on sediment differences; p46). Cape Hatteras to Florida represents a transitional or mixed zone (some American zoologists consider Cape Canaveral to be a zoogeographical boundary) (p135).

African Atlantic Region (p56-57)

- *Guinea fauna*: tropical fauna with indefinite boundaries, but roughly at Cape Verde (15° N) and about Mossamedes, Angola (15° S) or a little further S, near Great Fish Bay (16-17° S). The poorest of tropical fauna.
- Ascension (8° S) & St. Helena (16° S) islands have mix of fauna from West Indies and South Africa.

SOUTHERN HEMISPHERE: WARM-TEMPERATE SHELF FAUNA (Ch. 9)

SOUTHERN AFRICA

- From about Cape Frio (18°S) in the Atlantic to Algoa Bay (Port Elizabeth) (34°S) in the Indian Ocean.
- *Cape Province Fauna* (p187): subtropical from Algoa Bay to Cape Agulhas or the Cape Peninsula.
- *Namaqua Fauna* (p192): tropical/subtropical from the Cape Peninsula to about 18°S, at about Cape Frio.

AUSTRALIA/NEW ZEALAND

- In Australia, N boundary in the east at 32-34°S (north of Sydney), and in the west in the region north of Perth (p197). In New Zealand, N boundary at about the North Cape of the North Island (p203-204).
- On the basis of echinoderms Clark (1946) distinguished a *Peronian Province*, consisting of the most SE coast of New South Wales and the E coast of Tasmania, and a *Flindersian Province* over the rest of the Warm-Temperate region (p25-27).
- New Zealand fauna divided as follows:
  - *Auporian Province*: northern point of North Island.
  - *Cookian Province*: rest of North Island and northern part of South Island.
  - *Forsterian Province*: southern part of South Island and Stuart Island.
  - *Moriorian Province*: Chatham Islands.
  - *Rossian Province*: the "subantarctic islands" (Auckland & Campbell Islands, which climatically are cold-temperate but which have a "more or less pronounced faunistic affinity to New Zealand," p207) and Macquarie Island (climatically Antarctic?, p208).

SOUTH AMERICA (p208-210)

- N boundary at Pt. Aguja (6° S) or Gulf of Guayaquil (3° S). S boundary apparently north of Chiloe (at about 40-42°S, p214) (*Peru Fauna*). Temperature influenced by Peru or Humboldt Current, a branch of the West Wind Drift which runs N to Pt. Aguja then merges westwards into the South Equatorial Current, and by cold upwelling (between 3°S and 33°S, especially at about 5°S and 15°S). In winter the Equatorial Countercurrent turns S ("El Niño") and merges with Peru Current.
- Text is silent regarding the existence of a Warm-Temperate fauna on Atlantic side.

SOUTHERN HEMISPHERE: COLD-TEMPERATE (ANTIBOREAL or SUBANTARCTIC) SHELF FAUNA (Ch. 10)

<u>South America</u> (p214)

- From N of Chiloe Island (40-42°S) around to possibly the mouth of Rio de la Plata (35-37°S), plus Falkland Islands.
- Notes *Chilenean* and *Patagonian* faunas (noting, however, that Norman (1937) places the latter's boundary at 42°S), and less clearly a *Magellan Fauna*.

SOUTHERN HEMISPHERE: POLAR (ANTARCTIC) SHELF FAUNA (Ch. 10, p220)

- *Low Antarctic*, consisting of South Georgia and Kerguelen, and *High Antarctic* consisting of the rest of the Antarctic coast

Appendix E. Estimating the Number of Shops Selling Bait Species and the Annual Numbers Sold.

