When one code = 2,300 species: Expanding our understanding of the trade in aquatic marine wildlife

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Abstract

The trade of marine ornamental animals for home and public aquaria has grown into a major global industry. Since the 1990s, the aquarium hobby has shifted focus from fish-only systems to miniature reef ecosystems. Millions of marine fishes and invertebrates are removed from coral reefs and associated habitats each year, and the majority of animals are imported into the United States, with the remainder sent to Europe, Japan, and a handful of other countries. This shift in aquarium complexity demands increases in not only the volume but also the diversity of species harvested by collectors. Collectors must now supply the trade with species sought for both aesthetics as well as ecosystem services (e.g., species that contribute to the life support services of aquaria). Despite the recent growth and diversification of the aquarium trade, to date, data collection is not mandatory, and hence comprehensive information on species volume or diversity is wanting. The lack of this information makes it impossible to study trade pathways. Without species-specific volume and diversity data, it is unclear how importing and exporting governments can oversee this industry effectively and how sustainability should be encouraged To expand our knowledge and understanding of this trade, and to be able to effectively communicate this new understanding, we introduce the publically-available Marine Aquarium Biodiversity and Trade Flow online database (https://www.aquariumtradedata.org/). This tool was created as a means to assess the volume and diversity of marine fishes and/or invertebrates imported into the US over four years (2005, 2008, 2009, and 2011) and one month of additional data in 2000. To create this tool, invoices pertaining to shipments of live marine fish and invertebrates were scanned and analyzed for species name, quantity, country of origin, and city of import destination. The results for October 2000 as well as the year between June 2004 and May 2005 have been published (Rhyne et al. 2012,

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http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0035808; Balboa 2003). Here we focus on the later three years of data and also produce estimated volume of species imported to create complete calendar years for 2000, 2004, and 2005. The three-year aggregate totals (2008, 2009, 2011) indicate that just under 2,300 fish and 725 invertebrate species were imported into the US, even though each year, just shy of 1,800 fish and 550 invertebrate species were traded. Overall, the total number of live marine animals decreased between 2008 and 2011. In 2008, 2009, and 2011, the total number of individual fish (8.2, 7.3, and 6.9 million) and invertebrates (4.2, 3.7, and 3.6 million) assessed by analyzing the invoice data are roughly 60% of the total volumes recorded through the LEMIS dataset. Using these complete years, we back-calculated the number of individuals imported in 2000, 2004, and 2005. These estimates (9.3, 10.8, and 11.2 million individual fish per year) were consistent with the known three years of data. These data are also used to demonstrate how the trade of Banggai cardinalfish (*Pterapogon kauderni*) and clownfish (*Amphipiron ocellaris* and *A. percula*) can be better understood. This database can help create more effective management plans for the traded species, and if moved to a real-time format, could help in the detection of illegal trade.

Introduction

There is no clear picture of the number of species or individuals of marine ornamental fish and invertebrates involved in the aquarium trade, primarily a result of insufficient global tracking of the import and export of these animals (Bruckner 2001; Fujita et al. 2013; Green 2003; Lunn and Moreau 2004; Tissot et al. 2010; Wabnitz et al. 2003). Increasing the sustainability of the marine ornamental animal industry should be considered a primary initiative ("low hanging fruit") for the entire aquarium industry transport chain, including aquarium retailers (Tlusty et al. 2013). Increasing the sustainability of the ornamental transport chain is achieved through a more thorough understanding of the magnitude of the trade (Fujita et al. 2013), which begins by sufficiently assessing the scale of imports into the US (the primary destination for the global trade of ornamental animals) (Rhyne et al. 2012b). Once the annual volume of US imports is realized, other relevant issues that lead to environmental and economic benefits can then be tackled, including animal quality and shipping survival (less fishing effort as fewer fish are need to maintain the trade).

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The ornamental fish hobby is extremely large, although the exact magnitude of the trade is unknown. It is estimated that the US imports 190 million freshwater and marine fishes annually (AVMA 2007). The ornamental fish trade faces a multitude of potential threats, including reduced biodiversity from over extraction, habitat destruction in source countries (Francis-Floyd and Klinger 2003; Gopakumar and Ignatius 2006), and negative impacts of species invasions in the US and elsewhere (Chucholl 2013; García‐Berthou 2007; Holmberg et al. 2015; Padilla and Williams 2004). Despite these threats, the aquarium trade has unique and massive potential for good (Rhyne et al. 2014), including saving threatened species from the brink of extinction through the development of captive breeding programs (Tlusty 2002) and catalyzing habitat preservation through sustainable supply-side practices, be it aquaculture or wild fisheries. These sustainable practices include stewardship, mechanisms for sustainable livelihoods via poverty alleviation, and the protection of threatened ecosystems that are otherwise unguarded and unregulated (Rhyne et al. 2014). Finally, consumer education of aquarium trade sustainability can promote widespread public appreciation for the world's aquatic ecosystems, with the ultimate goal of ensuring the natural world is left intact for future generations (Tlusty et al. 2013). While a proactive stance can transform a large consumer base into a powerful agent for biodiversity, conservation, and human well being, inaction will likely amplify the deleterious threats currently faced by the trade. Currently, the lack of oversight leading to a poor concept of the trade volume and subsequent regulatory inefficiency has greatly hampered the development of a sustainable industry.

Multiple sources of data have been used to monitor the trade of marine ornamental animals (Woods 2001, Green 2003, Balboa 2003, Wabnitz et al. 2003, Smith et al. 2008). However, not all of these data systems are sufficient for, or were even intended for, monitoring the aquarium trade. For example, compulsory data are maintained under federal mandates for species listed by the Convention on the International Trade in Endangered Species (CITES). However, previous studies found that CITES records were inaccurate, incomplete, or insufficient (Bickford et al. 2011; Blundell and Mascia 2005; Rhyne et al. 2012b). Furthermore, CITES-listed species (namely stony corals, giant clams, and seahorses) account for only a fraction of the total trade in aquatic ornamental animals. Only a handful of studies (e.g. Rhyne et al. 2012b; Smith et al. 2009; Smith et al. 2008) have attempted to quantify the movement of non-CITES-listed aquarium species from source to market. The Global Marine Aquarium Database (GMAD) is a voluntary data reporting system, developed to provide publicly available data on the marine aquarium trade (Green 2003). Until the dataset presented here, GMAD has been the only source for aquarium trade data recorded at the species level. Unfortunately, this data source only covers a few years of data and omits important export countries (i.e., Haiti). The voluntary nature of the GMAD does not allow for complete coverage of imports or exports from countries and requires users to model trade volumes. Furthermore, in the decade and a half spanning the data and the current time period, the aquarium trade has been transformed by new technologies and husbandry breakthroughs (Rhyne and Tlusty 2014). In addition, by CITES and GMAD, the Law Enforcement Management Information System (LEMIS) database has been used to better understand the aquarium trade. In the US, the United States Fish and Wildlife Service (USFWS) inspects wildlife shipments and maintains species-specific data of shipments per CITES requirements in LEMIS. However, within LEMIS, non-CITES-listed fish and invertebrate species are listed with general codes (i.e., marine aquarium tropical fish, regardless of species, are coded MATF). Recording data in this generalized manner eliminates specific information regarding the diversity and volumes of species traded (Smith et al. 2009), which are of critical importance when assessing how the live animal trade influences ecosystem risks, such as introductions of non-native species and diseases. The need for accurate accounts of aquarium trade flow continually increases, although the current monitoring methods remain static (Bickford et al. 2011). The lack of specific data systems for recording all species exported and imported for the wildlife trade raises two main concerns: (1) because of the lack of trade data, it is unclear how importing and exporting governments can monitor this industry effectively; (2) it is also unclear how sustainability should be encouraged given the paucity of data.

To date, outside of Rhyne et al.'s analysis of 2005 US import data (2012b), the species-specific information provided on trade invoices has not been adequately catalogued or compared to associated shipment declarations. Here we report on the development of the Marine Aquarium Biodiversity and Trade Flow online database (https://www.aquariumtradedata.org/), a public portal to anonymized marine ornamental trade data collected through trade invoices. We describe an additional three years (2008, 2009, 2011) of fish and invertebrate invoice-based data from US imports that were analyzed for country of origin, city of import, and quantity of species and individuals associated with each port. We also relate the findings back to annual aquarium trade data from the LEMIS database. Rhyne et al. (2012) described one contiguous year of import data, based on a 12-month period from June of 2004 until May of 2005, and Balboa (2003) described data from October 2000. To address the missing months of data from these years and to increase the scope of the dataset, we modeled data for the missing months of 2000, 2004, and 2005. This work provides continued accounting of the volume, biodiversity, and trade pathways for marine ornamental fish and invertebrate species beyond the information given in voluntary reporting systems (Wabnitz et al. 2003) and LEMIS. This work provides a further demonstration that LEMIS, while well designed for import/export compliance and personnel management of USFWS staffing needs, is not designed to monitor the data-rich marine ornamental aquarium trade. Finally, using this database, we present two case studies (the Banggai cardinalfish, *Pterapogon kauderni*, and the orange clownfish, *Amphiprion percula*) that demonstrate the use of these data as tools to better understand the trade in marine species and promote industry sustainability.

Methods

The goal of this project was to evaluate the number of aquarium species imported into the US, and to create a trade path analysis of the diversity of aquatic animals involved in the trade. The methods used to analyze trade invoices were described by Rhyne et al. (2012b) and are briefly summarized here. We reviewed all shipment declarations and the attached commercial invoices held by USFWS coded as Marine Aquarium Tropical Fish (MATF) for 2008, 2009 and 2011 as indicated in the LEMIS database. While about 22,000 invoices were marked as containing MATF in the LEMIS database, we only recovered about 20,000 shipment declarations and their attached invoices. Invoices were considered a true statement of shipping contents. We were not able to assess the veracity of the information contained on the invoice. Shipment information (date, port of origin, and destination port) was collected from the declaration page, and species and quantity information was tabulated from the associated invoices and then cataloged into a database. Both manual entry and automated optical character recognition (OCR) software (ABBYY FlexiCapture 9.0) customized for wildlife shipments (Fig 1) were utilized to retrieve the above information from these documents. The input method varied with invoice quality and length. Manual entry was utilized when invoices were of poor quality (blurry, speckled, darkened, fonts less than six point, handwritten, or less than 1/2 page), whereas all others were read using the OCR software. Once all necessary data were captured, species names were verified using World Register of Marine Species (WoRMS Editorial Board 2015), FishBase (Froese and Pauly 2015), and the primary literature (Appeltans et al. 2011; Froese and Pauly 2011). We corrected species information only when species names were misspelled, listed under a junior synonym, or listed by only a common name. A database entry (a fish species from a specific shipment-date combination) was identified as being 'unknown' only when a common name was used to which multiple species could be matched (e.g., colorful damsel or unknown damsel), when exporters marked a species as 'Assorted' (e.g., assorted damsels), or when exporters marked a species under genus only (e.g., *Chrysiptera* sp.).

In accordance with Rhyne *et al.* (2012b), this report focused on major geographic trade flows, the frequency of invoice detail to the species level, and how invoice data compared to LEMIS data. Invoice data for both fish and invertebrates were retrieved concurrently. To help organize and visualize the trade data, a publically accessible representation of the trade data was created: the Marine Aquarium Trade Biodiversity and Trade Flow data resource website (https://www.aquariumtradedata.org/). This web-based graphical user interface, powered by the open source JavaScript library D3 (http://d3js.org/), is both data-rich and visually appealing, and allows users to query over 29,000 invoices containing over 2.7 million marine ornamental animal import records.

