Aquatic Invasive Species Vector Risk Assessments:

A Vector Analysis of the Aquarium and Aquascape ('Ornamental Species') Trades in California

Final Report July 2012

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

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Table of Contents

Shipments of aquarium species at SFO air cargo facility. **Photo: R. Fontana**

Executive Summary

The aquarium and aquascape trade in marine and estuarine species ('marine ornamental species') is lucrative and has resulted in the introductions of some considered to be the world's worst invasive species. These species include the seaweed (*Caulerpa taxifolia*), which was costly to eradicate in California, and the lionfish (*Pterois volitans*), which has not yet been reported in California.

Our objective was to characterize to the degree possible the risk to California posed by the marine ornamental species trade in non-indigenous species. To guide collection and analysis of data, we used a simple conceptual model as a starting point for risk assessment. The model assumed that the risk from non-indigenous ornamental marine and estuarine species is proportional to 1) the flux of organisms entering the state, 2) successful establishment after introduction, and the 3) impact (broadly defined).

Our preliminary ***Key Findings*** (highlighted within Results section) are:

- Based on available data, only 13 species of non-indigenous marine ornamental species have been introduced between 1853-2011
- The majority of these species (9 representing 69%) established successfully post-introduction
- The flux of non-indigenous marine ornamental species imported into California is high
    - Over 11 million individual non-indigenous animals were imported into LA and SF in 2009
    - At least 179 species were imported into SFO on a single day in 2012
    - Non-indigenous species are being imported from eight temperate countries of origin although the majority originated from the tropical Indo-Pacific region
    - Imported species potentially capable of tolerating California's marine environment include barramundi (restricted species in CA) and lionfish
    - The majority of the imported ornamental species were listed in non-specific categories as 'marine tropical fish' and 'other invertebrates'
    - Information to estimate the number of imported ornamental species that stay in California or come in via non-Californian ports ('trans-shipments') cannot be obtained through agencies but might be available from the industry
    - Importations of California Restricted Species probably account for a limited number of species and individuals, but data are inadequate to determine the actual numbers
- Propagule pressure, which is one important measure to estimate the probability of a non-indigenous species being introduced, could not be estimated due to limitations in data

- Impacts of non-indigenous seaweeds and molluscs are poorly-studied (~25% of peer-reviewed publications)
  - Impact studies were found for only one of the five introduced ornamental mollusc species and for the seaweed *Caulerpa taxifolia*

- Non-indigenous species of concern (*Caulerpa taxifolia*, lionfish) are available for sale in California aquarium stores and over the internet

- The regulatory authority for non-indigenous ornamental marine species is fragmented across and within federal and state agencies

- There is no central source of information on the species, the regulations, the permits and other relevant records

Although the flux of non-indigenous marine ornamental species is high, the vector has not been a major contributor to the large number of species introduced to California. This small number however includes some of the species considered to spread fastest and cause harm (i.e., are highly invasive) in marine waters.

A central coordinated permit process and database for all regulated species will benefit industry, government at all levels, and researchers. We recommend that the current permitting process be streamlined and centralized with a single permit for live organisms that would be recognized by all authorizing agencies. A streamlined single permit would facilitate a centralized and coordinated database to bring together relevant permit data and allow more accurate and complete data management and dissemination. Information on trans-shipment into and out of California should be required on all permits. Reporting the volume in a standardized unit of importations and trans-shipments out of and into California should be mandatory. Better enforcement of labeling of live species imported and for sale should be encouraged.

It is clear from our colleagues investigating other vectors (aquaculture, fishing and recreational vessels, live seafood and bait) that data are insufficient to perform even the simple model proposed to assess the risks these vectors pose for California. In the absence of standardized data available within and across vectors, we reviewed expert-knowledge solicitation as an alternative to guide California in assessing the risks these vectors pose and developed a template for a future expert-knowledge elicitation of the impacts of marine non-indigenous species in California.

We recommend that California pursue a quantitative cross-vector assessment for marine non-indigenous species even in the face of limited data for the ornamental vector. Vector management is widely acknowledged as the most effective means to reduce future costs from non-indigenous species, but until a cross-vector assessment is conducted, California will be left with managing non-indigenous species on a species-by-species basis.

Introduction and Background

This report is devoted to assessing the aquarium and aquascape (hereafter referred to as 'ornamental') trade as a potential pathway for the introduction of non-indigenous marine and estuarine ('brackish') species into California and the potential impacts. We define 'non-indigenous' as a species introduced by human influence outside of its native range (Lodge et al. 2006). The term 'invasive species' is reserved for a non-indigenous species that spreads widely beyond its point of introduction, is locally abundant, spreads into natural communities, or has caused or likely to have an ecological or economic impact (National Invasive Species Council 2001).

Aquarium keeping is a highly popular hobby, second only to photography. Exotic marine plants and animals are prized for their beauty and novelty, making the ornamental trade lucrative, on the order of US $1 billion annually worldwide for marine fishes and invertebrates alone (Wabnitz et al. 2003, SCBD 2010). For example, the value of an ornamental marine fish species can be over 80 times higher than its value as a fishery species (Wabnitz et al. 2003). The United States accounts for well over 50% of the marine aquarium fishes and invertebrates being sold (Wabnitz et al. 2003, Tissot et al. 2010). Due to the high value of the marine ornamental trade, it is being promoted as a means of sustainable development in many countries from which specimens are collected. As a result, attention has been paid to the environmental effects of the trade resulting from collection and shipping practices and strategies to manage and mitigate the undesirable effects (e.g., Bruckner 2005). Far less attention has been devoted to the potential 'downstream' environmental effects of releasing non-indigenous species into waters where they might establish and become invasive in the sense of causing environmental or societal harm.

The ornamental plant trade potentially poses less of a threat of introducing non-indigenous marine species than the animal trade because most ornamental plants are freshwater species, with the notable exception of the seaweed *Caulerpa taxifolia*. The water garden industry, however, is equally lucrative; it was estimated as worth over $1 billion in the U.S. (Kay and Hoyle 2001). The plants being traded are highly invasive. For example, Les and Mehrhoff (1999) found that 76% of all aquatic plants introduced in southern New England have escaped from cultivation. It is also likely that several of the most costly aquatic water weed invasions in the San Francisco estuary's upper reaches resulted from the ornamental trade, including the aquatic horticulture species Brazilian water weed (*Egeria densa*) and water hyacinth (*Eichornia crassipes*).

The ornamental trade pathway for introducing non-indigenous marine and estuarine species has received less attention than better-studied pathways (synonymous with 'vectors' in this report), such as ballast water. Even aquaculture has been better-studied as a vector than the ornamental trade. Globally, the vectors attributed with introductions of the majority of marine and estuarine non-indigenous species to date are ballast water (~25% of known introductions), hull fouling (~25%), and aquaculture (~25%) (Carlton and Cohen 1995, Thresher 1999, Ruiz et al. 2000, Williams 2007, Williams and Smith 2007), with the remaining quarter made up by other vectors including the ornamental trade. The ornamental vector includes both non-indigenous species for display and non-indigenous species 'hitch-hiking' along. Aquarium species are very hardy and are often released fully-grown or at least large (Duggan et al. 2006), increasing the likelihood they will survive, establish, reproduce and spread if released (Keller and Lodge 2007).

Although the number of marine and estuarine (hereafter lumped as 'marine') species introduced through the ornamental trade is lower compared to introductions through shipping and boating and aquaculture, the trade has been growing rapidly and is a serious vector resulting in damaging introductions: fully one-third of the world's most invasive aquatic species have been attributed to this vector (Padilla and Williams 2004). One of California's most costly introductions (*Caulerpa taxifolia*, Anderson 2005) was attributed to the marine aquarium trade, based on DNA evidence (Wiedenmann et al. 2001). *Caulerpa taxifolia* (Mediterranean invasive strain) cost California more than $6 million to eradicate.

Potential risk of ornamental non-indigenous species in California's marine and estuarine waters

The risk posed to natural resources and society by a non-indigenous species is a function of the likelihood that a species will:

- Be introduced
- Establish
- Spread
- Cause 'harm' (Lodge et al. 2006, Williams and Grosholz 2008).

Our overarching project goal was to assess data for each step in the invasion pathway for marine ornamental species in California, to support a future comparison of the ornamental species vector to five other non-shipping vectors of potential concern to the state (fishing vessels, recreational vessels, aquaculture, live seafood, live bait). Data are scarce for these vectors in general and specifically for California.

Some general information is available for each step of the pathway for marine ornamental species to become invasive and cause damage to California's resources. For many non-indigenous species, the likelihood of being introduced is highly correlated with how many individuals of a species are arriving at the locale of interest over time (Ruiz et al. 2000, Colautti et al. 2006, Hayes and Barry 2008). The flux of non-indigenous species, also termed 'propagule supply', is generally high in the ornamental vector. For example, between 1997-2002, the number of marine ornamental fishes imported into the U.S. was estimated between 1,500,000 to over 3,000,000 (Wabnitz et al. 2003). Many if not the majority of these individuals enter through Los Angeles International Airport (LAX), because the Indonesia-Philippines Coral Triangle region is the origin of most of the species (Wabnitz et al. 2003).

Although the flux of non-indigenous marine ornamental species into California is assumed to be high, the risk that high numbers pose might be offset because most of the imports are tropical species not likely to survive and establish populations if released into temperate California waters. If, however, an ornamental species is able to tolerate and reproduce in the state's waters, the odds are that it might be highly damaging, given the past history of established ornamental species (see above, Keller and Lodge 2007). Lionfish is an example of an ornamental species of concern (Semmens et al. 2004). Native to the Indo-Pacific region, lionfish (*Pterois volitans*) was introduced into the southeastern seaboard of the U.S. It has spread not only to tropical Caribbean waters but also into temperate waters (Whitfield et al. 2007, Freshwater et al. 2009). Lionfish are voracious predators and their introduction engendered great media and management attention (see box in Discussion section). Although lionfish have not been reported from California, several lionfish species, including *P. volitans*, are being imported into the State. Aquarium stores in California list them as available for sale over the internet (see Results).

Objectives

The overall objective of the project was to generate the first comprehensive estimate of the number of species in the ornamental vector in California, the proportion of species that have or are likely to become a significant management problem based on documentation of previous invasive history and life history characteristics, and the flux or 'propagule supply', which is the number of individuals circulating in the vector (if data are available). Propagule supply provides a first-cut estimate of the importance of this vector for introducing non-indigenous marine species to California. Ideally, it would be important to estimate propagule size (number of individuals released in a single event) and propagule number (the number of discrete release events) (Lockwood et al. 2005, Colautti et al. 2006). As described below, data on the flux of non-indigenous species in the vector are important but not sufficient for assessing the risk posed by ornamental species; risk assessment must include information on establishment, spread, and impact.

Risk assessment for non-indigenous species has been practiced largely on a species-by-species basis ('black list' approach). Few risk assessments have been completed for invasive marine species because of the burden of completing an assessment for *all* species of interest. There is usually insufficient introduction, establishment, and impact data to perform rigorous, quantitative analyses of relative invasion vector strengths even for single species (Ruiz and Carlton 2003, Herborg et al. 2007, Molnar et al. 2008, Kuhnert et al. 2010). Well over 250 marine and estuarine non-indigenous species have been introduced to California (Ruiz et al. 2000). This number is undoubtedly underestimated and represents only the species known to have been introduced, as opposed to species circulating in the vector and poised for introduction. A risk assessment framework, however, is an important goal and provides a conceptual model to guide data collection and analysis. Despite challenges in performing a risk assessment, it can be worth the investment (Springborn et al. 2011). For example, Australia's risk assessment program provided net economic benefits even in the face of the economic gain from introducing potentially invasive non-indigenous plants for specific profits (such as timber), thus supporting investment in risk assessments (Keller et al. 2007).

The most effective means to reduce future costs of invasive species is the prevention of new introductions by managing the responsible vectors (Lodge et al. 2006). This recognition points to *vector* risk assessment as a means to determine allocation of the limited research and management resources dedicated to invasive species. That said, assessing the relative risks of various vectors circulating non-indigenous marine species has not yet been developed (Hayes and Sliwa 2002, Simberloff 2005, SCBD 2010). Nonetheless, important information can be provided to guide managing the risk of non-indigenous aquatic species in California and to identify gaps for future formal risk assessments.

Conceptual Risk Assessment Model - There are many conceptual frameworks for assessing the risk imposed by non-indigenous species (e.g., Catford et al. 2009, Blackburn et al. 2011, Wonham and Lewis 2009, Gurevitch et al. 2011, Olden et al. 2011, Thomsen et al. 2011a, b). Some favor matching niches of native and non-native to predict occurrence, some take a spatially-explicit landscape approach (which sites are vulnerable to invasions?), some include management actions, and others focus on propagule pressure or address how the recipient community shapes the success or failure after introduction. With the exception of ones that completely ignore impacts, all the frameworks are based on understanding factors that influence the main consecutive steps in the invasion process: delivery of the species, introduction, establishment, spread, and impact.

Starting in 2008, the Ocean Science Trust (OST) initiated a series of workshops involving scientists working on vectors for non-indigenous marine species in California. OST then developed the Aquatic Invasive Species (AIS) Project, dedicated to six vectors, of which the ornamental trade was one. The authors of this report collaborated with teams working on other vectors to develop a consensus for the following simple and broad conceptual model as a starting point for a comparative risk assessment of the *vectors*, to guide data collection and assess the availability of data to complete a risk assessment. This model is:

$$\text{Risk} \propto f\,(P_{introduction} \times P_{establishment/spread}) \times P_{Impact}, \text{ where} \qquad (1)$$

$P_{introduction}$ is the probability that a vector will introduce a non-indigenous species to California,

$P_{establishment/spread}$ is the probability species in the vector will establish possibly spread once introduced, and

P_{Impact} is the probability that species associated with the vector will cause ecological or economic harm to native ecosystems and society.

Risk in this model is specific to an individual vector, as opposed to species. We used this model to guide the data to be collected and analyzed. Given the lack of information on the ornamental marine species vector in general and specifically for California, $P_{introduction}$ was addressed in the simplest, first-cut way as the flux of individuals in the vector as they are delivered over time. $P_{establishment/spread}$ can be estimated most simply as the proportion of species introduced that successfully establish. P_{Impact} has been the most challenging term because 1) impact data are species-specific and sparse and 2) many of the non-indigenous marine species introduced to California cannot be ascribed to a single vector. Data sources for impacts can be found in published studies, but a numeric scoring of an impact must be made before such impacts could be incorporated into a more formal semi-quantitative risk assessment, or an expert opinion solicitation must be performed for the vectors (see Discussion).

The specific components of this study were to determine: 1) the non-indigenous species and numbers associated with the vector, 2) the first report of each introduction, 3) changes in introduction rates, 4) the portion of introduced species that successfully established, 5) literature available on impacts, 6) historical and future trends in the vector, 7) vector-specific characteristics, and 8) management options and control points.

Methods

We employed a two-part approach to our objectives, guided by the conceptual risk assessment model described in Objectives above, which addresses the probability of introduction, establishment and spread, and impact. One, we gathered information about the vector, the species associated with the ornamental trade and their likelihood of introduction, and information on the regulatory and management framework relevant to the vector. Two, we evaluated the impact posed by select taxa (seaweeds, molluscs) as documented in the scientific literature. The sources of information generally list more than one vector as a possible source of establishment (i.e., a species is 'polyvectic'), which is an issue for a cross-vector assessment. Nevertheless, databases can support a first best-estimate about the relative contributions of introductions by vector.

Non-indigenous species attributed to the ornamental species trade

We used the following sources to construct a database of non-indigenous species associated with the ornamental vector: 1) NEMESIS-California database (historical), 2) US Fish & Wildlife Service (USFWS) inspection records for importations of live organisms into the ports of Los Angeles and San Francisco (historical and current), and 3) California Department of Fish & Game (CDFG)'s Restricted Species permits (historical and current). We also accompanied the USFWS on an inspection tour of aquarium shipments arriving at San Francisco airport, to assess the propagule supply of ornamental species imported into California and to better understand the regulatory framework.

1) NEMESIS-California database - We extracted a list of introduced and established non-indigenous species in California attributable to ornamental trade from the NEMESIS database (National Exotic Marine & Estuarine Species Information System, Fofonoff et al. 2003 *http://invasions.si.edu/nemesis/index.html*). NEMESIS is a project of the Smithsonian Environmental Research Center (SERC) and was compiled from peer-reviewed scientific literature and the gray literature starting as early as 1853 through the present. A subset of the NEMESIS data, species introduced to California (CA NEMESIS) was comprehensively reviewed by SERC for all records through 2006, with the addition further details, such as dates of first and subsequent records on a bay-by-bay basis. Species were added to CA NEMESIS through 2011. NEMESIS CA includes species known to be non-native, those thought to have established populations, as well as species that have failed to establish or have gone extinct since becoming established. Species whose non-native status is uncertain, defined as "cryptogenic", are not included.

SERC researchers assigned species to vectors based on a thorough review of the literature, basing these decisions on a number of factors including any direct links to vectors, species' life history characteristics and history of vector operation in specific locations (for example, ballast water might be excluded as a potential vector from a water body that cannot accommodate large commercial vessels, or in cases where a species was reported from a location before ballast water was used in commercial shipping). In some cases, species were assigned a single vector, however, in most cases, several vectors were possibly and/or likely ('polyvectic').

We cross-referenced the NEMESIS list against two other sources: 1) a database complied for the Coastal Environmental Quality Initiative (CEQI) project, a literature review that included reports of non-native and cryptogenic species from estuaries and bays within California, (Williams and Grosholz, unpublished data) and 2) a database of non-native algae literature review from 1995 through 2006 compiled by Williams and Smith (2007). We updated the algal database with a search of the literature from 2006 through 2011.

We modified the NEMESIS database slightly regarding species listed for the vector. We removed species that were obligate (or nearly so) freshwater species based on available literature. Additionally, we updated some species names and higher taxonomic classifications.

We checked the NEMESIS-California database against three of our own lists and modified the ornamental species in the database accordingly and in consultation with SERC. We used: 1) a database compiled for the Coastal Environmental Quality Initiative (CEQI, UC Marine Council) project resulting from a major literature review that included reports of non-indigenous and cryptogenic species reported from estuaries and bays within California (Williams and Grosholz, unpublished data), 2) a global database of non-indigenous algae compiled by Williams and Smith (2007), and 3) the list of aquarium fishes from Chang et al. (2009). We updated the algal database with a search of the literature from 2006 through the end of 2011.

Because NEMESIS data are historical, they do not address the current flux of ornamental species into California. The following two data (#2 and 3 below) sources address the species flux question.

2) US Fish & Wildlife Service (USFWS) inspection records for importations - The US Fish and Wildlife Service is responsible for carrying out inspections and enforcing regulations regarding the importation of live animals into the United States. California's major ports of entry are located in the San Francisco Bay and Los Angeles regions. USFWS Office of Law Enforcement keeps electronic records of imports entering the country through various ports in the Law Enforcement Management Information System (LEMIS) database.

To obtain these data, we filed a Freedom of Information Act (FOIA) request for inspection records for the state's major ports, Los Angeles and San Francisco. Records were requested for calendar year 2009 (the most recent year for which USFWS considered the records were complete). A year was the longest time period for which LEMIS was able to deliver records for each port; longer time periods resulted in too many records and the search system 'timed-out'. To limit our search to the relevant species we made the following request using USFWS fields and categories: in the "wildlife description" field, "live specimen," "fingerling," and "live rock"; in the "purpose" field, "breeding," "educational," "personal," "scientific," "commercial," "reintroduction," and "zoos"; in the "source" field, "bred in captivity," "confiscated," "source unknown," and "wild captured." We asked for records from all exporting countries. Data were returned in a per shipment-by-'species'-code record format. Each record included shipment code, taxa imported and in what quantities, wildlife description, purpose of the import, organism source, source country of the imported taxa, the source country of the imported species, port of entry, and action taken by USFWS (i.e., cleared, seized, etc.). These records were sorted to remove strictly tropical species and duplicate or incomplete records.