Lower bound estimate of the number of retail businesses selling live saltwater bait species in each region, based on the screening calls, mail survey and site visits (Table 16)

	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	31	11	2	0	44
Bloodworms	0	11	8	1	6	26
Lugworms	0	1	2	0	13	16
Grass shrimp	0	17	4	0	0	21
Ghost shrimp	0	12	5	1	6	24
Mud shrimp	0	2	2	0	0	4
Mussels	0	0	0	0	4	4
Sand crabs	0	0	0	0	1	1
Longjaw mudsucker	0	8	8	0	0	16
Staghorn sculpin	0	9	2	0	0	11
Shiner surfperch	0	3	1	0	0	4
Plainfin midshipmen	0	1	0	0	0	1
Northern anchovies	0	1	0	0	4	5
Pacific sardines	0	0	0	0	4	4
Live saltwater bait	0	34	12	2	24	72

Upper bound estimate of the number of retail businesses selling live saltwater bait species in each region, calculated by proportionally increasing the regional lower bound estimates to the estimated upper bound number of shops selling live saltwater bait retail (Table 5)

	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	35	12	2	0	49
Bloodworms	0	12	9	1	7	29
Lugworms	0	1	2	0	14	17
Grass shrimp	0	19	4	0	0	23
Ghost shrimp	0	13	5	1	7	26
Mud shrimp	0	2	2	0	0	4
Mussels	0	0	0	0	4	4
Sand crabs	0	0	0	0	1	1
Longjaw mudsucker	0	9	9	0	0	18
Staghorn sculpin	0	10	2	0	0	12
Shiner surfperch	0	3	1	0	0	4
Plainfin midshipmen	0	1	0	0	0	1
Northern anchovies	0	1	0	0	4	5
Pacific sardines	0	0	0	0	4	4
Live saltwater bait	0	38	13	2	26	79

	Number of sellers reporting	Reported numbers sold annually, from mail survey (Table 11)	Average number sold annually per reporting seller
Pileworms	12	248,150	20,679
Bloodworms	10	184,900	18,490
Lugworms	2	6,740	3,370
Grass shrimp	7	7,253,050	1,036,150
Ghost shrimp	9	258,720	28,747
Mud shrimp	2	13,200	6,600
Mussels	1	24,000	24,000
Sand crabs	0		
Longjaw mudsucker	5	71,600	14,320
Staghorn sculpin	4	85,970	21,493
Shiner surfperch	3	41,300	13,767
Plainfin midshipmen	1	43,200	43,200
Northern anchovies	1	500,000	500,000
Pacific sardines	0		

Lower bound estimate of the number or organisms sold, by species and region

	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	641,049	227,469	41,358	0	909,876
Bloodworms	0	203,390	147,920	18,490	110,940	480,740
Lugworms	0	3,370	6,740	0	43,810	53,920
Grass shrimp	0	17,614,550	4,144,600	0	0	21,759,150
Ghost shrimp	0	344,964	143,735	28,747	172,482	689,928
Mud shrimp	0	13,200	13,200	0	0	26,400
Mussels	0	0	0	0	96,000	96,000
Sand crabs	–	–	–	–	–	–
Longjaw mudsucker	0	114,560	114,560	0	0	229,120
Staghorn sculpin	0	193,437	42,986	0	0	236,423
Shiner surfperch	0	41,301	13,767	0	0	55,068
Plainfin midshipmen	0	43,200	0	0	0	43,200
Northern anchovies	0	500,000	0	0	2,000,000	2,500,000
Pacific sardines	–	–	–	–	–	–
Live saltwater bait	0	19,713,021	4,854,977	88,595	2,423,232	27,079,825

Upper bound estimate of the number or organisms sold, by species and region

	Northern	Bay	Delta	Central	Southern	Total
Pileworms	0	723,765	248,148	41,358	0	1,013,271
Bloodworms	0	221,880	166,410	18,490	129,430	536,210
Lugworms	0	3,370	6,740	0	47,180	57,290
Grass shrimp	0	19,686,850	4,144,600	0	0	23,831,450
Ghost shrimp	0	373,711	143,735	28,747	201,229	747,422
Mud shrimp	0	13,200	13,200	0	0	26,400
Mussels	0	0	0	0	96,000	96,000
Sand crabs	–	–	–	–	–	–
Longjaw mudsucker	0	128,880	128,880	0	0	257,760
Staghorn sculpin	0	214,930	42,986	0	0	257,916
Shiner surfperch	0	41,301	13,767	0	0	55,068
Plainfin midshipmen	0	43,200	0	0	0	43,200
Northern anchovies	0	500,000	0	0	2,000,000	2,500,000
Pacific sardines	–	–	–	–	–	–
Live saltwater bait	0	21,951,087	4,908,466	88,595	2,473,839	29,421,987