To expand coverage of the data for months that were not recorded (11 months in 2000, five months in 2004 and seven months in 2005), we used monthly patterns to back-calculate the estimated number of fish and invertebrates for the most voluminous species (those that exceeded 100,000 individuals across the entire database) imported into the US. Fish records from invoice data for 2004 and 2005, as well as fish and invertebrates for 2000, were then used to calculate estimated import numbers of the most voluminous species. These "voluminous species" were comprised of 29 fish and 20 invertebrate species and represented 84.5% and 83.0% of the total number of individuals imported for all years in this dataset. The proportional monthly imports of voluminous species were determined from the 2008, 2009, and 2011 data. Assuming that 2000, 2004, and 2005 have a similar monthly proportion, each of these years were adjusted by an estimated total of animals determined for the unknown months

$$(n_{\{known\ 00\ 04\ or\ 05\}}/\overline{Pr}_{(m\{08\ 09\ 11\})}) - n_{\{known\ 00\ 04\ or\ 05\}})$$

(where n is the known number of imports for 1, 5 or 7 months), Pr is the average proportion of known imports from corresponding months from 2008, 2009 and 2011. This estimated number of animals was then allocated across the unknown months proportionately for 2000, 2004 and 2005. We also generated estimates for the source countries and ports of import. A similar method was used to determine the estimated number of fish originating from each country and arriving at specific US ports, except values were created from all imports, not only for the most voluminous. These additional individual animals were added to the Marine Aquarium Trade and Biodiversity Flow Database as "estimated fish" and "estimated invertebrates" to provide a basis for yearly comparison of the total imports.

Results

The Marine Aquarium Biodiversity and Trade Flow website allows users to generate database queries from dropdown menus. Initial queries can be filtered through large-scale source areas such as ocean basins or countries of origin for a defined time period (Fig. 2). Following user selections, the software compiles detailed information in the form of maps, timeline charts, and other data charts that allow users to access data at a level uncommon in user interfaces for the wildlife or seafood trades. On further analysis, it is possible, using the "species" tab, to query a single taxonomic family, genus, or species for one or more countries and/or ports of entry. The user-friendly dropdown menus are tree-based and progressive. Figure 3 demonstrates successive screens where the user has successively selected the family Pomacentridae, the genus *Amphiprion*, and the species complex *Amphiprion percula* and *A. ocellaris*. The dashboard displays (1) a distribution map depicting the relative geographic abundance using proportionally-sized red dots, and (2) two graphs displaying export country- and port of entry-specific volumes for the selected query.

To enhance the utility of the website and promote the dissemination of the data, the user can download charts and graphs of data queries. Users can also share these charts directly to Facebook and Twitter (Fig. 4). Further, to ensure the data within the invoice-based database is an accurate representation of the trade, users can report possible errors in data or features on the website. Using social media we can ensure that the level of data quality on the site increases over time. If users find species that are likely incorrect in distribution or taxa, we can examine the invoice record, verify its contents, and then update the database if needed. This system also logs how users interact with the database, which provides feedback on the number and types of queries users generated.

General trends - In 2008, a total of 8,299,467 individual fishes (97.4% identified to species-level) representing 1,788 species were imported into the US. The total number of fishes imported decreased to 7,102,246 in 2009 and decreased further to 6,892,960 in 2011. However, the number of species imported actually increased to 1,798 by 2011. While no more than 1,800 species were imported in a single year, and 2,278 unique species were imported across the three-year span (Table 1).

A similar decreasing trend was observed for the trade in invertebrates during this time period, although the invertebrate data were less voluminous and specious compared to the fish data. A total of 4.3 million invertebrates representing 545 species were imported into the US in 2008. The total number of invertebrates imported decreased to about 3.7 million in 2009 and 2011 (Table 2). A total of 724 species were imported over the three-year span, which is greater than in any one year (545 species). Compared to fishes, relatively fewer invertebrates were identified to a species-level (72.9%).

Export Countries – 45 countries in total exported marine fishes to the US during the three years (Table 1), although 41, 37, and 36 countries were noted in 2008, 2009, and 2011, respectively. The Philippines exported 56% of the total volume (12.7 million fishes, Fig. 5). The overall volume of fishes traded decreased by 17% between 2008 and 2011, which is largely explained by the decreased exports of the Philippines and Indonesia across the three years. Third-ranked Sri Lanka exported consistently across the three years. Exports from fourth-ranked Haiti decreased by nearly 50% between 2008 and 2011.

The US imported marine invertebrates from a total of 38 countries during the three years (Fig. 6, Table 2), although only 27 (2008, 2009) or 28 (2011) countries were noted per year. The volume (number of individuals) exported per year decreased 14% between 2008 and 2011, a rate similar to that of fish. The countries exporting the greatest volume over the three years were the Philippines (3.6 million invertebrates) and Haiti (3.1 million invertebrates). The number of individual invertebrates exported from the Philippines increased by 24% between 2008 and 2011. This was likely a response to the decrease in volume from Haiti (52% decline from 2008 to 2011, likely due to earthquake activity in 2010). Third-ranked Indonesia (1.8 million invertebrates) exported a consistent volume across the three years. Even though Indonesia was third in volume, it exported the most species (413) during the three years. The Philippines and Sri Lanka were second and third respectively in terms of the number of species exported to the US.

Species – More than half (52%) of the total fish imported into the US (identified to species, Table 3) were represented by 20 species. There was a great deal of consistency within these top 20 species between the years of this study. The species ranking was identical between 2008 and 2009, and only the 20th ranked fish was different in 2011 (the blueband goby, *Valenciennea strigata,* replaced the royal gramma, *Gramma loreto*). The order of the top seven fish species was consistent across the years, and represented nearly 33% of the total fish imports. The green chromis, *Chromis viridis*, was the most popular fish species across all three years (>10% of total fish imports) and was exported by 13-16 different countries, depending on the year. This *Chromis* species was unique in being collected from a large number of countries. The only other fish that was equally sourced from a large number of countries (an average of 15 per year) was the blue tang, *Paracanthurus hepatus*, (Table 3a, Fig 7), although Indonesia and the Philippines exported the majority of *P. hepatus*. Invertebrates demonstrated a similar but more extreme trend. The top 20 species of invertebrates imported into the US were responsible for approximately 75% of total imports (identified to species-level, Table 3b). Yet there was more variability in the invertebrate top 20 species list compared to the fish list. Only the top two species (the scarlet hermit crab, *Paguristes cadenati,* and the scarlet skunk cleaner shrimp, *Lysmata amboinensis*) were consistently ranked across the three years. Overall, 25 invertebrate species were represented on the three yearly top 20 lists (Table 3b).

Each country tended to export one species (fish / invertebrate) more than the remaining exporting countries. Overall, the single most imported species averaged 37% (fish) or 63% (invertebrates) of total species volume exported from that country (Table 4, Table 5). In general, countries that exported greater quantities of marine animals relied less on the contribution of the single most important species to export volume (Fig. 8). Regardless, the proportion of the single most important species is greater than what would be expected at random. At random, each species from a country that exports 10 species would represent 10% of that country's total exported volume. The countries in which a single species contributes to even 10% of species volume still export hundreds and even thousands (e.g., Philippines) of total species (Table 4, Table 5).

Comparison to LEMIS data – USFWS has only compiled marine ornamental trade data for non-CITES-listed species from the LEMIS database. LEMIS data is produced by US-based importers from shipment declarations, where importers input shipment data into the required 3-177 declaration form and present the completed shipment declaration with corresponding invoice to USFWS prior to shipment clearance. We have demonstrated elsewhere (Rhyne et al. 2012b) that this method of gathering import data is fraught with errors; first, importers commonly mislabel shipments as containing marine aquarium species when they only contain freshwater fish, non-marine species, or non-aquarium fish (all increasing the total number of fish reported in the LEMIS database); second, the data do not appear to be updated if shipments are canceled or modified (there is sometimes a significant mismatch between the number of individuals on the declaration and the corresponding values on the invoices); third, importers commonly misrepresent the country of origin and source (wild/captive bred) of species in shipments. As previously discussed (Rhyne et al. 2012), LEMIS is a tool designed for internal use by USFWS, primarily relating to volume of boxes arriving at ports and CITES compliance. Shipments of non-CITES-listed species and/or unregulated species are not held to any data integrity standards, so declaration forms and invoices need only represent the import/export companies and shipment details accurately. We propose that the invoice-based method of data collection presented here can rectify many of the data deficiency issues that currently exist within the marine ornamental trade. Through this work, it was observed that the number of fishes imported into the US was routinely 60-72% of the import volumes reported by the LEMIS database (Fig. 9). A large proportion of the declaration form overestimate was a result of importers misclassifying shipments as containing MATF when they only contained freshwater species. Occasionally, entire freshwater shipments were erroneously listed as MATF. A second unknown portion of this error was missing invoices. Not all invoices were recovered from the system. Several hundred records were either missing the invoice or exhibited invoice/declaration mismatch, making the data impossible to verify. Similarly, invoice-based data reported a total of 45 countries exporting MATF, which was only 60% of the 76 export countries reported by the LEMIS database (Table 6). These extraneous countries represented 5, 6, and 11% of the total volume of MATF imported into the US according to the LEMIS database during 2008, 2009, and 2011 respectively (Table 6). Third is that the declaration is typically completed day/s before the order is packed, and thus there will be variation between estimated and actual order volume. Finally, there was a lack of adherence to differentiating "wild caught" and "aquacultured" animals (Rhyne et al. 2012a). The case studies presented below use the invoice-based dataset to shed light on this discrepancy.

Estimated Fish- To back-calculate estimated total number of imported fishes (2000, 2004, and 2005) or invertebrates (2000), we first determined the proportion of individuals imported during the time interval (one month for 2000, seven months for 2004, and five months for 2005) based on the three years for which we had a complete 12-month dataset (2008, 2009, and 2011). For these three years, there was variation between months, but the inter-month variation was less than that of the between-month variation (Fig 10, upper line graph) suggesting that monthly import volumes were proportionately consistent. This proportion was then used to calculate the number of individuals that should have been imported within that calendar year. As an example, in October of 2000, 810,705 fish and 124,308 invertebrates were imported. During the years 2008, 2009 and 2011, October represented on average 8.7% and 8.6% of the yearly fish and invertebrate imports into the US. Thus, it can be estimated that 9,327,754 fish and 1,442,859 invertebrates were imported into the US during calendar year 2000. Following this example, 10,766,706 and 11,229,443 fish were imported into the US in 2004 and 2005 respectively (Fig. 10, lower bar graphs).

Confusion between "wild" and "aquaculture" production

- The Banggai cardinalfish, *Pterapogon kauderni*, is a popular marine fish in the aquarium trade (ranked the 10^{th}, 11^{th}, and 8^{th} most imported fish into the US during 2008, 2009, and 2011, Table 5). It was one of the original marine ornamental aquaculture success stories (Tlusty 2002), which was supposed to reduce the need for wild fish. However, all *P. kauderni* imported during this three-year span were reported as wild fish. Yet import data from Thailand (outside the natural geographic range of *P. kauderni*) suggest this is not the case (Fig. 11).

To determine if the volume of aquacultured *P. kauderni* imported into the US has increased in recent years, we reviewed invoice data from Los Angeles-based importer Quality Marine for two additional recent years of imports. At our request, all shipments of MATF from Thailand to Quality Marine (representing aquacultured fish over the period of March 2012 to July 2014) were supplied and reviewed. The export volume followed the typical aquarium trade pattern of lower volumes exported in the summer months (June-August) and in December (Fig. 12). Interestingly in 2013, the only year with a 12-month data set starting in January and ending in December, the volume of *P. kauderni* (~120,000 individuals/year) was approximately 75% of the average total import volume of this species recorded per year for 2008, 2009 or 2011. Given the life history of the species (small brood sizes), the commercial producer of these fish has made significant investments in the culture of the species. The number of broodstock and space dedicated to this species' production is likely large and highly commercialized.

Further, these fish were listed on import declarations ranging in size from 1-1.5 inches. A 1-inch fish is smaller than the average wild-caught fish (personal observation), and instead represents the typical size of an aquacultured shipment. Shipment manifests also list the number of Dead On Arrival (DOA) from previous shipments and are extremely low. A DOA rate of <0.5% is rare for wild caught fish and, again, represents DOA values consistent with a shipment of aquacultured fish.