US Fish and Wildlife Service inspections: port visit - To better understand the policies and procedures by which inspections are carried out by the US Fish and Wildlife Service and to gain a snapshot view of live species arriving to San Francisco ports, we visited the USFWS offices in Burlingame, near the San Francisco International Airport (SFO) in March 2012. We met with inspection staff and toured holding facilities for seized shipments and specimens awaiting further identification. We then accompanied agents to the airport to observe a routine one-day inspection of live organisms arriving in air cargo at SFO. At the air cargo facilities, USFWS wildlife inspectors and special agents examined aquarium shipments and compared the organisms shipped to the packing list and USFWS worksheets on CITES (Convention on the Trade in Endangered Species)-listed species and other species of concern. To better understand volume, composition and condition of species arriving to the state via the aquarium trade, we collected information on the common and scientific names of these species shipped for the aquarium trade, the numbers of each taxon, the condition of the organisms (dead, unlikely to survive, alive, alive/active), the type of packaging, discrepancies between shipment contents and packing lists, and actions taken by USFWS agents. We also took photos of some organisms for taxonomic identifications. Collectively we have familiarity with Indo-Pacific fishes, invertebrates, and algae, having spent >500 hours conducting research on tropical Pacific coral reefs. We used Allen et al. (2003) as a fish identification guide. USFWS provided access to documents for the shipments after redacting all information on importers.

To better understand regulations and practices currently in place, we wanted to determine:

- Coordination of agencies potentially involved in regulating live animal imports (i.e., USDA, CDFA, CDFG, and USFWS)
- Types of inspections officials routinely carry out on the documents and/or packages
- Details on typical bills of lading or other documents associated with the incoming cargo
- % of packages opened for inspection
- Triggers for an inspection
- Level of USFWS resources, in terms of staffing and taxonomic expertise, to prevent illegal species from entering the US
- USFWS opinion of whether resources (staffing, taxonomic expertise) to determine whether documents adequately reflect cargo contents

3) California Department of Fish and Game Restricted Species Permits data - Permits are required to possess, import, and transport species on California's Restricted Species list. Restricted species are relevant to our study because they are largely non-indigenous (or transgenic) and potentially invasive. We reviewed all records held at CDFG's License and Revenue Branch in Sacramento for restricted species within the state and extracted those pertaining to marine species over the time period 1988 through August 4, 2011. Each permit contained information on permit type (purpose of possessing the species), species permitted, permittee's city, the number of animals allowed, and, if available, origin of animal, port of entry, age of animals. Data were recorded on a year by permit by species (occasionally individual depending how the permit was filed) basis. After data were collected, species were vetted for habitat using FishBase (www.fishbase.org), World Registry of Marine Species (www.marinespecies.org), and Encyclopedia of Life (eol.org) to remove any non-marine or non-brackish species.

Statewide temporal and spatial trends in introductions

We used data from NEMESIS-California to characterize spatial and temporal trends in the statewide rate of ornamental trade-mediated introductions. Because actual dates of introduction and/or establishment are generally unknown, we used the year of the first report for the state as a proxy for year of introduction. In reality, in nearly all cases, species were first introduced some unknown time before they were first reported in the literature. We examined temporal trends using first reports on both a statewide (reported from anywhere in California) and a bay-wide (reported from a specific bay or water body) basis.

Impacts of non-indigenous species introduced by ornamental trade

We searched the peer-reviewed scientific literature to create a database of studies on the impacts of NEMESIS list of non-indigenous algae and mollusc species introduced in

California. These broad taxonomic groups make up a significant portion of the non-indigenous species in California. The time span for the BIOSIS search was 1926 to the end of the year 2011.

All searches were completed with the following terms in BIOSIS:
Topic=(Adventive OR Alien OR Bioinvasi* OR Biosecur* OR Exotic* OR Foreign OR Introduc* OR Incursion* OR Invad* OR Invasi* OR Nonendemic* OR Nonendemic* OR Non indigenous OR Nonindigenous OR Nonnative* OR Nonnative* OR Nuisance* OR Pest* OR Pest) AND Topic=(species name in quotes, e.g. "Sargassum muticum") AND Timespan=1926-2011.*

Searches were also carried out using synonyms for the current species name. We used WoRMS (World Registry of Marine Species; http://www.marinespecies.org/) and AlgaeBase (http://www.algaebase.org/) for lists of synonyms. We performed an initial sort by reading through the returned titles (>95% of papers for most species were not relevant). We sorted secondarily by reviewing abstracts and obtaining articles. Data from the relevant impact studies were extracted and entered into the spreadsheet. Papers were retained for potential further review and analysis. For each study, the following data were extracted: authors, year of publication, non-indigenous species name, vector and species origin if listed in article (for comparison, not actually used to attribute to vector), recipient habitat type (e.g., bay, intertidal zone, etc.) and location, impacted entity, the response variable, details on the types of impacts (various types within environmental, ecological, human health, economic impact categories), direction of effect, study type and setting, statistical analysis, and availability of mean effect sizes and error terms. The mean effect size and error terms provide an indication of whether data were adequate to perform a formal statistical meta-analysis of impacts. The study types were categorized as observational (lacking statistical analysis, limited comparisons, models, calculations), mensurative, or experimental (Williams 2007, Williams and Smith 2007). Mensurative and experimental studies included a replicated statistical design; experimental studies involved manipulations of native organisms and/or the non-indigenous species. Only mensurative and experimental studies were included in the impact analyses. A case as used in statistical meta-analyses is defined as a single result or effect for a single response variable; thus, an experiment or study or publication can include multiple cases.

Control points and management options - state and federal regulations

To assess control points and potential management options, we researched current state and federal regulations controlling the importation, movement and possession of live marine species in the state of California, with particular interest in any measures designed to control and/or manage non-indigenous species.

To better understand regulations and their enforcement, we had discussions with officials and reviewed written information about relevant permits and procedures at the following management agencies:

- California Department of Fish and Game, Eureka office: controls aquaculture and research permits and permits for importation of live fish for seafood
- California Department of Fish and Game, Sacramento office: issues permits for species on the state's Restricted Species list
- California Department of Fish and Game, Marine Region, Bodega Marine Laboratory
- California Department of Fish and Game, Invasive Species Program
- USDA Animal & Plant Health Inspection Service (APHIS), Plant Protection & Quarantine (PPQ)
- USFWS Law Enforcement Division

Ornamental species for sale in aquarium shops in the San Francisco Bay-Delta Area

As far as we could determine, no agency keeps a list of aquatic ornamental species for sale in the state of California. As a snapshot of the aquarium species in trade in the state, we used data collected from earlier surveys of aquarium stores in southern California (Zaleski and Murray 2006) and the Sacramento and San Francisco Bay Area (Chang et. al 2009, Williams and Schroeder unpublished data).

Internet availability: Rapid assessment of availability of live aquarium organisms, including *Caulerpa*, via Internet

Prohibited, restricted, and potentially invasive non-indigenous species are readily available over the internet, which is a major challenge for the management and regulation of invasive species (Padilla and Williams 2004, Walters et al. 2006). We did a preliminary rapid assessment of the online availability to California residents of prohibited non-indigenous aquarium species by conducting two targeted internet searches: 1) availability of *Caulerpa* spp. for purchase by California residents, and 2) online information on stock and internet purchase of same from aquarium stores in the San Francisco Bay area.

Nine *Caulerpa* species (*taxifolia, cupressoides, mexicana, sertulariodes, floridana, ashmeadii, racemosa, verticillata, scapelliformis* [sic; correct epithet is *scalpelliformis*]) are illegal to ship into the state of California due to invasion risk. On March 8, 2012, we assessed readily available information on the California shipping status of *Caulerpa* when making online purchases. These searches were conducted using the Google search engine and the search terms "live *Caulerpa* for aquariums" or "live *Caulerpa*." Only websites that appeared to be selling *Caulerpa* spp. were examined further.

To estimate the extent of online live stock lists for saltwater aquaria, we analyzed San Francisco Bay area aquarium store websites. This search was conducted on March 6-7, 2012 using the Google search engine and the search terms *"aquarium stores in San Francisco Bay area."* The search terms, "*aquarium stores in San Francisco Bay area,"* did not identify Petco and other large box stores. A secondary search was conducted on June 23, 2012 using the Google search engine and the search terms, "*pet stores."* The three major pet store chains each with over 20 Bay Area locations (Petco, PetSmart, Pet Food Express) were analyzed for the extent of online live stock lists for saltwater aquaria.

Results

Non-indigenous marine species introduced to California attributable to the ornamental species trade

Key finding - *We found 13 non-indigenous marine and brackish water species reported from California associated with the ornamental species trade (Table 1). The majority of these species (69%) established successfully, as typical for ornamental introductions (SCBD 2010).*

Seven species established in at least one location in the state, three have failed to establish, two have an unknown population status, and one (*Caulerpa taxifolia*) established but was eradicated at the two sites of introduction. Only two (*Caulerpa taxifolia*, *Melanoides tuberculatus)* of the 13 species were attributed solely to the ornamental trade vector; the rest are polyvectic (i.e., the ornamental trade is one of several possible vectors). Two of the 13 species have been reported from two bays each for a total of 15 records (Fig. 1). These represent 4.7% of the total 278 non-native marine species reported for the state in NEMESIS CA.

The first report of a non-native ornamental species introduced to California marine/brackish waters was *Limulus polyphemus* in 1917 (NEMESIS; Carlton 1979 reviews various early reports, although these are associated with oyster transplants). From 1917 until 1960 only three species linked to the ornamental trade were reported from California bays. Since 1960 there have been 12 reports, with 6 new reports from 2001-2007 (the last year for which NEMESIS reported an ornamental species) as the sole vector (Fig. 1).

Nearly all of these species were documented in San Francisco Bay (Fig. 2). The other occurrences were near the state's major urban centers of Los Angeles and San Diego. This result is not surprising given aquarium owners and stores are more abundant in these densely populated areas. Evaluation of trends over time, such as changes to introduction or establishment rates, or to primary versus secondary spread, was not possible given only two non-indigenous species were attributed solely to this vector.

Estimating the flux of non-indigenous ornamental marine species to California

Key finding - *The flux of marine animals through the ports of Los Angeles (LA) and San Francisco (SF) was very high. In 2009 a minimum of over 11 million individuals representing a minimum of 102 species entered these ports, almost exclusively as aquarium shipments arriving in air cargo. There were over 16,000 records for temperate species entering these ports.* ***.*** *A 'record' can be one to thousands of individuals. On a* *single day in 2012, over 7,000 individual organisms entered California through SFO. Lack of information on trans-shipment to other states from California ports of entry is a major gap in determining the risk the aquarium vector poses in California.* The detailed information regarding ornamental marine species entering the ports of LA and SF is provided below.

We estimated the influx of non-indigenous ornamental species into California in two ways. First, USFWS LEMIS records provided information on the volume, composition, and origin of species entering through state's ports. Second, we obtained similar data during USFWS inspections of aquarium shipments arriving at SFO on a single 'snapshot' day. Of note is that the information available was restricted to animals; USFWS is not responsible for regulating plant importations.

Table 1. Species introduced to California associated with the trade in ornamentals, the year of first report of the species in the state, and the bay from which it was first reported. Some species might have been transferred into the state via multiple vectors; for others the ornamental trade is the only attributed vector. Fishing Vessels 'Fish. Vessels', Recreational Vessels ('Rec. Vessels'). Data source: NEMESIS-California.

Species	Taxonomic group	Year of First Record	Bay of First Record	Vectors
Bullia rhodostoma	Molluscs-Gastropods	1966	San Francisco	Ballast Ornamental
Busycotypus canaliculatus	Molluscs-Gastropods	1938	San Francisco	Aquaculture Ornamental
Caulerpa taxifolia	Algae	2000	San Pedro	Ornamental
Chaetogaster diaphanous	Annelids-Oligochaetes	1986	San Francisco	Ballast Ornamental
Cordylophora caspia	Coelenterates-Hydrozoans	1930	San Francisco	Aquaculture Fish.Vessels Ornamental Rec.Vessels
Littoridinops monroensis	Molluscs-Gastropods	2005	San Francisco	Ballast Ornamental

Melanoides tuberculatus	Molluscs-Gastropods	1989	San Francisco	Ornamental
Limulus polyphemus	Horse shoe crab	1917	San Francisco	Ornamental Other
Potamopyrgus antipodarum	Molluscs-Gastropods	2003	San Francisco	Ornamental Rec.Vessels
Procambarus clarkia	Crustaceans-Crayfish	1966	San Francisco	Aquaculture Ornamental Other Seafood
Uromunna sp. A	Crustaceans-Isopods	1989	San Francisco	Ballast Fish.Vessels Ornamental Rec.Vessels
Vallicula multiformis	Ctenophores	2007	San Diego	Ballast Fish.Vessels Ornamental Rec.Vessels
Varichaetadrilus angustipenis	Annelids-Oligochaetes	1982	San Francisco	Ornamental Other

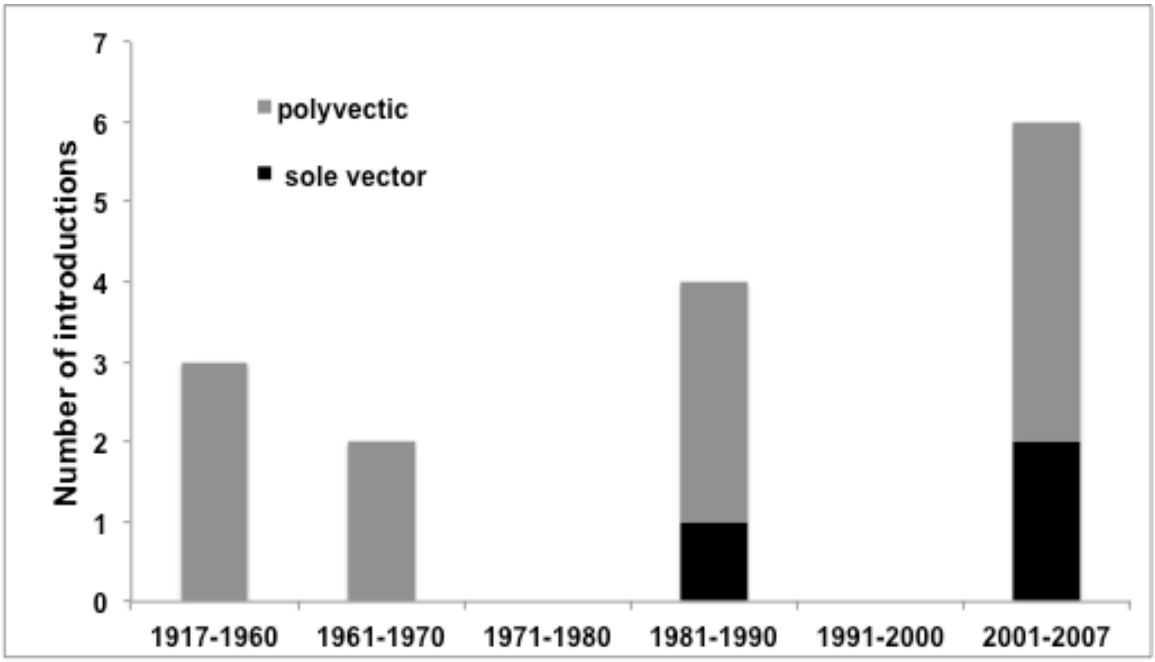


Figure 1. The number of introductions to California bays and estuaries of non-native species associated with ornamental trade by decade. Gray bars represent species for which the ornamental trade is one of several likely modes of introduction ('polyvectic'); black bars represent those for which ornamental trade is the only likely vector ('sole'). Data source: NEMESIS CA.

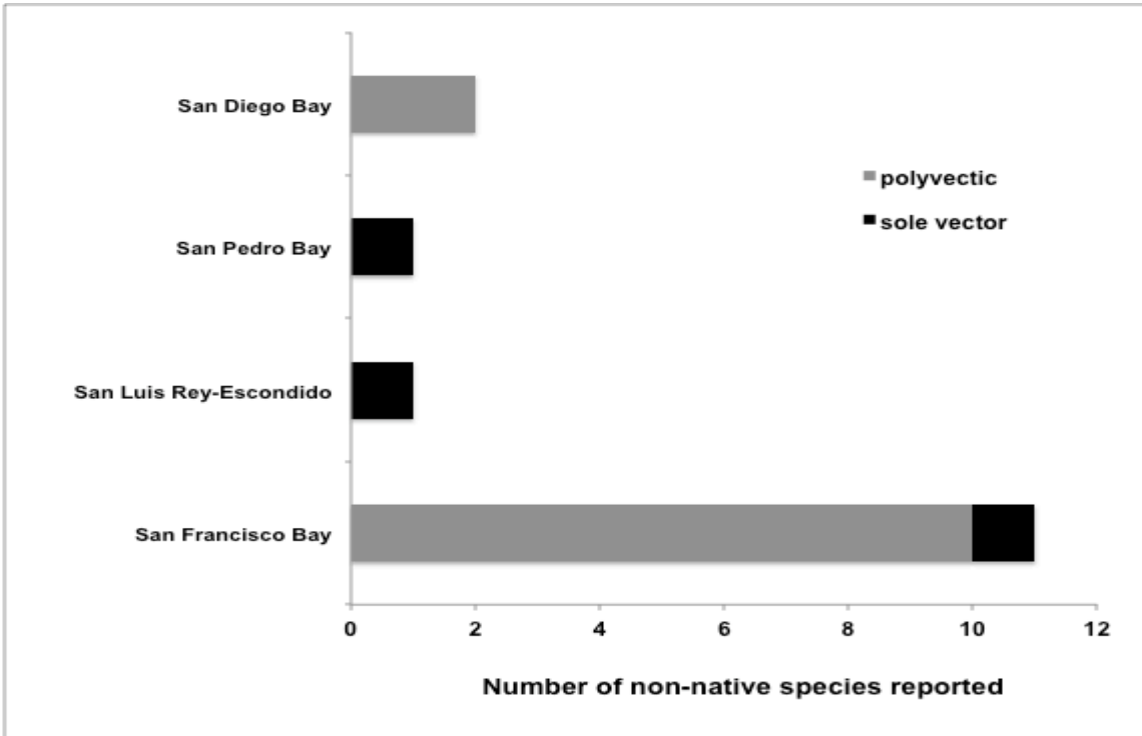


Figure 2. The number of introductions to California bays of non-indigenous species associated with ornamental trade by water body. Gray bars represent species for which the ornamental trade is one of several likely vectors for introduction ('polyvectic'); black bars represent those for which ornamental trade is the sole likely vector. Data source: NEMESIS CA.

The flux of organisms coming into the state in 2009 via the ports of LA and SF, primarily through air cargo (USFWS, pers. com.), was highly variable by taxa (Tables 2 and 3). Importers have the option of reporting volume of each taxon within a shipment in the unit of their choice, though primarily reports are in number of specimens, followed by kilograms. Annual volumes of marine organisms imported into LA ranged from two to over 7 million individual specimens and from seven to just over 238,000 kilograms. In total, 250,504 kilograms, and 10,700,366 individuals specimens were imported into LA in 2009. For SF, the ranges were 5 to ~2,971 and 1 to 342,325 for kilograms and individual specimens, respectively. The totals imported via SF in 2009 were 4,478 kilograms and 519,551 individual specimens. While these figures represent the volume brought into these two ports, it is not possible to account for the actual quantities that remain in California as the agency does not collect information on the ultimate destination of the imports once they are cleared. Records on trans-shipment are not kept by any agency insofar as we could determine. It is reasonable to assume that some of these species remain in the state, but additional species, entering through other ports such as Miami International Airport, likely are trans-shipped to California.

