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

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Introduction

The live seafood trade imports a variety of marine invertebrates and fish into California from other parts of the world and sells them, often still alive, to the general public through food markets and via the internet. Unlike many other invasion vectors, however, the live seafood trade does not involve directly releasing or exposing these organisms to California waters (as ballast water, hull fouling, the live bait trade and aquaculture all do). Live seafood organisms are imported for the purpose of human consumption, and for the seafood organism to be introduced into the environment some act or accident must break the pathway from food seller to human stomach, and divert the organism into the water. There appear to be three main mechanisms for this:

- the accidental escape or discharge into coastal waters of live seafood organisms from the holding tanks of shore-side food dealers or restaurants;
- the intentional discarding into coastal waters of sick or damaged (but still viable) seafood organisms, excess seafood organisms, or otherwise unwanted seafood organisms by food dealers, restaurants or consumers; or
- the intentional release of live seafood organisms into coastal waters either to try and establish a fishery, or as religious (Buddhist) or secular (animal rights) mercy releases.

In addition, organisms associated with live seafood, including parasites and epibiota, may reach coastal waters by any of these mechanisms, as well as when dead seafood organisms, their shells or their shipping/packing media (such as seaweed) are discarded into coastal waters.

The overall goal of this project is to assemble, summarize and analyze the information needed to assess the risk of the trade in live marine seafood introducing and establishing non-native species in California waters. To those ends, we investigated the scale and scope of the live seafood trade; identified trade and hitchhiker species; estimated the numbers transported into and sold in California's coastal counties; and identified organisms that were introduced and established by the seafood trade in the past.

Previous Studies

There have been few studies of the live marine seafood trade as an invasion vector. Miller (1969) reported on the live Atlantic organisms found in the seaweed (*Ascophyllum nodosum*) used as packing for live New England lobsters, *Homarus americanus*, shipped to California, and Carlton (1979) described this mechanism, stating that the Atlantic periwinkle *Littorina littorea* was apparently introduced into San Francisco Bay by it (referring to several collections of one to six specimens since 1968, but no established population). Cohen and Carlton (1995) listed "in seaweed packing for live New England baitworms or lobsters" as the vector or a possible vector for three non-native species established in California. Cohen *et al.* (1995) and Carlton and Cohen (2003) discussed this vector for one of these species, the Atlantic green crab *Carcinus maenas*. Olson

(1999) reported finding 5-11 multicellular organisms, mainly in the seaweed packing, in three shipments of New England lobsters ordered online and received in Washington state, but did not identify the species. Weigle (2002) and Weigle *et al.* (2005), as part of a study of non-shipping vectors of bioinvasions, surveyed wholesale seafood dealers in Massachusetts to assess the species and quantities of live and fresh marine seafood organisms imported from outside New England, and exported to locations out of New England, and to understand some aspects of the holding and handling of these species. Weigle (2007) conducted a similar survey for Maine. Chapman *et al.* (2003) developed a list of non-native bivalve species available in western U.S. markets from publications, Internet searches and personal observations, determined which of these had become established in various regions, calculated a past rate of establishment, and used the binomial distribution to calculate the probability of non-native seafood bivalves becoming established in the future.

Methods

<u>Definitions, Classifications and Scope</u>

We identified marine species sold as live seafood in California, and assembled information in order to assess:

- the source region where it is harvested or grown
- the regions where it is sold in California
- the quantities sold
- the shipping and packing media used (*e.g.* seaweed, seawater), and how these are disposed of
- holding procedures
- hitchhiker species
- prior invasion history in California.

This study addresses both trade species (the organisms that are intended to be sold as seafood) and hitchhiker species (any species that are transported and sold with the trade species, including any seaweed used to pack the trade species, any organisms that are attached to the trade species or packing seaweed or found on or in among them, and any parasites carried by trade or hitchhiker species).

We classified species as native, non-native or cryptogenic. These are explicitly location-contingent terms. A species is classified as native in reference to its presence within its native range,[1] and classified as non-native when referring to its presence or potential presence elsewhere. Cryptogenic is applied to species in reference to locations where

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[1] 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 neither appropriate nor helpful.

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 (2004a).

This study's focus is the risk of species invasions in California resulting from the commercial trade in live marine seafood species in California. Thus we look at introduction pathways that involve, at some stage, a legal commercial transaction with a buyer of live marine seafood located in California. Our primary interest was in seafood species collected or grown outside of California and transported into the state for live sale, but we also compiled and analyzed some information on species grown or collected within the state. We used two systems to organize the data regionally: bioregions, dividing the state into Northern, Central and Southern California regions with boundaries at Cape Mendocino and Point Conception; and county regions, dividing the coastal counties into North, Bay, Central and South regions (Appendix A).

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

Data Sources

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.[2] Given the

[2] 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

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 us and the other research teams through a special arrangement with OST, lists "Discarded Seafood" as a possible vector for 48 introductions into California bays involving 14 marine species. We considered the evidence for each of these being introduced by the commercial trade in live marine seafood in California.

Survey of Seafood Wholesalers

Following the methods of Weigle (2002, 2007) and Weigle *et al.* (2005), in Sept.-Dec. 2011 we used online business directories (www.yellowpages.com) to compile a list of wholesale seafood dealers located in California's coastal counties.[3] We conducted some screening calls to eliminate duplicate entries, that is, entries of the same business under variant or different names or at different addresses.

We prepared a survey booklet (Appendix B) and other survey materials (Appendix C) and in Mar. and Apr. 2012 conducted a mail survey using Dillman's Total Design Method (Dillman 1978; Salant and Dillman 1994). Survey questions addressed the types and quantities of live marine seafood 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, the geographic region and proximity of facilities to coastal waters, and the geographic regions the seafood species are shipped to. 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.

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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).

[3] This included 34% of California's counties, covered about 22% of the state's area, and extended 15-60 miles from the coast (Appendix A).

- 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 live seafood imports and sales.

In the data sheets, seafood species identified by variable trade or common names in the responses were converted to scientific names and standard common names. Quantities reported in pounds were converted to numbers of organisms using estimates based on online seafood websites, our observations of live seafood for sale during site visits, and other information (Appendix D). The summary sheets were formatted to automatically calculate summary data.

Site Visits and Examination of Seafood Species

We further investigated the types of live marine seafood species sold in California by visiting retail food markets in the San Francisco Bay Area and Los Angeles/Orange County area, with a focus on Chinese food markets, since previous investigations had indicated these generally carried a wider variety of live seafood species than non-Chinese food markets. We identified seafood species sold by gross visual examination in the store or, where necessary, by purchase and examination or dissection in the laboratory. To assist in the identification of the trade species and associated hitchhiker species we used 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 appropriate taxonomic experts.

When available, we recorded relevant information from signs, including the common name of the species, the source region and whether it was farmed or wild-caught. If the proprietors or salespeople were open to conversation we asked them about species in the store and species that were sold by the store at other times, source regions, quantities, etc. In these conversations, we identified ourselves as researchers and described the focus of our study. On some site visits we were assisted by a translator who was fluent in Cantonese.

We investigated the hitchhiker species transported with live seafood species by gross visual examination of the seafood species in the store, noting associated or attached organisms, and purchasing seafood items as needed in order to identify or confirm the identity of the hitchhiker species by dissecting and examining samples under a microscope in the laboratory. All hitchhiker specimens that we collected were preserved and will be deposited with the California Academy of Sciences.

We purchased several lots of the Atlantic periwinkle *Littorina littorea* to look for parasites. We examined the foot color of live snails, which is an indicator of infection by the digenean trematode *Cryptocotyle lingua* (Willey and Gross 1957; Huxham *et al.* 1993; Wood *et al.* 2007), and dissected the snails We also looked for parasites in a few specimens of other seafood organisms that we purchased.

Live Seafood Online

We searched the internet for live seafood offered for sale and shipment to consumers in California, and recorded the species offered, source regions and the number of websites offering each species.

Analyses

We reviewed the data and methods used by Chapman *et al.* (2003) to estimate the probability of future successful introductions of bivalve species via the live seafood trade, corrected several data issues, and recalculated the probabilities.

Results

The California Trade in Live Marine Seafood

Results from Survey

In any survey errors of several types may arise, including:

- Miscommunication errors, *i.e.* a respondent understanding a question to mean something other than what the survey designer intended, or providing an answer that the surveyor misunderstands.
- Bias in the return of surveys, in “item nonresponse” (skipping some questions) or in “early termination” (ending the survey before getting to all questions) (Dillman 1978), *i.e.* some parties not returning or completing surveys for reasons related to the content of the survey questions (such as not wanting to disclose information that might lead to regulatory actions), so that the answers received do not represent an unbiased sample of the surveyed population.
- Inaccurate and misleading answers, including answers intended to discourage regulatory actions, or answers that the surveyed parties thinks the surveyor wants (“social desirability bias”—Dillman 1978).

While good survey design can help to minimize these types of error, all surveys remain subject to them to a greater or lesser degree. This should be borne in mind when considering the survey results.

We assembled an initial list of 450 businesses in California's coastal counties from the businesses listed under wholesale seafood categories in an online directory. After screening calls to eliminate businesses that were listed more than once under different names or addresses, we mailed surveys to the remaining 411 businesses. Five of these also turned out to be duplicates, 12 were not seafood wholesalers, five confirmed that they were out of business, and 53 had moved with no forwarding address (Table 2), which we took as an indication that they were out of business. Of the remaining 336, we received completed surveys from 127, one sent the questionnaire back with a note stating that he chose not to participate in the survey, and the rest did not respond. The overall response rate was 39%, which compares well with rates of 26% (Weigle 2002; Weigle *et al.* 2005) and 30% (Weigle 2007) in previous mail surveys of wholesalers of live marine seafood. Response rates varied among regions from 25% to 46%. Most of the respondents were located the South county region (62% of the total) or Bay county region (31% of the total).

Table 2. Breakdown of screening results by county region.

Business category	North	Bay	Central	South	All
Duplicate	1	2	0	2	5
Not a seafood wholesaler	0	2	3	7	12
Confirmed out of business	0	3	1	1	5
Moved with no forwarding address	1	14	7	31	53
Replied	3	40	6	80	129
No Answer	9	48	7	142	206
Refused to answer	0	1	0	0	1
Total	14	110	24	263	411
% replies	25%	45%	46%	36%	39%

Of the 129 respondents to the survey, 38 (29%) reported that they sell live marine seafood. If the businesses that did not respond to the survey are similar to those that did, then extrapolating to the 411 businesses in the survey list suggests a total of 121 wholesale businesses selling live marine seafood in California's coastal counties. Sixty-one percent of the respondents that sell live marine seafood are located south of Point Conception.

The survey respondents reported selling at least 30 species of live marine seafood (Table 3), and provided a total of 121 records (respondent x species) of seafood species sold. These species included one echiurid worm, 12 bivalves (clams, mussels, oysters, scallops), one cephalopod, six decapods (shrimp, crabs, lobsters) and ten fish. In addition, one surveyed business that communicated with me by email but did not submit a survey reported selling two snail species ("periwinkle," probably *Littorina littorea*, and "conch," probably *Busycotypus canaliculatus*). The most commonly reported species were, in order, American lobsters, Dungeness crab, spot prawn, Pacific oysters and red abalone (Table 3).

Table 3. Reported species; number of sellers among survey respondents, by species; species source type according to survey respondents.