The shipment manifests have common errors that can be observed on the 3-177 USFWS declarations. On several occasions the importer incorrectly indicated that shipments were wild animals ("W"). After examining the invoices and associated documents, (i.e., health certificates, and certification of aquaculture) we determined that all shipments of *P. kauderni* from Thailand to Quality Marine during the period examined were captive-bred ("C"), and the importer mistakenly selected "W" in the Source box (Box 18B, 3-177 form). Given the current proposed Endangered Species Act (ESA) listing for P. *kauderni*, accurate and timely trade data are essential to the management of this species.

– ***The orange clownfish*** Similar to the Banggai cardinalfish, clownfishes exported from Southeast Asia are commonly labeled as wild while many are in fact captive-bred. This inaccuracy is compounded by the misidentification of clownfishes on export invoices, especially between species with similar morphological appearances (e.g., *Amphiprion ocellaris* and *A. percula*). The Marine Aquarium Biodiversity and Trade Flow online database not only sheds light on source-errors (as seen in the Banggai cardinalfish case study) but also on potential species misidentifications.

Recently, the orange clownfish (*Amphiprion percula*) was proposed to be listed as threatened or endangered under the ESA, mainly due to its small geographic distribution and obligate relationship with giant sea anemones prone to bleaching events in the Coral Triangle. However, the proposition was also based on the assumption that out of the 400,000 individuals from the *percula/ocellaris* complex imported into the US in 2005 (Rhyne et al. 2012b), (a) all specimens were wild caught, and (b) *A. percula* and *A. ocellaris* were equally traded, with 200,000 individuals of each species being harvested. Utilization of The Marine Aquarium Biodiversity and Trade Flow online database removes the need for these assumptions. While in 2008, 2009 and 2011 831,398 individual clownfishes of the *percula/ocellaris* complex were imported into the US (Fig 13), only 163,547 individuals were *A. percula* (24.5%). These data suggest that the original assumptions of trade volume used to petition for ESA listing were strongly overestimated.

Further, the Countries of Origin feature of the database revealed that of the ten export countries of *A. percula*, seven countries (41% of all individuals) fall outside the natural geographic range of this species (Fautin and Allen 1997; Froese and Pauly 2015) (Table 7). Furthermore, five of the seven non-native locations are established producers of aquacultured *A. percula*. Based on this, 7% of the non-native individuals are likely aquacultured specimens. The remaining two non-native countries (Singapore and the Philippines) account for the residual 93% of the non-native individuals and are likely misidentifications. Interestingly, both Singapore and the Philippines fall within the natural geographic range of *A. ocellaris*, which is commonly confused with *A. percula*. While these individuals may be misidentified, it is also important to note that Singapore is a known trans-shipping country, and could have imported their specimens from another country, making the true origin of these specimens unattainable. Furthermore, Singapore is a leader in aquaculture production of ornamental fish, and thus many clownfish could be of aquaculture origin.

In summary, 41% of *A. percula* imported into the US over the three-year span (a) were misidentified as to species or export country, (b) were misidentified as to source (wild versus aquaculture production), or (c) represent a recently expanded home range not yet noted within the scientific literature. Regardless of the reason, the contribution of *A. percula* imports to the *percula*/*ocellaris* complex is not only substantially less than assumed, it is likely even lower based on the high percent of geographic anomalies reported here. Ultimately, this case study confirms the need for more accurate and detailed trade data, such as that provided via The Marine Aquarium Biodiversity and Trade Flow Database, for any potential ESA listing activity.

Discussion

The deficiency of meaningful data relating to the global marine aquarium trade hinders progress toward its effective management (Foster et al. 2014; Fujita et al. 2013; Rhyne et al. 2012b). Access to meaningful data will allow for immediate feedback regarding trade activity, which will increase public engagement in trade sustainability and guide responsible trade management. Currently, there is no system for tracking species-level import/export data for the marine aquarium trade. This is exacerbated by the lack of standard recordkeeping between different countries (Green 2003). Coupled to this is the fact that present data systems are either overly general, based on declaration forms (LEMIS), or specific to the trade of rare and threatened species (CITES, Foster et al. 2014). The Global Marine Aquarium Database (Green 2003) has attempted to make sense of some of these discrepancies, but can be difficult to use based on its data structures and relational databases. These complications and data limitations make misinterpretation possible, as has occurred where trade volumes have been erroneously reported as under- or overestimates. Without changes to the current data system used to assess trade pathways, data inaccuracies and misinterpretations could have potentially costly consequences (e.g., use of such data to affect ESA listing status) of social, economic, and ecological proportions. These costs will only be exacerbated as the aquarium industry continues to grow.

For these reasons, we created a publically accessible, anonymized web portal for invoice-based trade data of ornamental marine animal imports into the US. This portal was linked to an invoice-based assessment of the import trade to the US over four years. Capturing invoice-based data can waylay many of the deficiencies of the extant databases. These data should prove useful to both conservation organizations and government agencies by overcoming the aquarium trade data deficiency that currently exists. The benefit of the more detailed invoice data we focused on here is that it allowed for a truer estimate of aquatic wildlife trade. There have been recent ESA petitions for both the Banggai cardinalfish (NOAA 2014) and the orange clownfish, with some of the assumptions in the ESA petition being based on incorrect trade data. In each of these cases, we demonstrated that increased knowledge of production areas and modalities do not support the base assumptions of the ESA petition.

The assumptions of the ESA listing were erroneous in part because of inaccurate reporting of the source (wild, captive-bred, farmed) of shipped animals. For example, exporters will often mark farmed corals as wild corals, even when, ironically, they have proper CITES permits for the export of farmed corals (Rhyne et al. 2014). Many exporters do not have the proper paperwork or government support needed to accurately mark corals as captive-bred or farmed on CITES documents, often because of the onerous process required to certify that corals are of a farmed origin. Consequently, importers must report shipments as wild, regardless of true source. While improved analysis of invoices will help limit some of this misreporting, it will not be totally unabated until a full fishery/farm to retail traceability program is initiated.

Development of the Marine Aquarium Biodiversity and Trade Flow online database (https://www.aquariumtradedata.org/) is a first step toward improving the data, which will allow for better management and oversight of the trade in marine aquatic animals. However, the invoice analysis was necessarily developed from a post-import standpoint. The shipments were accepted at import, the paperwork processed, and the invoices stored, only to be recovered from storage and delivered for analysis within this program. However, the OCR data processing has the potential to be utilized in real time. This would allow for shipment diagnostics to be conducted, which could potentially identify misidentified or even illegal shipments. Such an import risk-based screen tool exists under the FDA's Predictive Risk-based Evaluation for Dynamic Import Compliance Targeting program (http://www.fda.gov/ForIndustry/ImportProgram/ucm172743.htm), and we propose that a similar model would be effective for the wildlife trade. Ultimately, such an analysis would provide support to port agents to help them more effectively monitor and police the aquatic trade.

While it was not implicitly necessary to estimate the number of individuals imported for years of incomplete data (2000, 2004 and 2005), we felt it important given the graphical nature of the presentation of the Marine Aquarium Biodiversity and Trade Flow online database. A common query without the estimated number of fish would result in a figure where the total number of indivudals in 2000 was 8% while 2004 and 2005 data would be approximately half that of 2008, 2009 and 2011. Therefore, the estimated fish numbers were created to create a more cohesive visual presentation of data, and to avoid the incorrect analysis that numbers of US imports of marine ornamental fish and invertebrates are increasing. The trade has decreased from its peak in 2005 following the economic recession and a shift to smaller tank sizes (Rhyne and Tlusty 2012; Rhyne et al. 2012a).

In summary, wildlife data tracking systems require improvement (Chan et al. 2015; Foster et al. 2014); we are beyond the age of tracking animal shipment volume solely for the purpose of assessing port agent staffing needs. The systems currently in place have proven ineffective in producing meaningful data that can move the aquarium trade toward sustainability and conservation (Vincent et al. 2014). The invoice-based dataset presented here, while set up as a post-import assessment tool, has the strong potential to be easily modified into a real-time aquarium trade data monitoring system. The ability to monitor (Wallace et al. 2014) aquarium trade pathways real-time is the crucial next step to effectively manage the trade of marine ornamental wildlife for the home aquairum industry.

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Table 1. Countries that ship fish into the United States over 3 years (2008, 2009, and 2011). Data include the number of species identified correctly, the number of individuals imported (Quantity, total #), the % individuals known identified to the species level, and the number of species that over 1,000 individuals are caught per time period.

	2008				2009				2011				2008-2011			
Export Country	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000
Australia	115	12,877	100.0	3	162	8,773	100.0	2	199	9,573	99.6	1	298	31,224	99.9	6
Belize	49	9,472	99.9	4	45	8,846	99.4	3	39	14,976	99.6	4	63	33,351	99.6	6
Brazil	71	8,742	99.4	3	61	3,349	98.5	0	45	2,005	99.5	0	87	14,147	99.2	2
Canada	2	52	100.0	0	2	3	100.0	0	1	26	42.3	0	5	81	81.5	0
Cook Islands	23	4,763	100.0	2	27	3,317	100.0	2					34	8,080	100.0	2
Costa Rica	22	7,903	100.0	2	46	3,538	100.0	0	28	6,139	88.1	2	53	17,580	95.8	4
Curaçao	15	529	100.0	0	26	1,383	100.0	0	34	3,367	99.7	1	47	5,279	99.8	1
Dominican Republic	26	22,121	86.3	3	19	28,944	77.2	4	48	34,272	96.7	8	52	93,872	86.5	8
Egypt									20	953	92.1	0	20	953	92.1	0
Eritrea	52	9,506	99.6	2	44	3,986	99.3	0					62	13,519	99.5	2
Fed States of Micronesia									131	5,550	97.4	0	131	5,550	97.4	0
Fiji	187	115,520	98.9	28	228	88,289	97.8	19	311	156,680	97.6	25	363	362,444	98.1	44
French Polynesia (Tahit	106	42,846	99.9	6	101	30,187	99.5	3	73	29,011	99.0	3	144	102,182	99.5	7
Ghana	19	509	99.8	0	19	686	96.1	0	22	708	95.5	0	33	1,931	96.8	0
Guatemala	3	1,055	100.0	0	3	343	100.0	0					3	1,398	100.0	0
Haiti	99	240,552	97.7	23	114	215,909	97.6	23	89	126,799	99.0	19	133	588,516	97.9	30
Hong Kong	9	262	99.2	0	4	5	100.0	0	1	16,510	0.3	0	14	16,777	1.9	0
Indonesia	973	2,402,733	97.2	214	1,009	1,998,195	96.9	186	992	1,867,946	97.3	181	1,284	6,331,781	97.2	234
Israel					7	666	100.0	0	10	21,985	100.0	2	10	22,651	100.0	0
Japan	44	1,133	100.0	0	92	1,137	100.0	0	62	569	92.4	0	132	2,839	98.5	0
Kenya	173	144,211	97.7	27	210	139,129	97.8	24	186	101,910	99.0	21	249	388,376	98.1	39
Kiribati	67	122,971	99.1	6	52	78,812	98.2	7	72	105,679	97.6	6	103	308,889	98.4	8
Malaysia	11	622	99.8	0					1	13	100.0	0	12	635	99.8	0
Mauritius	63	823	93.4	0					41	680	98.2	0	81	1,503	95.6	0
Mexico	90	5,174	99.4	1	40	12,688	96.2	2	62	15,135	98.6	3	118	33,504	97.8	5
Netherlands Antilles	9	319	100.0	0									9	319	100.0	0
New Caledonia	2	84	100.0	0	2	75	100.0	0	17	387	99.7	0	17	546	99.8	0
Nicaragua	72	8,986	98.0	2					31	1,847	93.2	0	83	10,833	97.2	1
Papua New Guinea	132	6,816	99.8	2	111	8,313	98.6	2					176	15,243	99.1	2
Philippines	980	4,694,961	97.5	255	1,053	4,024,693	97.3	248	1,016	3,901,058	97.3	258	1,320	12,732,212	97.4	315
Rep of Maldives	141	24,574	96.4	5	109	22,093	98.9	4	67	34,360	100.0	11	174	81,275	98.6	19
Rep of the Marshall Isl	96	37,972	94.0	6	138	115,686	75.1	9	139	142,068	78.7	13	227	334,174	78.8	19
Saudi Arabia	16	326	100.0	0	4	19	100.0	0					20	345	100.0	0
Singapore	36	2,606	100.0	1	14	2,520	99.8	1	42	13,949	99.5	4	71	19,081	99.6	3
Solomon Islands	134	47,262	96.5	8	133	34,773	94.9	6	138	41,673	92.5	10	180	125,588	94.7	15
Sri Lanka	419	202,632	98.0	30	468	217,116	97.1	34	461	212,407	96.7	28	633	638,606	97.2	57
Taiwan	33	1,511	98.1	0	29	897	85.3	0	26	2,444	100.0	1	63	5,007	96.3	0
Thailand	10	39,887	100.0	3	3	8,310	100.0	1					10	48,197	100.0	0
The Bahamas	85	951	100.0	0	45	432	99.8	0	8	297	100.0	0	98	1,681	99.9	0
Tonga	207	27,857	89.5	6	92	8,047	92.3	2	82	2,676	91.0	0	227	39,253	90.2	8
United Arab Emirates									7	77	85.7	0	7	77	85.7	0
United Kingdom	32	3,710	98.6	1									32	3,710	98.6	0
Vanuatu	190	19,704	97.2	3	123	12,671	96.8	1	183	14,405	94.1	0	240	47,195	96.2	11
Vietnam	146	14,593	99.8	1	112	6,545	99.1	1	102	4,826	99.5	0	183	26,022	99.6	6
Yemen	10	10,340	100.0	3	14	11,871	100.0	3					16	22,211	100.0	3
Total	1,788	8,299,467	97.4	443	1,780	7,102,246	96.7	411	1,798	6,892,960	96.7	413	2,278	22,538,637	97.0	518