The very broad categories of 'Other Live Invertebrates', 'Marine Tropical Fish', 'Crustaceans', and 'Molluscs' made up the bulk of the imports. The number of records reported to at least genus level was low (14%) at LA (Fig. 3). At SF, proportionally more organisms were identified to lower taxonomic levels (Fig. 4). These four non-specific codes together accounted for 86% and 47% of the records for Los Angeles and San Francisco, respectively, in 2009 (Fig. 5).

Strikingly, imports also came from a number of temperate locations, although most imports to both LA and SF came from Indonesia and the Philippines. There were at least 36 unique species codes for imported ornamental species from temperate countries (Table 4). This finding indicates that species are being imported to California from regions with similar climate conditions. Vietnam, Sri Lanka, South Korea, China and Australia were also major exporter countries (Fig. 6 – 9, Table 5).

For 2009, 52,616 USFWS records were available from LA and 4,123 from SF. To determine the flux of temperate taxa into these ports, we eliminated taxa that were strictly tropical (some 'tropical fish' have temperate affinities), as well as incomplete or duplicate records. It was necessary to use the USFWS-designated species codes as a proxy for taxonomic richness because most organisms were not identified to species level in the database (although these identifications may exist on paper copies of shipping records, see section on USFWS SFO visit to follow). The species codes underestimate true species diversity (USFWS, pers. com.). After these adjustments, the records netted a total of 13,542 records from LA and 2,744 from SF. For LA, 62 taxa (species codes) had been imported from 47 countries of origin and 47 countries of export. For SF shipments came from 19 countries of origin and 21 countries of export and contained 71 taxa (species codes).

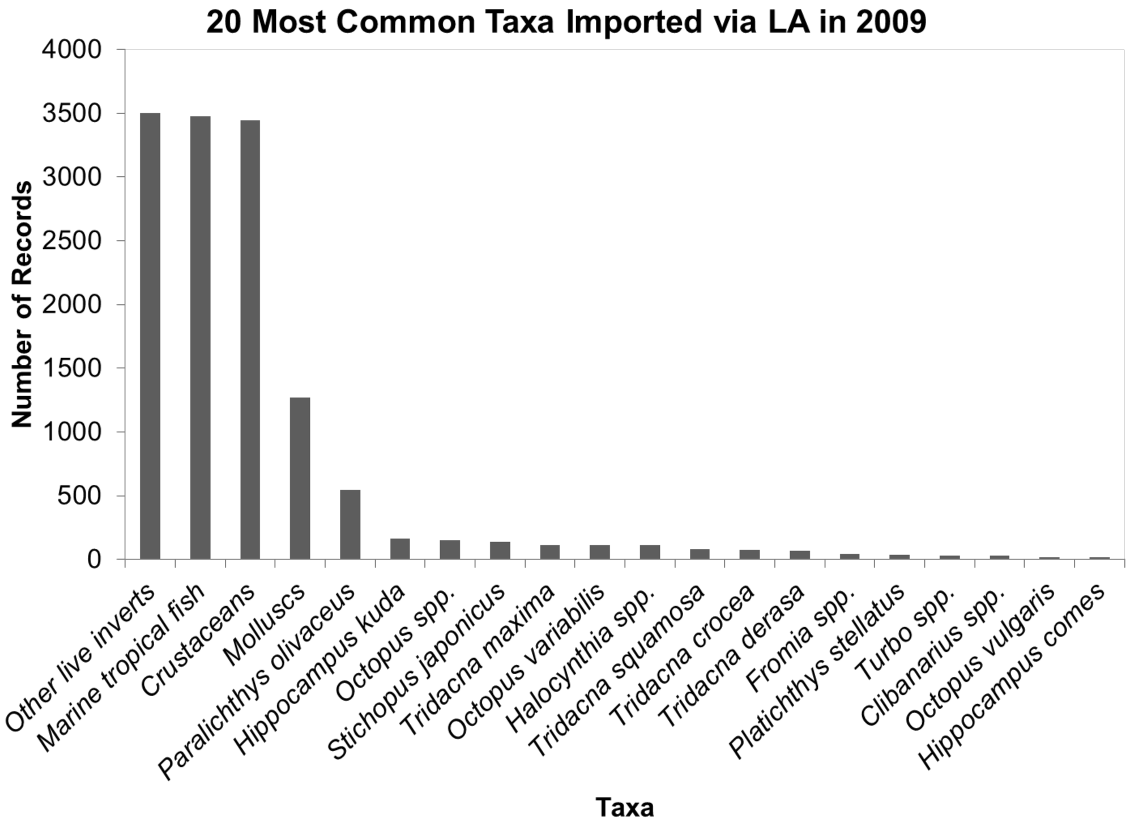


Figure 3. The number of records for the 20 most common species codes for imports into LA in 2009. The broad categories of "other live invertebrates" "marine tropical fish" and "crustaceans" were by far the most common imports. Data source: USFWS LEMIS.

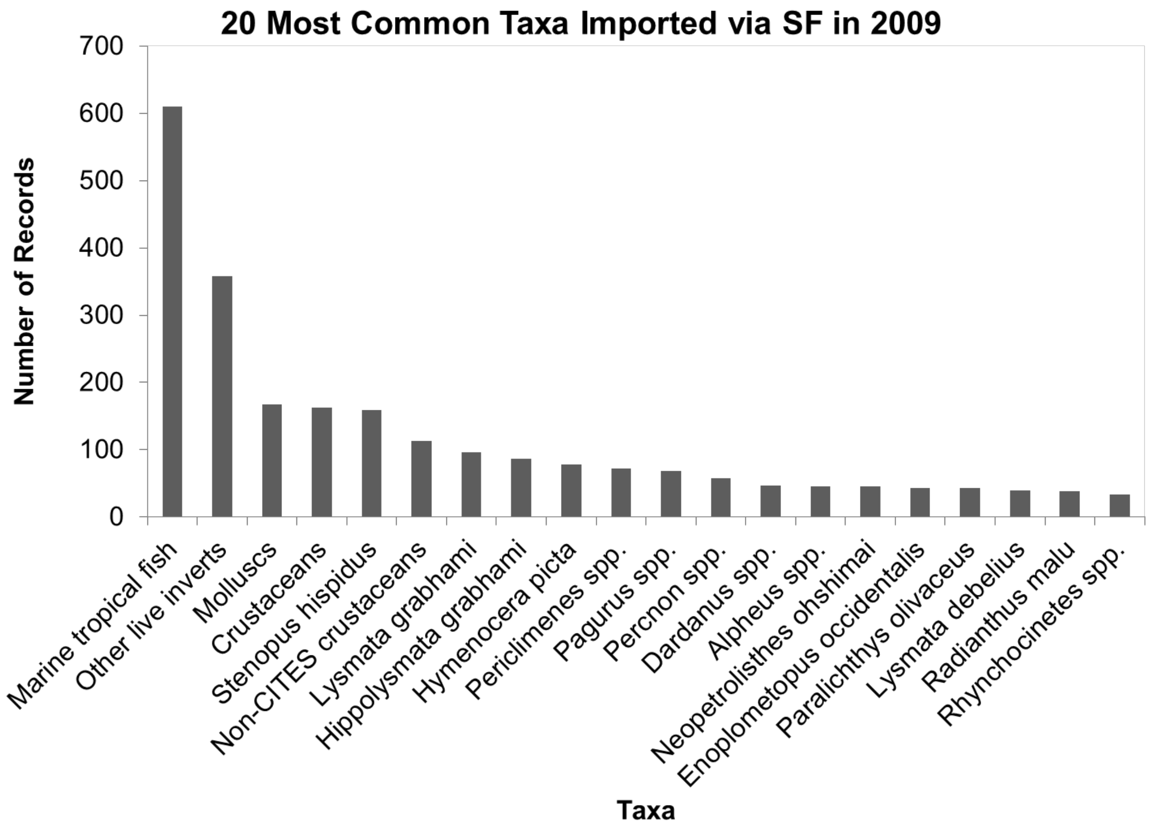


Figure 4. The number of records for the 20 most common species codes for imports into SF in 2009. The broad categories of "marine tropical fish" "other live invertebrates" were the largest, with more than 300 records each. 'Molluscs', 'crustaceans', and the banded coral shrimp *Stenopus hispidus* all had more than 100 records. Data source: USFWS LEMIS.

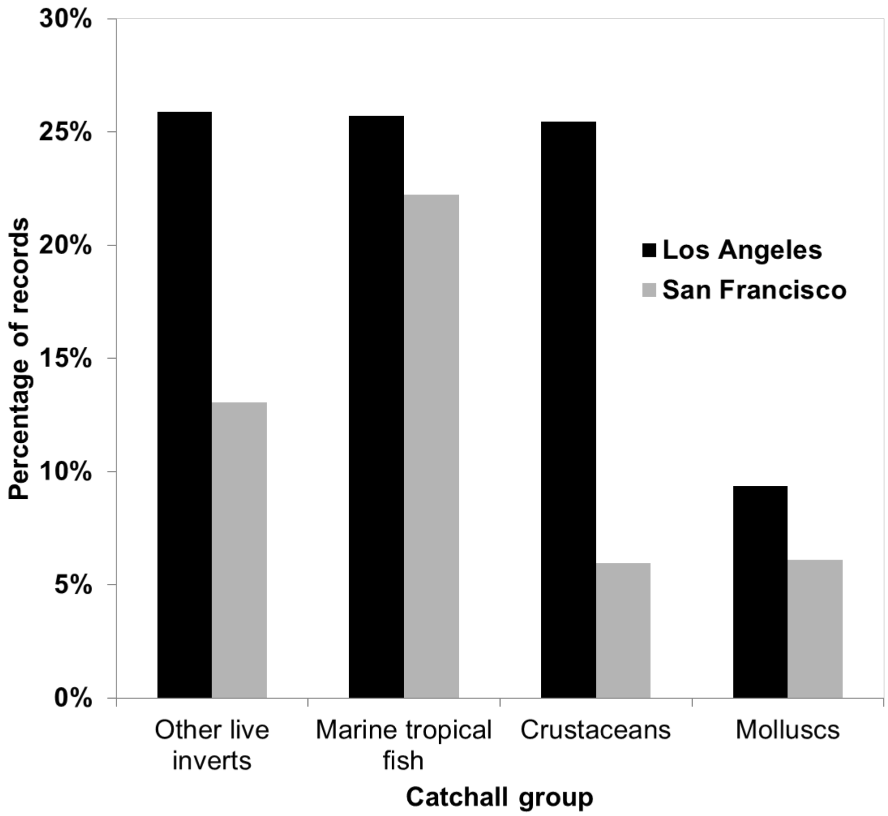


Figure 5. Percentage of records for generic ('catchall') USFWS species codes by port. The total numbers of records for potentially temperate species are 13,542 and 2,744 for Los Angeles and San Francisco, respectively. Data source: LEMIS FOIA request for 2009 records.

Table 2. Annual sum of each species by unit imported into LA in 2009 from USFWS LEMIS data. Importers can report volume in quantities of their choice. Weight and number represent totals reported for each volume estimate independently. A number in both columns does not necessarily equate to the number of specimens reported; weight might be reported for only a portion of the number or visa versa.

Species	**Kilograms**	**Number of Specimens**
Aurelia aurita		110
Babylonia species		2400
Casmaria species		1
Clibanarius species		93300
Crustacean	120	1821568
Cucumaria miniata	20	
Cucumaria species	20	
Enteroctopus species		30
Fish non-cites		707
Fromia species		17711
Gymnothorax species		3
Haemulon species		20
Halichoeres species		5
Halocaridina species	0.81	
Halocynthia species	2666	4992
Heteractis species		24
Heterodontus species		12
Hippocampus abdominalis		164
Hippocampus barbouri		70
Hippocampus barbouri		34
Hippocampus breviceps		30
Hippocampus comes		1065
Hippocampus erectus		76
Hippocampus histrix		100
Hippocampus ingens		300
Hippocampus kelloggi		25
Hippocampus kelloggi		185
Hippocampus kuda		20
Hippocampus kuda		3715
Hippocampus kuda		22761
Hippocampus reidi		495
Hippocampus spinosissimus		25
Hippoglossus species		1240

Loligo species	25	
Lysmata amboinensis		1715
Macrocheira kaempferi		4
Mollusc	0.38	724034
Non-CITES entry crustacean	0.34	5113
Non-CITES entry fish	48	
Non-CITES entry other inverts	11	24
Octopus species	2226	7700
Octopus variabilis	1395	6740
Octopus vulgaris	812	1392
Other live inverts in trop fish & shipments	263	831779
Pagurus species		25
Paralichthys olivaceus	238082	20511
Pentaceraster species		2
Phycodurus eques		45
Pinctada species		3000
Platichthys stellatus	953	
Potamotrygon motoro		4
Scomber species	7	
Sebastes species	363	
Stichopus japonicus	1942	600
Stichopus species	17	
Strombus species		45
Tridacna crocea		16136
Tridacna derasa		8447
Tridacna maxima	350	13912
Tridacna squamosa		5612
Tropical fish (marine spp.)	1183	7011210
Turbo species		71128
TOTAL	**250,504**	**10,700,366**

Table 3. Annual sum of each species by unit imported into SF in 2009 from USFWS LEMIS data. Importers can report volume in quantities of their choice. Weight and number represent totals reported for each volume estimate independently. A number in both columns does not necessarily equate to the number of specimens reported; weight might be reported for only a portion of the number or visa versa.

Species code	Kilograms	Number of Specimens
Alpheus species		689
Caridina japonica		800
Caridina species		780
Crustacean		14841
Cucumaria species	77	
Danio rerio		108
Dardanus species		1529
Diacanthurus species		2
Enoplometopus occidentalis		217
Enoplometopus species		58
Entacmaea quadricolor		1
Enteroctopus dofleini		3
Fromia species		89
Gnathophyllum species		15
Haliotis species		1
Halocynthia species	200	111
Hippocampus abdominalis		12
Hippocampus barbouri		24
Hippocampus kuda		440
Hippocampus kuda		115
Hippocampus kuda		20
Hippoglossus species	413	
Hippolysmata grabhami		5642
Hippolysmata species		15
Holacanthus clarionensis		1
Holacanthus species		52
Hymenocera picta		505
Lates calcarifer		24000
Limulus species		2
Linckia laevigata		28
Lysmata amboinensis		3385
Lysmata debelius		1625
Lysmata grabhami		7508
Lysmata species		627
Mollusc		28723
Nautilus pompilius		20

Neopetrolisthes ohshimai		307
Non-CITES entry crustacean		10308
Non-CITES entry fish		59
Non-CITES entry other inverts	5	2685
Octopus species	393	10
Octopus variabilis	18	8
Octopus vulgaris	14	
Ophiomyxa species		10
Other live inverts in trop fish & shipments	9	54773
Pagurus species		2657
Palaemonetes species		1900
Panulirus species		27
Panulirus unicolor		46
Panulirus versicolor		83
Paralichthys olivaceus	2971	950.9
Percnon species		2629
Periclimenes species		796
Petrolisthes species		6
Phycodurus eques		6
Protoreaster lincki		164
Radianthus malu		868
Radianthus species		744
Rhynchocinetes species		1302
Rhynchocinetes uritai		490
Saron marmoratus		79
Squilla species		2
Stenopus hispidus		2114
Stichopus japonicus	378	49
Stoichactis species		195
Strongylocentrotus species		100
Tridacna crocea		440
Tridacna derasa		38
Tridacna maxima		154
Tridacna squamosal		113
Tropical fish (marine spp.)		342325
Uca species		1125
TOTAL	**4,478**	**519,551**

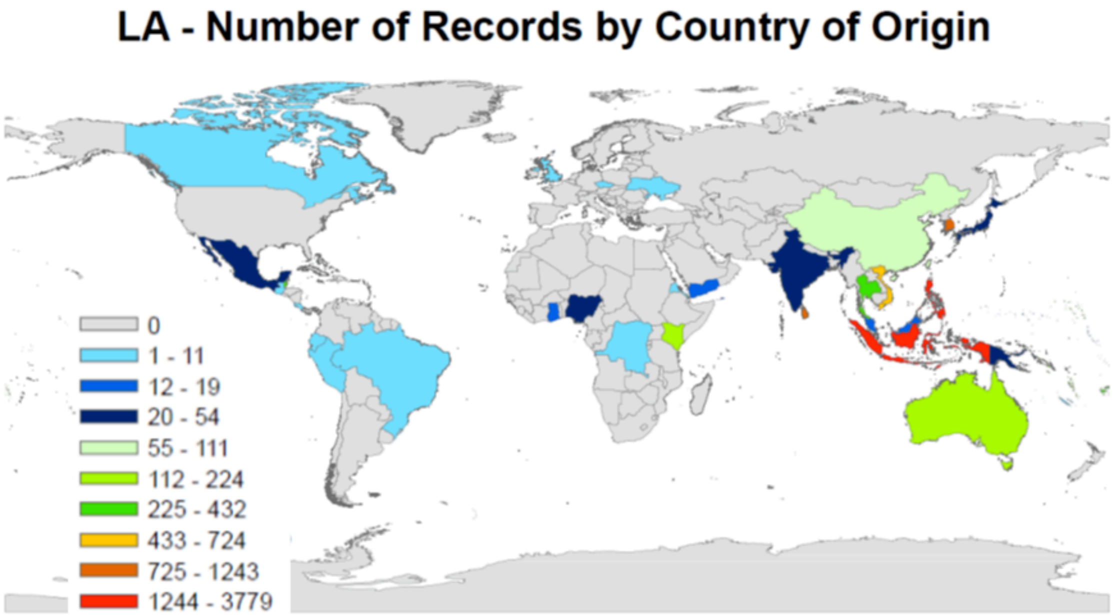


Figure 6. The number of records by country of origin for imports (source of organisms) into LA. The major source region is Indonesia and the Philippines (see Figure 7 below for details), South Korea, Sri Lanka, Vietnam, Australia, and China are major importers. Data source: USFWS LEMIS.