Appendix F. Vector Diagnoses of Discarded Bait Listings in the NEMESIS/California Database that are not Considered to be Introductions via the Trade in Live Saltwater Bait

In the NEMESIS/California database, Discarded Bait was listed as a possible vector for 74 introductions involving 22 species. It was listed as the only possible vector for six introductions involving six species, and as one of two to six possible vectors for 68 introductions involving 16 species. Each introduction is a record of a species in a "bay" as defined by NEMESIS, which is a region of the California coast that in some cases consists of an actual bay and in others may include multiple bays. Correspondence indicated that NEMESIS' Discarded Bait vector includes the bait species, packing seaweed and hitchhiking organisms, and includes the disposal of surplus animals and accidental or humane releases (G. Ruiz, P. Fofonoff, pers. comm.). It also includes the harvesting of a bait species by individual anglers in one site and its use and release in another, an element that is not part of the bait trade vector addressed in this paper, as it does not involve the commercial trade in live saltwater bait species. Although the correspondence explained that the Discarded Bait vector was considered to be insignificant prior to 1945 (P. Fofonoff, pers. comm.), four of the 74 introductions have initial records prior to 1945.

One puzzling aspect of the NEMESIS/California database is that both San Francisco Bay and San Pablo Bay are treated as distinct bays, even though San Pablo Bay is a part of San Francisco Bay.[1] It is unclear whether introductions from San Francisco Bay to San Pablo Bay (whatever that may mean), or introductions in the reverse direction, were among the possibilities included when vectors were assigned, and the correspondence didn't clarify this. However, we were informed that the separate listing of San Pablo Bay was a "quirk" that should be fixed (P. Fofonoff, pers. comm.).

Accordingly, of the 74 introductions that listed Discarded Bait as a vector, we deleted five that were introductions to San Pablo Bay. Of the remaining 22 species and 69 introductions, we judged that the evidence is good enough to classify seven established species (involving 12 introductions) as possible or probable introductions via the bait trade (*Codium fragile* subsp. *fragile*, *Aglaothamnion tenuissimum*, *Polysiphonia denudata*, *Maritrema arenaria*, *Microphallus similis*, *Microphallus pygmaeus* group, *Littorina saxatilis* and *Carcinus maenas*). These are diagnosed in the main text of this report. In addition, the evidence suggests that three introductions listed involving two species (*Ascophyllum nodosum* and *Littorina littorea*) that are not established likely resulted, at least in part, from the bait trade. For the remaining 54 introductions, involving 13 species (Table F-1), our analysis suggests that there is only a remote possibility that these introductions occurred as a result of live fishing bait being sold in California, and that the live bait trade should not be classified as a possible vector. To explain this conclusion, diagnoses are provided below for several of these introductions.

[1] The map polygon for San Pablo Bay in the database actually covers Southeast Farallon Island.

Assigning vectors involves making a distinction between transport scenarios that appear probable enough to be counted as a possible vector for a particular introduction, and scenarios that seem so improbable as to not warrant classification as a possible vector for that introduction. Although different authorities may draw the line between these differently, in any single study or database the line should be drawn consistently. That is, if a vector A is assigned to an introduction X, then (1) vector A should also be assigned to all other introductions where the evidence for vector A is as strong or stronger than it is for introduction X, and (2) introduction X should have assigned to it all other vectors for which the evidence is as strong or stronger than it is for vector A. For many of the introductions in Table F-1 that did not appear to be the case, though we did not try to list or discuss the consistency problems here.

Table F-1. Introductions that should not be classified as possibly introduced by the live saltwater bait trade, but which are listed in the NEMESIS/California database with Discarded Bait as a possible vector.