Table 2. Countries that ship invertebrates into the United States over 3 years (2008, 2009, and 2011). Data include the number of species identified correctly, the number of individuals imported (Quantity, total #), the % individuals known identified to the species level, and the number of species that over 1,000 individuals are caught per time period.

	2008				2009				2011				2008-2011			
	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000	Species (# known)	Quantity (total #)	Quantity (% known)	Species > 1,000
Australia	3	231	37.2	0	16	1,881	99.8	0	34	1,020	90.6	0	43	3,132	92.2	1
Belize	8	49,515	56.1	2	7	83,922	57.3	3	12	292,176	58.2	6	17	425,613	57.8	7
Brazil						1	0.0							1	0.0	
Canada	1	2	100.0	0						28	0.0		1	30	6.7	0
China	3	1,260	100.0	0									3	1,260	100.0	0
Costa Rica					3	64	100.0	0					3	64	100.0	0
Curaçao					1	15	100.0	0	4	911	89.1	0	5	926	89.3	0
Dominican Republic	6	93,781	99.9	2	5	133,056	100.0	2	18	107,103	96.3	4	19	333,940	98.8	4
Federated States of Micronesia										1	0.0			1	0.0	
Fiji	6	52,228	15.4	2	9	25,502	20.5	1	23	28,462	22.4	3	29	106,192	18.5	4
French Polynesia (Tahiti)		766	0.0		3	48	47.9	0					3	814	2.8	0
Ghana	3	2,395	12.2	0	3	135	100.0	0	3	768	53.5	0	5	3,298	25.4	0
Guatemala		3,000	0.0											3,000	0.0	
Haiti	55	1,409,841	92.5	24	63	1,011,683	93.3	24	47	676,134	94.4	26	79	3,097,658	93.2	34
Hong Kong	1	1,520	100.0	1					1	23,255	100.0	1	1	24,775	100.0	1
Indonesia	323	709,736	61.2	57	317	610,264	64.9	51	301	575,657	68.6	48	413	1,895,657	64.6	90
Japan	8	425	76.5	0	17	556	64.0	0	12	168	91.1	0	25	1,149	72.6	0
Kenya	18	13,955	57.0	2	17	44,426	26.1	2	22	14,750	53.7	1	30	73,131	37.6	6
Kiribati		6	0.0			18	0.0		1	80	15.0	0	1	104	11.5	0
Mauritius	1	198	100.0	0									1	198	100.0	0
Mexico	24	1,429	99.4	1	8	4,035	97.6	2	17	17,678	53.3	2	38	23,142	63.9	5
New Caledonia										4	0.0			4	0.0	
Nicaragua	30	58,918	83.8	8					19	31,052	74.5	3	41	89,970	80.6	11
Papua New Guinea	23	2,323	90.5	0	21	6,336	83.9	2					34	8,659	85.6	3
Philippines	259	1,111,002	71.5	65	294	1,154,255	65.6	67	284	1,380,014	68.2	75	395	3,645,271	68.4	118
Republic of Maldives	3	95	21.1	0	2	686	2.6	0		890	0.0		4	1,671	2.3	0
Republic of the Marshall Islands	3	47,362	100.0	2	7	200,088	42.1	5	24	39,588	68.8	3	29	287,038	55.4	6
Saudi Arabia						5	0.0							5	0.0	
Singapore	15	2,654	45.9	0	11	2,063	64.7	0	11	7,017	56.7	1	21	11,734	55.7	2
Solomon Islands	17	12,521	51.4	2	10	4,084	67.4	1	8	16,753	43.7	2	21	33,358	49.5	3
Sri Lanka	63	251,373	90.2	11	60	309,053	91.9	9	54	261,004	88.1	11	87	821,430	90.2	17
Thailand	1	250	100.0	0									1	250	100.0	0
The Bahamas	9	92	97.8	0	6	28	78.6	0					13	120	93.3	0
Tonga	18	135,089	65.6	3	8	31,214	61.0	2	8	81,918	52.6	1	23	248,221	60.7	3
United Arab Emirates										2	0.0			2	0.0	
United Kingdom									2	4	100.0	0	2	4	100.0	0
Vanuatu	8	672	99.9	0	4	96	97.9	0	5	132	79.5	0	11	900	96.7	0
Vietnam	25	293,733	8.1	6	23	108,699	27.2	5	24	106,411	12.2	4	38	508,843	13.1	8
Grand Total	545	4,256,372	73.4	137	537	3,732,213	73.1	126	535	3,662,980	72.2	138	724	11,651,565	72.9	220

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Table 3. The top 20 fish (A) and Invertebrates (B) imported into the US during 2008, 2009, and 2011.

A. Fish

	2008			2009			2011		
Rank	Species	% Total	# Countries	Species	% Total	# Countries	Species	% Total	# Countries
1	*Chromis viridis*	10.2%	13	*Chromis viridis*	10.5%	16	*Chromis viridis*	11.6%	13
2	*Chrysiptera cyanea*	5.6%	8	*Chrysiptera cyanea*	5.0%	8	*Chrysiptera parasema*	4.7%	6
3	*Dascyllus trimaculatus*	5.0%	11	*Dascyllus trimaculatus*	4.4%	12	*Chrysiptera cyanea*	4.4%	7
4	*Dascyllus aruanus*	3.7%	9	*Chrysiptera parasema*	3.6%	4	*Dascyllus trimaculatus*	3.7%	10
5	*Chrysiptera parasema*	3.5%	3	*Dascyllus aruanus*	3.3%	9	*Dascyllus aruanus*	3.6%	8
6	*Amphiprion ocellaris*	3.2%	10	*Amphiprion ocellaris*	3.0%	10	*Nemateleotris magnifica*	3.0%	8
7	*Nemateleotris magnifica*	2.7%	12	*Nemateleotris magnifica*	2.4%	12	*Amphiprion ocellaris*	3.0%	10
8	*Chrysiptera hemicyanea*	2.6%	2	*Chrysiptera hemicyanea*	2.4%	3	*Pterapogon kauderni*	1.9%	5
9	*Dascyllus melanurus*	1.8%	3	*Dascyllus melanurus*	2.0%	6	*Centropyge loricula*	1.9%	9
10	*Pterapogon kauderni*	1.8%	3	*Paracanthurus hepatus*	1.7%	14	*Pseudocheilinus hexataenia*	1.6%	9
11	*Pseudocheilinus hexataenia*	1.4%	13	*Pterapogon kauderni*	1.7%	4	*Dascyllus melanurus*	1.6%	3
12	*Paracanthurus hepatus*	1.3%	16	*Centropyge loricula*	1.6%	7	*Sphaeramia nematoptera*	1.5%	7
13	*Synchiropus splendidus*	1.3%	3	*Pseudocheilinus hexataenia*	1.6%	12	*Chrysiptera hemicyanea*	1.5%	3
14	*Centropyge loricula*	1.3%	8	*Valenciennea puellaris*	1.4%	10	*Synchiropus splendidus*	1.5%	5
15	*Labroides dimidiatus*	1.3%	13	*Synchiropus splendidus*	1.4%	5	*Valenciennea puellaris*	1.4%	7
16	*Salarias fasciatus*	1.3%	8	*Gramma loreto*	1.3%	6	*Paracanthurus hepatus*	1.3%	15
17	*Gramma loreto*	1.2%	6	*Salarias fasciatus*	1.3%	10	*Salarias fasciatus*	1.2%	11
18	*Valenciennea puellaris*	1.1%	9	*Sphaeramia nematoptera*	1.3%	6	*Centropyge bispinosa*	1.2%	14
19	*Centropyge bispinosa*	1.1%	12	*Labroides dimidiatus*	1.1%	13	*Labroides dimidiatus*	1.1%	11
20	*Sphaeramia nematoptera*	1.0%	7	*Centropyge bispinosa*	1.1%	12	*Valenciennea strigata*	0.9%	10

B. Invertebrates

	2008			2009			2011		
Rank	Species	% Total	# Countries	Species	% Total	# Countries	Species	% Total	# Countries
1	*Paguristes cadenati*	22.0%	3	*Paguristes cadenati*	20.9%	2	*Paguristes cadenati*	14.0%	4
2	*Lysmata amboinensis*	10.2%	6	*Lysmata amboinensis*	13.5%	8	*Lysmata amboinensis*	12.3%	8
3	*Clibanarius tricolor*	8.0%	1	*Clibanarius tricolor*	5.7%	2	*Mithraculus sculptus*	7.3%	3
4	*Mithraculus sculptus*	5.1%	3	*Mithraculus sculptus*	4.2%	2	*Trochus maculatus*	4.6%	3
5	*Stenopus hispidus*	2.9%	11	*Lysmata debelius*	3.0%	5	*Condylactis gigantea*	3.3%	4
6	*Trochus maculatus*	2.7%	1	*Calcinus elegans*	2.8%	4	*Clibanarius tricolor*	2.7%	2
7	*Nassarius venustus*	2.6%	1	*Trochus maculatus*	2.8%	2	*Stenopus hispidus*	2.6%	10
8	*Tectus fenestratus*	2.5%	2	*Stenopus hispidus*	2.7%	12	*Lysmata debelius*	2.5%	3
9	*Dardanus megistos*	2.4%	5	*Tectus fenestratus*	2.5%	3	*Entacmaea quadricolor*	2.4%	12
10	*Percnon gibbesi*	2.3%	5	*Tectus pyramis*	2.4%	4	*Dardanus megistos*	2.4%	6
11	*Tectus pyramis*	2.1%	2	*Percnon gibbesi*	2.3%	3	*Protoreaster nodosus*	2.3%	5
12	*Lysmata ankeri*	2.0%	1	*Condylactis gigantea*	2.1%	5	*Nassarius dorsatus*	2.2%	1
13	*Lysmata debelius*	2.0%	5	*Sabellastarte spectabilis*	1.7%	5	*Percnon gibbesi*	1.8%	5
14	*Condylactis gigantea*	1.9%	5	*Heteractis malu*	1.5%	6	*Nassarius venustus*	1.6%	1
15	*Sabellastarte spectabilis*	1.8%	4	*Lysmata ankeri*	1.5%	1	*Sabellastarte spectabilis*	1.6%	4
16	*Heteractis malu*	1.4%	6	*Protoreaster nodosus*	1.3%	4	*Nassarius distortus*	1.6%	1
17	*Calcinus elegans*	1.3%	3	*Engina mendicaria*	1.2%	2	*Heteractis malu*	1.5%	4
18	*Archaster typicus*	1.3%	6	*Entacmaea quadricolor*	1.1%	12	*Lysmata ankeri*	1.5%	1
19	*Engina mendicaria*	1.2%	2	*Nassarius distortus*	1.1%	1	*Pusiostoma mendicaria*	1.4%	2
20	*Stenorhynchus seticornis*	1.1%	5	*Archaster typicus*	1.1%	4	*Archaster typicus*	1.4%	6

Table 4. The most commonly imported fish species for each export country, and its overall contribution to the total number of known individuals (identified to a species level) for each of three years.