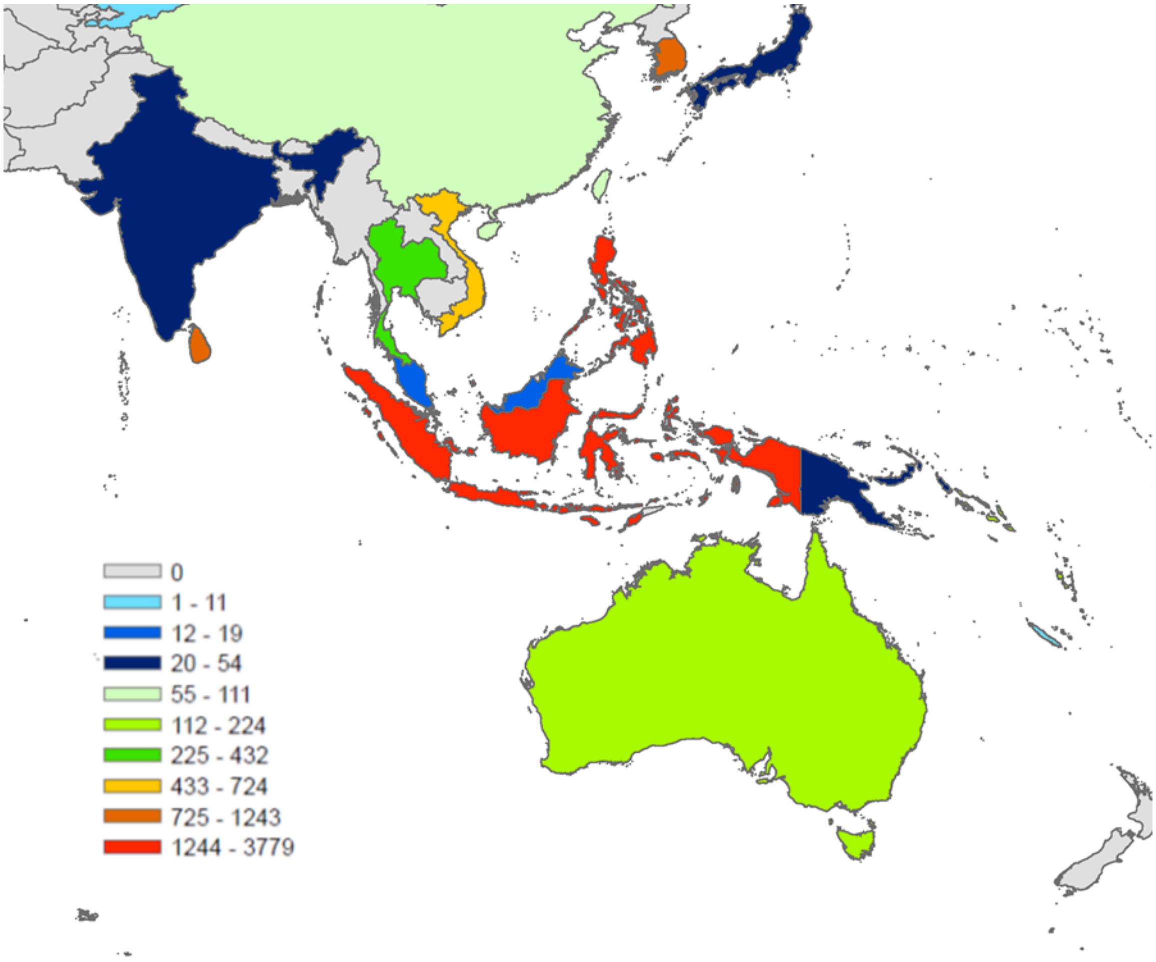


Figure 7. The number of records by country of origin in the Indo-Pacific region coming into LA. Color coding is the same as Figure 6. Data source: USFWS LEMIS.

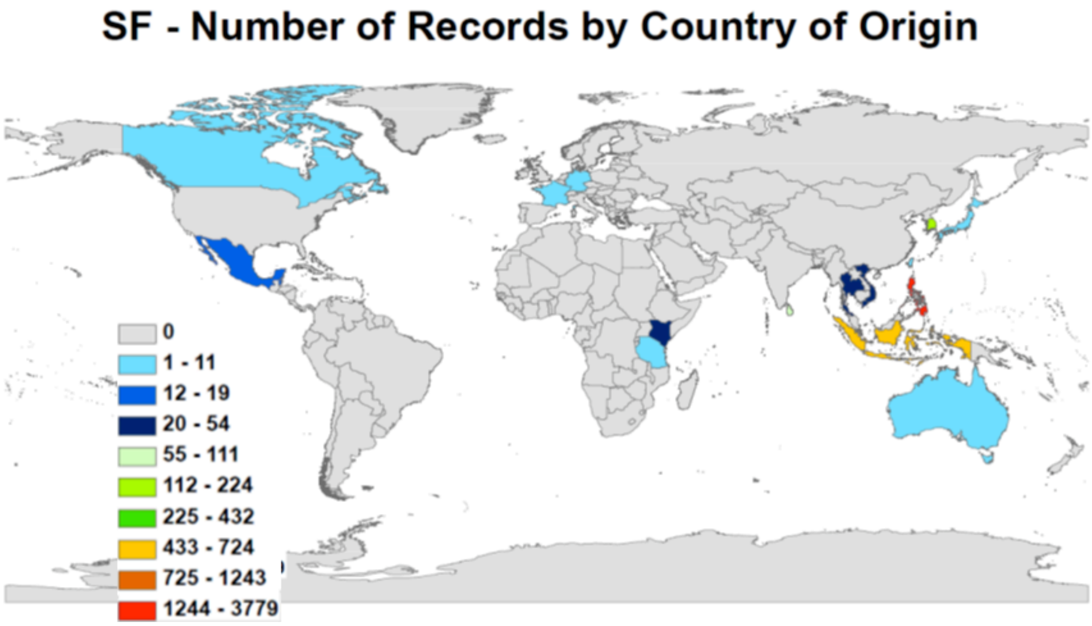


Figure 8. Number of records of imports by country of origin for SF. Although overall numbers are lower, patterns are similar to LA in that most imports originate in Indonesia and the Philippines (Figure 9 below). Data source: USFWS LEMIS.

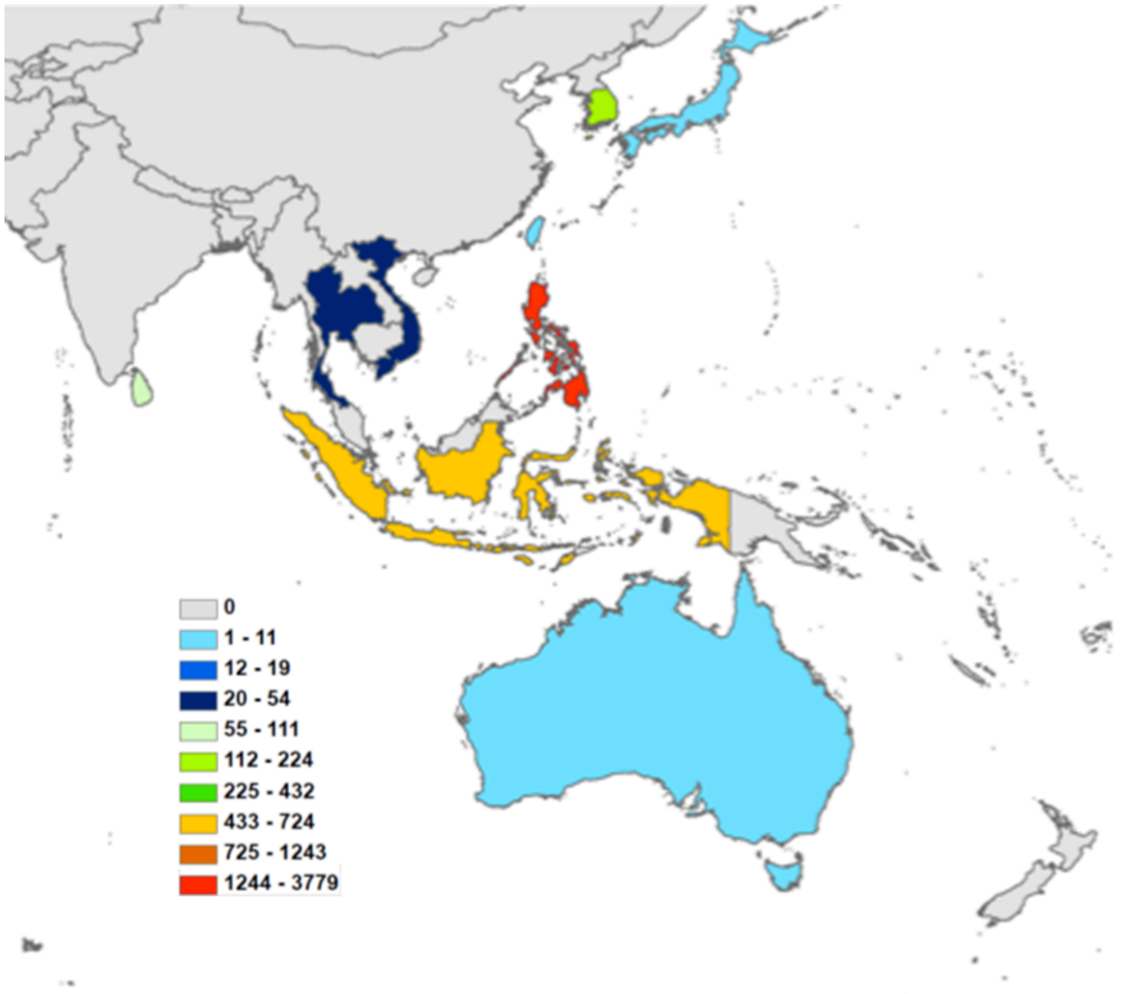


Figure 9. The number of records by country of origin in the Indo-Pacific region for imports into SF. Color coding is the same as Figure 8. Data source: USFWS LEMIS.

There were 23 and 47 records for SF and LA, respectively, which list a temperate location for the origin of the taxon. Of these records ~95% and ~91% have matching species origin and country of export origin, representing a direct shipment rather than a trans-shipment for SF and LA, respectively. For LA, the remaining 9% appear to be typographic errors in the database. For LA, these records included shipments from seven countries; for SF, there were six countries of origin (Tables 4, 5). The only clear trans-shipment record was for *Holocanthus* spp. from France routed through Mexico shipped into SFO.

Table 4. Lists of species codes entering SF and LA from temperate countries. Tropical species (primarily corals from Australia) were removed, except for fish because it is a large, inclusive field.

SF Temperate List
Cucumaria species
Enteroctopus dofleini
Haliotis species
Halocynthia species
Hippocampus abdominalis
Hippocampus barbouri
Hippocampus kuda
Hippoglossus species
Holacanthus species
Non-CITES entry
Octopus species
Octopus variabilis
Octopus vulgaris
Other live inverts
Paralichthys olivaceus
Phycodurus eques
Stichopus japonicus
Strongylocentrotus species
Tropical fish (marine spp.)

LA Temperate List
Aurelia aurita
Casmaria species
Crustaceans
Cucumaria miniata
Cucumaria species
Enteroctopus species
Gymnothorax species
Halocynthia species
Heteractis species
Heterodontus species
Hippocampus abdominalis
Hippocampus barbouri
Hippocampus breviceps
Hippocampus kuda
Hippoglossus species
Loligo species
Macrocheira kaempferi
Noncites entry fish
Noncites entry invertebrates
Octopus species
Octopus variabilis
Octopus vulgaris
Other live inverts
Paralichthys olivaceus
Phycodurus eques
Platichthys stellatus
Scomber species
Sebastes species
Stichopus japonicus
Stichopus species
Strombus species
Tropical fish (marine spp.)

Table 5. Records for species of interest for temperate countries. Gray boxes are most likely typographical errors in which the country of origin was switched with the country of export, rather than actual trans-shipments.

Country of Origin	Country of Export	# of LAX Records	# of SFO Records
Australia	Australia	11	5
Canada	Canada	5	3
Czech Republic	Czech Republic	1	0
Germany	Germany	0	1
Great Britain	Great Britain	1	0
France	Mexico	0	1
Japan	Japan	7	2
Norway	Philippines	3	0
Kyrgyzstan	South Korea	1	0
South Korea	South Korea	18	11
	Total	**47**	**23**

USFWS SFO inspection observation- We estimated the flux of ornamental species into SFO during USFWS inspections of shipments considered 'typical' by the agency at SFO. The majority of shipments come into SFO once weekly or semi-weekly and equal to ~20% of the volume that arrives in LAX (USFWS, pers. com), one of the top three ports of entry for aquarium organisms along with John F. Kennedy (JFK) and Miami (MIA) international airports (USFWS, pers. com.).

USFWS inspected one aquarium shipment from the Philippines (29 boxes of live fishes) and one from Indonesia (38 boxes of fishes and invertebrates) over the course of 3 hours and ~ 3 hours after arrival in air cargo. The Indonesian shipment comprised 9 boxes of corals/live rock and 29 boxes of 'live tropical fishes and others'. We collected data on 34 (52%) of the boxes in both shipments, all 34 of which were inspected by USFWS staff. Staff opened every box labeled 'live coral and other' and every bag (with one organism each) in each box to compare contents to the species and numbers on the invoice. Bags were not labeled, requiring expert identification by inspectors. Boxes of non-CITES fishes and invertebrates were spot-checked because the inspection focuses on CITES-listed organisms. USFWS personnel noted that in general there are sufficient staff to inspect only ~25% of all live and perishable air cargo shipments.

At least 179 species were included in the shipments and at least 7,356 individual organisms, based on the invoices ('packing lists'). The invoices included the USFWS species code, the common name, scientific name, the quantity, unit price and total price per species and, for only some of the organisms, the size ('sm/md/lg'). One importer provided a breakdown of the total number of organisms by taxa (2,051 individuals; 1,698 fishes, 57 molluscs, 100 invertebrates, 196 crustaceans). The other importer provided a total (172) only for live corals (35, broken down by genera and/or species) plus 'substrates' (137 "unidentified Scleractinia"); the numbers of fishes and invertebrates were listed by taxa only box by box, which added up to ~2,498 fishes and other invertebrates.

Labeling and identification of organisms by the shippers was problematic for 59% of the boxes examined. Box contents did not match the inventory (fish on packing list but not in box; fish in box but not on packing list), common names were incorrectly assigned to a family (goby for a pipefish) although the species name was correct, and organisms were listed with both incorrect common and incorrect scientific names, e.g., two different blenny species listed on the invoice were actually the ringed pipefish *Doryrhamphus dactyliophorus*). One invoice listed *Diadema antillarum*, which is a tropical Atlantic sea urchin. Importers are required to alert USFWS to shipments of venomous organisms by notation on the packing list, but venomous organisms (lionfishes) were packed indiscriminately among non-venomous organisms. Together, 20 lionfishes were imported, including 5 *Pterois volitans*, the 'common' lionfish invasive from North Carolina to the Caribbean (listed as 'black peacock' or 'red', respectively, in the shipments). 'Substrate', also listed as 'unidentified Scleractinia', which is known as 'live rock' in the aquarium trade, was inspected to differentiate it from CITES-listed corals, but not inspected by USFWS for associated organisms.

'Live rock' is a USFWS designation for any piece of hard substratum and its attached community of organisms. Exporters label live rock both 'substrate' and 'unidentified Scleractinia' seemingly indiscriminately and irrespectively of a USFWS code specifically for 'live rock'. Because prohibited *Caulerpa* and unknown 'hitch-hiker species can be introduced on live rock, it is a management concern (Zaleski and Murray 2006, Bolton and Graham 2006). Live rock is also a lucrative component of the aquarium trade (M. Meyers, Pet Industry Joint Advisory Council, pers. com.). We observed pieces of 'substrate' covered with several seaweeds (*Halimeda* sp., coralline and fleshy red crusts), zooanthids, and algal turf, which is a diverse mixed community of small-statured (< 1-2 mm) species that can grow larger under the right conditions, such as release from herbivory. Live rock also enters as 'substrate' under USFWS code 3115 for 'unidentified Scleractinia'. It is not clear whether an importation is an unidentified coral species or live rock, and thus, it is difficult to determine the quantity of live rock being imported, let alone the species associated with live rock.

Labeling Live Rock- Live rock is lucrative for the aquarium trade. Live rock represents an entire marine community. Species of invasive *Caulerpa* can grow from live rock.

On a single day at SFO, 137 pieces of live rock arrived as 'substrate' (Unidentified Scleractinia). In 2009 at LAX, there were 435 records for live rock designated across 18 different USFWS codes.


Photo: C. Zabin

To compare contents of the shipments to the invoice, USFWS staff relied on their taxonomic training and experience and internet searches from their electronic devices. The taxonomic expertise of the officials was high for corals (to species, due to CITES listing of many coral species) and fishes, but not for seaweeds. Officials indicated they could virtually always make an identification of the taxa they needed to regulate, which we observed was the case. They efficiently focus on knowing the listed species, not on identifying every species in the shipments. In cases when an organism cannot be identified, it is transferred to the holding facility until identification can be confirmed through a network of experts.

Lack of information on trans-shipment to other states from California ports of entry is a major gap in determining the risk the aquarium vector poses for California (see also Wabnitz et al. 2003). After inspection, USFWS staff resealed boxes and cleared them for Customs. The agency does not collect information on the ultimate destination of these imports once they are cleared because it is not responsible for interstate commerce.

Shipping practices for ornamental species entering San Francisco Airport

Key finding - *We estimated there was high survival (98%) of the fishes and corals inspected by USFWS at SFO. Although this survival rate is underestimated, loss during shipping probably will not substantially diminish the influx of non-indigenous species to California as estimated by USFWS importation records.*

The manner in which ornamental species are shipped can affect their condition and thus their ability to survive in the vector. Because every specimen in every box in the shipments could not be examined, the survival rate is an underestimate. In some cases, we could note only that some fish were dead in the box. Organisms were shipped in cardboard boxes containing Styrofoam coolers in which individuals were packed singly in double plastic bags secured with rubber bands. One shipment contained newspaper to insulate the organisms from thermal stress. Some boxes had up to three layers of bags each separated by a Sytrofoam layer. The maximum number of fishes (medium-sized damsel fishes) packed in a box was 220.

CDFG Restricted Species Permits

Key Finding - *Restricted species likely represent a smaller risk of introducing non-indigenous species to California than importations because they represent fewer species and fewer allowable numbers and none are reported as introduced to California to date. At least 20 marine and estuarine species were permitted between 2000-2010, primarily for research and exhibition purposes. Information on Restricted Species permits was inadequate to estimate fluxes of restricted non-indigenous species into California through this permitting pathway because post-permit reports are not required.*

Of the primarily freshwater and terrestrial species in the Restricted Species permit records, 22 mostly brackish and some marine species were included on 31 unique permits representing a total of 61 unique permit-and-year combinations (permits must be renewed annually) (Table 6**)**. Of the 22 unique restricted species, one was a hybrid and five were transgenic. Two species were permitted as both transgenic and not. The number of permits issued for marine or brackish species increased from one or two before 2000 to a maximum of nine in 2010 (Fig. 10).

The information gained from Restricted Species permits was insufficient to determine either if the restricted animals were actually present in California or, if so, the quantity (see barramundi exemplar below). Permits are required to transport, import, or possess a species, and thus, permits address restricted species that could be, but not necessarily were actually, imported to and transported within California. Permit allowances represent an upper bound on the quantity of restricted species. The numbers of individuals of a species reported in possession is provided only at the time of the application. Although most permits allow fewer than ten individuals of a given species, research and aquaculture permits often allow for many more. For example, one permit allowed up to 100,000 individuals of *Dreissena rostriformis bugensis* and *Dreissena polymorpha*. Several permits for sharks allowed between 20 and 40 individuals, and one allowed for 100. All permits allowing for larger numbers of sharks were for State Resident Dealers/Brokers.

Importation of barramundi *(Lates calcarifer*), a Restricted Species

Barramundi, a predatory fish highly prized for eating is a restricted species in California. Barramundi is potentially invasive in California because it can live in temperate waters. In 2009, 24,000 individuals were imported into SFO. The disposition of these fish is unknown.

Marine and brackish restricted species have been permitted in the state of California under nine designations (Table 6). Each of these designations represents potential pathways for releasing non-indigenous species. Most relevant to the ornamental vector are ‘AZA (Association of Zoos and Aquariums) Detrimental’, ‘Resident Dealer/Broker’, and various types of ‘Exhibition’. ‘Research Detrimental’ was the most common permit type; ‘AZA (Association of Zoos and Aquariums) Detrimental’, ‘Resident Dealer/ Broker’, and various types of ‘Exhibition’ were the other common permit types (Table 6). Our survey of Restricted Species permits brought to light how research and exhibition aquarium facilities could represent an undocumented pathway for release (Appendix 3).