Taxon group	Species	Location*	Alternate vectors**
Gastropoda	*Urosalpinx cinerea*	Newport Bay	
Bivalvia	*Arctica islandica*	Humboldt Bay	DS
Bivalvia	*Geukensia demissa*	_CDA_P029	FC
Isopoda	*Orthione griffenis*	_CDA_P065	
Isopoda	*Orthione griffenis*	Morro Bay	ND
Amphipoda	*Ampelisca abdita*	_CDA_P062	OA(A),F(RB),DS
Amphipoda	*Ampelisca abdita*	_CDA_P062	BW,FC,FA(nO)
Amphipoda	*Ampelisca abdita*	Elkhorn Slough	FC,OA,FA(nO)
Amphipoda	*Ampelisca abdita*	San Francisco Bay	BW,FC,OA,FA(nO)
Amphipoda	*Ampelisca abdita*	Tomales Bay	F(RB),OA(A),DS
Amphipoda	*Ampithoe longimana*	_CDA_P058	F(RB),F(CS),DS
Amphipoda	*Ampithoe longimana*	Morro Bay	F(RB),F(CS),DS
Amphipoda	*Ampithoe longimana*	Newport Bay	BW,F(RB),DS
Amphipoda	*Ampithoe valida*	_CDA_P023	FC
Amphipoda	*Ampithoe valida*	_CDA_P058	BW,F(RB),F(CS),DS
Amphipoda	*Ampithoe valida*	_CDA_P062	BW,FC
Amphipoda	*Ampithoe valida*	_CDA_P095	OA(A),F(RB),ND
Amphipoda	*Ampithoe valida*	_CDA_P112	F(RB),OA(A),DS
Amphipoda	*Ampithoe valida*	Humboldt Bay	BW,F(CS),OA(A),F(RB),DS
Amphipoda	*Ampithoe valida*	Mission Bay	F(RB),BW,DS
Amphipoda	*Ampithoe valida*	Morro Bay	OA(A),F(RB),F(CS),DS
Amphipoda	*Ampithoe valida*	Newport Bay	BW,F(RB),DS
Amphipoda	*Ampithoe valida*	San Diego Bay	BW,F(CS),F(RB),DS
Amphipoda	*Ampithoe valida*	San Pedro Bay	BW,FC
Amphipoda	*Ampithoe valida*	Tomales Bay	F(RB),OA(A),DS
Amphipoda	*Jassa marmorata*	_CDA_P022	F(RB),BW,DS

Taxon group	Species	Location*	Alternate vectors**
Amphipoda	*Jassa marmorata*	_CDA_P058	F(RB),ND,F(CS),DS
Amphipoda	*Jassa marmorata*	_CDA_P086	F(RB),DS
Amphipoda	*Jassa marmorata*	_CDA_P112	F(RB),OA(A),DS
Amphipoda	*Jassa marmorata*	_CDA_P143	F(RB),DS
Amphipoda	*Jassa marmorata*	Humboldt Bay	BW,F(CS),OA(A),F(RB),DS
Amphipoda	*Jassa marmorata*	Morro Bay	F(RB),OA(A),F(CS),DS
Amphipoda	*Jassa marmorata*	San Diego Bay	BW,F(CS),F(RB),DS
Amphipoda	*Jassa marmorata*	Tijuana Estuary	F(RB),BW,DS
Amphipoda	*Jassa marmorata*	Tomales Bay	F(RB),OA(A),DS
Amphipoda	*Melita nitida*	Humboldt Bay	BW,F(CS),OA(A),F(RB),DS
Amphipoda	*Microdeutopus gryllotalpa*	Humboldt Bay	BW,F(CS),F(RB),DS
Decapoda	*Carcinus maenas*	Humboldt Bay	BW,ND
Decapoda	*Carcinus maenas*	Morro Bay	ND
Decapoda	*Palaemon macrodactylus*	_CDA_P022	DS
Decapoda	*Palaemon macrodactylus*	Mission Bay	BW,DS
Decapoda	*Palaemon macrodactylus*	Morro Bay	DS
Decapoda	*Palaemon macrodactylus*	San Pedro Bay	BW,ND
Decapoda	*Palaemon macrodactylus*	Santa Monica Bay	BW,ND
Decapoda	*Palaemon macrodactylus*	Tijuana Estuary	BW,ND,DS
Actinopterygii	*Acanthogobius flavimanus*	_CDA_P022	ND
Actinopterygii	*Acanthogobius flavimanus*	_CDA_P045	ND
Actinopterygii	*Acanthogobius flavimanus*	_CDA_P061	ND
Actinopterygii	*Acanthogobius flavimanus*	_CDA_P112	ND
Actinopterygii	*Acanthogobius flavimanus*	Elkhorn Slough	ND
Actinopterygii	*Acanthogobius flavimanus*	Mission Bay	ND
Actinopterygii	*Acanthogobius flavimanus*	San Diego Bay	BW,ND
Actinopterygii	*Acanthogobius flavimanus*	Santa Monica Bay	ND
Actinopterygii	*Acanthogobius flavimanus*	Tomales Bay	ND