Common name	Scientific name	Number of sellers	Wild-caught	Farmed
Spoon Worm	*Urechis unicinctus*	1	1	
Red Abalone	*Haliotis rufescens*	7		7
Clam	(unidentified)	3		2
Northern Quahog	*Mercenaria mercenaria*	3		2
Manila Clam	*Ruditapes philippinarum*	3		3
New Zealand Cockle	*Chione stutchburyi*	2		1
Pacific Geoduck	*Panopea abrupta*	1		1
Edible Mussel	*Mytilus edulis*	3		2
Bay Mussel	*Mytilus* sp.	3		2
New Zealand Mussel	*Perna canaliculus*	2		1
Pacific Oyster	*Crassostrea gigas*	7		6
Virginia Oyster	*Crassostrea virginica*	3		2
Kumamoto Oyster	*Crassostrea sikamea*	2		1
Flat Oyster	*Ostrea edulis*	1		
Scallop	(unidentified)	1	1	
Whiparm Octopus	*Octopus variabilis*	1	1	
Spot Prawn	*Pandalus platyceros*	10	9	1
Blue Crab	*Callinectes sapidus*	3	3	
Dungeness Crab	*Cancer magister*	18	17	
King Crab	*Paralithodes camtschaticus*	2	2	
Crab	(unidentified)	1		1
American Lobster	*Homarus americanus*	22	22	
California Lobster	*Panulirus interruptus*	5	4	1
Giant Sculpin	*Myxocephalus polyacanthocephalus*	1	1	
Black Cod	*Notothenia microplepidota*	2	1	1
Ling Cod	*Ophiodon elongatus*	1		
Bastard Halibut	*Paralicthys olivaceus*	3		3
Starry Flounder	*Platichthys stellatus*	1		1
Thornyhead	*Sebastolobus* sp.	2	2	
Rockfish	*Sebastes* sp.	1		1
Sheepshead	*Semicossyphus pulcher*	1	1	
Sea Urchin	*Strongylocentrotus* sp.	1		
Sea Cucumber	*Stichopus japonicus*	1	1	

The source areas for these species reported by the wholesalers generally conformed to our prior understanding of where these species are primarily harvested or farmed. A few surprises for us were: a report of littleneck clams (*Mercenaria mercenaria*) imported from Florida (which might possibly include a related species, *M. campechiensis*); blue crab (*Callinectes sapidus*) more often reported from Texas and Louisiana than from Maryland; and starry flounder and king crab, species that occur in U.S. waters, reported in part from South Korea.

Table 4. Source regions of species according to survey respondents.

Common name	Reported source region (number of respondents reporting)
Spoon Worm	South Korea (1)
Clam (unidentified)	CA, OR, WA (1); Southern CA (1); East Coast FL (1)
Northern Quahog	East Coast (1); VA (1); FL (1)
Manila Clam	British Columbia, WA, CA (1); British Columbia, WA (2)
New Zealand Cockle	New Zealand (2)
Pacific Geoduck	Southern CA (1)
Pacific Oyster	British Columbia, WA, OR, Central CA (1); Canada, WA, OR, CA (1); Canada, WA (1); WA (1); Northern & Central CA; Central CA (1); Southern CA (1)
Virginia Oyster	New Brunswick, NY, Cape Cod (1); Canada, WA, OR, CA (1); VA (1)
Kumamoto Oyster	British Columbia, WA, OR, Central CA (1); Canada, WA, OR, CA (1)
Flat Oyster	New Brunswick (1)
Scallop (unidentified)	East Coast (1)
New Zealand Mussel	New Zealand (2)
Edible Mussel	Canada (1); Prince Edward Island (2)
Bay Mussel (*Mytilus*)	Prince Edward Island, WA, CA (1); Canada, US, Mexico (1); Canada (1)
Red Abalone	CA (1); Central CA (2); So CA (2); Baja CA (1)
Whiparm Octopus	South Korea (1)
Spot Prawn	Central CA (2); Northern & Southern CA (1); Central & Southern CA (1); Southern CA (4)
Blue Crab	MD, LA (1); LA (1); TX (1)
Dungeness Crab	AK, Canada, WA, OR, Northern & Central CA (1); Canada, WA, OR, CA (1): British Columbia, WA, OR (1); WA, OR, Northern CA (1); OR (1); CA (1); Northern CA (1); Northern & Central CA (2); Central CA (4); Monterey CA (1); ME or Canada (1)
King Crab	AK, South Korea (1)
Crab (unidentified)	Southern CA (1)
American Lobster	Nova Scotia, New Brunswick, ME, NH (1); Canada/New England (1); Canada, ME (4); East Coast (2); ME (4); ME, NY (1); ME, Boston (1); MA (1); Boston (1)
California Lobster	Southern CA (3); CA, Mexico (1)
Giant Sculpin	Mexico (1)
Black Cod	Southern CA (1); Southern CA, Mexico (1)
Ling Cod	Canada, Mexico (1)
Bastard Halibut	South Korea (3)
Starry Flounder	South Korea (1)

Common name	Reported source region (number of respondents reporting)
Thornyhead	Central CA (1); Southern CA, Mexico (1)
Rockfish	Southern CA (1)
Sheepshead	Southern CA, Mexico (1)
Sea Urchin	Northern CA (1)
Sea Cucumber	South Korea (1)

Based on the survey responses, the majority of wholesalers handling live marine seafood are in the Southern California bioregion, south of Point Conception (60%), with 35% in the Central California bioregion and 5% in the Northern California bioregion, north of Cape Mendocino (Table 5). The distribution of the numbers of live organisms sold wholesale is similar to the distribution of wholesalers, with 65%, 34% and 1% sold by wholesalers in the Southern, Central and Northern California bioregions, respectively (Table 5). Twenty-five percent of these are exported or transshipped to locations outside of California (Table 6). About 80% of the live New Zealand bivalves that arrive in California are shipped on to other sites through Southern California, and 26% of the live American lobsters that arrive from the East Coast are shipped out, again through Southern California wholesalers. Of the live organisms that remain in the state, 64%, 35% and 1% are sold to businesses in the Southern, Central and Northern California bioregions, respectively (Table 6). This closely parallels the distribution of the wholesalers, suggesting, at least at this gross level of analysis, that once wholesalers receive live seafood it is rarely shipped across bioregional boundaries to retail establishments in other regions of the state. A closer examination of the data supports this, especially for imported species: for example, all of the reported worms, octopus, crab, fish and sea cucumbers imported from South Korea, and all the bivalves imported from New Zealand that are not transshipped are received by Southern California wholesalers and sold to Southern California retailers; and all the flat oysters reported from New Brunswick are received by Central California wholesalers and sold to Central California retailers (Tables 5 and 6). Overall, 95% of wholesalers reported that 100% of their California sales were to retailers located within the same bioregion.

Seventy-nine percent of the respondents that sell live marine seafood hold those species in tanks of water. Thirty percent of these discharge that water into a water body, with 18% filtering or treating it first and 12% discharging it without treatment. Of the businesses selling live marine seafood, 39% are within 500 feet of a salt or brackish water body.

The most commonly reported packing materials that seafood organisms arrive in are ice, ice packs and seawater. There are five reports of seaweed used as packing for lobsters from the East Coast and one report of seaweed packing for octopus from South Korea. One business located within 500 feet of a salt or brackish water body reported disposing of the packing materials into a water body.

Table 5. Number of wholesalers and number of organisms handled annually, by species and bioregion.

Common name	Northern California	Central California	Southern California	All
Spoon Worm			1 (9,500)	1 (9,500)
Red Abalone		3 (27,500)	4 (569,000)	7 (596,500)
Clam (unidentified)		2 (60,000)	1 (108,000)	3 (168,000)
Northern Quahog		2 (32,600)	1 (100,000)	3 (133,000)
Manila Clam		2 (716,300)	1 (975,000)	3 (1,690,000)
New Zealand Cockle			2 (1,890,000)	2 (1,890,000)
Pacific Geoduck			1 (1,800)	1 (1,800)
Edible Mussel		3 (1,100,000)		3 (1,100,000)
Bay Mussel (*Mytilus*)		2 (60,000)	1 (600,000)	3 (660,000)
New Zealand Mussel			2 (1,260,000)	2 (1,260,000)
Pacific Oyster		4 (501,000)	3 (278,000)	7 (779,000)
Virginia Oyster		3 (501,000)		3 (501,000)
Kumamoto Oyster		2 (498,000)		2 (498,000)
Flat Oyster		1 (375,000)		1 (375,000)
Scallop (unidentified)		1 (33,000)		1 (33,000)
Whiparm Octopus			1 (14,000)	1 (14,000)
Spot Prawn		1 (17,500)	9 (3,700,000)	10 (3,720,000)
Blue Crab		1 (200)	2 (11,000)	3 (11,200)
Dungeness Crab	2 (52,500)	11 (119,000)	5 (281,000)	18 (452,500)
King Crab			2 (8,700)	2 (8,700)
Crab (unidentified)			1 (2,700)	1 (2,700)
American Lobster	2 (51,500)	10 (65,000)	10 (1,380,000)	22 (1,500,000)
California Lobster			5 (32,000)	5 (32,000)
Giant Sculpin			1 (5,300)	1 (5,300)
Black Cod			2 (2,500)	2 (2,500)
Ling Cod			1 (2,700)	1 (2,700)
Bastard Halibut			3 (32,200)	3 (32,200)
Starry Flounder			1 (460)	1 (460)
Thornyhead		1 (5,000)	1 (8,700)	2 (13,700)
Rockfish			1 (450)	1 (450)
Sheepshead			1 (3,200)	1 (3,200)
Sea Urchin		1 (140)		1 (140)
Sea Cucumber			1 (7,300)	1 (7,300)
All species	2 (104,000)	13 (4,110,000)	22 (7,950,000)	37 (12,170,000)

Table 6. Number of organisms and percent of total shipped to each bioregion annually.

	Northern California	Central California	Southern California	Outside of California
Spoon Worm			9,500 (100%)	
Red Abalone	200 (0.03%)	27,700 (5%)	442,000 (74%)	126,000 (21%)
Clam (unidentified)		60,000 (36%)	108,000 (64%)	
Northern Quahog		32,600 (25%)	100,000 (75%)	
Manila Clam		716,000 (42%)	975,000 (58%)	
New Zealand Cockle			403,000 (21%)	1,490,000 (79%)
Edible Mussel		1,100,000 (100%)		
Bay Mussel		60,000 (9%)	600,000 (91%)	
New Zealand Mussel			195,000 (15%)	1,060,000 (85%)
Pacific Oyster		501,000 (64%)	278,000 (36%)	
Virginia Oyster		501,000 (100%)		
Kumamoto Oyster		498,000 (100%)		
Flat Oyster		375,000 (100%)		
Scallop (unidentified)		33,300 (100%)		
Whiparm Octopus			14,000 (100%)	
Spot Prawn	9,000 (0.2%)	26,500 (1%)	2,910,000 (78%)	770,000 (21%)
Blue Crab			11,200 (100%)	10 (0.1%)
Dungeness Crab	37,500 (8%)	91,200 (20%)	307,000 (69%)	11,500 (3%)
King Crab			8,000 (92%)	670 (8%)
Crab (unidentified)			2,700 (100%)	
American Lobster	37,600 (3%)	56,800 (4%)	1,020,000 (68%)	382,000 (26%)
California Lobster			29,000 (92%)	2,700 (8%)
Giant Sculpin			5,300 (100%)	
Black Cod			2,300 (100%)	
Ling Cod			2,700 (100%)	
Bastard Halibut			31,700 (98%)	500 (2%)
Starry Flounder			460 (100%)	
Thornyhead			13,300 (99%)	170 (1%)
Rockfish			450 (100%)	
Sheepshead			3,100 (98%)	60 (2%)
Sea Urchin		140 (100%)		
Sea Cucumber			7,300 (100%)	
All species	84,300 (1%)	4,080,000 (26%)	7,480,000 (48%)	3,840,000 (25%)

Results from Site Visits

We conducted 72 site visits to 44 retail seafood stores in the Bay Area and Los Angeles County, visiting each store on 1-4 dates between September 2011 and April 2012. On these visits we observed 30 species of live marine seafood: four gastropod, ten bivalve, six decapods, nine fish and one sea urchin species (Table 7). We included two anadromous species (sturgeon and sea-run trout) in our tally of marine fish, as well as tilapia (since some tilapia species can colonize brackish water).