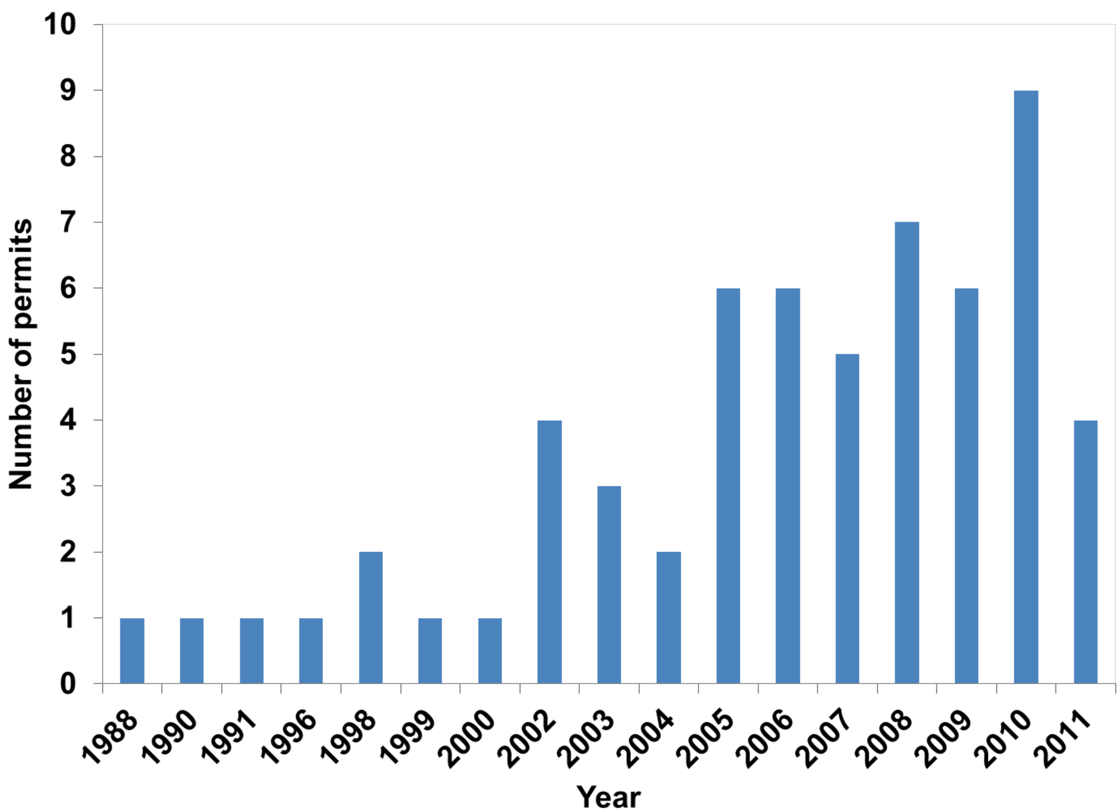


Figure 10. Number of restricted species permits issued by CDFG that included marine or brackish species by year. Data source: CDFG.

Table 6. List of marine/brackish species on the California Restricted Animals list and permit types for this species that were recorded in CDFG issued permits. AZA: Association of Zoos and Aquariums.

Species in permits	Permit Types (Number of permits)
Alligator mississippiensis	Research Detrimental Species (10)
Caiman crocodilus	Resident Exhibiting (4)
Caiman sclerops crocodilus (synonym of *C. crocodilus*)	Resident*Broker/Dealer (4)
Caiman crocodilus X *Caiman yacare*	AZA Detrimental Species (5)
Carcharhinus leucas	Nonresident Exhibiting (4)
Carcharhinus melanopterus	Aquaculture (1)
Carcharhinus plumbeus	Native Species Exhibiting and Resident Exhibiting (1)
Dreissena rostriformis bugensis	AZA Detrimental Species/Native Species Exhibiting (1)
Esox lucius	Scientific/Public Health Research Permit (1)
Gar	Exhibiting Permit (1)
Lampetra tridentate	
Lates calcarifer	
Lepisosteus oculatus	
Lepisosteus tristoechus	
Oreochromis niloticus	
Oryzias latipes	
Perca flavescens	
Petromyzon marinus	
Transgenic *Gasterosteus aculeatus*	
Transgenic *Oncorhynchus mykiss*	
Transgenic *Oreochromis niloticus*	
Transgenic *Oryzais latipes*	
Transgenic *Sparus aurata*	

Ornamental species for sale in aquarium shops in California

The ornamental marine species available for purchase in California is important to estimating propagule supply, but it is not readily available. Below we present relevant data extracted from published literature for California and unpublished data from a limited pilot survey undertaken in 2002.

Nineteen species of non-indigenous marine fishes with the potential to survive if introduced have been available for sale in a sample of aquarium stores in the San Francisco Bay-Delta area (Table 7, Chang et al. 2009). These species undoubtedly under-represent the diversity of fish species sold as pets in the state and obviously exclude invertebrates, aquatic plants or algae. In this study, researchers visited a stratified sample of 54 large chain and small independent stores, where they counted and identified species in aquaria. They identified which species sold in the region could survive in the SF Bay-Delta, based on temperature and salinity tolerances. Of the 19 species that have been available for sale, 815 individuals of *Chromis viridis* (green chromis) were imported to SFO on the day of our visit.

Table 7. Marine fishes available for sale in aquarium stores in the San Francisco Bay-Delta area and potentially able to survive in the same area. Data from Chang et al. 2009.

Abudefduf saxatilis	Sergeant major
Acanthostracion quadricornis	Scrawled cowfish
Aluterus schoepfii	Orange filefish
Centropyge argi	Pygmy angelfish
Chaetodontoplus personifer	Blueface angelfish
Chaetodipterus faber	White angelfish
Chromis viridis	Green chromis damsel
Choerodon fasciatus	Harlequin tuskfish
Dactylopterus volitans	Flying gurnard
Diodon holocanthus	Porcupine pufferfish
Epinephilus morio	Red grouper
Halaelurus lineatus	Banded cat shark
Histrio histrio	Sargassumfish
Lepidoblennius marmoratus	Western jumping blenny
Microgobius gulosus	Clown goby
Myripristis jacobus	Bigeye squirrelfish
Rhinopias argolipa	Red scorpionfish
Stonogobiops yasha	Yasha Hase goby

Information on the species of the seaweed *Caulerpa* available for sale in California's aquarium stores is available in Zalesky and Murray (2006) for southern California, a study repeated by Diaz et al. (2012) and our own limited survey of east San Francisco Bay-area stores (Table 8). Zaleski and Murray surveyed 50 stores in San Diego, Orange, and Los Angeles counties. They found that 97% of the stores sold live rock and that in 18% of the total number of stores visited, the live rock had visible species of *Caulerpa*, including prohibited species. Stores (52%) also sold 14 varieties of *Caulerpa*. *Caulerpa* formed the bulk of the stock in seaweeds; other seaweeds for sale were available in only 6% of the stores surveyed. All but three *Caulerpa* species had temperate distributions and thus, are potentially invasive in California (Table 8). Only *C. taxifolia* has been documented as established (and eradicated).

Table 8. Species of the seaweed *Caulerpa* with temperate distributions sold in aquarium stores in California. These species represent potential invasions; *C. taxifolia* established and was eradicated in the region. Data are from Zaleski and Murray (2006) for southern California (San Diego, Orange, Los Angeles counties, n = 50 stores) and Williams and Schroeder (unpublished, 2002) for northern California (Alameda, Albany, Berkeley, Oakland, n = 15 stores). 'Wholesale' indicates the store was not open for sales to the public.

Species	**Southern CA**	**Northern CA**
C. brachypus	x	x
C. cupressoides		wholesale
C. racemosa	x	wholesale
C. racemosa var. *lamourouxii*	x	
C. racemosa var. *macrophysa*	x	
C. racemosa var. *peltata*	x	
C. serrulata	x	wholesale
C. sertularioides	x	
C. taxifolia (established and eradicated)	x	wholesale
C. peltata	x	
C. prolifera	x	
C. webbiana	x	

Diaz et al. (2012) repeated the Zaleski and Murray (2006) survey to assess the effectiveness of California state legislation (AB 1334) to regulated species of *Caulerpa*. Although the species were not reported in this paper, clearly *Caulerpa* spp., including *C. taxifolia*, were as available for sale as prior to the legislation.

In the eastern region of San Francisco Bay (Alameda, Albany, Berkeley, Oakland), we visited 12 aquarium stores (independent and chain) and called three others over a two-day period in December 2002, to gauge the response to a person indicating that s/he was interested in buying *Caulerpa*, as a pilot survey of the availability of *Caulerpa* species for sale. Two stores were dedicated to freshwater species. Of the remaining 13 stores, 4 (31%) sold live rock (all from Tonga) and three (23%) did not sell live or marine plants. Five species of *Caulerpa* spp., all with temperate distributions, were handled in three (33%) of the 10 stores offering live marine plants (two retail, one wholesale, Table 8). Staff in only one store remarked that "selling salt water plants was banned about six months ago," presumably in reference to AB 1334.

Internet availability of non-indigenous ornamental species

Key finding - *Our web search for sites offering live Caulerpa supported the understanding that, despite federal law prohibiting its interstate commerce, it is readily available and sold over the internet (Walters et al. 2006). Our search also indicated that invasive lionfish are available for sale over the internet from aquarium stores around San Francisco Bay.*

Our web search for sites revealed a total of ten advertisements of live *Caulerpa* for sale over the internet from five websites over a two-day period. These advertisements were from two eBay sellers in Washington state and New Jersey, three Florida-based companies, and one company based in the United Kingdom. Three (30%) of these advertisements listed the illegal or legal shipping status of specific *Caulerpa* species being sold. Only one of these advertisements listed the reason for not shipping to California as the invasion risk of *Caulerpa*. Additionally, only one (10%) of the ten advertisements explained how to properly dispose of *Caulerpa*.

The websites for seven locally owned and managed aquarium stores in the San Francisco Bay area were examined for live ornamental stock. Four (57%) of these aquarium store websites provided lists of live stock. This online listing of live stock usually included a general taxa inventory with or without pricing of the stock the stores currently have or have had in the past. Only one of seven stores updates their listings regularly due to its operation of an online business for internet sales.

Three of these four non-chain stores sold, or have at some point in the past sold, species of lionfish. Lionfish were included on the online live stock lists variously as 'Voltan Lionfish', 'Antennata', 'Dwarf (Lion)', 'Dwarf (Fuzzy)', 'Fu-Manchu', 'Radiata', 'Volitan', 'Volitan (Red)'. The fourth store did not, but it specializes in brackish water species and freshwater.

Additionally, the websites of the two most prominent pet store chains in the San Francisco Bay-area, Petco and PetSmart, were examined for live ornamental stock. These two chains have over 60 store locations within the area. PetSmart specializes in freshwater aquaria species only. Petco has 34 Bay Area locations with an aquatics department selling marine and brackish water animals and plants. Additionally, Petco has an extensive online listing of live stock along with its operation of an online business for internet sales. Pet Food Express was the third 'pet store' with at least 20 locations in the San Francisco Bay-area, however their websites did not list aquatic animals.

Petco also listed the online availability-for-sale of six species of lionfish as 'Black Volitan, Devil, Antennata, Dwarf Zebra, Russel's, Radiata.' Three of these lionfish species, 'Dwarf (Fuzzy),' 'Volitan,' and 'Dwarf Zebra,' sold at Bay Area stores were listed on the invoice for shipments into SFO on the day of our visit.

We also searched Walmart web sites but they did not provide online stock lists. Only aquarium supplies are available for internet sales. A search of 'Walmart aquarium fish' revealed that primarily freshwater fishes are sold, but the information came from forums as opposed to the company's web sites.

Impacts of non-indigenous species introduced by ornamental trade

Key finding - *Our literature review of algal and mollusc species supported the general understanding that ecological and economic impacts of non-indigenous species are poorly studied and largely based on anecdote (Ruiz et al. 1999, Williams and Grosholz 2008, Thomsen et al. 2011a, b).*

Our literature searches for impacts uncovered over 28 types of responses to non-indigenous seaweeds and molluscs (Table 9). We searched specifically for the one ornamental seaweed and five ornamental molluscs introduced to California and attributed to the ornamental vector (Table 10). Literature on impacts was available only for the seaweed *Caulerpa taxifolia* and the New Zealand mud snail (*Potamopyrgus antipodarum*, the New Zealand mud snail). None of these impact studies were conducted in California. No results were found for human health or economic impacts. Below we summarize the results for the two ornamental species.

Caulerpa taxifolia is considered one of the world's worst invasive species and thus, has been well-studied. Nevertheless, only 25% of the articles for *C. taxifolia* addressed impacts (49 articles of 194 uncovered by the search). These articles included 136 cases in which *C. taxifolia*'s impact was evaluated. The majority (84%, n = 114) of these cases showed an effect, whereas in 16% (n = 22) of the cases there was no evident effect of the seaweed on the environment and/or native species (Fig. 11). Of the 114 cases demonstrating an effect, the majority was negative (73%, n = 57 cases) showing a reduction in the response variable, but positive effects, denoting an enhancement, were also evident (27%, n = 21 cases) (Fig. 12) as were changes (neither positive or negative) (32%, n = 36). *C. taxifolia*'s effects included metabolic, developmental, reproductive, growth, and behavioral responses of animals and/or seagrasses exposed to it and community-level responses in species diversity and abundances. All impact studies on *C. taxifolia* were conducted in European or Australian waters. Notably, impacts were not measured during the infestation in California due to the focus on eradication (Withgott 2002). However, one study (Williams and Grosholz 2002), which was not uncovered because it did not match the search, reported a negative correlation between the seaweed and a native seagrass in southern Huntington Harbor, California.

The literature on impacts of the ornamental molluscs uncovered results only for *Potamopyrgus antipodarum*, which accounted for less than 1% of the literature searched for all five molluscs in the vector (2 of 258 articles reviewed). The two papers reported eight cases of impacts. Five of these cases (63%) showed an effect and three (38%) showed no effect on the invaded environment and/or other species (Fig. 13).

Quantitative data (number of cases, mean experimental effect and variance) for ornamental species were too limited for a formal statistical meta-analysis of impacts across species and vectors, although there were a sufficient number of cases (n = 136) for a future meta-analysis on the impacts of *Caulerpa taxafolia*.

Table 9. Categorization of response variables reported in literature on impacts of invasive seaweeds and molluscs.

GENERAL IMPACT CATEGORY	EXAMPLES of Response Variables
Abundance	**density, % cover, biomass, settlement, recruitment**
Behavior	**burial depth, burrowing, foraging, habitat preference**
Feeding	**feeding preference, consumption rates, predation, absorption, fecal quality**
Fitness	**growth, reproduction, survival**
Diversity	**richness, evenness, community structure, assemblages, composition**
Geophysical	**filtration, nutrient cycling, erosion, flow rates**
Geographic Range	**shifts in geographic range**
Human Health	**human health, economic impact**

Table 10. All algae and mollusc species entering into California via the ornamental vector for which impact literature searches were completed.

Taxa	Species	Sole or Polyvectic	CA Status
algae	*Caulerpa taxifolia*	Sole	ERADICATED
mollusc	*Busycotypus canaliculatus*	Poly	ESTABLISHED
mollusc	*Bullia rhodostoma*	Poly	FAILED
mollusc	*Littoridinops monroensis*	Poly	ESTABLISHED
mollusc	*Melanoides tuberculatus*	Sole	ESTABLISHED
mollusc	*Potamopyrgus antipodarum*	Poly	ESTABLISHED

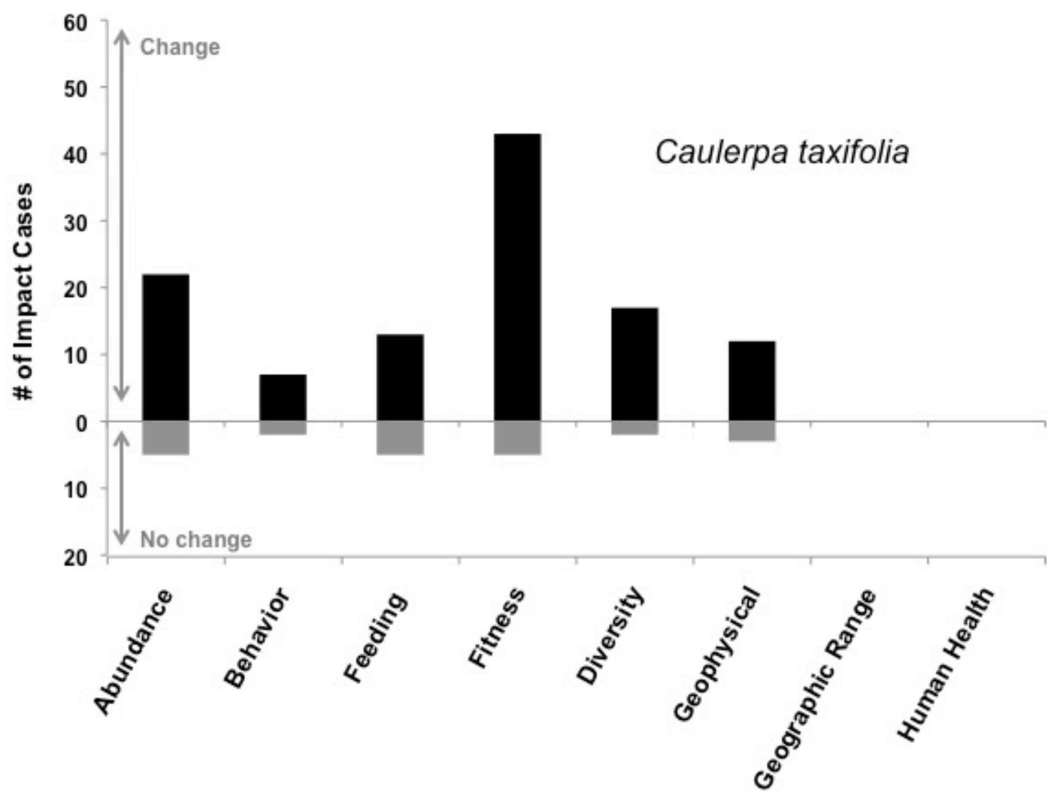


Figure 11. Summary of number of cases reported in the literature searched in which the presence of the seaweed *Caulerpa taxifolia* was associated with a change in a response variable. 'Change' includes a positive or negative difference in a response variable as well as responses that have no direction, such as a change in community structure. The cases were derived from mensurative and experimental impact studies.

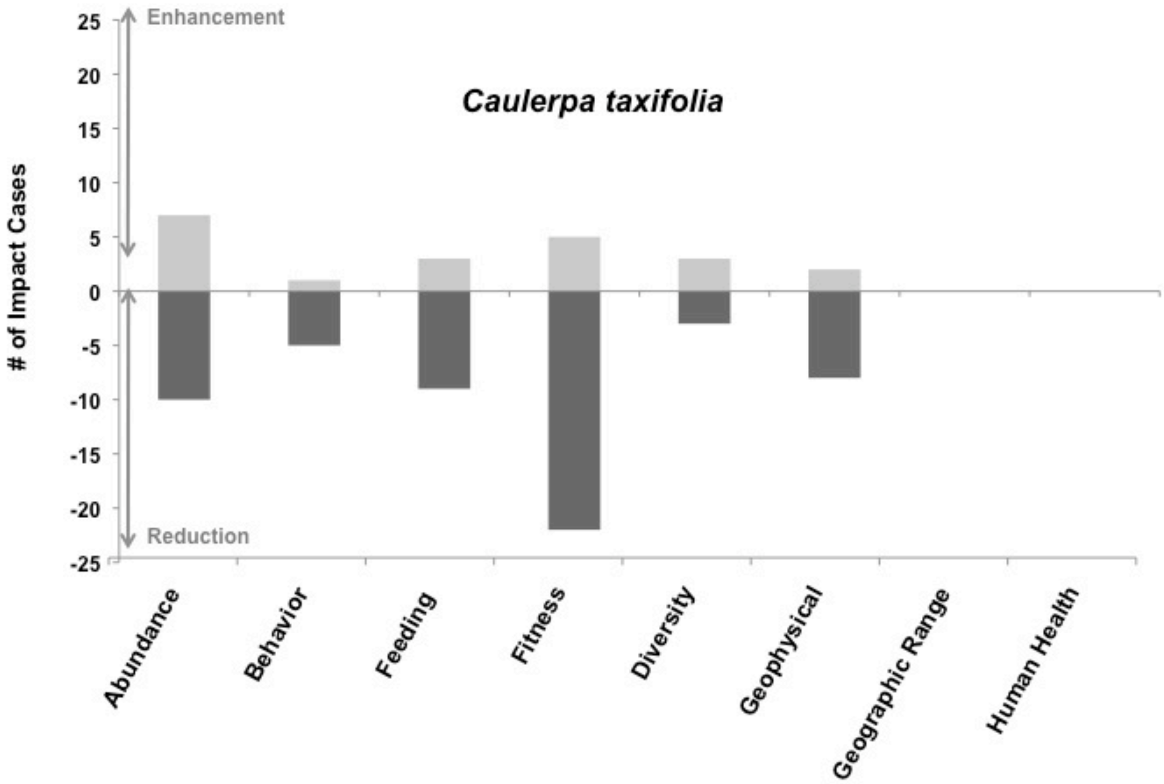


Figure 12. Summary of number of cases reported in the literature searched in which the presence of the seaweed *Caulerpa taxifolia* was associated with a positive or negative difference in a response variable. The cases were derived from mensurative and experimental impact studies.