* The location of the introduction as listed in the NEMESIS/California database in the “bayname” field.

** The alternate vectors as listed in the NEMESIS/California database:

BW = Ballast Water
DS = Discarded Seafood
FA(nO) = Fisheries Accidental (not Oyster)
FC = Fouling Community
F(CS) = Fouling (Commercial shipping)
F(RB) = Fouling (Recreational Boats)
ND = Natural Dispersal
OA = Oyster Accidental
OA(A) = Oysters-Accidental (Atlantic)

SELECTED VECTOR DIAGNOSES

Urosalpinx cinerea

NEMESIS listing: Introduced into Newport Bay (first record: 1957). Discarded Bait is listed as the sole vector.

Diagnosis: The Atlantic oyster drill *Urosalpinx cinerea* was introduced into San Francisco Bay by 1890 in shipments of Atlantic oysters plant in the bay for culturing, and was found in Tomales Bay in 1935 and Humboldt Bay in 1941 (Carlton 1979; Cohen & Carlton 1995). Introduction to these latter two bays was also almost certainly with oysters planted for culturing. *Urosalpinx cinerea* was reported by Human (1971), who stated that “a moderate amount of shore fishing takes place at the site, which suggests that *Urosalpinx* may have been introduced with purchased fish bait.” This may be a reference to transport in the seaweed packing of Maine bait worms, as such worms were sold in the Newport Bay area in the early 1970s (Carlton 1979, at p. 61), although *Urosalpinx* has never been reported in the *Ascophyllum* packing for live bait or seafood (Tables 24-27). However, there is a specimen of *U. cinerea* collected from Newport Bay in 1957 in the L.A. County Natural History Museum (Carlton 1979), which may be before bait worms were imported from Maine, and V. Human reported in correspondence to J. Carlton that *U. cinerea* had been collected in Newport Bay “for over 30 years” (Carlton 1979, at p. 386) thus pushing its introduction to the bay back to around 1940 or earlier, long before our earliest record of Maine bait worms imported into California. Introduction via the bait worm trade thus seems very unlikely or impossible.

According to Barrett (1963), the Newport Oyster Company was established around 1933, operating oyster beds and holding oysters in floats in Newport Bay “for the production of domestic and imported cocktail oysters.” It seems very likely that *U. cinerea* discovered in the bay around 1940 arrived on oyster stock brought in either from other oyster-producing bays on the Pacific Coast (Tomales or Humboldt Bay) or from the East Coast.

Arctica islandica

NEMESIS listing: Listed as a failed introduction into Humboldt Bay in 1998, with Discarded Bait and Discarded Seafood listed as possible vectors.

Diagnosis: Although the ocean quahog *Arctica islandica* is sometimes sold as bait on the East Coast, there is no record of it ever having been imported and sold in California as bait. Since it lives offshore at depths of 14-256 m (mainly at 21-65 m) (Cargnelli *et al.* 1999), it would not occur in *Ascophyllum nodosum* gathered intertidally for bait worm packing. It is thus virtually certain that *Arctica islandica* did not arrive in Humboldt Bay via the bait trade.

The Humboldt Bay record consists of pieces of shell from a maximum of five clams, found on a gravel beach. The Discarded Bait listing for this species in the NEMESIS/California database is presumably based on the suggestion of Chapman and Miller (1999) that the shells are the remains of clams purchased in a seafood market and used as fishing bait. Chapman and Miller (1999) state that there is no evidence that these clams were live when discarded, nor is there any way to know whether they were alive, fresh but dead, or frozen when purchased (if they did come from a seafood market). Normally we would not consider the discarding of dead shells to be an introduction.