	2008		2009		2011	
Export Country	**1° Species**	**%**	**1° Species**	**%**	**1° Species**	**%**
Australia	Amphiprion ocellaris	42.3%	Choerodon fasciatus	14.7%	Choerodon fasciatus	16.9%
Belize	Gramma loreto	22.4%	Gramma loreto	27.0%	Holacanthus ciliaris	25.8%
Brazil	Holacanthus ciliaris	23.0%	Holacanthus ciliaris	28.6%	Holacanthus ciliaris	44.5%
Canada	Eumicrotremus orbis	76.9%	Rhinoptera jayakari	66.7%	Eptatretus stoutii	42.3%
Cook Islands	Pseudanthias ventralis	45.0%	Pseudanthias ventralis	46.0%		
Costa Rica	Thalassoma lucasanum	31.1%	Thalassoma lucasanum	28.0%	Elacatinus puncticulatus	28.1%
Curaçao	Elacatinus genie	28.0%	Liopropoma carmabi	18.6%	Gramma loreto	31.2%
Dominican Republic	Gramma loreto	59.8%	Gramma loreto	60.4%	Gramma loreto	36.0%
Egypt					Zebrasoma xanthurum	31.7%
Eritrea	Zebrasoma xanthurum	23.2%	Zebrasoma xanthurum	24.6%		
Federated States of Micronesia					Pseudanthias bartlettorum	12.3%
Fiji	Pseudanthias squamipinnis	9.6%	Pseudanthias squamipinnis	12.2%	Chromis viridis	20.3%
French Polynesia (Tahiti)	Neocirrhites armatus	43.9%	Neocirrhites armatus	64.6%	Neocirrhites armatus	68.0%
Ghana	Balistes punctatus	20.2%	Balistes punctatus	36.3%	Holacanthus africanus	41.4%
Guatemala	Selene brevoortii	58.8%	Selene brevoortii	64.7%		
Haiti	Gramma loreto	33.8%	Gramma loreto	31.2%	Gramma loreto	32.9%
Hong Kong	Zebrasoma flavescens	76.3%	Dascyllus trimaculatus	40.0%	Chordata	99.7%
Indonesia	Chromis viridis	10.5%	Chromis viridis	8.9%	Chromis viridis	10.8%
Israel			Premnas biaculeatus	34.7%	Amphiprion ocellaris	88.7%
Japan	Parapriacanthus ransonneti	66.2%	Parapriacanthus ransonneti	13.5%	Paracentropogon rubripinnis	14.2%
Kenya	Labroides dimidiatus	15.5%	Labroides dimidiatus	14.2%	Labroides dimidiatus	12.0%
Kiribati	Centropyge loricula	70.1%	Centropyge loricula	63.2%	Centropyge loricula	65.1%
Malaysia	Amphiprion ocellaris	35.7%			Paracanthurus hepatus	100.0%
Mauritius	Amphiprion chrysogaster	12.0%			Macropharyngodon bipartitus	13.2%
Mexico	Holacanthus passer	49.5%	Holacanthus passer	35.8%	Holacanthus passer	39.0%
Netherlands Antilles	Elacatinus genie	58.9%				
New Caledonia	Chaetodontoplus conspicillatus	84.5%	Chaetodontoplus conspicillatus	85.3%	Cirrhilabrus laboutei	40.3%
Nicaragua	Apogon retrosella	22.4%			Acanthemblemaria hancocki	39.5%
Papua New Guinea	Amphiprion percula	29.7%	Paracanthurus hepatus	23.4%		
Philippines	Chromis viridis	11.7%	Chromis viridis	13.3%	Chromis viridis	13.6%
Republic of Maldives	Acanthurus leucosternon	12.9%	Acanthurus leucosternon	12.7%	Acanthurus leucosternon	14.7%
Republic of the Marshall Islands	Centropyge loricula	53.7%	Centropyge loricula	41.9%	Centropyge loricula	40.1%
Saudi Arabia	Dascyllus marginatus	30.7%	Anampses caeruleopunctatus	36.8%		
Singapore	Amphiprion ocellaris	42.3%	Amphiprion ocellaris	73.0%	Amphiprion percula	31.6%
Solomon Islands	Paracanthurus hepatus	19.4%	Paracanthurus hepatus	33.7%	Paracanthurus hepatus	20.4%
Sri Lanka	Valenciennea puellaris	22.5%	Valenciennea puellaris	21.1%	Valenciennea puellaris	26.8%
Taiwan	Pomacanthus maculosus	24.8%	Pomacanthus maculosus	19.4%	Amphiprion ocellaris	55.2%
Thailand	Amphiprion ocellaris	87.8%	Amphiprion ocellaris	90.5%		
The Bahamas	Haemulon sciurus	17.5%	Chromis cyanea	11.5%	Haemulon flavolineatum	88.9%
Tonga	Centropyge bispinosa	14.8%	Centropyge bispinosa	12.7%	Meiacanthus atrodorsalis	9.6%
United Arab Emirates					Zebrasoma xanthurum	63.6%
United Kingdom	Amphiprion ocellaris	76.5%				
Vanuatu	Centropyge loricula	9.4%	Chrysiptera rollandi	12.8%	Chromis viridis	6.9%
Vietnam	Nemateleotris magnifica	8.3%	Nemateleotris magnifica	16.7%	Chaetodontoplus septentrionalis	12.3%
Yemen	Zebrasoma xanthurum	48.2%	Zebrasoma xanthurum	47.6%		
Grand Total	Chromis viridis	10.0%	Chromis viridis	10.2%	Chromis viridis	11.2%

Table 5. The most commonly imported invertebrate species for each export country, and its overall contribution to the total number of known individuals (identified to a species level) for each of three years.

	2008		2009		2011	
Export Country	**1° Species**	**%**	**1° Species**	**%**	**1° Species**	**%**
Australia	Pseudocolochirus violaceus	75.6%	Actinia tenebrosa	46.1%	Actinia tenebrosa	37.2%
Belize	Mithraculus sculptus	72.5%	Mithraculus sculptus	51.9%	Mithraculus sculptus	65.3%
Canada	Enteroctopus dofleini	100.0%				
China	Actinia equina	70.5%				
Costa Rica			Lysmata wurdemanni	78.1%		
Curaçao			Lysmata wurdemanni	100.0%	Paguristes cadenati	94.7%
Dominican Republic	Paguristes cadenati	92.2%	Paguristes cadenati	95.1%	Paguristes cadenati	88.0%
Fiji	Linckia laevigata	78.0%	Linckia laevigata	87.0%	Linckia laevigata	36.5%
French Polynesia (Tahiti)			Holothuria (Halodeima) atra	52.2%		
Ghana	Actinia tenebrosa	85.3%	Actinia equina	94.8%	Lysmata grabhami	99.5%
Haiti	Paguristes cadenati	46.3%	Paguristes cadenati	47.1%	Paguristes cadenati	43.6%
Hong Kong	Entacmaea quadricolor	100.0%			Entacmaea quadricolor	100.0%
Indonesia	Trochus maculatus	19.3%	Trochus maculatus	19.1%	Trochus maculatus	30.3%
Japan	Aurelia aurita	52.9%	Aurelia aurita	58.7%	Catostylus mosaicus	29.4%
Kenya	Lysmata amboinensis	56.0%	Lysmata amboinensis	69.0%	Lysmata amboinensis	48.9%
Kiribati					Panulirus versicolor	100.0%
Mauritius	Heteractis magnifica	100.0%				
Mexico	Pentaceraster cumingi	74.9%	Turbo fluctuosus	40.1%	Dardanus megistos	59.7%
Nicaragua	Turbo fluctuosus	49.2%			Coenobita clypeatus	52.3%
Papua New Guinea	Archaster typicus	45.7%	Archaster typicus	36.5%		
Philippines	Lysmata amboinensis	15.9%	Lysmata amboinensis	18.8%	Lysmata amboinensis	16.3%
Republic of Maldives	Echinaster (Echinaster) sepositus	50.0%	Echinaster (Echinaster) seposit	83.3%	Pusiostoma mendicaria	45.9%
Republic of the Marshall Islands	Engina mendicaria	70.8%	Calcinus elegans	45.2%		
Singapore	Tectus niloticus	41.1%	Entacmaea quadricolor	34.7%	Sabellastarte spectabilis	54.0%
Solomon Islands	Archaster typicus	46.4%	Archaster typicus	65.8%	Archaster typicus	66.7%
Sri Lanka	Lysmata amboinensis	61.9%	Lysmata amboinensis	63.7%	Lysmata amboinensis	60.7%
Thailand	Gecarcoidea natalis	100.0%				
The Bahamas	Ophiocoma alexandri	46.7%	Ancylomenes pedersoni	22.7%		
Tonga	Nassarius venustus	92.0%	Nassarius venustus	77.6%	Nassarius venustus	99.2%
United Kingdom					Chrysaora quinquecirrha	50.0%
Vanuatu	Linckia multifora	28.2%	Entacmaea quadricolor	56.4%	Entacmaea quadricolor	54.3%
Vietnam	Macrodactyla doreensis	34.1%	Macrodactyla doreensis	36.5%	Entacmaea quadricolor	40.1%
Grand Total	**Paguristes cadenati**	**22.1%**	**Paguristes cadenati**	**20.9%**	**Paguristes cadenati**	**14.3%**

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Table 6. Countries reported on LEMIS database to export fish to the U.S.. Shaded countries are those represented on the invoice-based assessment of fish imports to the US.