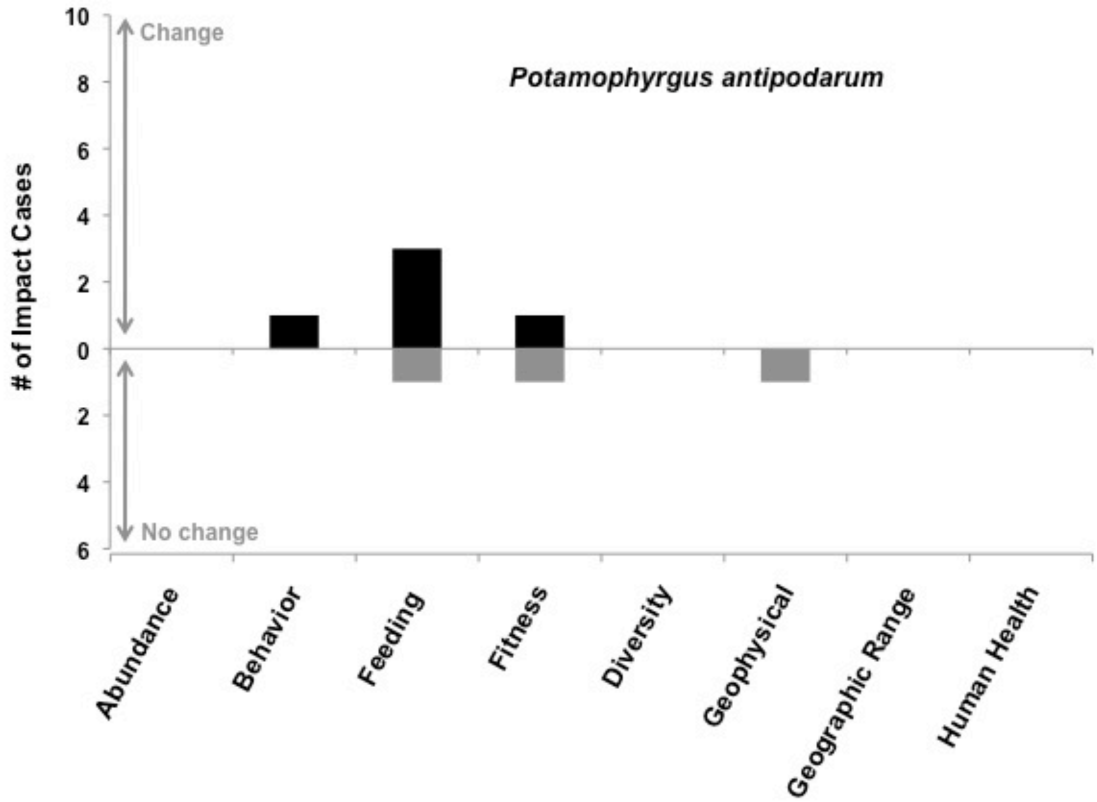


Figure 13. Summary of number of cases reported in the literature searched in which the presence of the New Zealand mud snail *Potamophyrgus antipodarum* was associated with a positive or negative difference in a response variable. 'Change' includes a positive or negative difference in a response variable as well as responses that have no direction, such as a change in community structure. The cases were derived from mensurative and experimental impact studies. The absence of bars ('zero' on y-axis) indicates no data were available for those specific response variables.

Control points and panagement options- state and federal regulations

Key Finding- *As noted in other studies, including one specific to California (Muir 2011), there is a patchwork of regulatory authorities and codes governing AIS, making it difficult for all stakeholders to navigate available information and regulations.*

The legal authority to regulate the intentional importation of aquatic non-indigenous species is dispersed across and within federal and state agencies (Fig. 14). One branch of the government is not always aware of the authority and regulations of another, and plants and animals are regulated differently. There is no single source of information on regulations concerning aquatic non-indigenous species applicable to California, except the report by Muir (2011). Although this report is available on the State's Library web site (http://www.library.ca.gov/crb/11/11-001.pdd), it was not linked to other agency web sites dedicated to aquatic non-indigenous species as of April 2012.

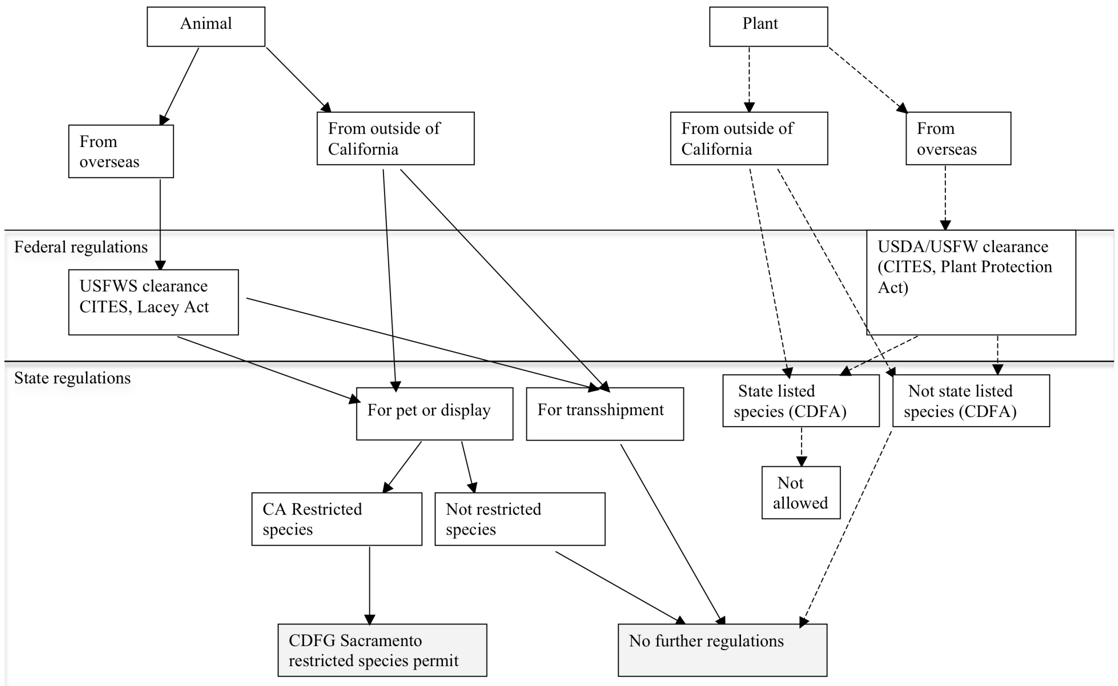


Figure 14. A flow chart outlining the processes and agencies involved in regulating the importation of species for ornamental trade. Solid lines (animals), dashed lines (plants). Additional regulations may exist at county and city levels, however, few border inspections exist below federal levels.

To address the need for 'one-stop shopping' for information and for regulations regarding non-indigenous species in California, the Invasive Species Council of California (ISCC) has published an invasive species list (http://ice.ucdavis.edu/invasives/home/species) for California that combines lists of problematic plants (CDFA's Noxious Weeds) and animals (CDFG's prohibited and restricted species). This list is continuously updated and is significant in providing a source ('first source' column) for the state regulatory code for each species. ISCC also solicited opinions on the threat rankings for the list.

Federal regulations- Live organisms imported into the state from outside of the US must clear customs and if they contain live wildlife or wildlife (i.e., animal) products, they also require clearance from USFWS.

The Lacey Act of 1900 prohibits the importation of listed "injurious species", which is regulated by USFWS. USFWS is also responsible for regulation of CITES codes, as well as regulations from the countries of origin (see below), but these do not specifically address invasive species. Few non-indigenous marine or estuarine species are listed under the Lacey Act. Mitten crabs (in the genus *Eriocheir*) and snakeshead fishes (family Channidae) are two exceptions.

The USFWS office at Burlingame, CA provided an example of how the agency manages its mandate under the Lacey Act and CITES for species entering the US, including live organisms imported for the aquarium trade. The office is responsible for the maritime ports of Oakland and San Francisco, the international airports of San Francisco, Oakland, and San Jose (air cargo and passenger baggage), and mail and shipping facilities (e.g., DHL and FedEx). The importer is required to submit documents 48 hours in advance of the arrival of live and perishable goods, including collecting or other permits if required by the country of origin, which is then recorded by USFWS. To manage the volume of wildlife importations by the inspection staff (of seven), USWFS inspects all international air cargo for CITES-listed species but 'spot-checks' non-CITES goods, prioritizing live organisms, and conducts random checks on mail facilities. Most of the shipments inspected are designated for the pet trade, primarily freshwater and marine fishes and invertebrates and some reptiles and amphibians. Flights coming in from specific regions are also targeted for inspection. For example, SFO is a major entry point for African hunting trophies; an African hunting trophy shipment was inspected between inspections of the aquarium shipments on the day we visited.

USFWS cooperates with US Department of Agriculture and Customs Agency for passenger baggage. USDA is responsible for inspecting imported plants and plant products. The seaweed *Caulerpa taxifolia* "aquarium strain" is prohibited from importation under the Federal Plant Protection Act and regulated by USDA. The Burlingame USFWS office has offered cross-training on an 'as needed' basis to facilitate cooperation among agencies (e.g., on Asian medicinals or ivory). An example of cooperation between USFWS and USDA is that although shellfish and fisheries products are exempt from USFWS inspection, USFWS conducts random checks on live and frozen seafood, which is typically imported in compliance with regulations. USFWS is expected to know and uphold national laws pertaining to wildlife of exporting countries, supported by a central database of national wildlife laws by country (violations are referred to diplomatic channels through the national office). USFWS also collaborates with California Department of Fish & Game on importation of state-prohibited species (e.g., piranhas, venomous reptiles, shark fins, and stingrays). USFWS relies heavily on their internal intelligence network for tracking violations and suspects.

State regulations- The state of California prohibits the importation of certain species through its Administrative Code. One code (Title 14, Section 671) deals with the importation, transportation, and possession of restricted speces except by special permit issued by CDFG. Restricted species permits can include special conditions aimed at preventing escapes of these species. These permits are for 1 year, after which they must be renewed. A permit is required to obtain or possess an animal, but having a permit does not dictate an actual importation; thus, records for species and number of animals reflected by permits is probably overestimated. Nearly all of the species on the state's restricted species lists are terrestrial or strictly freshwater.

The regulation of invasive marine aquatic plants is split between CDFG and CDFA. CDFA regulates aquatic plants listed as Noxious Weeds (California Administrative Code, Title 3, Section 4500, Table 11), except for *Caulerpa* spp., which is regulated by CDFG. CDFG (Code 2300) is mandated with enforcing the state law (AB 1334) making it illegal to possess, transport, transfer, release alive, import or sell *Caulerpa taxifolia, Caulerpa sertularioides, Caulerpa mexicana, Caulerpa ashmeadii, Caulerpa scalpelliformis, Caulerpa racemosa* (and all varieties of *C. racemosa), Caulerpa cupressoides, Caulerpa verticillata,* and *Caulerpa floridana.* This split in authority for aquatic plants between CDFA and CDFG is presumably why *Caulerpa* spp. does not appear among the marine and estuarine noxious weeds on California's Noxious Weed list of 2010 (last update available online). However, "*Caulerpa* spp." ("feather algae") does appear as an entry on the web "Encycloweedia" list of "weeds", which is available on the same CDFA web site. The *Caulerpa* example highlights the challenge of updating websites and making the information consistent across sites.

Another example of the difficulty of keeping information on non-indigenous species consistent and updated also involves *Caulerpa*. The ISSC invasive species list includes only three species of *Caulerpa*, two of which are not regulated by the CDFG code, which was not referenced in the list as the exiting regulatory authority for these species. *C. taxifolia* was the only regulated species on the list; however, the ISSC 'first source' column refers to Oregon's Noxious Weed listing instead of the existing CDFG code. This oversight is puzzling given that *Caulerpa taxifolia* was the subject of a highly publicized eradication in southern California under the authority of the federal Noxious Weed Act of 1999, through re-delegation of authority to CDFA.

CDFG has the authority to prohibit and control species on its prohibited and restricted lists, but does not have enforcement agents at state ports. The USFWS inspectors we interviewed stated they are aware of California state regulations and can prevent imports that violate state code; however, they were not aware of regulations for *Caulerpa taxifolia,* however.

No inspections exist for ornamental species entering California from other states. Additionally, we are unaware of any laws that prohibit the release of these species into the wild, except for Restricted Species and *Caulerpa* spp.

Table 11. Marine and estuarine plants listed as Noxious Weeds in the California Code of Regulations, Title 3 (Food & Agriculture, Division 4 (Plant Industry), Chapter 6 (Weed Free Areas and Weed Eradication Areas), Subchapter 6 (Noxious Weed Species, Section 4500 (Noxious Weed Species). This list was last updated in 2010. Sources: http://www.cdfa.ca.gov/plant/ipc/weedinfo/winfo_list-pestrating.htm (last viewed 4/15/2012).

Cotula coronopifolia (brassbuttons)
Emex spinosa (Spiny emex, devil's thorn)
Lepidium latifolium (perennial pepperweed, tall whitetop)
Limonium ramosissimum ssp. *provinciale* (Algerian sea lavendar)
Spartina alterniflora (& S. as. x. S. f. hydrids) (smooth cordgrass, Atlantic cordgrass, and hybrids)
Spartina anglica (common cordgrass)
Spartina densiflora (dense flowered cordgrass)
Spartina patens (saltmeadow cordgrass)
Salsola soda (opposite leaf Russian thistle)
Tetragonia tetragonioides (New Zealand spinach)
Undaria pinnatifidia (wakame)
Zostera japonica (Japanese eelgrass, dwarf eelgrass)

Discussion

The risk to California posed by trade in non-indigenous marine and estuarine ornamental species is a function of the numbers of organisms introduced to California, the proportion of these that establish, their spread rate, and their ecological, economic, and societal impacts. Only a small number (13) of non-indigenous ornamental marine species have been California, despite importations of millions of non-indigenous organisms yearly. Although the number of recorded introductions of non-indigenous ornamental species is small, 69% of these introduced species established successfully (see Results from NEMESIS data).

There are notable gaps in information for a comprehensive assessment of the risk of the ornamental species vector to California's marine waters. We assessed the flux of organisms into California as a first and seemingly easiest step toward assessing the number of individuals that could be introduced, which can be related to the probability of introducing non-indigenous species (Lockwood et al. 2005, Colautti et al. 2006). Our results are based on state and federal permit records and the NEMESIS database of known introduced and established non-indigenous species. These data are retrospective as opposed to direct measurements of the volume and species currently circulating in the vector, although we supplemented these data with direct observations of ornamental importations to SFO and a preliminary internet searches for ornamental e-commerce. This volume might be overestimated, based on a recent study of ornamental marine species imported into the U.S. in 2004-2005 that also found a high diversity of species entering U.S. ports but that the volume was overestimated by 27% (Rhyne et al. 2012). Another limitation is that the most readily-accessible data are for species imported from foreign countries, leaving interstate trade, both via the internet or through trans-shipments, virtually unquantified as a source of non-indigenous ornamental species in California.

Determining the rate of establishment of non-indigenous species requires knowing the number of both established and failed species. The establishment rate should be the number of species established divided by the total number of species introduced (number of species established plus the number of species that failed to establish). Estimating establishment is imprecise due to the lag time between the arrival of a species and its discovery and established species can go undetected (Costello et al. 2007, Miller et al. 2007). Information about failed species is difficult to obtain because species can arrive and quickly disappear. For vectors that include intentional introductions such as aquaculture, the rate of failure is better known than for those vectors that lead to unintentional introductions, such as fouling.

Another major data gap in risk assessment is the internet trade in aquarium species. Kay and Hoyle (2001) examined the water garden industry and found every aquatic and wetland plant listed as a noxious weed federally or at least in one state was found on sale over the internet. Internet sales are a problem for regulation and management (Padilla and Williams 2004, Walters et al. 2006). Our brief search of the internet indicated both prohibited *Caulerpa taxifolia* and invasive lionfish are readily available for sale in California. To help track and apprehend illegal internet sales of regulated species, USDA developed an internet web crawler that resulted in several arrests for illegal trade in prohibited aquatic invasive species (J. Smith, Animal & Plant Health Inspection System, USDA, pers. com.). This system could be available to California to track interstate sales.

Influx of non-indigenous marine organisms into California, introduction, and establishment

Site and species-specific characteristics of the vector are important to guiding the management of non-indigenous species (Hayes and Barry 2008, Vander Zanden and Olden 2008, Thomsen et al. 2011a, b). Fundamentally, species in the ornamental trade are hardy and typically large, although size was not reported frequently in the data we reviewed, which predispose them to success (Padilla and Williams 2004). The release or escape of ornamental species is most probable in coastal urban areas. Below we discuss the findings and data gaps specifically for non-indigenous marine ornamental species and the vector as it operates and is managed in California.

First, we consider why so few non-indigenous ornamental marine species have been introduced despite the high flux into California. Putting the issue of whether they have gone undetected aside as unanswerable, one explanation could be that these organisms are trans-shipped outside of California. Even if species entering through ports in California are trans-shipped, a large but unknown volume of ornamental animals entering JFK and MIA are trans-shipped into California, according to USFWS officials. Although we could not determine how many non-native species imported into LAX and SFO remain in California, at least 90% of the taxa shipped from temperate countries were temperate species, indicating that tropical species had not been trans-shipped via temperate locales. Trans-shipment data are available only from the shippers in the trade. Information on trans-shipment is a major data gap for assessing the risk posed by this vector.

An alternative explanation for the low introduction rate for ornamental marine species is that they are rarely released (or again, go undetected). We know of no studies that estimate the release rate of ornamental marine species. A few freshwater studies have estimated release probabilities for aquarium fishes of about 5-6 of 100 fishes held (Gertzen et al. 2008, Strecker et al. 2011). Although the release rate was low in these studies, the volume of fishes recorded was sufficiently high to conclude that the aquarium trade was an important vector. In contrast, a study of freshwater aquarists in the Houston area found that 82% of the sample population would or did release their fishes (Weeks 2012).