Ampelisca abdita

NEMESIS listing: Introduced into Tomales Bay (first record: 1969) and Bolinas Lagoon (1971), with Discarded Seafood, Fouling (Recreational Boats) and Oysters Accidental (Atlantic) also listed as possible vectors.

Diagnosis: *Ampelisca abdita* is a small, tube-dwelling amphipod native to the northwest Atlantic coast from central Maine to the eastern Gulf of Mexico (Bousfield 1973). It is common in oyster beds and in fouling and could be readily transported in ship, boat or equipment fouling or in transfers of oysters between sites. As it sometimes migrates into the water column (Chapman 1988), transport in ballast water, though probably less likely, cannot be ruled out as a possible mechanism. It was first collected on the Pacific Coast in San Francisco Bay in 1954 (Carlton 1979), though Chapman (1988) argued that it might have been present for a long time before.

Cohen and Carlton (1995) listed ballast water and transport with Atlantic oysters as possible vectors for its introduction from the Atlantic into San Francisco Bay. Its limited occurrence in the water column and the late date of its discovery relative to the period of commercial plantings of Atlantic oysters (*Crassostrea virginica*) in San Francisco Bay reduce the probability of ballast water or oysters being the vector; despite the long distance involved, hull fouling on ships should probably be added as a possible vector.

Ampelisca abdita's occurrence in Tomales Bay and Bolinas Lagoon is most readily explained as an introduction from the abundant population in nearby San Francisco Bay, where densities above 10,000/m^2 are common (Hopkins 1986) (or possibly first into one of these two bays and thence into the other), either as fouling on boat hulls or possibly on some type of fishing, construction or other equipment, or as natural dispersal (for a drift study supporting the latter possibility see Conomos 1979). Considering Chapman's (1988) comments on the potential for long-delayed discovery, transfer on oyster plantings from either San Francisco Bay, or perhaps directly from the Atlantic coast, is also a possibility (the last recorded commercial plantings in Tomales Bay of *Crassostrea virginica* from the Atlantic coast were in 1875, but there were some experimental plantings of the European flat oyster *Ostrea edulis* from Milford, Connecticut in the 1960s (Dahlstrom 1964; Carlton 1979)).

Since *A. abdita*'s native range includes the source region for the worms *Alitta virens* and *Glycera dibranchiata* imported live into California for use as fishing bait, it is possible that it could have arrived in these two bays in the seaweed packing for these species; but the lack of any record of this species in studies of this bait vector (Lau 1995; Cohen *et al.* 2001; Haska *et al.* 2011; Cohen 2012) and the limited volume of such seaweed that is likely to have been discarded into these two small bays prior to 1969 or 1971 (the regular importing of marine bait worms from Maine to California appears to have started in the late 1960s) suggests that this is a more remote possibility.

Considering all the evidence, *Ampelisca abdita* most likely arrived in Tomales Bay and Bolinas Lagoon from San Francisco Bay (either directly, or first into one of the two bays and thence into the other) via natural dispersal or as fouling on boat hulls or equipment. A less likely possibility is transfer on oyster plantings from either San Francisco Bay or the Atlantic coast, probably long before the dates of discovery. Introduction via the commercial trade in live bait is a remote possibility, perhaps roughly co-equal in probability with various other introduction scenarios that could be developed such as releases/escapes from scientific or academic work, or releases of ballast water into coastal waters in the general region outside of Tomales Bay and Bolinas Lagoon.

Ampithoe valida

NEMESIS listing: Introduced into Newport Bay (first record: 1942), Tomales Bay (1942), Morro Bay (1965), Bolinas Lagoon (1975), Bodega Bay (1975), Humboldt Bay (2000), Santa Catalina Island (2001), Mission Bay (2001) and San Diego Bay (2001). Discarded Seafood and Fouling (Recreational Boats) were also listed as possible vectors for all nine sites, and at various sites in different combinations Ballast Water (5 sites), Fouling (Commercial Shipping) (4 sites) and Oysters-Accidental (Atlantic) (5 sites) were listed as well.