Gastropod species were more commonly encountered in stores in the Bay Area than in Los Angeles County, especially the whelks and periwinkles (Table 8). Most bivalve species were also more common in the Bay Area, except for New Zealand Mussel; this is consistent with the data from the mail survey, which suggested that most New Zealand bivalves are imported into southern California and either transshipped out of the state or supplied to retailers in southern California. We encountered a greater diversity of crustaceans and fish in Los Angeles County, even though we visited 75% more shops and made 3.5 times as many site visits in the Bay Area.

Table 7. Number of site visits (and number of stores on at least one site visit) on which live marine seafood species were observed.

Common name	Scientific name	SF Bay Area	Los Angeles	Both Areas
Common Periwinkle	*Littorina littorea*	10 (5)	1 (1)	11 (6)
Knobbed Whelk	*Busycon carica*	2 (2)		2 (2)
Channeled Whelk	*Busycotypus canaliculatus*	23 (12)	1 (1)	24 (13)
Red Abalone	*Haliotis rufescens*	7 (3)	1 (1)	8 (4)
Northern Quahog	*Mercenaria mercenaria*	5 (5)	1 (1)	6 (6)
Manila Clam	*Ruditapes philippinarum*	37 (21)	7 (7)	44 (28)
Atlantic Surfclam	*Spisula solidissima*	3 (3)		3 (3)
Pacific Geoduck	*Panopea generosa*	4 (3)	2 (2)	6 (5)
Edible Mussel	*Mytilus edulis*	2 (2)		2 (2)
Bay Mussel	*Mytilus* sp.	3 (2)		3 (2)
New Zealand Mussel	*Perna canaliculus*	2 (1)	3 (3)	5 (4)
Pacific Oyster	*Crassostrea gigas*	19 (13)	4 (4)	23 (17)
Virginia Oyster	*Crassostrea virginica*	4 (3)		4 (3)
Kumamoto Oyster	*Crassostrea sikamea*	1 (1)		1 (1)
Spot Prawn	*Pandalus platyceros*	15 (7)	4 (4)	19 (11)
Green Mud Crab	*Scylla paramamosain*		1 (1)	1 (1)
Blue Crab	*Callinectes sapidus*	11 (8)	8 (8)	19 (16)
Pacific Rock Crab	*Cancer antennarius*		1 (1)	1 (1)
Dungeness Crab	*Cancer magister*	22 (10)	16 (16)	38 (26)
American Lobster	*Homarus americanus*	41 (20)	13 (13)	54 (33)
White Sturgeon	*Acipenser transmontanus*	25 (12)	1 (1)	26 (13)
Rainbow Trout	*Oncorhynchus mykiss*		1 (1)	1 (1)
Ling Cod	*Ophiodon elongatus*	6 (5)	1 (1)	7 (6)
California Halibut	*Paralichthys californicus*		1 (1)	1 (1)
Rex Sole	*Glyptocephalus zachirus*		2 (2)	2 (2)
Cabezon	*Scorpaenichthys marmoratus*	9 (5)	2 (2)	11 (7)
Rockfish	*Sebastes* sp.	17 (6)	3 (3)	20 (9)
Sheepshead	*Semicossyphus pulcher*		1 (1)	1 (1)
Tilapia	Tilapiini	23 (11)	15 (15)	38 (26)
Purple Sea Urchin	*Strongylocentrotus purpuratus*		2 (2)	2 (2)
Total visits and stores in area		56 (28)	16 (16)	72 (44)

Table 8. Percentage of visited stores in which live marine seafood species were observed on at least one visit.

Common name	Bay Area	Los Angeles	Both Areas
Common Periwinkle	18%	6%	14%
Knobbed Whelk	7%		5%
Channeled Whelk	43%	6%	30%
Red Abalone	11%	6%	9%
Northern Quahog	18%	6%	14%
Manila Clam	75%	44%	64%
Atlantic Surfclam	11%		7%
Pacific Geoduck	11%	13%	11%
Edible Mussel	7%		5%
Bay Mussel	7%		5%
New Zealand Mussel	4%	19%	9%
Pacific Oyster	46%	25%	39%
Virginia Oyster	11%		7%
Kumamoto Oyster	4%		2%
Spot Prawn	25%	25%	25%
Green Mud Crab		6%	2%
Blue Crab	29%	50%	36%
Pacific Rock Crab		6%	2%
Dungeness Crab	36%	100%	59%
American Lobster	71%	81%	75%
White Sturgeon	43%	6%	30%
Rainbow Trout		6%	2%
Ling Cod	18%	6%	14%
California Halibut		6%	2%
Rex Sole		13%	5%
Cabezon	18%	13%	16%
Rockfish	21%	19%	20%
Sheepshead		6%	2%
Tilapia	39%	94%	59%
Purple Sea Urchin		13%	5%

Live Seafood Online

Using appropriate search terms[4], we searched the Internet for live marine seafood species offered for retail sale online, and tabulated those sites that routinely offer shipment to a region that includes California. We found 38 species offered as live seafood, plus the seaweed *Ascophyllum nodosum*. The animals included 3 gastropods, 22 bivalves, 9 crustaceans, 3 sea urchins and an eel. The *Ascophyllum* is sold for use in clam or lobster bakes, either accompanying those items in a package purchase or sold separately; and it is also often used to pack lobster shipments. The most commonly offered species are American lobster, Virginia oyster, northern quahog, edible mussel and softshell clam, all of them from the East Coast. There are 13 other species that can be purchased from the East Coast, two bivalves from New Zealand, and a Japanese scallop grown in British Columbia. The websites offering these species are listed in Appendix E.

Table 9. Number of websites and stated source regions for live seafood offered online for retail purchase and shipment to California.

Common name	Scientific name	# of websites	Stated source region(s)
Rockweed	*Ascophyllum nodosum*	6	
Common Periwinkle	*Littorina littorea*	5	northwestern Atlantic, Nova Scotia
Channeled Whelk	*Busycotypus canaliculatus*	2	RI
Red Abalone	*Haliotis rufescens*	3	CA, Baja California
Northern Quahog	*Mercenaria mercenaria*	34	ME, MA, RI, CT, NY, MD, VA, FL
Manila Clam	*Ruditapes philippinarum*	14	British Columbia, WA
California Littleneck	*Protothaca staminea*	1	Puget Sound
New Zealand Cockle	*Chione stutchburyi*	2	New Zealand
Atlantic Surfclam	*Spisula soldissima*	1	northwestern Atlantic
Mahogany Clam	*Arctica islandica*	6	ME
Varnish Clam	*Nuttallia obscurata*	2	British Columbia
Softshell Clam	*Mya arenaria*	26	ME, MA, RI
Pacific Geoduck	*Panopea abrupta*	5	WA
Razor Clam	*Ensis directus*	4	MA
Edible Mussel	*Mytilus edulis*	33	Prince Edward Island, ME, RI
Mediterranean Mussel	*Mytilus galloprovincialis*	9	British Columbia, WA
Foolish Mussel	*Mytilus trossulus*	1	WA
New Zealand Mussel	*Perna canaliculus*	4	New Zealand
Pacific Oyster	*Crassostrea gigas*	21	AK, British Columbia, WA, OR, CA

[4] Including, in various combinations, “online,” “live,” “seafood,” and the common and scientific names of various seafood species.

Common name	Scientific name	# of websites	Stated source region(s)
Virginia Oyster	*Crassostrea virginica*	38	Prince Edward Island, New Brunswick, Nova Scotia, ME, NH, MA, RI, CT, NY, NJ, MD, VA, NC, FL, MS, LA, WA
Kumamoto Oyster	*Crassostrea sikamea*	15	British Columbia, WA, OR, CA
Flat Oyster	*Ostrea edulis*	6	ME; British Columbia; WA
Olympia Oyster	*Ostrea lurida*	5	WA
Bay Scallop	*Argopecten irradians*	4	MA
Atlantic Sea Scallop	*Placopecten magellanicus*	2	MA
Japanese Scallop	*Mizuhopecten yessoensis*	1	British Columbia
Spot Prawn	*Pandalus platyceros*	4	British Columbia, CA
Blue Crab	*Callinectes sapidus*	10	MD
Jonah Crab	*Cancer borealis*	3	ME, MA
Atlantic Rock Crab	*Cancer irroratus*	1	ME
Red Rock Crab	*Cancer productus*	1	CA
Dungeness Crab	*Cancer magister*	5	WA, OR
King Crab	*Paralithodes camtschaticus**	2	AK
American Lobster	*Homarus americanus*	44	Nova Scotia, ME, MA, RI
California Lobster	*Panulirus interruptus*	4	CA
Green Sea Urchin	*Strongylocentrotus droebachiensis*	2	ME
Red Sea Urchin	*Strongylocentrotus franciscanus*	2	CA
Purple Sea Urchin	*Strongylocentrotus purpuratus*	2	CA
American Eel	*Anguilla rostrata*	1	

* This could also be *Paralithodes platypus* or *Lithodes aequispinus*, which are also marketed as king crab.

Hitchhiker Organisms

Miller (1969) reported on the organisms that he found in the seaweed (*Ascophyllum nodosum*) packing for shipments of lobsters that were received from the northeastern U.S. by a seafood distributor in San Francisco (Table 10). Olson (1999) reported finding 5 to 11 multicellular organisms in New England lobster shipments received in Washington state. Elsewhere the organisms she found were described as diatoms, algae, snails, isopods, amphipods and crabs (Henderson 1998).

Table 10. Hitchhiker species reported in *Ascophyllum nodosum* used to pack lobster shipments received in San Francisco from the northeastern U.S. (Miller 1969).

Taxon group	Scientific name
Chlorophyta	*Chaetomorpha area*, *Cladophora* sp., *Enteromorpha* sp., *Ulva lactuca*
Phaeophyta	*Sphacelaria cirrosa*
Rhodophyta	*Ceramium* sp., *Polysiphonia* sp.
Porifera	*Leucosolenia* sp.
Hydrozoa	*Campanularia flexuosa*, *Clava leptostyla*, *Gonothyraea loveni*, *Obelia* sp., *Sertularia pumila*, *Tubularia* sp.
Platyhelminthes	*Monophorum* sp., *Monocoelis* sp., Rhabdocoela (several), Alleocoela (several)
Polychaeta	*Spirorbis* sp., several errant worms
Gastropoda	*Littorina littorea, Littorina obtusata*, *Mitrella lunata*
Bivalvia	*Mytilus edulis*
Cirripeda	*Balanus venustus*
Amphipoda	*Ampelisca* sp., Gammaridea (several)
Echinodermata	*Asterias forbesi*
Bryozoa	*Bowerbankia* sp., *Flustrellidra* sp., *Bugula* sp.

Table 11 shows additional species, not listed in Table 10, that were reported in *Ascophyllum nodosum* used as packing for shipments of live saltwater baitworms shipped from the northeastern U.S. to California, Connecticut or New York. Although these data may serve as an indication of the ability of these species to survive transport in *Ascophyllum* packing, it is uncertain whether they should necessarily be taken as evidence of what can be expected in lobster packing, since the seaweed used to pack baitworms is generally collected from different regions than is the seaweed used to pack lobsters, and may therefore have associated with it a somewhat different suite of organisms

Table 12 lists other organisms found attached to or otherwise contained in shipments with live marine seafood species sold on the Pacific Coast.

Table 11. Hitchhiker species reported in *Ascophyllum nodosum* used to pack live saltwater baitworms from the northeastern U.S. that were shipped to California, Connecticut or New York. Sources: Lau 1995; Carlton 1979, 1992a: Cohen *et al.* 2001b: Yarish *et al.* 2009: Haska *et al.* 2011; Cohen *et al.* unpubl. data.