As more attention has been paid to the ornamental species vector in recent years, factors that influence releases of non-indigenous species in the trade are becoming clearer. For example, the risk of release increases with the popularity of particular aquarium fish species, fish size, and fish aggressiveness (for freshwater aquarium fishes, Duggan et al. 2006, Weeks 2012). Hobbyist attitudes toward release also strongly influence likelihood of release, suggesting specific ways to target education (Weeks 2012). The distance between aquaria and waterways is another important factor that can influence the probability of release (Weigle et al. 2005). The proximity of recorded introductions to densely-populated urban areas (Fig. 2) could be viewed as additional support for distance-to-waterways as a factor influencing introductions. Finally, religious or other ceremonial releases of fishes, reptiles, and amphibians (Severinghaus and Chi 1999) have been reported anecdotally in the San Francisco Bay area. The anecdotes concern releases into freshwater pond and we are unaware of any studies dedicated to this pathway for ornamental species release into brackish or marine waters in this locale or others in the U.S.

The high volume of non-indigenous ornamental marine species being imported into California is a concern even if there is a low probability of release because a high percentage (69%) of known introductions have become established. Although the majority of the imported ornamental marine species are tropical, at least 34 temperate species were imported into LA and SF from eight countries of origin. These species represent the biggest concern for future introductions and establishments. Below we summarize information for taxa that merit special attention in California.

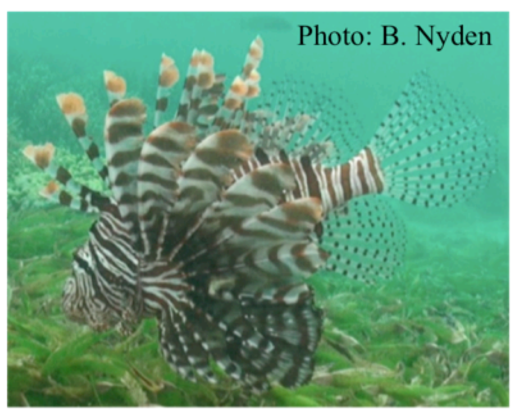
Barramundi (*Lates calcarifer*) is one species of concern that should be able to tolerate California's marine environments. Barramundi is a Restricted Species in California and we observed it in a shipment to SFO, yet we did not locate a Restricted Species permit for barramundi. The species could have been trans-shipped, a permit could have been obtained after we searched the existing records, or it could be held illegally. These possibilities highlight the difficulty in tracking the status of non-indigenous ornamental species in California.

The importation of live rock (labeled as ‘substrate’, ‘unidentified Scleractinia’) is another concern. Live rock is a potential pathway for the reintroduction of the highly invasive seaweed *Caulerpa taxifolia*, which infested two lagoons in southern California in 2000 (Jousson et al. 2000) and cost over $6 million to eradicate. *C. taxifolia* and other species can grow up from aquarium-traded live rock (Zaleski and Murray 2006). USFWS officials at SFO were not knowledgeable about *C. taxifolia*, although it was listed in 1999 as a Noxious Weed by USDA under the Plant Protection Act, which prohibits importation, entry, exportation or interstate commerce. The sale and possession of this and several other *Caulerpa* species is prohibited in California (AB 1334, chaptered in 2001). Two banned species (*C. taxifolia, C. racemosa*) and one unregulated species (*C. brachypus*) appear on ISCC’s invasive species list. If reintroduced to California, the potential for establishment is high. In the Mediterranean, it spread from the site of first record in 1984 to cover 131 km^2 in 103 sites along 191 km of coast in six countries by the end of 2000 (Meinesz et al. 2001).

The importation of lionfishes, including the invasive species *Pterois volitans*, represents another potential problem for California. This species is a highly invasive predator that spread rapidly from Florida, where it was first reported in 1999, north to North Carolina, south to Panama, Venezuela, and Columbia, west to the Gulf of Mexico, and throughout the Caribbean Sea by 2010 (Schofield 2010, Johnston and Purkis 2011). It can tolerate temperatures down to 10^oC in the invaded habitat (Kimball et al. 2004) and thus, could establish as far north as San Francisco Bay and possibly beyond. This and other lionfish species are available through internet sales from San Francisco Bay-area aquarium shops. Concern over introduced lionfishes led USFWS to begin drafting a national lionfish management plan.

Invasive Lionfish- All lionfish species are voracious predators and have venomous spines. The species *Pterois volitans* is a good example of an invasive aquarium species that now ranges from temperate waters in North Carolina to the Caribbean Sea.

A total of 20 lionfish were imported into SFO on a single day. Of these, five were invasive *Pterois volitans.*



Some of the other Indo-Pacific species entering SFO or available in aquarium stores potentially have temperature tolerances that would allow them to establish in bays at least in southern California, particularly under ocean warming. For example, in the case of *Caulerpa taxifolia*, recent sea surface temperatures of San Francisco Bay have been sufficiently warm to allow not only growth in the summer but overwintering (Williams and Schroeder 2004, Williams, unpublished data).

Impacts of non-indigenous ornamental marine species

Quantifying the impacts of marine non-indigenous species is recognized as a major information gap (Williams and Smith 2007, Williams 2007, Thomsen et al. 2009, 2011a, b), yet after an introduction has occurred, the subsequent decision to take management action often hinges upon on assessing potential impact. Impact data for ornamental species introduced to California are scarce and inadequate to guide ranking the ornamental vector compared to others in terms of impacts. To emphasize points made earlier, the introduction of *Caulerpa taxifolia* to California was attributed solely to the ornamental vector and the impacts of this seaweed are on average negative for native species and communities (Fig. 11, Williams and Smith 2007, Williams 2007, Thomsen et al. 2009, and references therein). Similarly, lionfish importations into California are a concern based on their ecological impacts as non-native predators in the eastern Atlantic and Caribbean regions (Albins and Hixon 2008, Morris and Whitfield 2009).

Given the paucity of impact data specific to the ornamental species introduced to California, a general discussion about assessing impacts of non-indigenous marine species is merited. It is safe to say that anecdotes about specific non-indigenous species generally account for the majority of available information on impacts. Published studies of impacts take a species-specific approach, with the exception of meta-analyses (Crain et al. 2008, Thomsen et al. 2009, 2011b). Although species-specific approaches are most tractable for experiments, they belie the fact that most bays and estuaries have been invaded by multiple non-indigenous species (see Grosholz et al. 2000, Newsom 2011 for experiments and a meta-analysis of effects of multiple non-indigenous marine species).

Impacts are also fairly unpredictable (Ruiz et al. 1999). When impact experiments are performed, they tend to be small and highly dependent on the specific habitat and response variable. This context-dependency of impacts circumscribes extrapolation from the literature on *Caulerpa taxifolia* and *Potamophyrgus antipodarum* because none of the studies were carried out in California. Impacts can also be 'multidirectional' in the sense of being in opposite directions depending on the response variable (Thomsen et al. 2009) or over time, as we found in this study. For an example of a multidirectional impact, Gribben and Wright (2006) completed a mensurative field study comparing various possible impacts of *C. taxifolia* on reproduction of the Sydney cockle, *Anadara trapezia*. They compared egg abundance between *C. taxifolia* beds and bare sediment. *A. trapezia* in bare sediment sites had significantly more oocytes than in *C. taxifolia* for the first 6-months of the study (Aug. to Jan), however, for the latter 6-month period there was no significant difference between habitats (Jan .to July). Similarly, Holmer et al. (2009)

completed a mensurative field study comparing sediment quality in *Posidonia oceanica* beds invaded by *Caulerpa* spp., including *C. taxifolia*. They found sedimentation rates were significantly higher in areas with *Caulerpa* compared to bare areas, however, sedimentation rates did not differ significantly between *Caulerpa* spp. and the other treatments (mixed areas, control *P. oceanica* beds).

Studies of impacts on the marine economy have not been expanded substantially beyond the few cited in Williams and Grosholz (2008); we found no new cases for ornamental species. Economic impacts are easy to rank but environmental and ecological 'impacts' are inherently laden with human values, open for discussion and in need of consensus opinion.

When managers are faced with a decision to eradicate or control a non-indigenous species, they evaluate the impact against the projected management costs. They are left to evaluate impact through extrapolation from anecdotes, impacts recorded in different geographical settings, general knowledge about the ecological role of the species (e.g., top predator, ecosystem engineer, Williams and Grosholz 2008), and the precautionary principle based on the 'average' negative effect of, for example, non-indigenous seaweeds (Schaffelke et al. 2006, Williams and Smith 2007, Thomsen et al. 2009). The paucity of impact data and the caveats listed above support the argument that vector management is the most effective means to reduce future impacts.

Future trends in the ornamental non-indigenous species

The aquarium trade is a lucrative business, particularly for developing nations. The invoiced value of the SFO shipments we examined totaled over $2500. The retail value is far higher. For example, the invoiced value of a single emperor angelfish (*Pomacanthus imperator*) was listed as $13 but its internet retail value was listed at $90 (as of March 2012).

Although the trade is lucrative and the U.S. is the major driver of the trade, the relationship between trade and introductions of non-indigenous species is difficult to assess (Lovell and Stone 2005). Globally, the marine aquarium trade grew very fast through 2000 (Fig. 15). Trade increase is consistent with both increased numbers of documented non-indigenous ornamental species (Fig. 1) and increased Restricted Species permit records (Fig. 10), but the data are too few to make definitive links between increased trade and introductions. For example, the data on documented introductions reflect primarily polyvectic species and increases in permits for Restricted Species potentially reflects better record keeping. Global trade in marine aquarium species fell off precipitously after 2000 (Fig. 15), perhaps due to the global economic recession. An update of these data is not readily available. Although there is a correlation between trade volume and the number of introductions of non-indigenous species in general, the relationship is not precise. Models based on international trade predict an increase in invasive species (molluscs, plant pathogens, insects) in general of ranging between 3-61% (Levine and D'Antonio 2003). Imports tend to be one of the better predictors of invasions (Dalmazzone 2000). In any case, the trade data for California are not readily available.

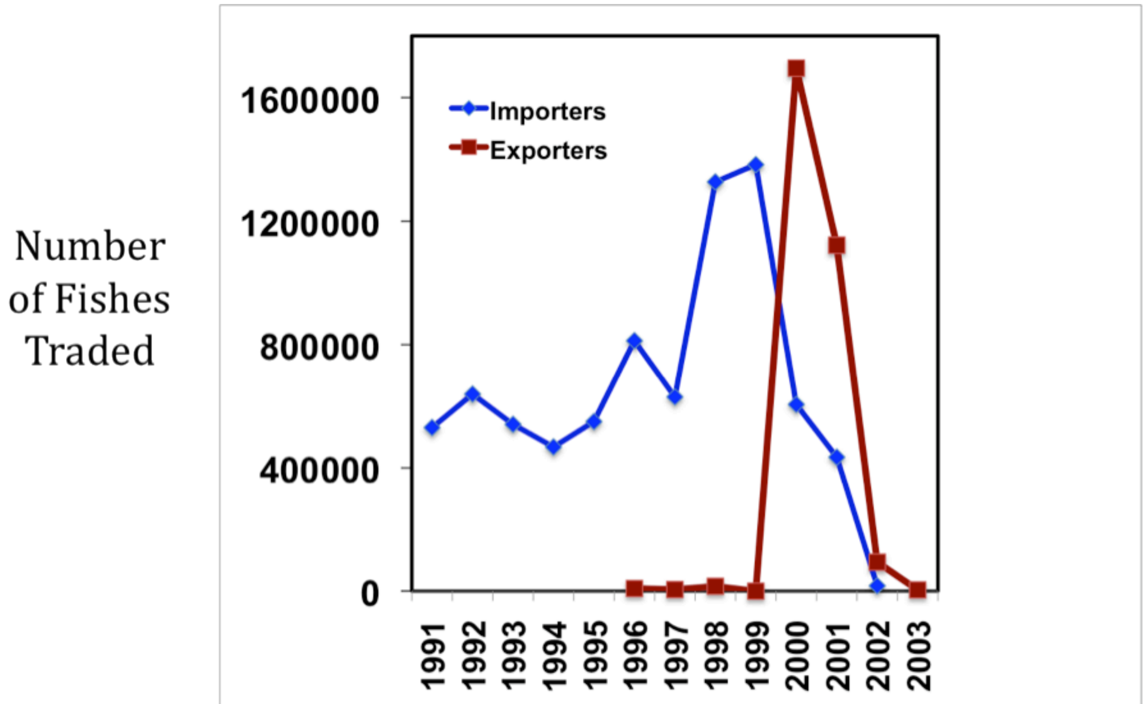


Figure 15. **Temporal trends in the global ornamental trade as indicated by numbers of marine fishes reported by importers and exporters (data derived from Wabnitz et al. 2003).** Import data generally are considered a better indicator of invasion rates than exporter data (Dalmazzone 2000).

Management opportunities

Key Finding - *A centralized database and information source on marine invasive species in California would help navigate the mosaic of regulations, determine the flux of these species, and future monitoring of these species. Given that regulation of ornamental species has not been as effective as desired, that best practices have been vetted, and that sectors of the trade have expressed interest in voluntary measures to reduce the threat, education campaigns offer an important avenue to reduce the risk. Importers should be required to report volume in individuals and trans-shipment volume and destination.*

A major challenge for management and for the trade alike is that information relevant to non-indigenous species or potentially invasive ornamental species is highly dispersed. Information regarding non-indigenous species of concern to California is dispersed over many different web sites and documents, many of which do not provide links to related sites or do not define how the information is articulated within the regulatory and management structure. From the user's standpoint, the information is difficult to summarize.

Highly-dispersed information and data also contributed to the challenge of characterizing the vector, particularly in terms of propagule supply. Numerous state and federal agencies (Fig. 14) are involved in regulating potentially invasive species, creating a mosaic of overlapping jurisdictions and also gaps. For example, a comparison between LEMIS records for 2009 and the restricted species database revealed an overlap of seven taxa (Table 12). While the fraction of restricted species imported is small (13 records out of 56,739 total in 2009), the number of specimens imported is significant. Over two million *Oreochromis* spp. specimens were imported. Another example where agency coordination would be important is for *Haliotis*. California restricts species within the genus *Haliotis* but LEMIS records specify only to the genus level. The issue of highly-dispersed information and data has been acknowledged repeatedly over time by the agencies and in the literature (Lodge et al. 2006, Williams and Grosholz 2008, Muir 2011). Given that reorganizing state and federal government is virtually impossible, better inter-accessibility to information and the creation of centralized databases could improve the situation.

Table 12. Comparison of imported species in the LEMIS database for San Francisco and Los Angeles in 2009 to restricted species permits. Table includes the port of arrival, number of records, and number of specimens from the LEMIS data and the year in which the species was permitted as a restricted species.

Species	Arrival Port	Number of Records	Number of Specimens	Restricted Species Permit Year
Oryzias spp.	LA	1	20	
Oryzias latipes				2005
Transgenic *Oryzias latipes*				2003
Oreochromis niloticus	SF	1	120,000	2010
Oreochromis spp.	SF	9	2,170,000	
Transgenic *Oreochromis niloticus*				2010
Lates calcarifer	SF	2	24,000	2011

To address the patchwork mosaic of governmental activities regarding invasive species at the federal level, Executive Order 13112, promulgated in 1999, created a cross-agency Invasive Species Council to foster coordination, which resulted in a National Invasive Species Management Plan. In 2009, California established a parallel management structure, the Invasive Species Council of California ('ISCC'; http://www.iscc.ca.gov/), chaired by the CDFA Secretary and vice-chaired by the Natural Resources Agency Secretary.

Improved labeling - Better labeling of imported wildlife is important to preventing introductions of non-indigenous species (Smith et al. 2008, 2009, Rhyne et al. 2012). The majority of the marine organisms imported into the ports of LA and SF in 2006 were coded in the USFWS LEMIS database generically as 'tropical marine fishes', 'other invertebrates', 'crustaceans', and 'mollucs' (Figs. 3, 4). 'Substrate' is an example of a largely uninformative code for an entire community of unidentified organisms. Our direct observations of shipments into SFO revealed labeling discrepancies between the invoices provided to USFWS inspectors and the organisms imported for just over half of the boxes inspected (see Results), although CITES-listed organisms were correctly labeled. If anything, the labeling of marine organisms imported through California ports was worse than reported for all wildlife imported into the U.S. in 2006 (Smith et al. 2009). Better labeling of imported wildlife is important to preventing introductions of non-indigenous species (Smith et al. 2008, 2009). Although USFWS has the authority to detain improperly labeled wildlife importations, the case will be deferred to the legal system with all its inherent issues (USFWS, pers. com.). Realistically, taxonomic knowledge of Indo-Pacific organisms, which compose the majority of importations, is so incomplete that even if there is the intent to label correctly, it will be difficult. Transference of new taxonomic knowledge to collectors and shippers also will be a limiting step in improvement of labeling imported organisms.

Best management practices - Regulation of invasive aquarium species (both plants and animals) has not proven effective (Jenkins et al. 2007). For example, despite state (AB 1334) and federal regulation of *Caulerpa taxifolia*, its availability in aquarium stores has not decreased (Walters et al. 2011, Diaz et al. 2012). Finally, resources have been too sparse for effective enforcement; prohibited species still slip through the screens (S. Ellis and W. Paznokas, CDFG, pers. com.; Jenkins et al. 2007).

Instead, voluntary initiatives by the industry (Burt et al. 2007, SCDB 2010) and public education offer more effective solutions to reducing the risk from this vector. The aquarium industry is particularly diffuse and movements of non-indigenous organisms once they have entered the U.S. are difficult to track, particularly over the internet. The Marine Aquarium Council (MAC, http://www.aquariumcouncil.org/) was initiated in 1998 to promote voluntary environmentally sustainable collection and delivery of aquarium organisms, through education and a certificate program. Initially, MAC's educational outreach focused on unsustainable collection practices but secondarily noted concern about aquarium release and the threat of introducing non-indigenous species. However, MAC has not been able to make significant strides toward its commitment to change aquarium collection practices, let alone prevent introductions of non-indigenous species. MAC recently has been promoting an international conference to assess the marine aquarium trade and the potential need for regulation of shipping and trans-shipping (shipment by intermediaries of imported aquarium organisms once they have cleared the entry port).

Another initially high profile industry partnership involved the Pet Industry Joint Advisory Council (PIJAC), the Federal Aquatic Nuisance Species Task Force (ANSTF), the US Fish and Wildlife Service (USFWS) and NOAA National Sea Grant College

Program. This program, with its own trademarked brand Habitattitude ™ , was an effort to use industry resources to help fund a national campaign to educate the public about the risk of releasing aquarium fish. This program has been less effective than originally billed with poor visibility even within the aquarium industry itself. Among the difficulties was that, although the program was initially successful in attracting participation with the larger chain aquarium stores, smaller stores were much less likely to participate, being not as tightly linked to the industry group (PIJAC). This example highlights one of the difficulties for education efforts in the future, which is the unwillingness of smaller "non-chain" aquarium stores to participate with and follow the program recommendations of the centralized industry organizations.

Best Management Practices for the aquarium trade focus on sustainable collection, collection, and husbandry practices (Cohen et al. 2010, SAIA draft *www.saia-online.eu)*. These practices would be greatly enhanced by inclusions of guidelines on the disposal and release of aquarium organisms.

We also recommend the adoption of industry-wide best management practices for commercial, educational and research aquaria. There are at least 46 such facilities associated with public displays, museums, universities, and non-profit institutions (Appendix 3). Some of the facilities routinely house non-native species and some portion maintain water systems that are at least partially open to the environment (J. Moore, CDFG, pers. com.). These facilities present at least a finite risk that organisms contained within could escape into the environment.

Coordination Across Vectors and Future Research Directions

A major goal of all six vector AIS teams was to identify the gaps in understanding the vectors as pathways for non-indigenous marine species in California, to provide useful information for management, and to assess the feasibility of a cross-vector risk assessment. To this end, the UC-Davis team was responsible for coordinating efforts and results across vectors. Below we describe the collaborative approach among the teams, co-directed by OST, and progress toward cross-vector assessments.

Step 1- Conceptual Model for Risk of Invasions. We developed a consensus for a first-cut simple conceptual risk assessment model to be used to guide collection and analysis of data from the various vectors (see Objectives section).