Diagnosis: *Ampithoe valida* is a small, tube-dwelling amphipod native to the northwest Atlantic coast from New Hampshire to Chesapeake Bay (Bousfield 1973). It is common in fouling and has been found on oyster beds, and could be readily transported in ship, boat or equipment fouling or in transfers of oysters between aquaculture sites. It was first collected on the Pacific Coast in San Francisco and Tomales bays in 1941, and was subsequently found and was reported as established in Morro Bay, Bolinas Lagoon, Bodega Bay and Humboldt Bay (Carlton 1979). NEMESIS' listings of Newport Bay, Santa Catalina Island, Mission Bay and San Diego Bay as sites where *A. valida* is established are apparently based on CDFG's Marine Invasive Species Program reporting these species as rare at these sites in 2001 (Fairey *et al.* 2002; Cohen and Carlton (1995) reported only a single record from Newport Bay, in 1942). As we have discussed elsewhere, records from the MISP database need to be verified.

Cohen and Carlton (1995) listed ballast water, ship fouling and transport with Atlantic oysters as possible vectors for *Ampithoe valida*'s introduction from the Atlantic to the Pacific Coast.

Ampithoe valida's occurrence in Tomales Bay is most readily explained as an introduction from San Francisco Bay in fouling on boat hulls or on some type of fishing, construction or other equipment, or as natural dispersal (for a drift study supporting the latter possibility see Conomos 1979); or as a delayed discovery of an introduction from the Atlantic with oyster stock imported for aquaculture (the last recorded plantings of *Crassostrea virginica* from the Atlantic coast in Tomales Bay were in 1875 (Carlton 1979)). Its occurrence in the other four central or northern California sites (Morro, Bodega and Humboldt bays and Bolinas Lagoon) could be due to transfers of oysters for aquaculture from Tomales Bay (or from one of the four bays colonized first); or for Morro or Humboldt Bays, possibly from the Atlantic (the last recorded plantings of *Crassostrea virginica* from the Atlantic coast were in 1911 in Humboldt Bay and 1938 in Morro Bay, but there were experimental plantings of the European flat oyster *Ostrea edulis* from Milford, Connecticut in both bays in 1963-1965 (Bonnot 1935; Dahlstrom 1964; Carlton 1979)); or as fouling on boats or equipment or by natural dispersal from San Francisco or Tomales Bay (or from one of the four bays colonized first). The four southern California records from 2001 (San Diego, Mission and Newport bays and Santa Catalina Island), if valid, could be due to fouling on boats or equipment or natural dispersal from the previously invaded Pacific Coast bays; or for some of the sites, transfers of aquaculture oysters from previously invaded Pacific Coast bays, or delayed discoveries of oysters imported from the Atlantic coast for aquaculture (there are records of *Crassostrea virginica* from the Atlantic planted in San Diego Bay in the 1880s and held in Newport Bay in the 1930s, *C. gigas* possibly from Japan or Pacific Coast sites planted in Newport Bay in the 1930s-1940s, and an experimental planting of oysters (species and source not known) at Santa Catalina Island in the 1960s (Carlton 1979). *A. valida* could also have arrived in San Diego Bay in ballast water.

Since *Ampithoe valida's* native range does not extend as far north as Boothbay Harbor, Maine, which is the main (or possibly sole) source region for marine bait worms imported as live fishing bait into California from the Atlantic Coast (Cohen 2012), it is unlikely that it arrived in these bays as a result of the commercial trade in these worms. In addition, the first records of *A. valida* in Tomales and Newport Bays are prior to the earliest record of live bait imports to California from Maine in the mid-1950s, and *A. valida* was not found by any of studies of species associated with shipments of live marine bait worms from Maine (Lau 1995; Cohen *et al.* 2001; Haska *et al.* 2011; Cohen 2012; Crawford (2001) reported finding *Ampithoe rubricata* in the seaweed packing of Maine baitworms, but as discussed by Cohen (2012), the taxa identified in that study require verification).