Taxon group	Scientific name
Chromista	*Pteridomonas* sp.
Apicomplexa	Eimeriidae
Ciliophora	*Aspidisca* sp., *Diophrys* sp., *Euplotes* sp., *Holosticha* sp.
Sarcodina	*Hartmannella* sp., *Platyamoeba* sp.
Foraminifera	*Trochammina inflata,* 1 other species
Ascomycete	*Pleospora* sp.
Bacillariophyta	*Bacillaria* sp., *Caloneis* sp., *Chaetoceros* sp., *Cocconeis* sp., *Cylindrotheca* sp., *Fragilaria* sp., *Melosira* sp., *Navicula* sp., *Neofragilaria* sp., *Nitzschia* sp., *Odontella* sp., *Pseudonitzschia multiseries*, *Skeletonema costatum*, *Tabularia* sp., *Thalassiosira* sp.
Pyrrophycophyta	*Alexandrium fundyense*, *Peridinium* sp.
Craspedophyta	*Monosiga* sp.
Chrysophyta	*Paraphysomonas* sp.
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*, *Elachistea fucicola,* pieces of *Fucus spiralis* and *F. vesiculosus*
Plantae	pieces of *Zostera* sp. and *Spartina* sp.
Nematoda	unidentified sp.
Platyhelminthes	unidentified sp.
Oligochaeta	*Enchytraeus albidus*
Polychaeta	*Fabricia sabella*, *Spirorbis spirillum,* Capitellid sp.
Gastropoda	*L. saxatilis*, *Lacuna vincta*, *Hydrobia* spp.
Bivalvia	*Gemma gemma*, *Mercenaria mercenaria*, *Mya arenaria*, *Modiolis modiolis*
Acarina	2 *Halacarus* spp., Cryptostigmatid? sp.
Insecta	Chironomid sp. (larva), Dipteran sp. (larva), Coleopteran sp.
Ostracoda	unidentified sp.
Copepoda	*Tigriopsis* sp., Harpacticoid sp., Cyclopoid? sp.
Tanaidacea	unidentified sp.
Isopoda	*Jaera marina*
Amphipoda	*Hyale nilssoni, Eulimnogammarus obtusatus*, *Jassa falcata*, Talitrid? sp., *Caprella penantis*
Decapoda	*Carcinus maenas*

Table 12. Hitchhiker species collected or observed in association with live marine seafood. Collections and observations on seafood sold in California from this study or A. Cohen unpubl. data, unless otherwise noted.

Seafood species	Source region	Hitchhiker species	Hitchhiker's taxon group	Comment
Common Periwinkle	northwestern Atlantic	white coralline alga	Rhodophyta	Attached to shell
Channeled Whelk	northwestern Atlantic	*Busycon carica*	Gastropoda	In shipping box
Channeled Whelk	northwestern Atlantic	Acmaeidae	Gastropoda	On shell
Channeled Whelk	northwestern Atlantic	*Balanus improvisus*	Cirripeda	Attached to shell
Channeled Whelk	northwestern Atlantic	*Carcinus irroratus*	Decapoda	In shipping box
Knobbed Whelk	northwestern Atlantic	green alga	Chlorophyta	In shipping box
Knobbed Whelk	northwestern Atlantic	*Balanus improvisus*	Cirripeda	Attached to shell
Red Abalone	California	encrusting red alga	Rhodophyta	Attached to shell
Atlantic Surfclam	northwestern Atlantic	unidentified hydroid	Hydrozoa	Attached to shell
Pacific Geoduck	Pacific Coast	*Ulva* sp.	Chlorophyta	Attached to shell
New Zealand Mussel	New Zealand	green alga	Chlorophyta	Attached to shell
Pacific Oyster	Washington	*Ulva* sp.	Chlorophyta	Attached to shell
Pacific Oyster	Washington	Acmaeidae	Gastropoda	On shell
Pacific Oyster	Washington, California	*Balanus* sp.	Cirripeda	Attached to shell
Virginia Oyster	Prince Edward Island	*Balanus* sp.	Cirripeda	Attached to shell
Kumamoto Oyster	Oregon	*Balanus* sp.	Cirripeda	Attached to shell
American Lobster	northwestern Atlantic	*Balanus improvisus*	Cirripeda	Attached to shell
American Lobster	northwestern Atlantic	*Carcinus maenas*	Decapoda	In lobster tank*
Purple Sea Urchin	Pacific Coast	*Ulva* sp.	Chlorophyta	On shell

* Observed in a restaurant tank in Coos Bay, Oregon in 1988 (Carlton 1989; Cohen *et al.* 1995).

We purchased four lots of the Atlantic periwinkle *Littorina littorea* from three seafood markets in the Bay Area and examined them for parasites by (a) foot color and (b) dissection. Examination by foot color involves allowing the snails to climb up the side of a glass jar and determining whether the foot is the normal light color or is discolored (dark, yellowed). A discolored foot strongly correlates with infection by the digenean trematode *Cryptocotyle lingua* (Willey and Gross 1957; Huxham *et al.* 1993; Wood *et al.* 2007). The results for the 602 snails that we dissected are shown in Table 13. Twelve (2%) were classified as definitely infected based on dissection, and 47 (8%) were classified as possibly infected. Among the active snails, there was a strong correlation between foot discoloration and infection, making it likely that they were infected by *Cryptocotyle lingua*.

Table 13. Results of the examination and dissection of 602 snails (*Littorina littorea*) purchased from seafood markets in the San Francisco Bay Area.

			Lot				
			1	**2**	**3**	**4**	**All**
Active Snails	Foot Test Positive	Infected	5	1	4	0	10
		Possibly Infected	1	1	2	0	4
		Not Infected	1	0	0	0	1
		Total	7	2	6	0	15
	Foot Test Negative	Infected	0	1	0	1	2
		Possibly Infected	2	0	0	3	5
		Not Infected	80	73	34	90	277
		Total	82	74	34	94	284
Inactive Snails		Infected	0	0	0	0	0
		Possibly Infected	12	2	18	6	38
		Not Infected	64	37	84	80	265
		Total	76	39	102	86	303
All Snails		Infected	5	2	4	1	12
		Possibly Infected	15	3	20	9	47
		Not Infected	145	110	118	170	543
		Total	165	115	142	180	602

Past Introductions

We reviewed the scientific literature and the available databases for non-native species established in California that we judged were possibly or probably introduced by the live marine seafood trade. We determined that one established species was probably introduced and one established species was possibly introduced by this trade, and that several occurrences that did not result in established populations probably also resulted from this trade.

The NEMESIS/California database includes 14 marine species and 48 introductions (introductions of a species to a distinct coastal water system in California) that list Discarded Seafood as a possible vector. Six of these introductions are not listed as established. Of the 42 introductions, involving 11 species, that are listed in the database as established, none appear to us to be possible or probable introductions via the live marine seafood trade. Of the six introductions, involving five species, that are listed in the database as failed or unknown status rather than established, three appear to us to be possible or probable introductions via the live marine seafood trade. The reasons for not counting the rest as seafood 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 2004a,b,c). The explanations for our vector assignments are explained below.

Cohen and Carlton (1995) list three species from the Atlantic—the rough periwinkle *Littorina saxatilis*, the green crab *Carcinus maenas* and the red seaweed *Aglaothamnion tenuissimum* (as *Callithamnion byssoides*)—as having possibly been introduced into San Francisco Bay in the "seaweed packing for live New England bait worms or lobsters." For these species, however, it is far more likely that they were introduced with bait than with lobsters, as discussed below; the same is true for a few other species with similar histories (Cohen 2012). Other than this listing of these three species as *possible* seafood trade introductions, none of the major reviews and surveys of non-native marine organisms on the Pacific Coast of North America have identified a single established organism as having been introduced by the commercial trade in live seafood (Carlton 1975, 1979; Cohen *et al.* 1998, 2001a; Wasson *et al.* 2001; Boyd *et al.* 2002; Cohen 2004a,b,c; Wonham and Carlton 2005).

Carlton and Cohen (1998), Cohen *et al.* (2001b) and Brown (2004) argue that *Littorina saxatilis* was introduced into San Francisco Bay with bait worms imported from New England. *L. saxatilis* is native to the both the American and European sides of the North Atlantic. It was first found on the Pacific Coast in 1993 at Emeryville Marina on the east shore of San Francisco Bay. It was discovered immediately adjacent to a public boat-launching ramp that is frequently used by anglers. For several years, the entire population was contained within a 10 m stretch of cobble-covered beach on one side of the boat ramp. In subsequent years it was discovered at eight additional sites in San Francisco Bay (Carlton and Cohen 1998; Brown 2004), and in each one it occurs in populations that cover a small stretch of shore near a popular fishing spot, boat-launching ramp or small-boat dock. *L. saxatilis* has crawl-away (*i.e.* non-planktonic) larvae, and is a very slow disperser: in the Atlantic it typically takes 2-10 yr to colonize new habitats within a range of one km or less (Reid 1996), and it displays significant genetic variation even over short distances (Berger 1973). The populations in San Francisco Bay show little genetic variation, indicating that they derive from a single Atlantic location (Brown 2004). These factors together suggest that *L. saxatilis* was introduced several times into San Francisco Bay by a fishing-related activity that repeatedly transported the periwinkle to the Bay from a single site on the Atlantic Coast. The New England baitworm-packing companies are all located within a small part of the Maine coast, most of them in or near the town of Wiscasset on Boothbay Harbor, and *L. saxatilis* is commonly reported (and often abundant)[5] in the *Ascophyllum* packing for Maine baitworms. Thus it seems extremely likely that *L. saxatilis* was introduced into Sam Francisco Bay with baitworms rather than lobsters. The amount of lobster-packing seaweed that ends up in the Bay must be fairly small compared to the amount of bait-packing seaweed that is routinely discarded there (Cohen *et al.* 2001b), and Miller (1969) did not find *L. saxatilis* in the lobster-packing seaweed that he examined in San

[5] Cohen *et al.* (2001b) estimated that in the late 1990s over 10,000 *Littorina saxatilis* were discarded into San Francisco Bay each year.

Francisco, though he reported that both *Littorina littorea* and *L. obtusatus* were common (see Table 10).

For the other two species that Cohen and Carlton (1995) listed as possibly introduced with seaweed packing for baitworms or lobsters, the crab *Carcinus maenas* and the seaweed *Aglaothamnion tenuissimum*, the main argument for transport with baitworms rather than lobsters is that the quantity of lobster-packing seaweed that ends up in the Bay must be fairly small compared to the large amount of bait-packing seaweed that is regularly discarded there (Cohen *et al.* 2001b). In addition, *C. maenas* has been collected in shipments of Maine baitworms received in the Bay Area (Cohen *et al.* 2001b; Hackman 2002), it is abundant in the intertidal *Ascophyllum nodosum* in Boothbay Harbor and it is common in the *Ascophyllum* examined in bait-packing facilities in Maine (A. Cohen unpubl. data; Crawford 2001; 15 were collected in a random 250 g sample of the seaweed—S. Crawford, pers. comm.). Cohen *et al.* (1995) and Carlton and Cohen (2003) analyze in detail the possible vectors that have transported *C. maenas* around the world.

One established species that may have been introduced via the live seafood trade is an Atlantic clam, the Northern quahog *Mercenaria mercenaria*. It has been in Colorado Lagoon, an extension of Alamitos Bay, since at least 1967 (Crane *et al.* 1975), though the population collapsed between 1980 and 2000 and may be going extinct (Burnaford *et al.* 2011). The introduction may have resulted from a half-bushel of quahogs flown in from New York and planted in Alamitos Bay by “a local delicatessen owner” in 1951-52, or possibly from a similar but unreported planting directly into the Lagoon (Crane *et al.* 1975). If these plantings were of quahogs that had been shipped to California for sale as live seafood, then this is an introduction via the live seafood as defined in this study; if, however, they were ordered and shipped specifically for planting in California waters, then the introduction would be classified as a different vector.