	2,008		2,009		2,011		2008-2011	
Country	LEMIS	**Invoice (%)**	LEMIS	**Invoice (%)**	LEMIS	**Invoice (%)**	**LEMIS**	**Invoice (%)**
Antarctica					49		49	
Australia	16,908	76.2	13,973	62.8	10,545	90.8	41,426	75.4
Barbados					82		82	
Belgium	266						266	
Belize	19,957	47.5	18,214	48.6	27,840	53.8	66,011	50.5
Brazil	61,247	14.3	15,342	21.8	3,179	63.1	79,768	17.7
Canada	53	98.1	119	2.5	56	46.4	228	35.5
Cayman Islands	14						14	
China	354,093		126,218		44,151		524,462	
Christmas Island					1,712		1,712	
Colombia	24,386				12,594		36,980	
Congo, The Democratic Republic of the			185				185	
Cook Islands	4,793	99.4	3,330	99.6			8,123	99.5
Costa Rica	38,904	20.3	15,770	22.4	6,220	98.7	60,894	28.9
Cuba	20						20	
Curacao		..		..	2,992	112.5	2,992	176.4
Czech Republic	1,154		428,022		80,500		509,676	
Dominican Republic	58,497	37.8	64,254	45.0	39,687	86.4	162,438	57.8
Ecuador			5,990				5,990	
Egypt					755	126.2	755	126.2
Eritrea	2,796	340.0	3,046	130.9			5,842	231.4
Fed States of Micronesia					5,515	100.6	5,515	100.6
Fiji	138,801	83.2	119,535	73.9	171,364	91.4	429,700	84.3
French Polynesia (Tahiti)	50,261	85.2	30,789	98.0	30,914	93.8	111,964	91.3
Ghana	1,119	45.5	982	69.9	808	87.6	2,909	66.4
Guatemala	7,755	13.6	343	100.0			8,098	17.3
Guinea	357						357	
Haiti	306,084	78.6	280,196	77.1	135,890	93.3	722,170	81.5
Hong Kong	205,408	0.1	25,806	0.0	141,888	11.6	373,102	4.5
India	5,374		4,932				10,306	
Indonesia	3,044,574	78.9	2,743,170	72.8	2,228,446	83.8	8,016,190	79.0
Israel	22		818	81.4	25,990	84.6	26,830	84.4
Japan	1,911	59.3	1,790	63.5	820	69.4	4,521	62.8
Kenya	175,607	82.1	178,715	77.8	123,248	82.7	477,570	81.3
Kiribati	143,615	85.6	93,586	84.2	118,164	89.4	355,365	86.9
Korea, Republic of					6		6	
Malaysia	6,516	9.5	11,937		15,255	0.1	33,708	1.9
Mauritania	184						184	
Mauritius	6,465	12.7			681	99.9	7,146	21.0
Mexico	5,147	100.5	15,805	80.3	22,331	67.8	43,283	77.4
Morocco	141						141	
Netherlands			87		175		262	
Netherlands Antilles	2,178	14.6	1,558		628		4,364	7.3
New Caledonia	317	26.5	86	87.2	617	62.7	1,020	53.5
New Zealand					1		1	
Nicaragua	15,647	57.4			2,120	87.1	17,767	61.0
Nigeria	4,005		4,249		9,446		17,700	
Norway	196		2,853		2,903		5,952	
Papua New Guinea	11,899	57.3	13,167	63.1			25,066	60.8
Peru	80,963		67,609		10,395		158,967	
Philippines	5,504,928	85.3	4,815,066	83.6	4,545,933	85.8	14,865,927	85.6
Rep of Maldives	27,215	90.3	23,572	93.7	37,423	91.8	88,210	92.1
Rep of the Marshall Isl	50,143	75.7	163,433	70.8	152,000	93.5	365,576	91.4
Saudi Arabia	7,304	4.5	2,131	0.9			9,435	3.7
Sierra Leone	244						244	
Singapore	310,090	0.8	279,794	0.9	325,715	4.3	915,599	2.1
Slovakia	119						119	
Solomon Islands	66,057	71.5	58,397	59.5	42,562	97.9	167,016	75.2
Sri Lanka	337,521	60.0	1,807,583	12.0	1,981,399	10.7	4,126,503	15.5
Suriname			214				214	
Taiwan	54,623	2.8	47,430	1.9	6,950	35.2	109,003	4.6
Tanzania, United Republic of	253						253	
Thailand	207,582	19.2	115,952	7.2	1,117,626		1,441,160	3.3
The Bahamas	1,557	61.1	1,524	28.3	1,397	21.3	4,478	37.5
Tonga	57,120	48.8	13,787	58.4	2,474	108.2	73,381	53.5
Trinidad and Tobago			107,805		46,360		154,165	
Tunisia	558						558	
Ukraine	93						93	
United Arab Emirates					79	97.5	79	97.5
United Kingdom	3,721	99.7	583		4		4,308	86.1
United States	828		87		45		960	
Vanuatu	22,850	86.2	15,538	81.5	15,924	90.5	54,312	86.9
Various States	31,771		13,369		23,350		68,490	
Vietnam	26,621	54.8	10,832	60.4	9,597	50.3	47,050	55.3
Yemen	20,230	51.1	13,114	90.5			33,344	66.6
Zambia			1,286				1,286	
TOTAL	**11,529,062**	**72.0**	**11,783,973**	**60.3**	**11,586,805**	**59.5**	**34,899,840**	**64.6**
Σ countries w/o invoice data	505,041		776,984		1,350,027		1,499,694	

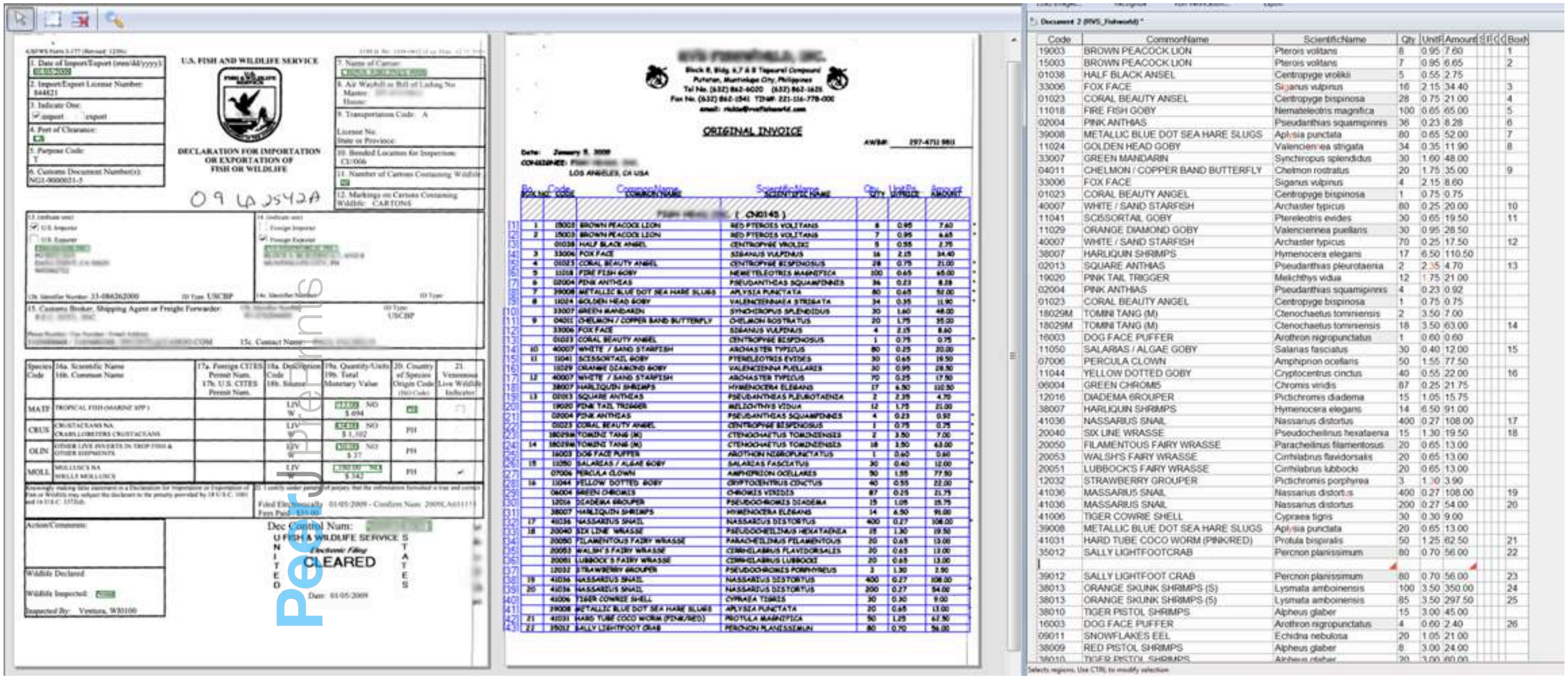

Figure 1. The FlexiCapture 9.0 verification screen for the capture of invoice data to incorporate into the Marine Aquarium Trade Database. Left) Declaration, Center) image of invoice, Right) invoice table from OCR results. Note: brown shaded areas indicate autocorrected fields, red flags indicate errors for user to correct.

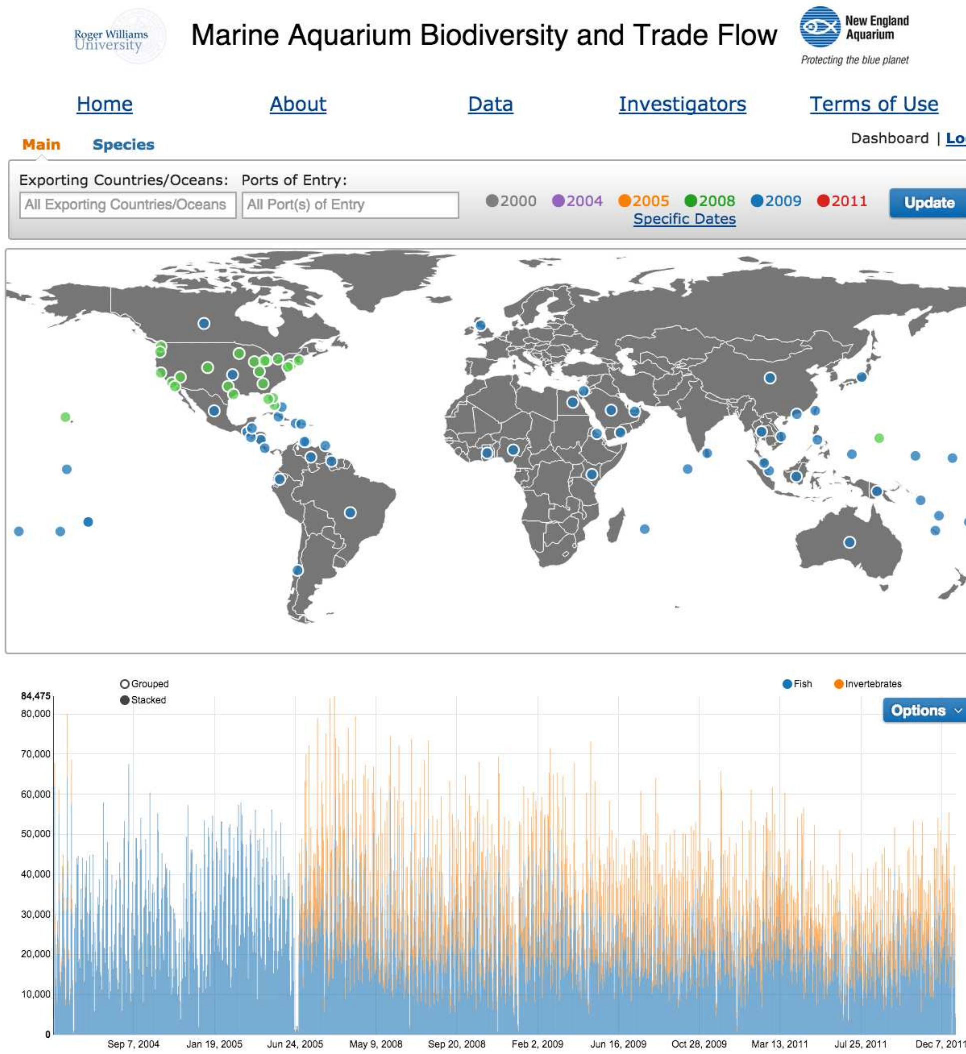

Figure 2. Country level dashboard page of the web portal, aquariumtradedata.org. Top) Trade flow map showing nodes of exporting nations and ports of entry in the U.S. Bottom) Timeline chart of US fish and invertebrate imports based on user selected dates.