Considering all the evidence, the *Ampithoe valida* reported in these bays most likely arrived from San Francisco Bay or from another previously invaded Pacific coast bay via natural dispersal, as fouling on boat hulls or equipment, or, for some of the bays, in transfers of oysters for aquaculture. For some of the bays, transport with plantings of *Crassostrea virginica* from the Atlantic coast is possible (in some of these bays, such plantings occurred as late as the 1930s), or with experimental plantings of *Ostrea edulis* from Connecticut in the 1960s. Ballast water (from San Francisco Bay, or much less likely from the Atlantic) is a possibility for San Diego Bay.

Jassa marmorata

NEMESIS listing: Introduced into La Jolla (first record: 1990), Santa Catalina Island (1990), Half Moon Bay (1990), Morro Bay (1990), San Diego Bay (1990), Humboldt Bay (2000), Bodega Bay (2001), Crescent City Harbor (2001), Tomales Bay (2001) and Tijuana Estuary (2005). Discarded Seafood and Fouling (Recreational Boats) were also listed as possible vectors for all ten sites, and at various sites in different combinations Ballast Water (4 sites), Fouling (Commercial Shipping) (4 sites) and Oysters-Accidental (Atlantic) (4 sites) and Natural Dispersal (for Santa Catalina Island only) were listed as well.

Diagnosis: *Jassa marmorata* is a tube-dwelling amphipod native to the northwest Atlantic coast from Texas to southern Newfoundland, with introduced populations in Europe, the South Atlantic, Australia and New Zealand (Bousfield 1973; Conlon 1990; Cohen & Carlton 1995). Taxonomic issues have prevented a clear understanding of *J. marmorata*'s distribution and its global invasion history has not been articulated. It is common in fouling, including ship hulls, pilings, buoys, etc., and occurs in oyster beds, and could be readily transported in ship, boat or equipment fouling or in transfers of oysters between sites. It has also been collected in ballast tanks after a 15-day voyage (Cohen & Carlton 1995). The first records on the Pacific coast of specimens that appear to be this species (estuarine members of the *Jassa falcata* group) are from the early 1940s in northern California and Baja California.

Cohen and Carlton (1995) listed ballast water and ship fouling as possible vectors for *Jassa marmorata*'s initial introduction to the Pacific coast. They considered introduction with oysters used in aquaculture to be less likely due to the lag between the main period of oyster imports from the Atlantic (late 1800s to early 1900s) and the first report of possible *J. marmorata* on the Pacific coast (1940s).

The ten Pacific coast sites listed with initial records in 1990 or later are most readily explained as introductions from previously invaded Pacific coast sites via hull or equipment fouling, or natural dispersal. For some bays, oyster transfers for aquaculture is another possibility; and for San Diego Bay, *J. marmorata* could have arrived in ballast water from San Francisco Bay. The San Diego Bay records could also be introductions from overseas in ballast water or hull fouling, and the Morro Bay, Humboldt Bay and Tomales Bay records could be due to imports of the Pacific oyster *Crassostrea gigas* from Japan for use in aquaculture, which appear to have occurred at least into the 1970s (Carlton 1979).

Less likely possibilities include introduction from overseas to Humboldt Bay in ballast water or hull fouling (there is relatively little overseas ship traffic to Humboldt Bay); introduction from the Atlantic to Morro Bay, Humboldt Bay or Tomales Bay with oyster plantings (there were experimental plantings of the oyster *Ostrea edulis* from

Connecticut in the early 1960s); and introduction from the Atlantic in the seaweed packing for the worms *Alitta virens* and *Glycera dibranchiata* imported live into California for use as fishing bait.

Considering all the evidence, the *Jassa marmorata* reported in these bays most likely arrived from San Francisco Bay or another previously invaded Pacific coast bay via natural dispersal, as fouling on boat hulls or equipment, or, for some of the bays, in transfers of oysters for aquaculture, or, for San Diego Bay, in ballast water. For some of the bays, transport with plantings of *Crassostrea gigas* from the Japan (which continued into the 1970s) is also possible. More remote possibilities are introduction to Humboldt Bay in ballast water, to some of the bays with experimental plantings of *Ostrea edulis* from the East Coast, or introduction from the East Coast with bait worms.