There is one other established, non-native species in California for which it seems a case might eventually be made that it arrived via the seafood trade. The Channeled Whelk *Busycotypus canaliculatus*, which is established in San Francisco Bay, is generally considered to be an accidental introduction with Atlantic oysters, *Crassostrea virginica*, which were shipped across the country in large numbers and planted in the Bay from 1869 until the practice largely ended between 1910 and 1920 (*e.g.* Carlton 1979, 1992; Cohen and Carlton 1995). However, the first record of the Channeled Whelk in San Francisco Bay did not occur until 1938 or 1948 (the historical record is unclear, as discussed in Carlton (1979)). The Channeled Whelk is a very large and conspicuous snail, by far the largest in San Francisco Bay, and it seems unlikely that it could have been present, even in modest numbers, for 20 or 30 years without being noticed. Possibly it arrived with a small shipment of Atlantic oysters made after 1920. On the other hand, by the 1930s (and possibly earlier) there was a small fishery for Channeled Whelk serving Italian restaurants and Chinese markets in the New York City area (Mitchell 1939, 1947), and channeled whelk have been shipped live to Chinese food markets in the San Francisco Bay Area since at least the 1990s. If cross-country shipments of live whelk to serve Chinese markets or Italian restaurants in the San

Francisco Bay Area had started by the 1930s or 1940s, this could be a seafood trade introduction. While inquiries that we made of older Italian restaurateurs yielded no evidence of earlier imports of Channeled Whelk, historical research might shed further light on this.

The live marine seafood trade is probably also the source of several releases of non-native species in California that failed to become established. For example, it is highly likely that some or all of the more substantial populations of *Littorina littorea* that have been found in San Francisco Bay and Anaheim Bay in the last decade were the result of deliberate releases by private individuals of *L. littorea* purchased live in seafood markets in California, in order to try to establish a local population of these edible snails. The evidence for this includes the uniform size of these snails (all within the size range commonly found for sale in Chinese food markets), and the presence on specimens collected from San Francisco Bay of an Atlantic barnacle, a white coralline alga, and a spionid worm burrowed in the snail's shell that are not, so far as we know, otherwise present in San Francisco Bay, but which appear to be common on *L. littorea* on the Atlantic Coast (and we also found one of these—the coralline alga—on *L. littorea* in California seafood markets). These facts demonstrate that the snails in these populations are the arriving generation (that is, they spent their youth on Atlantic shores), and the size of these populations thus indicates that they must be a deliberate introduction (there are far too many—several thousands of snails in some cases—to have arrived as discards from bait worm or lobster packing). While it would be possible to obtain large numbers of live *L. littorea* by either collecting them on the East Coast and transporting or shipping them to California, or by purchasing them from a company that sells live marine specimens for use in education or research, it would be easier and cheaper to buy them from food markets in California, and this is almost certainly the source of these large releases of *L. littorina*. There is no evidence that any of these *L. littorea* populations in California has successfully reproduced; all have disappeared or declined in size, either because of eradication efforts, natural mortality, or a combination of the two (Chang *et al.* 2011).

There have been two occurrences of small asexually reproducing populations of *Ascophyllum nodosum* in San Francisco Bay. One, located near a restaurant that served lobsters imported from New England, may have derived from either the packing used for lobster shipments or from the packing used for live baitworms imported from New England. The other population, at sites in the vicinity of San Leandro Bay, did not appear to be near any restaurants or markets, and presumably derived from discarded bait packing. These populations are greatly reduced or no longer present, having been removed by hand in eradication efforts (Miller *et al.* 2004; N. Cosentino-Manning, pers. comm.). A few other records of small numbers of live non-native species in California waters were possibly or probably derived from releases of organisms purchased live from food markets, including a record of the Atlantic quahog *Mercenaria mercenaria* in Mission Bay, several records of the blue crab *Callinectes sapidus* in and near San Francisco Bay, a record of the American lobster *Homarus americanus* in San Francisco Bay, and records of the American and European eels, *Anguilla rostrata* and *Anguilla*

anguilla, in the Delta (Carlton 1975, 1979, 1982; Carlton and Cohen 1995; A. Cohen, unpubl. data).

In summary then, although the live marine seafood trade has almost certainly been the source of several small releases of non-native species into California waters, there is at most evidence that it was the source of one uncertainly established population, and that it might possibly be the source of another. And as far as we are aware, the evidence is as scarce or scarcer that the commercial live seafood trade is responsible for established non-native marine species anywhere else in the world.

<u>Estimating the Probability of Future Introductions</u>

Chapman *et al.* (2003) estimated the probability that bivalves available from live seafood markets in the Northeastern Pacific region (NEP) would become established in the NEP. Their method was to (1) calculate a past rate of establishment by determining the fraction of all non-native bivalves available in NEP live seafood markets that had become established in the NEP, (2) multiply that fraction by the number of non-native bivalves available in NEP live seafood markets that had not become established in the NEP to get an estimate of the most probable number of these that would become established, and then (3) use the binomial expansion to assign different probabilities to different numbers established.[6] They determined that 24 non-native bivalves were available in the NEP for sale as live seafood (their Table 2), ten of which they classified as having established, self-sustaining populations in the NEP.[7]

Keller and Lodge (2005) provided a critique, noting discrepancies in the numbers, questioning whether all the species listed as being available for sale as live seafood actually were, and arguing that the method overestimates the expected future number of invasions because the bivalves that have not become established are likely to be more refractory—that is, less likely to become established—than the bivalves that have already become established. Chapman *et al.* (2005) replied, defending their analysis.

We share Keller and Lodge's concerns, but believe there is a greater problem with the use of ten established species in the numerator of the fraction describing the past rate of establishment. Based on the literature and our knowledge of Pacific Coast bioinvasions, we believe that several of these species are not established in the NEP, and that most of those that are established were not introduced via the live seafood

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[6] They also conducted two alternate estimates in which the past rate of establishment was calculated by determining the fraction of all bivalves available in NEP live seafood markets that had become established (a) anywhere in the world, and (b) anywhere but the NEP. We do not discuss these alternate calculations (which make less sense to us), but the methodological and data quality concerns are the same.

[7] The ten species are: *Crassostrea ariakensis*, *Crassostrea gigas*, *Crassostrea sikamaea*, *Crassostrea virginica*, *Mizuhopectin yessoensis*, *Mya arenaria*, *Mytilus edulis*, *Mytilus galloprovincialis*, *Petricolaria pholadiformis* and *Ruditapes philippinarum* (J. Chapman, pers. comm.), though some doubt was expressed over whether *C. virginica* is reproductive in the NEP. The reference in the Abstract to 11 established species is an error as is the refernce to the establishment rate as "10/22 = 0.45" (J. Chapman, pers.comm.).

trade. Table 14 lists the ten bivalves and the treatment of these species in two bioinvasions reviews: Carlton (1992) which reviews global invasions by mollusks and lists all non-native mollusks established in the NEP, and Wonham and Carlton (2005) which reviews bioinvasions in the Pacific Northwest (PNW, defined as the portion of the NEP between Cape Mendocino in northern California and the Queen Charlotte Islands in British Columbia).

Table 14. Non-native bivalves considered to be established in the Northeastern Pacific by Chapman *et al.* (2003), and the classification of these bivalves by two bioinvasions reviews. Carlton (1992) gives the status in the Northeastern Pacific and the vector. Wonham and Carlton (2005) give the decade of the first record in the Pacific Northwest for established species and the vector. First Pacific Coast Record is for established populations in the Northeastern Pacific based on Carlton (1979) and Cohen and Carlton (1995).

Scientific name	Common name	Carlton 1992 (NEP)*	Wonham & Carlton 2005 (PNW)*	First Pacific Coast Record
Crassostrea ariakensis	Suminoe Oyster	–	–	–
Crassostrea gigas	Pacific Oyster	Established [1]	1910s [4]	1912
Crassostrea sikamea	Kumamoto Oyster	–	–	–
Crassostrea virginica	Virginia Oyster	Established [1]	1915s [4]	1914
Mizuhopecten yessoensis	Japanese Weathervane	Not Established [1]	–	–
Mya arenaria	Softshell Clam	Established [2]	1880s [4,5]	1874
Mytilus edulis	Edible Mussel	–	–	–
Mytilus galloprovincialis	Mediterranean Mussel	Established [3]	–	1900-1947
Petricolaria pholadiformis	False Angelwing	Established [2]	1940s [4]	1927
Ruditapes philippinarum	Manila Clam	Established [1,2]	1930s [4]	1924

* Vector:
[1] Fisheries: intentional release
[2] Fisheries: accidental release with commercial oyster industry
[3] Ships (fouling and boring)
[4] Associated with introductions of Atlantic or Pacific oysters
[5] Deliberately released for a variety of purposes, including marsh restoration, erosion control, cattle forage, and gardens

Of the ten species, Carlton (1992) lists only six as established in the NEP and Wonham and Carlton (2005) list five as established in the PNW (they do not include the Mediterranean mussel, which was reported in wild populations (*i.e.* not in aquaculture operations) only south of Cape Mendocino—Sarver and Foltz 1993; Geller *et al.* 1994; Geller 1994). Of the six established species, none are listed or reported in these two studies as established via the live seafood trade. Rather, nearly all the established species are listed as a result of commercial oyster plantings (in Carlton 1992, Vector 1 for oyster species and Vector 2 for other species; in Wonham and Carlton 2005, Vector 4). Two of the non-oyster species only became available in Pacific Coast seafood markets *after* their accidental introduction and establishment via commercial oyster plantings (the Softshell Clam, established by 1874 and first reported in the seafood markets in 1881, and the Manila Clam, established by 1924 and first reported in the seafood markets in 1941; these clams were also spread along the coast in part by intentional plantings after their initial establishment—Carlton 1979). As discussed above, the only established non-native marine bivalve for which there is good evidence suggesting that it was introduced via the live seafood trade is the Northern Quahog, *Mercenaria mercenaria*.

Table 15 shows the 24 bivalves reported by Chapman *et al.* (2003) to be available for sale as live seafood in the NEP, and the 18 bivalves that we found to be available for sale in California, either through food markets (combining data from Our surveys and site visits, Tables 3 and 7) or online (Table 9). Of seven species that Chapman *et al.*

Table 15. Non-native bivalve species reported for sale as seafood (including online sale) in the Northeastern Pacific region.