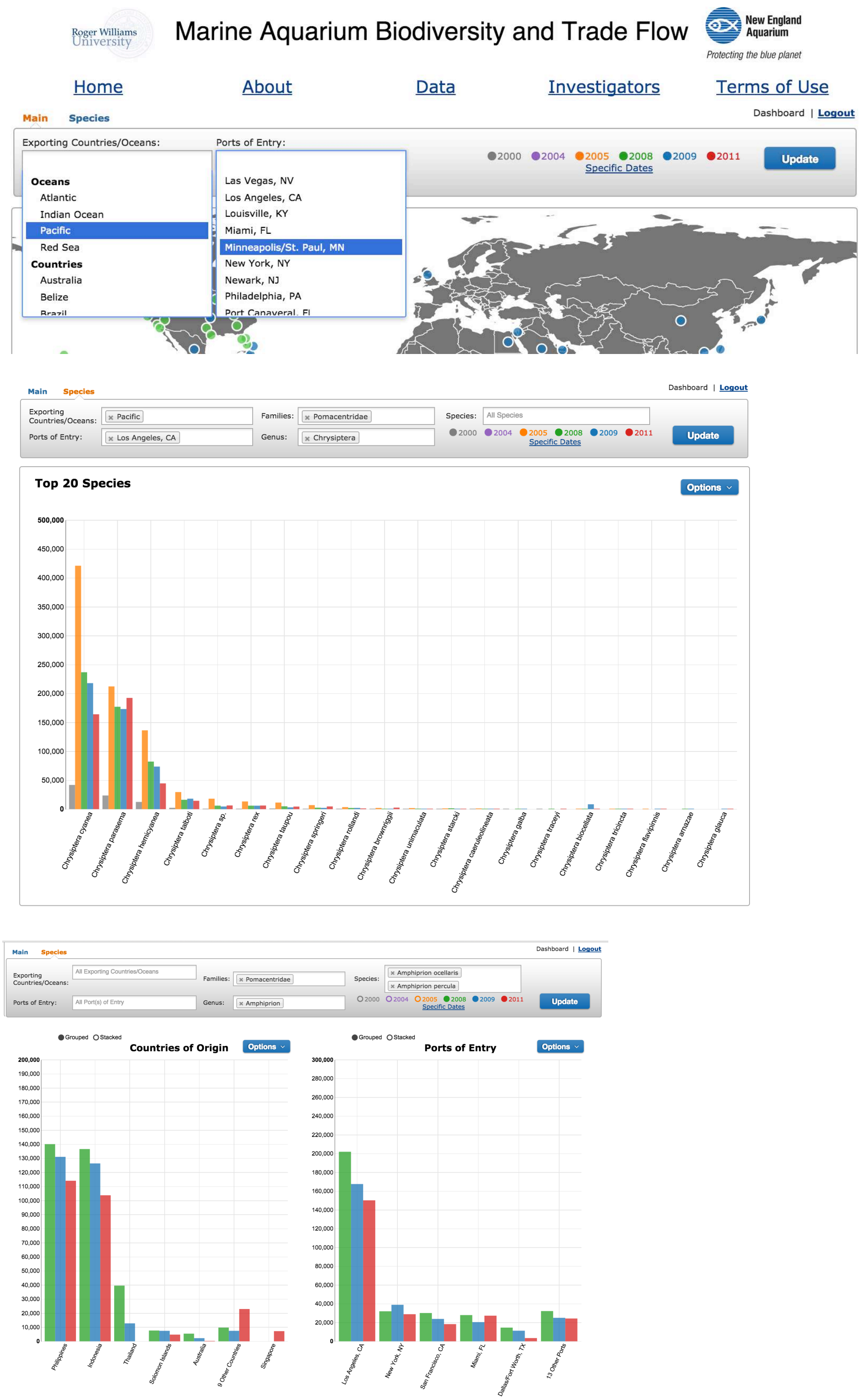

Figure 3. Drop down menu for user-generated queries. Top) Countries/Ocean with Ports of Entry. Users can select any combination of Oceans, Countries, and Ports of Entry. Middle) Demonstration of the Taxa selectors with top 20 species chart. Bottom) Countries of Origin and Ports of Entry for the species selected.

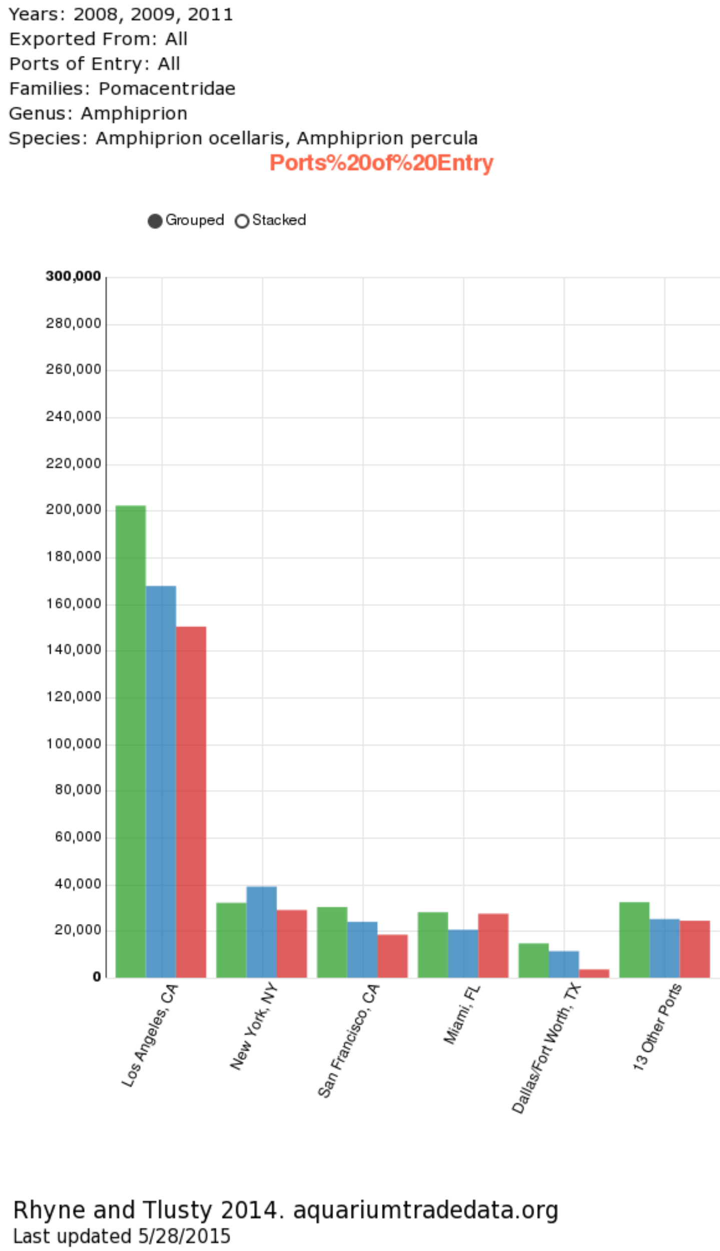

Figure 4. Exported chart from user-generated query. Header automatically includes user generated query that generated the image. Footer automatically includes attributes of the data as well as provides user with information about when the data was lasted updated.

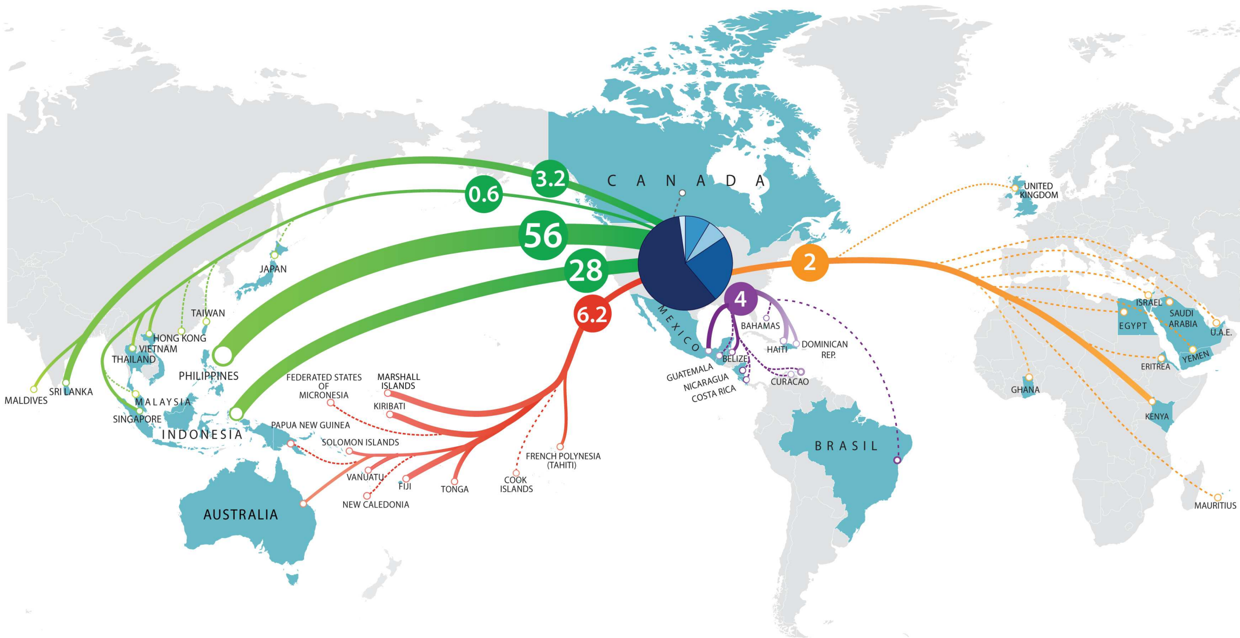

Figure 5. Trade flow of marine aquarium fishes from source nations to United States over 2008, 2009 and 2011. Numbers on lines indicates percent of trade. Pie chart in United States represents Ports of Entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW).

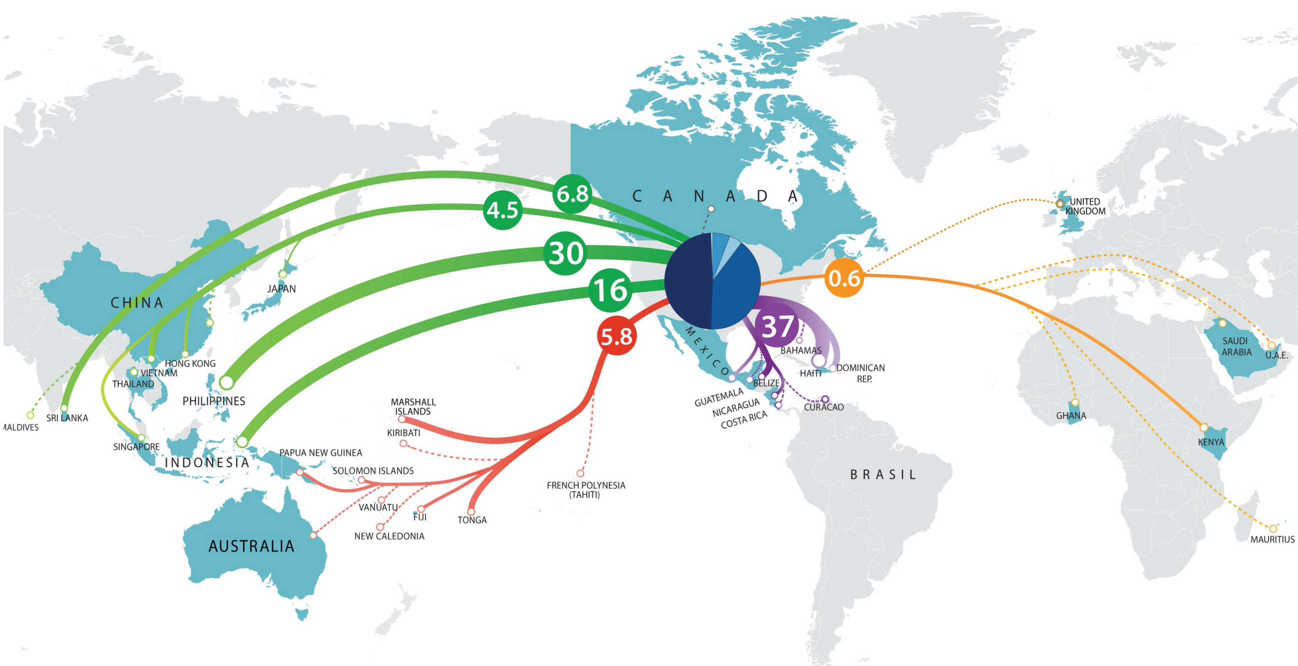

Figure 6. Trade flow of marine aquarium invertebrates from source nations to United States for 2008, 2009 and 2011. Numbers on lines indicate percent of trade. Pie chart in United States represents Ports of Entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW).