Step 2- Impacts Database. We developed a coordinated approach to collecting data on impacts across vectors. We jointly developed an impact database that included ecological, human health, and economic impacts, to be populated by SERC (crustaceans) and UCD (seaweeds, molluscs) based on literature searches using identical search terms. We also developed an initial expert judgment survey template for future evaluation of impact (Appendix 2) because we uncovered a paucity of data.

Step 3- Data Gaps and Vector Risk Comparisons. This step is to outline an approach to develop a more refined model for a cross-vector risk assessment. Development is an ongoing discussion by SERC, UCD, and OST. As mentioned in the Introduction and Objectives, a cross-vector risk assessment, even of the most qualitative manner, has not been achieved to our knowledge. The types of data we gathered have been used to inform single species invasion risk assessments in some marine ecosystems (Campbell 2009). *However, we know of no existing risk assessment approaches that characterize relative risks of multiple invasion vectors for multiple species.* There are other types of risk assessment techniques for evaluating relative invasion risk that might be scalable for multiple species and vectors (reviewed in Wonham and Lewis 2009). All of these approaches require significant amounts of data, which proved to be unavailable for most of California's non-indigenous marine species and the vectors delivering them.

The data collected by research teams funded by the Ocean Protection Council to assess six vectors for marine non-indigenous species in California should enable assignment of species to vectors based on a combination of species trait information, year of first record, and timing of vector operation. Vector assignment will allow a first-cut relative comparison of the vectors to which introductions have been attributed and expand upon Foss et al. (2007). A similar comparison could be made based on the number of established species, to ascertain whether species in one or the other vector is more likely to succeed (simple ratio of established/introduced). At a minimum, this type of analysis can be used to recommend changes in policy and outline future research needs for a specific region (for example see Moser and Leffler 2009).

As now obvious for the impacts of ornamental species (see Results), relying solely on peer-reviewed, published data severely restricts the species that can be assessed across the full conceptual risk model incorporating introduction, establishment, and impact. To increase the pool of assessable species, several protocols have been developed for generating semi-quantitative expert assessments based on focused literature reviews, surveys, and workshops that incorporate unpublished information about traits, distributions, and other factors (Orr et al. 1993, Hayes 2002, Hayes et al. 2002, NISC 2003, Orr 2003, ANSTF & NISC 2007, Therriault and Herborg 2008, Acosta and Forrest 2009). These approaches inform our efforts to develop a robust multi-species, multi-vector risk assessment process.

Expert knowledge in risk assessment

Expert judgment is an increasingly important tool for risk analysis in data-poor situations. In addition to assessing species-vector associations, expert knowledge has also been extended to assign semi-quantitative scores to species impacts and introduction and establishment probabilities for selected species and, in more limited cases, vectors (Orr et al. 1993, Hayes 2002, Hayes et al. 2002, NISC 2003, Orr 2003, ANSTF & NISC 2007, Therriault and Herborg 2008, Acosta and Forrest 2009). For example, in perhaps the most quantitatively comprehensive, expert-based invasion risk assessment, Hayes (2002) used shipping records and species distributions to estimate invasion potential, and a web-based questionnaire to assess economic, ecological, and health impacts for potential marine invaders in New Zealand. Through the use of interval arithmetic, he tracked uncertainty and combined ecological and economic impact measures.

As the systematic use of expert knowledge in invasion ecology and management is growing, initial efforts to assess its accuracy revealed that expert knowledge can accurately assess invasion risk (Daehler et al. 2004) and non-indigenous species distributions (Marvin et al. 2009). However, there is also concern about the growing use of expert knowledge in ecological management amid evidence that experts commit systematic errors about subjective risk decisions in information-poor situations (Burgman et al. 1996, Regan et al. 2002). Likewise, there is evidence that expert accuracy diminishes when experts are asked to make judgments beyond their region of expertise (Murray et al. 2009), as well as concerns about how the structure of expert elicitation processes affects the range and quality of the judgments rendered (Tversky and Kahneman 1974). Finally, there is also concern about the weight placed on expert judgment by decision makers (Keith 1996).

To address these concerns, best practices for expert elicitation processes have been developed that attempt to mitigate various biases and address issues of inclusion, unequal expertise, and ambiguity in problem presentation (Linstone and Turoff 1975, Cooke 1991, Lele and Allen 2006, MacMillan and Marshall 2006, Kuhnert et al. 2010, Burgman et al. 2011a, Burgman et al. 2011b, Martin et al. 2012).

Gaps and challenges

Our most difficult challenge is to develop a means to link species-vector assignments with fluxes and impacts. There is no standard metric for the number of individuals circulating in the vector, and for vectors such as ornamental species, the flux has been difficult to estimate.

Another complication is that most non-indigenous marine species in California can be assigned to more than one probable vector, i.e., they are ‘polyvectic’. Critical to determining the relative strength of these vectors will be judging the importance of each vector to the introduction, establishment, and impacts of polyvectic species. To our knowledge, no methods currently exist for partitioning and aggregating relative vector strength across polyvectic species.

Future research directions

With OST, we have co-developed two future approaches to help close data gaps in cross-vector risk assessments.

Expert Elicitation- The first approach is to develop an expert elicitation approach. Surveys similar to the one developed for impacts (Appendix 2) also could be useful in future efforts to assess expert knowledge of relative vector importance for polyvectic species, introduction and establishment probabilities, patterns of secondary spread, and other topics that are data-poor for most of our species and vectors. Such surveys and related discussions among experts could build towards an estimation of overall vector risk that reflects uncertainty among experts at different steps of the invasion process.

We believe that including stakeholders and non-scientists will be important in a good expert elicitation (see Weeks 2012). We also suggest using an arithmetic scale for evaluation in order to determine variances across experts and to assess uncertainty. Breaking the elicitation into several steps that include different types of experts was also recommended during OST's Science Advisory Team (SAT) meeting in Spring 2012.

The importance of including the hobbyists in expert elicitation was revealed through use of an 'invasion potential' scorecard developed for aquarium fishes in Texas (Weeks 2012). One component was a survey of hobbyists to determine the factors that influence the probability of releasing ornamental fishes. Although the scorecard did not determine quantitative/qualitative risk or impacts, it did assess the potential of a species becoming established based on its availability in the trade, its release likelihood based on attitudes of the releaser, and the ecological determinants of survival and reproduction. The scorecard offers a relatively time-efficient means to screen species with high invasion potential in the trade.

Vector Analysis- We also propose to directly estimate the flux of species by sampling across multiple vectors over a concurrent standardized time period, which we call the 'vector blitz'. To our knowledge, there has never been an attempt to quantitative standardized measure of the propagule supply across vectors. We are seeking support for developing this vector analysis as a pilot study. To this end, California Sea Grant will fund a 2-day workshop in 2012 to design a vector blitz and to advance the ongoing collaboration between SERC and UCD, to develop cross-vector risk assessment, including through expert elicitation.

Recommendations

Overarching recommendation- *We recommend that California pursue a cross-vector assessment for marine non-indigenous species even in the face of limited data for the ornamental vector. Vector management is acknowledged widely as the most effective means to reduce future costs from non-indigenous species, but until a cross-vector assessment is tackled, California will be faced managing on a species-by-species basis.*

Many of the specific recommendations below have been made repeatedly in the past for non-indigenous species in general but bear re-emphasis. Recommendations are separated into short-, intermediate- and long-term ones for management followed by research recommendations.

It is critical to involve the ornamental species industry in shaping and implementing recommendations.

Management Recommendations

Short term (< 2 years)

- Implement a single digital permit for non-indigenous species in California
- Cross-link all agency websites on non-indigenous species
- Implement a 'Don't release' campaign and assess outcomes
- Enforce labeling requirements for importations
- Enhance visibility and accessibility of web information on importation of live species to California starting with a permit pathway diagram (e.g., Fig. 14), including internet links to Best Management Practices currently available
- Cross-train USFWS inspection agents on *Caulerpa taxifolia* (USDA) and on *Caulerpa* species prohibited by California (CDFG)
- List lionfish as a Restricted Species by its Latin name(s) (*Pterois volitans*, *Pterois volitans/miles, Pterois miles*) and by all common names used on internet purchase sites and importation invoices (including common, red, voltans, volitans, red volitans, black peacock, Indian)
- Initiate discussion with stakeholders improving record keeping and data to determine the relative risk of the vector
- Enhance regulation of internet sales through the use of web crawlers

Intermediate term (2 – 5 years)

- Require reporting volume of importations in standard units, preferably as individuals
- Require information on trans-shipping of importations on state and federal permits
- Require reporting of Restricted Species in possession
- Digitize and centralize a database on species regulated within both California (including local to state level) and the U.S.
- Centralize authority for regulation of invasive species in California
- Provide sufficient resources to support agency mandates (e.g., a surcharge for importations of live organisms or purchases of non-indigenous species)
- Develop and adopt industry-wide best management practices for commercial, educational, and research aquaria

Longterm (> 5 years)

- Conduct a cross-vector risk assessment
- Provide more support for, and higher numbers of, USFWS inspection and enforcement agents in California and nationally
- Collaborate with the ornamental industry to certify aquarium stores for sustainable collecting and best management practices
- Rectify California non-indigenous species listings with federal listings to streamline agency workloads and foster highly successful cooperation across agencies (e.g., in New York)

Research

- Conduct a standardized sampling of species and volumes circulating within the main vectors ('vector blitz')
- Conduct a cross-vector risk assessment based on expert knowledge
- Quantify trans-shipping flux
- Conduct an assessment of internet availability of ornamental marine species
- Investigate the feasibility of 'white lists' and 'black lists' for ornamental marine species
- Analyze marine aquarist behaviors in California to estimate the probabilities of release and other determinants of the probability of introduction and possible incentives to reduce the risk
- Conduct regular surveys of non-indigenous marine species in California, with better coverage of critical habitats (seagrass, kelp)
- Reassess the numbers and kinds of introduced and established ornamental marine species in California
- Investigate the diversity (richness, numbers of individuals) of species imported or trans-shipped as live rock
- Conduct community-level ecological impact experiments
- Conduct economic impact assessments of the aquarium trade
- Investigate ceremonial animal releases in California
- Improve knowledge about non-indigenous marine plants

Summary and Conclusions

Millions of highly diverse non-indigenous ornamental marine species are being imported annually into California yet only 13 such species have been introduced. Even if few ornamental species have been released, the high volume and the high probability of establishment signal concern for California. Although most of the flux consists of tropical species, there are at least 34 species deemed able to tolerate California's current marine climate. Two ornamental taxa of special concern are the seaweeds *Caulerpa* spp. and lionfishes (*Pterois volitans, P. miles*), based on impact studies and spread rates. *Caulerpa* spp. are available for sale in California and lionfish are being imported.

The highly dispersed information on the trade and its regulation and enforcement in California is a challenge for the trade, government from local to federal levels, and researchers. A centralized and coordinated permit and data archive system will be beneficial to all, particularly if reporting is mandatory for volume and trans-shipment figures.

California seeks to allocate its resources effectively and efficiently to manage non-indigenous marine species through vector-based management. The results of this study and its sister studies on aquaculture, fishing and recreational vessels, and live seafood and bait uncovered gaps in data. These gaps include propagule pressure estimates for several vectors, including ornamental species. Importantly, no standardized metric to estimate the numbers of individuals circulating across vectors was found. Data on impacts is also scarce and comes largely from studies conducted outside of California. Although these data gaps will not allow even the most basic model for cross-vector risk assessment to be completed, the combined results from the AIS projects are deemed sufficient to support at least a preliminary expert knowledge elicitation about the relative risks these vectors represent for California.

Acknowledgments

We are indebted to the gracious state and federal agency officials for their time and interest in this project, despite the fact that all were seriously overburdened with other responsibilities; in interest of security, we are not mentioning them by name. We also thank the Executive Director (S. McAfee) and staff of the Ocean Science Trust for facilitating this project, especially the project managers R. Gentry and E. Kramer-Wilt. We gratefully acknowledge the Ocean Protection Council for funding this project. M. Englebrecht, Librarian, Cadet Hand Library, Bodega Marine Laboratory, helped with literature searches for impacts. We thank D. Catania, M. Flannery, C. Piortrowski, B. van Syoc and G. Williams of the California Academy of Sciences for their expertise during the USFWS inspection of aquarium shipments at SFO.

Useful Web Sites

- Invasive Species Council of California (ISCC):
  http://ice.ucdavis.edu/invasives/home/species
- California CDFA Noxious Weed list (2010):
  http://www.cdfa.ca.gov/plant/ipc/weedinfo/winfo_list-pestrating.htm
- California Invasive Plant Council's weed list:
  http://www.cal-ipc.org/ip/inventory/weedlist.php
- Managing Coastal Aquatic Invasive Species in CA: existing policies & policy gaps.
  http://www.library.ca.gov/crb/11/11-001.pdf
- NEMESIS (National Exotic Marine & Estuarine Species Information System):
  http://invasions.si.edu/nemesis/

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APPENDICES

Appendix 1. List of Acronyms

AB – Assembly Bill
ACOE – United States Army Corps of Engineers
AIS – Aquatic Invasive Species
ANSTF – Federal Aquatic Nuisance Species Task Force
APHIS – Animal & Plant Health Inspection Service (USDA)
BIOSIS – Biosciences Information Service
CA – California
CDFA – California Department of Food & Agriculture
CDFG – California Department of Fish & Game
CEQI – Coastal Environmental Quality Initiative
CITES – Convention on International Trade in Endangered Species
FG – Fish & Game Permit (CDFG)
FOIA – Freedom of Information Act
ISCC – Invasive Species Council of California
JFK – John F. Kennedy International Airport
JARPA – Joint Aquatic Resource Permit Application
LA – Los Angeles
LAX – Los Angeles International Airport
LEMIS – Law Enforcement Management Information System (USFWS)
MAC – Marine Aquarium Council
MIA – Miami International Airport
NEMESIS – National Exotic Marine and Estuarine Species Information System
NIS – Non-Indigenous Species
NISC – National Invasive Species Council
NOAA – National Oceanic and Atmospheric Administration
NWP – Nationwide Permit (ACOE)
OST – Ocean Science Trust
PIJAC – Pet Industry Joint Advisory Council
POU – Proof of Use Reports (CDFG)
PPQ – Plant Protection & Quarantine (APHIS, USDA)
SAIA – Sustainability Aquarium Industry Association
SAT – Science Advisory Team
SCBD - Secretariat of the Convention on Biological Diversity
SERC – Smithsonian Environmental Research Center
SF – San Francisco
SFO – San Francisco International Airport
UC – University of California
UCD – University of California, Davis
USDA – United States Department of Agriculture
USWFS – United States Fish & Wildlife Service
WoRMS – World Register of Marine Species

Appendix 2. A template for expert elicitation survey for invasive species impacts.

This survey was designed to elicit expert judgment about invasive species impacts in cases where experts are given access to our invasive species impacts database.

Health

A. Rate the impact of this species to human health
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Economic 1

A. Rate the ability of this species to obstruct/damage aquatic waterways.
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Economic 2

A. Rate the ability of this species to cause nuisance fouling (eg clogging cooling water pipes, fouling turbines)
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Economic 3

Rate the ability of this species to cause loss of aquaculture or commercial or recreational fisheries harvest
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Economic 4

Rate the ability of this species to cause loss of public/tourist amenity or aesthetic values (eg spoiling beaches, restricting access to water)

1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 1

Rate the ability of this species to cause detrimental modification of physical habitat.
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 2

Rate the ability of this species to reduces native species abundance, cover, habitat, range, survival.
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 3

Rate the ability of this species to introduce and facilitate diseases or pathogens.
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 4

Rate the ability of this species to alter bio-geochemical cycles (eg chemical/nutrient composition of sediment).
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 5

Rate the ability of this species to induce novel behavioral or eco-physiological responses in native species.
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 6

Rate the ability of this species to cause genetic impacts (eg introgression and hybridisation).
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.

1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Ecological 7

Rate the ability of this species to alter light availability (e.g. when an aquatic invader covers an entire water body that would otherwise be open).
1 = no known impacts (reference species = xxx)
3 = moderate impacts (reference species = xxx)
5 = severe impacts (reference species = xxx)

B. Which studies are you basing your assessment upon?

C. List any un-published characteristics of the species, vector, recipient ecosystem, or native community that influence your assessment

D. Rate your uncertainty about your impact score from 1-5.
1 = very certain based on documented impacts in high quality studies. (reference species = xxx)
3 = moderate certainty based on limited and/or inferential studies with weak statistical power. (reference species = xxx)
5 = very uncertain, assessment is based completely upon unpublished characterizations. (reference species = xxx)

Appendix 3. A table of public aquaria in California.

Aquarium/Laboratory Name	Affiliated Organizations	City	Closed or Open System
Marine Environmental Quality Branch	USN SPAWAR Systems Center	San Diego	Open
SeaWorld of California		San Diego	Chlorinated
Coastal Waters Laboratory	San Diego State University	San Diego	Open
Birch Aquarium	University of California, San Diego (Scripps)	La Jolla	Open System + Closed System
Scripps Institute of Oceanography	University of California, San Diego	La Jolla	Open System + Closed System
Southwest Fisheries Science Center (SWFSC)	National Oceanic and Atmospheric Administration (NOAA)	La Jolla	Open
SeaLife Aquarium	LEGOLAND California	Carlsbad	Closed
Southern California Coastal Water Research Project		Costa Mesa	Closed
Kerckhoff Marine Laboratory	CalTech California Institute of Technology	Corona del Mar	Open
Aquarium of the Pacific	Aquarium of the Pacific	Long Beach	Closed
Southern California Marine Institute (Ocean Studies Institute)	Ocean Studies Institute (Occidental College, University of Southern California)	Terminal Island	Open
Cabrillo Marine Aquarium	Los Angeles City	San Pedro	Semi-Closed (drains to sand)
Wrigley Institute of Environmental Studies	University of Southern California	Avalon	Open

Pennington Marine Science Center	Boy Scouts of America	Avalon	Open
California Science Center		Los Angeles	Closed
Roundhouse Aquarium		Manhattan Beach	Open
The Sea Laboratory	Los Angeles Conservation Corps	Redondo Beach	Open
Heal the Bay	Santa Monica Pier Aquarium	Santa Monica	Open
Channel Islands Marine Resources Institute	Oxnard College	Ojai	Open
Ty Warner Sea Center	Santa Barbara Natural History Museum	Santa Barbara	Open
Marine Science Institute	University of California, Santa Barbara	Santa Barbara	Open
Camp KEEP	Kern Environmental Education Program	Los Osos	Closed
Morro Bay Aquarium		Morro Bay	Open
Marine Science Education and Research Center/Center for Coastal Marine Sciences (CCMS)	California State University, San Luis Obispo	San Luis Obispo	Open
Hopkins Marine Station	Stanford University	Pacific Grove	Open
Monterey Bay Aquarium		Monterey	Open System + Closed System
Monterey Bay Aquarium Research Institute (MBARI)		Moss Landing	Open
Moss Landing Marine Laboratories (MLML)	California State University System	Moss Landing	Open

Long Marine Laboratory/Institute of Marine Sciences	University of California, Santa Cruz	Santa Cruz	Open
Steinhart Aquarium	California Academy of Sciences	San Francisco	Closed
Aquarium of the Bay		San Francisco	Closed
Marine Science Institute (MSI)		Redwood City	Open
Romberg Tiburon Center for Environmental Studies	San Francisco State University	Tiburon	Open
Six Flags Discovery Kingdom		Vallejo	Closed
Bodega Marine Laboratory	University of California, Davis	Bodega Bay	Open
Telonicher Marine Laboratory	Humboldt State University	Trinidad	Open
Ocean World Aquarium/UnderSea World		Crescent City	Open