Scientific name	Common name	Chapman *et al.* 2003 (NEP)	This study (California)	This study (online)
Anadara granosa	Blood Clam	X		
Arctica islandica	Mahogany Clam	X		X
Argopecten irradians	Bay Scallop	X		X
Chione stutchburyi	New Zealand Cockle	X	X	X
Crassostrea ariakensis	Suminoe Oyster	X		
Crassostrea gigas	Pacific Oyster	X	X	X
Crassostrea sikamea	Kumamoto Oyster	X	X	X
Crassostrea virginica	Virginia Oyster	X	X	X
Cyrtodaria siliqua	Northern Propeller Clam	X		
Ensis directus	Razor Clam	X		X
Mercenaria mercenaria	Northern Quahog	X	X	X
Mizuhopecten yessoensis	Japanese Weathervane	X		X
Mya arenaria	Softshell Clam	X		X
Mytilus edulis	Edible Mussel	X	X	X
Mytilus galloprovincialis	Mediterranean Mussel	X	X	X
Nuttallia obscurata	Varnish Clam			X
Ostrea edulis	Flat Oyster	X	X	X
Ostrea puelchana	Argentine oyster	X		
Paphies australis	Pipi Clam	X		
Perna canaliculus	New Zealand Mussel	X	X	X
Petricolaria pholadiformis	False Angelwing	X		
Placopecten magellanicus	Atlantic Sea Scallop	X		X
Protothaca thaca	Chilean Clam	X		
Ruditapes philippinarum	Manila Clam	X	X	X
Spisula solidissima	Atlantic surfclam	X	X	X

listed that we did not find, six are species that are commonly sold as food in their native regions (the Blood Clam, Suminoe Oyster, Northern Propellor Clam, Argentine Oyster, Pipi Clam and Chilean Clam) and thus might reasonably be found on occasion for sale in markets in the NEP (including California) or online, even though we did not find them in this study. The seventh species, the False Angelwing, is well-known to shell collectors but we found no evidence that it is ever harvested and sold as seafood either in its native range in the northwestern Atlantic or in its invaded range in northern Europe (where it became established in the late 19th century and has become common and widespread). It thus seems unlikely that it has been sold as live seafood in the NEP.[8]

We found one bivalve species for sale online as live seafood that was not reported by Chapman *et al.* (2003), the Varnish Clam *Nuttallia obscurata* (two websites offered Varnish Clams harvested from British Columbia—Table 9). Like the Softshell and Manila clams, the Varnish Clam appears to have entered the seafood market on the Pacific Coast only *after* it became established there by other means.[9]

Table 16 lists the 24 non-native bivalve species that we believe, based on Chapman *et al.* 2003 and the evidence discussed above, may have been available for sale as live seafood in the NEP, either through markets or online (*i.e.*, all the species in Table 15 except for the False Angelwing). The table also shows which of these are established in the NEP, which of these appear to have become established in the NEP before they were available for sale as live seafood in the NEP,[10] and which of these may have become established via the live seafood trade. With these data, we can calculate the past rate of establishment of non-native bivalves in the NEP via the seafood trade as the number of bivalves established in the NEP via the seafood trade (either 0 or 1, from Table 16, column 5) divided by the number of species that had the potential to be introduced and established via the seafood trade (20, equal to the 24 non-native bivalves in the NEP seafood trade minus the four species that became established in the NEP before they became available in the seafood trade, from Table 16, column 4). The past rate is thus either 0 or 0.05.[11] The most probable number of future bivalve establishments via the seafood trade is estimated as the past rate times the 17 non-native bivalves in the seafood trade that haven't yet become established (Table 16, column 3), or 0 to 0.85.[12] If the Northern Quahog is assumed to have been introduced to the NEP via the seafood trade (so the past bivalve invasion rate via the seafood trade is 0.5), then the binomial probability of none of the 17 bivalve species becoming

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[8] The authors recently expressed tentative concurrence with this (J. Chapman, E. Coan, pers. comm.).

[9] Gillespie *et al.* (1999) reported that the Varnish Clam became established in the Pacific Northwest before around 1990, probably via ballast water; and assessed the potential for developing a fishery for the clam in British Columbia. At that time, harvesting and marketing as seafood was not allowed because the testing needed to satisfy Canada's shellfish safety requirements had not been completed; that and other steps would need to be completed before a fishery could be developed. We presume the Varnish Clam was not reported by Chapman *et al.* (2003) because it was not yet available for sale.

[10] In addition to the three species discussed above, the Mediterranean Mussel became established in the NEP sometime between 1900 and 1947 based on genetic evidence (Geller), which probably pre-dates its availability in Pacific Coast food markets.

[11] Compare to Chapman *et al.*'s rate of 0.417.

[12] Compare to Chapman *et al.*'s most probable number of 5.

Table 16. Status of non-native bivalve species offered for sale as seafood (including online sale) in the Northeastern Pacific region.

Scientific name	Common name	Established in the NEP	Established in the NEP before offered for sale there	Established in the NEP by the live seafood trade
Anadara granosa	Blood Clam			
Arctica islandica	Mahogany Clam			
Argopecten irradians	Bay Scallop			
Chione stutchburyi	New Zealand Cockle			
Crassostrea ariakensis	Suminoe Oyster			
Crassostrea gigas	Pacific Oyster	X		
Crassostrea sikamea	Kumamoto Oyster			
Crassostrea virginica	Virginia Oyster	X		
Cyrtodaria siliqua	Northern Propeller Clam			
Ensis directus	Razor Clam			
Mercenaria mercenaria	Northern Quahog	X		Possibly
Mizuhopecten yessoensis	Japanese Weathervane			
Mya arenaria	Softshell Clam	X	X	
Mytilus edulis	Edible Mussel			
Mytilus galloprovincialis	Mediterranean Mussel	X	X	
Nuttallia obscurata	Varnish Clam	X	X	
Ostrea edulis	Flat Oyster			
Ostrea puelchana	Argentine oyster			
Paphies australis	Pipi Clam			
Perna canaliculus	New Zealand Mussel			
Placopecten magellanicus	Atlantic Sea Scallop			
Protothaca thaca	Chilean Clam			
Ruditapes philippinarum	Manila Clam	X	X	
Spisula solidissima	Atlantic surfclam			

established via the seafood trade is 0.42, of one becoming established is 0.37, of two becoming established is 0.16, and of more than two becoming established is ≈0.05.

These estimates ignore the ‘refractory remnant species’ issue raise by Keller and Lodge (2005), which would tend to reduce these probabilities; and assume a generally similar level of opportunity for release and establishment as obtained in the past, such as similar numbers of organisms per species carried by the trade over a similar time period, similar handling procedures, and environmental conditions of similar suitability for the establishment of non-native species. Thus, these probabilities should increase if calculated over longer time periods, if the number of species or the numbers of individuals per species carried by the seafood trade increases, if handling procedures (by either the sellers or buyers) change in a way that increases the opportunities for escape or release, or if the receiving waters become more vulnerable to the establishment of non-native species. Alternately, by exploiting appropriate opportunities to affect these factors, management actions could reduce these probabilities.

Conclusions

The limited evidence of species being established in California (and as far as we know, anywhere in the world) as a result of transport in the live marine seafood trade, suggests that the risk of future invasion from this vector is low. The main reason for this is probably the fact that most live seafood that is imported is eaten, and even of that portion that isn't eaten (culls, waste, escapes, and diversions to other purposes such as aquarium pets or scientific research), probably only a small portion, and in most cases probably only a small number at a time, ends up in suitable marine waters for the organisms to survive. Still, if a large number at a time is discarded, or if an asexually reproducing organism is released in small numbers frequently enough, the risk of establishment can become significant. This, we think, is the lesson to be drawn from the recent occurrences in California waters of multiple populations of *Ascophyllum nodosum* and *Littorina littorea*. The fact that they have not yet become established should not be too reassuring, as they look a lot like bullets that we have so far, fortunately, dodged.

Releases of large numbers of live seafood organisms can occur in at least three ways: (1) as escapes from in-water seafood holding facilities, *i.e.* live seafood organisms held in cages or nets in coastal waters; (2) as mercy releases; and (3) as intentional plantings to establish a local population of an edible species.

We don't know of any in-water holding facilities for non-native seafood species in the coastal waters of the state (this is distinct from holding organisms in coastal water for aquaculture, which is common in various forms), but we suggest that they should not be allowed. If none currently exist, we recommend that steps be taken now to ban them; this would be harder to accomplish once they exist.

We don't know of any mercy releases of live seafood species by animal rights groups in California,[13] but Buddhist mercy releases of large numbers of animal "beings" into California's coastal waters have often occurred, frequently involving bait species (F. Lopez 2004; F. Wong pers. comm.; K. Fraser pers. comm.) but sometimes also seafood species (see Anonymous 2002, Wong 2002 for examples in other countries). The latter, for example, includes the frequent release into Lake Merritt, a brackish-water lagoon in Oakland, of freshwater turtles presumably purchased in the food markets of Oakland's

[13] The only release of a marine seafood species by an animal rights group that we know of is the 2008 release into Maine's costal waters of a 20-pound lobster (*Homarus americanus*) by a New York City restaurant, after an appeal by PETA (People for the Ethical Treatment of Animals) (Anonymous 2008). In general we suspect that mammals and birds are more attractive targets for release by animal rights activists than are seafood species. There is a report of the release of a store-bought lobster into Washington state waters by a customer "driven by guilt" (Henderson 1998); the high cost of lobsters probably keeps such releases rare.

Chinatown (C. Richards, pers. comm.), and the release of dozens of American lobsters into San Francisco Bay at Coyote Point (A. Cohen, unpubl. data). Such releases may be illegal, but we believe the best way to reduce this risk is to work with the Buddhist community to persuade practitioners to release local, native species that do not pose a risk of bioinvasion. Because some groups already do so (*e.g.* Buddhist releases of locally-caught bait shrimp and bait fish off the docks and back into the water in San Francisco Bay and in the Los Angeles Area), and because doing so fits well with Buddhist values by maximizing the number of beings released and the likelihood of their survival and by maintaining the integrity of the ecosystem, thoughtful public outreach is likely to be successful in reducing the releases of non-native species. Understanding the goals that practitioners hope to achieve by such releases, and offering alternative practices that achieve those goals equally well or better, will likely be key.

The third release mechanism—deliberate plantings to establish a food resource—is more challenging to manage. Public education may persuade some individuals, but probably not others. With 840 miles of coastline to protect, law enforcement cannot hope to catch most releasers in the act. More consistent monitoring of coastal waters for non-native species, and better funding and management of a program of rapid eradication when populations are found, may be the best line of defense.

Additional Issues

Dead Fresh or Frozen Seafood

Most seafood is sold "fresh" (dead and chilled) or frozen. Viruses can be transported in frozen fish or other frozen seafood,[14] and live parasites and hitchhiking organisms can be transported in or on fresh, dead seafood organisms. Even shells and remains that have been dried for a time are capable of carrying harmful organisms (Cohen and Zabin 2007, 2009). These issues are outside the scope of this study, which addresses live marine seafood.

Illegally or Non-commercially Imported Live Seafood

The importing and selling of live Chinese mitten crabs, *Eriocheir sinensis*, was banned under state and federal law after it was discovered that restaurants were importing them into California. We have documented that at least into the 1990s there were regular incidences of individuals travelling from Asia to the US Pacific coast by air carrying live mitten crabs, intended for consumption (Cohen and Carlton 1997). Some agency staff believe that importing these crabs live for sale in markets or restaurants continued after the legal ban. It is possible that either private or commercial smuggling of live mitten crabs intended for consumption eventually led to some being released and successfully establishing in California. These issues are outside the scope of this study, which addresses the legal commercial trade in live marine seafood.

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[14] 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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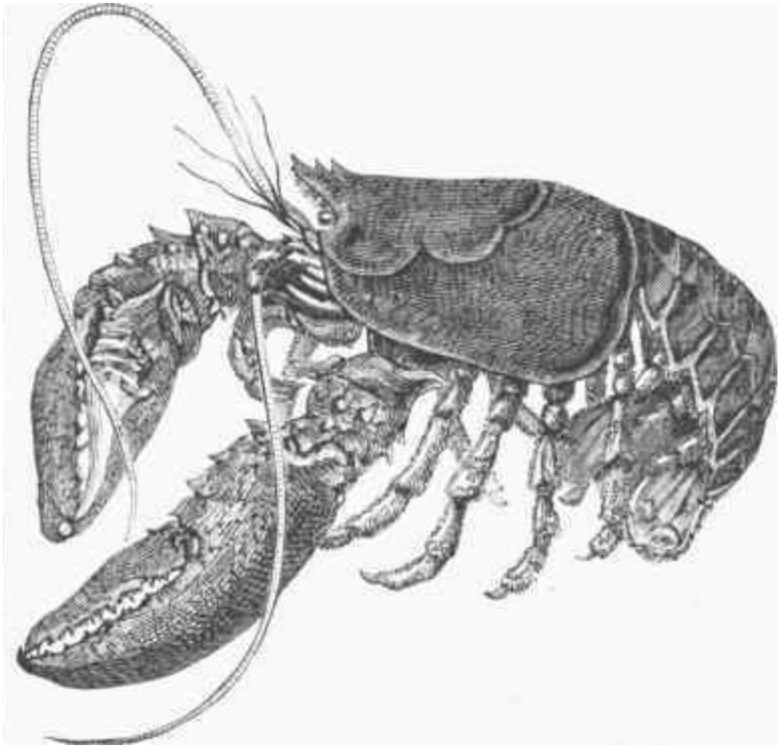
Appendix A. Coastal Counties Surveyed

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
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
Central	3	7,071
Southern	5	13,632
Coastal Counties	20	35,716
California	58	163,696

Live Saltwater Seafood Sold in California



CRAB
5994 McBryde Avenue
Richmond, CA 94805-1164

Section 1

Q-1. Do you sell or distribute <u>live</u> saltwater seafood? (*Circle one*)

1 YES *If yes ⇒ Please continue.*

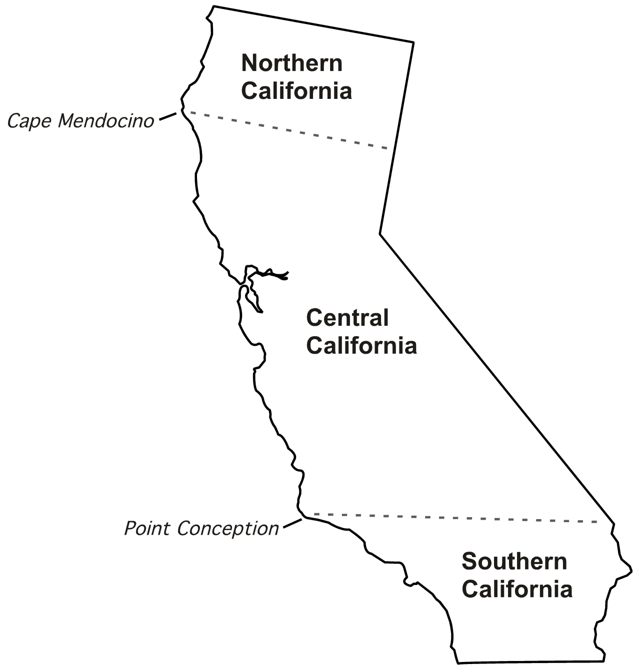
2 NO *If no ⇒ <u>Please return the survey</u> in the envelope provided, so we know that you do not sell or distribute live saltwater seafood.*

Q-2. Where is your facility located? (*Circle one – See map*)

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 seafood 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 STORMWATER DRAIN

5 OTHER (*Please describe*) ________________________________

6 DON'T KNOW

Q-5. How do you dispose of the packing material (such as ice, ice packs, seaweed, sea water, etc.) that live saltwater seafood arrives in? (*Circle all that apply*)

1 TRASH PICKUP/LANDFILL

2 INTO A WATER BODY

3 DISTRIBUTE WITH PRODUCT

4 OTHER (*Please describe*) ________________________________

Q-6. 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 seafood species you sell. On the following pages, please fill out one page for each live saltwater 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 estimates of quantities and percentages. Call or email us if you have any questions.

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

Q-7. Common or Trade Name of Seafood Species: ______________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ____

Q-12. What percentage do you ship to each region? (*See map on first page*) *Answers should add up to 100%*

1 NORTHERN CALIFORNIA (North of Cape Mendocino) ________%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) ________%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) ________%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. ________%

5 OUTSIDE OF THE U.S. ______%

Q-13. What type of packing material does this seafood species arrive in? (*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

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

Q-7. Common or Trade Name of Seafood Species: ___________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page*)

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. _____________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*)
Answers should add up to 100%

1 NORTHERN CALIFORNIA (North of Cape Mendocino) _______%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) _______%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) _______%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. _______%

5 OUTSIDE OF THE U.S. _____%

Q-13. What type of packing material does this seafood species arrive in?
(*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

These pages are for additional live saltwater seafood species:

Q-7. Common or Trade Name of Seafood Species: ______________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ____

Q-12. What percentage do you ship to each region? (*See map on first page*)
Answers should add up to 100%

1 NORTHERN CALIFORNIA (North of Cape Mendocino) ________%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) ________%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) ________%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. ________%

5 OUTSIDE OF THE U.S. ______%

Q-13. What type of packing material does this seafood species arrive in?
(*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

Q-7. Common or Trade Name of Seafood Species: ___________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ______________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*)
Answers should add up to 100%

1 NORTHERN CALIFORNIA (North of Cape Mendocino) _______%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) _______%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) _______%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. _______%

5 OUTSIDE OF THE U.S. _____%

Q-13. What type of packing material does this seafood species arrive in?
(*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

These pages are for additional live saltwater seafood species:

Q-7. Common or Trade Name of Seafood Species: ______________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. __________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*)
Answers should add up to 100%

1 NORTHERN CALIFORNIA (North of Cape Mendocino) ________%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) ________%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) ________%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. ________%

5 OUTSIDE OF THE U.S. ______%

Q-13. What type of packing material does this seafood species arrive in?
(*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

Q-7. Common or Trade Name of Seafood Species: ___________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page*)

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ______________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*) *Answers should add up to 100%*

1 NORTHERN CALIFORNIA (North of Cape Mendocino) ________%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) ________%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) ________%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. ________%

5 OUTSIDE OF THE U.S. ______%

Q-13. What type of packing material does this seafood species arrive in? (*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

These pages are for additional live saltwater seafood species:

Q-7. Common or Trade Name of Seafood Species: ____________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*) *Answers should add up to 100%*

1 NORTHERN CALIFORNIA (North of Cape Mendocino) ________%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) ________%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) ________%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. ________%

5 OUTSIDE OF THE U.S. ______%

Q-13. What type of packing material does this seafood species arrive in? (*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

Q-7. Common or Trade Name of Seafood Species: ___________________________

Q-8. Scientific Name, if known: ____

Q-9. Type: (*Circle all that apply*)

1 WILD-CAUGHT

2 FARMED

Q-10. Where is this species caught or farmed? *What country or state – if California, please state Northern, Southern or Central California (see map on first page)*

____

Q-11. Approximate amount sold each year:

Identify units: number, pounds, etc. ______________________________________

Q-12. What percentage do you ship to each region? (*See map on first page*)
Answers should add up to 100%

1 NORTHERN CALIFORNIA (North of Cape Mendocino) _______%

2 CENTRAL CALIFORNIA (Cape Mendocino to Pt. Conception) _______%

3 SOUTHERN CALIFORNIA (South of Pt. Conception) _______%

4 OUTSIDE OF CALIFORNIA BUT WITHIN THE U.S. _______%

5 OUTSIDE OF THE U.S. _____%

Q-13. What type of packing material does this seafood species arrive in?
(*Circle all that apply*)

1 ICE

2 ICE PACKS

3 SEAWEED

4 SEA WATER

5 NO PACKING MATERIAL

6 OTHER (*Please describe*) ____

Is there any other information you would like to tell us about the live saltwater seafood trade 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 (Seafood)
Street Address
City State Zip

Non-native saltwater species have harmed commercial and recreational fisheries, aquaculture operations, water systems, and 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 seafood wholesalers in the coastal counties of California, to participate in a short survey about live seafood sales. 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 <u>do</u> <u>not</u> 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 seafood species sold in California. Your company was selected at random from a list of seafood wholesalers 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 seafood wholesalers.

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 (Seafood)
Street Address
City State Zip

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

Company (Seafood)
Street Address
City State Zip

Three weeks ago I wrote you asking for your help on a survey of California seafood wholesalers. 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 seafood wholesalers 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 (Seafood)
Street Address
City State Zip

I am writing to you once again regarding our study of the California seafood 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 seafood 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 seafood wholesalers 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 bait, seafood 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 f or your convenience.

I want to assure you that any information provided will be kept confidential. No seafood business 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. Estimated average weights used to convert quantities given in pounds to number of organisms

Species	Average weight (lb)	Basis for average weight
Haliotis rufescens	0.2	farmed abalone reach marketable size at 4-6/lb - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418958
Clam (unidentified)	0.05	25-35/lb - http://www.marxfoods.com/live-clams 20/lb http://www.jpshellfish.com/manila_clams.php: small: 5-12/lb, large: 1-3/lb - http://www.marxfoods.com/Live-Quahog-Clams?sc=2&category=22784: 30-40/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5: 7-8/lb - http://www.marxfoods.com/Live-Mahogany-Clams?sc=2&category=22784; 10-13/lb - http://www.jpshellfish.com/mahogany_clams.php; 18-24 per 2 lb - http://www.harborfish.com/products/product-detail.php?id=62; 8-10/lb - http://www.qualityfreshseafood.com: 15-18/lb - http://www.citarella.com/Product.asp?SubDepartment=18&Department=5; 12-15/lb - http://www.marxfoods.com/Live-Steamer-Clams?sc=2&category=22784
Mercenaria mercenaria	0.1	small: 5-12/lb, large: 1-3/lb - http://www.marxfoods.com/Live-Quahog-Clams?sc=2&category=22784
Ruditapes philippinarum	0.04	25-35/lb - http://www.marxfoods.com/live-clams 20/lb http://www.jpshellfish.com/manila_clams.php
Chione stutchburyi	0.03	30-40/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5
Panopea abrupta	2.00	1.5-2lb ea - http://www.marxfoods.com/Live-Geoduck?sc=2&category=22784; weighs an average of 2.25 lb - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418959
Mytilus edulis	0.05	20-25/lb (http://newenglandlobster.net/shop/index.php?_a=viewDoc&docId=7); 25-30/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5; 20-25/lb (http://newenglandlobster.net/shop/index.php?_a=viewDoc&docId=7); 25-30/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5; 15-20/lb - http://www.marxfoods.com/Live-Maine-Mussels?sc=2&category=22785; 15-20/lb - http://www.marxfoods.com/Live-Maine-Mussels?sc=2&category=22785
Mytilus sp.	0.05	20-25/lb (http://newenglandlobster.net/shop/index.php?_a=viewDoc&docId=7); 25-30/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5; 20-25/lb (http://newenglandlobster.net/shop/index.php?_a=viewDoc&docId=7); 25-30/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5; 15-20/lb - http://www.marxfoods.com/Live-Maine-Mussels?sc=2&category=22785; 15-20/lb - http://www.marxfoods.com/Live-Maine-Mussels?sc=2&category=22785
Perna canaliculus	0.04	25-30/lb - http://www.citarella.com/Product.asp?SubDepartment=19&Department=5
Crassostrea gigas	0.4	large: ≈5lb/doz - http://www.pikeplacefish.com/buy/crab-and-shellfish/show/large-live-pacific-oysters/
Scallop (unidentified)	0.09	100 per 8-10 lb - http://www.marxfoods.com/Live-Bay-Scallops
Pandalus platyceros	0.1	giant spot shrimp: 25-30/lb, Colossal spot shrimp: 15/lb - http://www.great-alaska-seafood.com/shellfish.htm#Colossal%20Shrimp; Pandalus spp average 40-55/lb - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418997
Callinectes sapidus	1	Giovanni's Fish Market <info@giovannisfishmarket.com>
Cancer magister	2	2 lb ea - http://newenglandlobster.net/shop/index.php?_a=viewCat&catId=6; 1.5-3 lb ea - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418966; 2 lb ea - http://newenglandlobster.net/shop/index.php?_a=viewCat&catId=6; 1.5-3 lb ea - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418966
Cancer productus	1	Giovanni's Fish Market <info@giovannisfishmarket.com>
Paralithodes camtschaticus	7	4-10 lb ea - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418968
Crab (unidentified)	1.5	Giovanni's Fish Market <info@giovannisfishmarket.com>;
Homarus americanus	2	3 lb - http://newenglandlobster.net/shop/index.php?_a=viewCat&catId=2; 1-1.5 lb - http://www.allfreshseafood.com/p-lobsters.htm; 1.5-2.5 lb - http://www.joepattis.com/shop/select-type.cfm?typenum=86; 1-2.5 lb - http://216.119.70.95/market/Details.cfm?ProdID=94&category=; 1.5-3 lb - http://www.mcssl.com/store/4353898/lobsters; 1-1.125 to over 3 lb - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418977
Panulirus interruptus	1.25	avg 1.25 lb - http://www.catalinaop.com/Live_California_Spiny_Lobster_p/shellfish_c1.htm
Myoxocephalus polyacanthocephalus	4	based on Sebastes sp.: 2-5 lb is the most common - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418930; observations on site visits
Notothenia microplepidota	7	observations on site visits
Ophiodon elongatus	10	typical market size ≈10 lb - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418915; observations on site visits
Paralicthys olivaceus	6	observations on site visits
Platichthys stellatus	5	observations on site visits
Sebastolobus sp.	4	based on Sebastes sp.: 2-5 lb is the most common - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418930; observations on site visits
Sebastes sp.	4	2-5 lb is the most common - http://www.seafoodsource.com/seafoodhandbook.aspx?id=10737418930; observations on site visits
Semicossyphus pulcher	8	observations on site visits
Strongylocentrotus sp.	0.5	avg 1 lb ea - http://www.catalinaop.com/Live_Red_Black_Sea_Urchins_p/sushi_roe_3a4.htm; 3-7/lb - http://www.catalinaop.com/Live_Purple_Sea_Urchins_p/sushi_roe_3a5.htm
Stichopus japonicus	0.45	FAO publications, commercial size is 200 g

Appendix E. Live Marine Seafood Online

Websites that offer live marine seafood species for retail sale online, with routine shipment to California

http://www.alaskaoyster.com
http://www.allfreshseafood.com
http://www.americanmussel.com
http://www.bayoyster.biz
http://www.bluecrabtrading.com
http://www.blueislandoyster.com
http://www.catalinaop.com
http://www.catchapieceofmaine.com/
http://www.champlins.com
http://www.charlestonseafood.com
http://www.citarella.com
http://www.clambakeco.com
http://www.cotuitoystercompany.com
http://www.crabplace.com
http://www.crabs.net
http://www.dennisoysters.com
http://www.dorrlobster.com/
http://www.eastcoastgourmet.com
http://www.farm-2-market.com
http://www.fishermansfleet.com
http://www.fresh-seafood.net
http://www.freshfromtheboat.com
http://www.gayislandoysters.com
http://www.gilttaste.com
http://www.giovannisfishmarket.com
http://www.hamahamaoysters.com
http://www.harborfish.com
http://www.ilovebluesea.com
http://www.ipswichfishmarket.com
http://www.islandcreekoysters.com
http://www.joepattis.com
http://www.jpshellfish.com
http://www.legalseafoods.com
http://www.lintonseafood.com
http://www.livelob.com
http://www.lobsteranywhere.com
http://www.lobsters-online.com
http://www.lobsters4u.com
http://www.lobsterman.com
http://www.lobsterstogo.com
http://www.luckycatchlobster.com
http://www.mainelobsterdirect.com
http://www.marxfoods.com
http://www.marylandbluecrabexpress.com
http://www.mdcrabbers.com
http://www.nedsislandoysters.com
http://www.newenglandlobster.net
http://www.newmeadowslobster.com
http://www.olympiaoyster.com
http://www.ordercrabs.com
http://www.oysterfarm.com
http://www.paradiseshrimponline.com
http://www.patriotlobster.com
http://www.penncoveshellfish.com
http://www.pikeplacefish.com
http://www.prawnco.com
http://www.profish.com
http://www.qualityfreshseafood.com
http://www.rroysters.com
http://www.sagamorelobster.com
http://www.simplylobsters.com
http://www.taylorshellfishfarms.com
http://www.thefreshlobstercompany.com
http://www.trentonbridgelobster.com
http://www.vitaminseaseaweed.com
http://www.westcottbay.com
http://www.wholey.com
http://www.widowsholeoysters.com
http://www.wildedibles.com
http://www.winterharborlobstercoop.com
http://www.woodburyclams.com

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

In the NEMESIS/California database, Discarded Seafood was listed as one of two to six possible vectors for 48 introductions involving 14 marine 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. Documentation and correspondence indicated that Discarded Seafood includes the seafood species, packing seaweed and hitchhiking organisms, and includes the disposal of surplus animals and accidental or humane releases (G. Ruiz, P. Fofonoff, pers. comm.). Although the correspondence explained that the Discarded Seafood vector was considered to be insignificant prior to 1945 (P. Fofonoff, pers. comm.), four of the 48 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 42 *established* marine introductions that listed Discarded Seafood as a vector (Table F-1), we deleted seven that were introductions to San Pablo Bay (location CDA_P093 in Table F-1). Of the remaining 35 introductions involving nine species, we judged that in none of them was the evidence good enough to classify the introduction as a possible or probable introduction via the seafood trade. To explain this conclusion, vector diagnoses are provided below for several of these introductions.

The two introductions that we classified as either a possible introduction via the seafood trade (the Northern Quahog *Mercenaria mercenaria* introduced into Colorado Lagoon) or as an introduction for which a case might someday be made that it arrived via the seafood trade (the Channeled Whelk *Busycotypus canaliculatus* introduced into San Francisco Bay) are not listed as possible Discarded Seafood introductions in the NEMESIS/California database. These two introductions are diagnosed in the main text of this report.

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

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

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 do not address the consistency problems here.

Table F-1. Established introductions that should not be classified as possibly introduced by the live marine seafood trade, but which are listed in the NEMESIS/California database with Discarded Seafood as a possible vector.

Taxon group	Species	Location*	Alternate vectors**
Algae	*Polysiphonia denudata*	_CDA_P093	BW
Algae	*Undaria pinnatifida*	_CDA_P065	FA(nO),F(RB),ND
Bivalvia	*Ruditapes philippinarum*	_CDA_P093	OA(J)
Bivalvia	*Ruditapes philippinarum*	_CDA_P095	OA(J)
Bivalvia	*Ruditapes philippinarum*	_CDA_P112	OA(J)
Bivalvia	*Ruditapes philippinarum*	Humboldt Bay	OA(J)
Bivalvia	*Ruditapes philippinarum*	Newport Bay	BW,FI(O),FI(U)
Bivalvia	*Ruditapes philippinarum*	Tomales Bay	OA(J)
Amphipoda	*Ampelisca abdita*	_CDA_P093	BW,DB,F(CS),F(RB),OA(A)
Amphipoda	*Ampelisca abdita*	_CDA_P095	DB,F(RB),OA(A)
Amphipoda	*Ampelisca abdita*	Tomales Bay	DB,F(RB),OA(A)
Amphipoda	*Ampithoe longimana*	_CDA_P058	DB,F(CS),F(RB)
Amphipoda	*Ampithoe longimana*	Newport Bay	BW,DB,OA(A)
Amphipoda	*Ampithoe valida*	_CDA_P058	BW,DB,F(CS),F(RB)
Amphipoda	*Ampithoe valida*	_CDA_P093	BW,DB,F(CS),OA(A)
Amphipoda	*Ampithoe valida*	_CDA_P095	DB,F(RB),OA(A)
Amphipoda	*Ampithoe valida*	_CDA_P112	DB,F(RB),OA(A)
Amphipoda	*Ampithoe valida*	Humboldt Bay	BW,DB,F(CS),F(RB),OA(A)
Amphipoda	*Ampithoe valida*	Mission Bay	BW,DB,F(RB)
Amphipoda	*Ampithoe valida*	Morro Bay	DB,F(CS),F(RB),OA(A)
Amphipoda	*Ampithoe valida*	Newport Bay	BW,DB,F(RB),OA(A)
Amphipoda	*Ampithoe valida*	San Diego Bay	BW,DB,F(CS),F(RB)
Amphipoda	*Ampithoe valida*	Tomales Bay	DB,F(RB),OA(A)
Amphipoda	*Jassa marmorata*	_CDA_P022	BW,DB,F(RB)
Amphipoda	*Jassa marmorata*	_CDA_P058	DB,F(CS),F(RB),ND
Amphipoda	*Jassa marmorata*	_CDA_P086	DB,F(RB)
Amphipoda	*Jassa marmorata*	_CDA_P112	DB,F(RB),OA(A)
Amphipoda	*Jassa marmorata*	_CDA_P143	DB,F(RB)
Amphipoda	*Jassa marmorata*	Humboldt Bay	BW,DB,F(CS),F(RB),OA(A)
Amphipoda	*Jassa marmorata*	Morro Bay	DB,F(CS),F(RB),OA(A)
Amphipoda	*Jassa marmorata*	San Diego Bay	BW,DB,F(CS),F(RB)

Amphipoda	*Jassa marmorata*	Tijuana Estuary	BW,DB,F(RB)
Amphipoda	*Jassa marmorata*	Tomales Bay	DB,F(RB),OA(A)
Amphipoda	*Melita nitida*	_CDA_P093	BW,DB,F(CS),OA(A)
Amphipoda	*Melita nitida*	Humboldt Bay	BW,DB,F(CS),F(RB),OA(A)
Amphipoda	*Microdeutopus gryllotalpa*	Humboldt Bay	BW,DB,F(CS),F(RB)
Decapoda	Eriocheir sinensis	_CDA_P093	BW,FI(U)
Decapoda	*Palaemon macrodactylus*	_CDA_P022	DB
Decapoda	*Palaemon macrodactylus*	_CDA_P093	BW
Decapoda	*Palaemon macrodactylus*	Mission Bay	BW,DB
Decapoda	Palaemon macrodactylus	Morro Bay	DB
Decapoda	*Palaemon macrodactylus*	Tijuana Estuary	BW,DB,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
DB = Discarded Bait
FA(nO) = Fisheries Accidental (not Oyster)
FI(O) = Fisheries Intentional (Official)
FI(U) = Fisheries Intentional (Unofficial)
F(CS) = Fouling (Commercial shipping)
F(RB) = Fouling (Recreational Boats)
ND = Natural Dispersal
OA(A) = Oysters-Accidental (Atlantic)
OA(J) = Oysters-Accidental (Japanese)

SELECTED VECTOR DIAGNOSES

Ampelisca abdita

NEMESIS listing: Introduced into Tomales Bay (first record: 1969) and Bolinas Lagoon (1971), with Discarded Bait, 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 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, respectively, 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.

Ampelisca sp., possibly this species, was reported in the seaweed packing for New England lobsters arriving in California (Table 10; Miller 1969). However, the relatively small amount of lobster-packing seaweed that likely ends up in these two bays (with small human populations in the areas surrounding them, and thus few consumers of imported lobsters) makes the seafood trade an unlikely vector.

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 seaweed packing for live lobsters or live baitworms imported from the East Coast are remote possibilities, 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 Bait 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).

Ampithoe valida was not reported in the seaweed packing for New England lobsters arriving in California (Table 10; Miller 1969). In addition, the relatively small amount of lobster-packing seaweed that likely ends up in these bays (many of them with small human populations in the surrounding area, and thus few consumers of imported lobsters) makes the seafood trade an unlikely vector.

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 Bait 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.

Jassa marmorata was not reported in the seaweed packing for New England lobsters arriving in California (Table 10; Miller 1969). In addition, the relatively small amount of lobster-packing seaweed that likely ends up in these bays (many of them with small human populations in the surrounding area, and thus few consumers of imported lobsters) makes the seafood trade an unlikely vector.

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 in the seaweed packing for bait worms or lobsters.