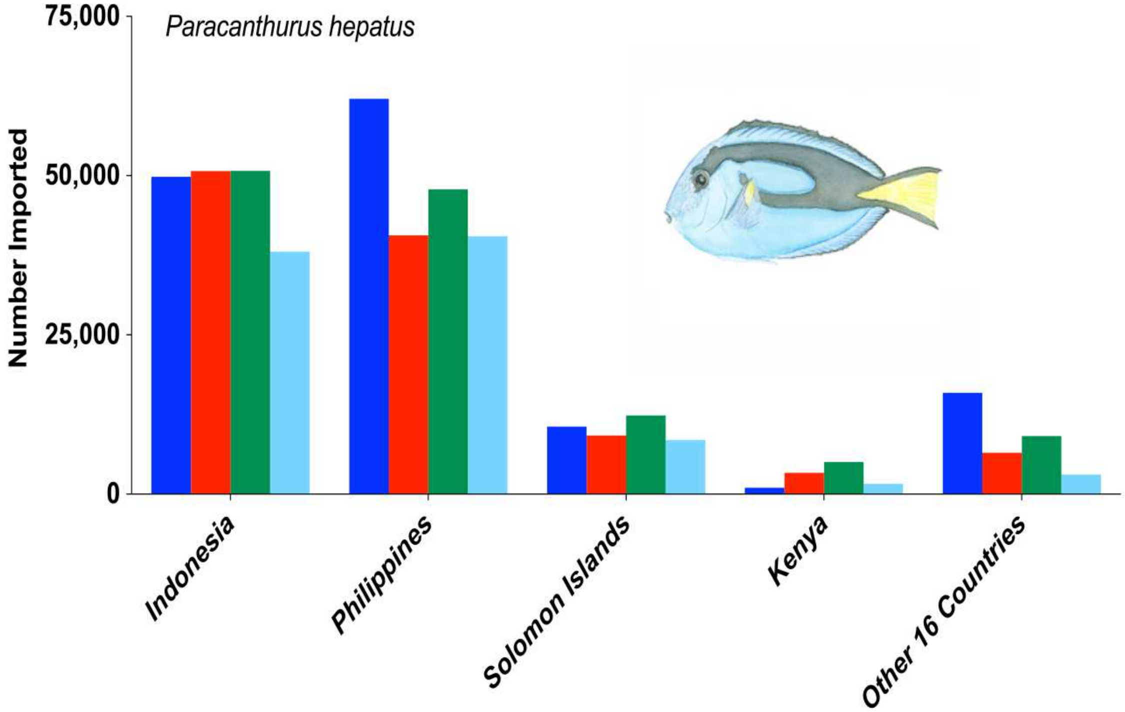

Figure 7. Top countries that exported *Paracanthurus hepatus* to the United States in 2005, 2008, 2009, and 2011. Artwork by Karen Talbot.

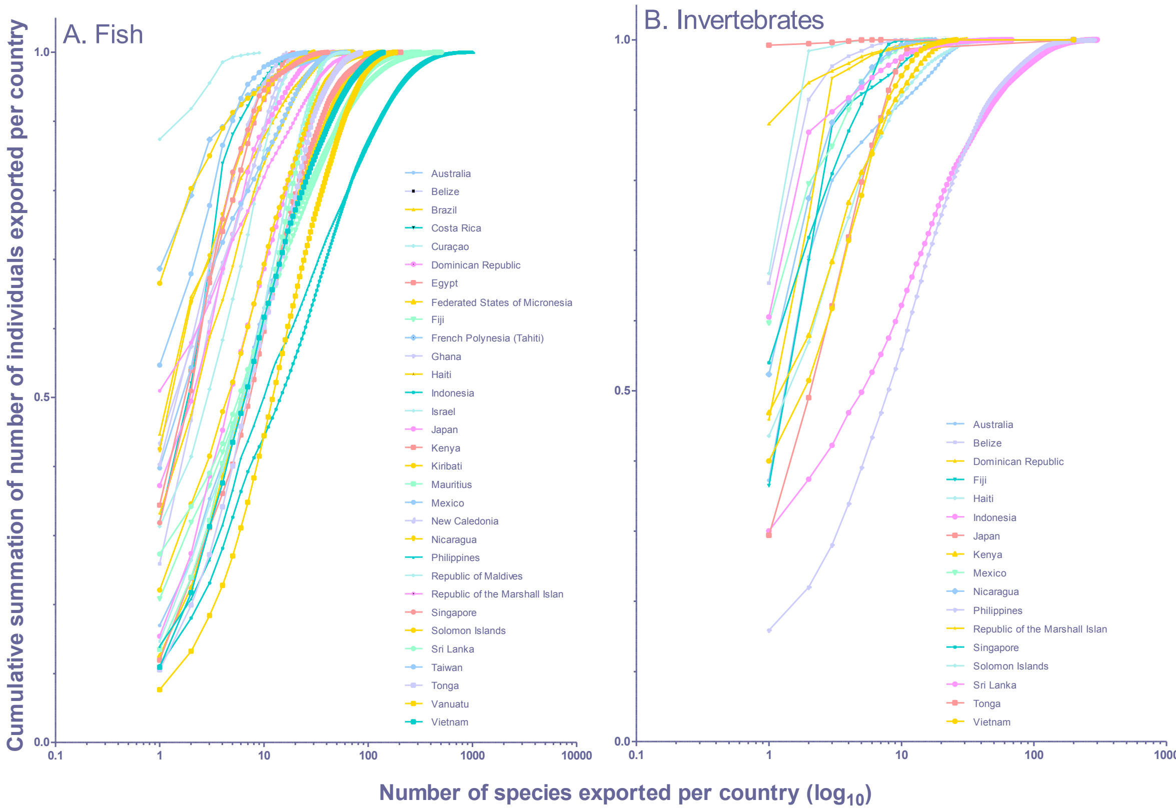

Figure 8. The cumulative summation the number of fish (A) or invertebrates (B) exported per country by rank order of species. The most exported species represents a significant proportion of the total individuals exported, and this importance decreases as a country exports a greater number of species.

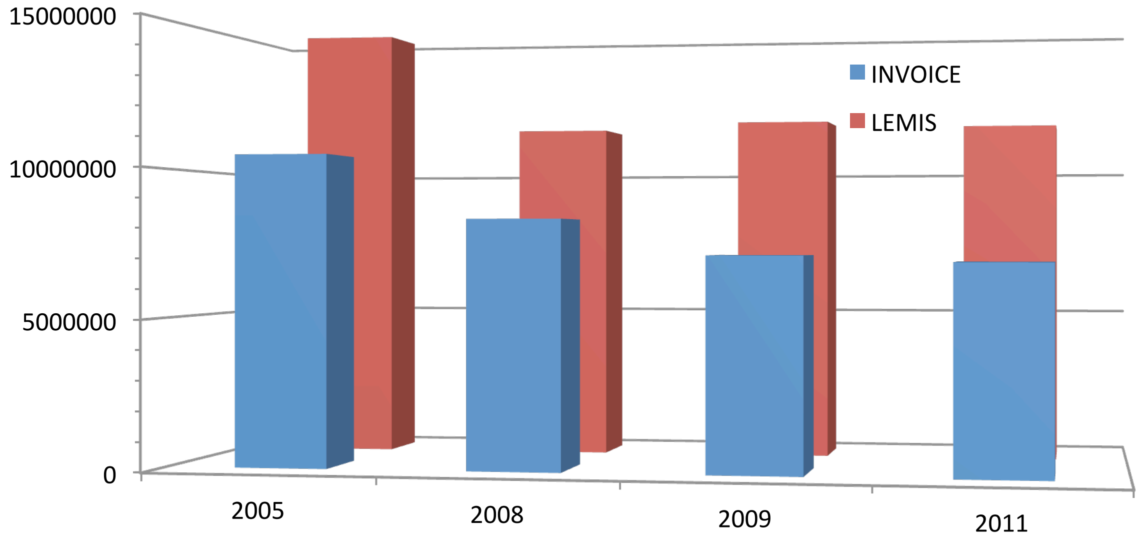

Figure 9. The comparison of the total number of fish imports according to LEMIS and this invoice-based data across 4 years, the three years reported here along with 2005 data presented in Rhyne et al. (2012).

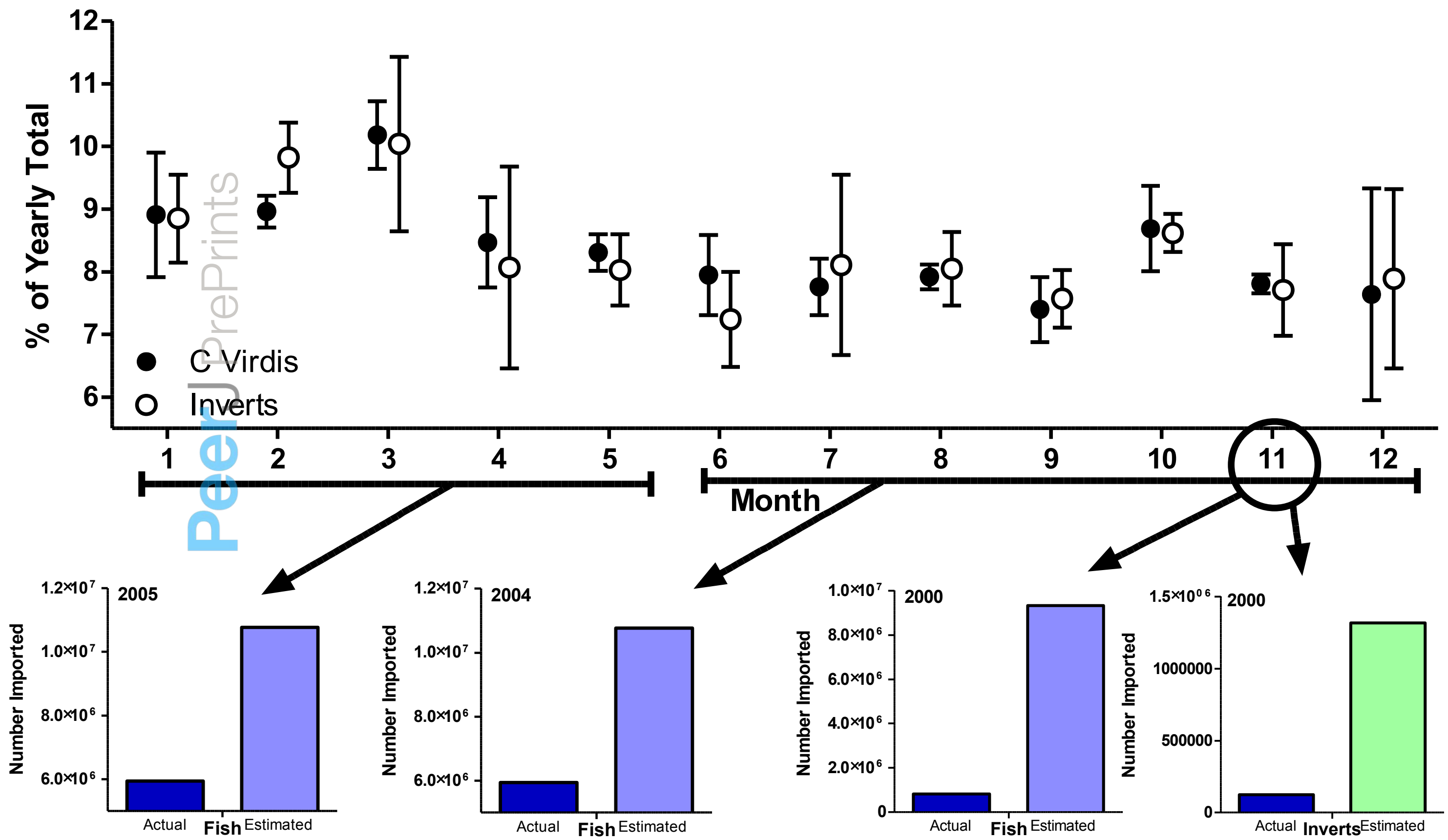

Figure 10. The determination of estimated numbers of ornamental fish and invertebrates imported into the US. The average number of individuals per month was determined for 2008, 2009, and 2011 (top). From here, the years for which there were incomplete data (2000, 2004, and 2005) were adjusted proportionally based on the assumptions that monthly import trends are consistent across years.

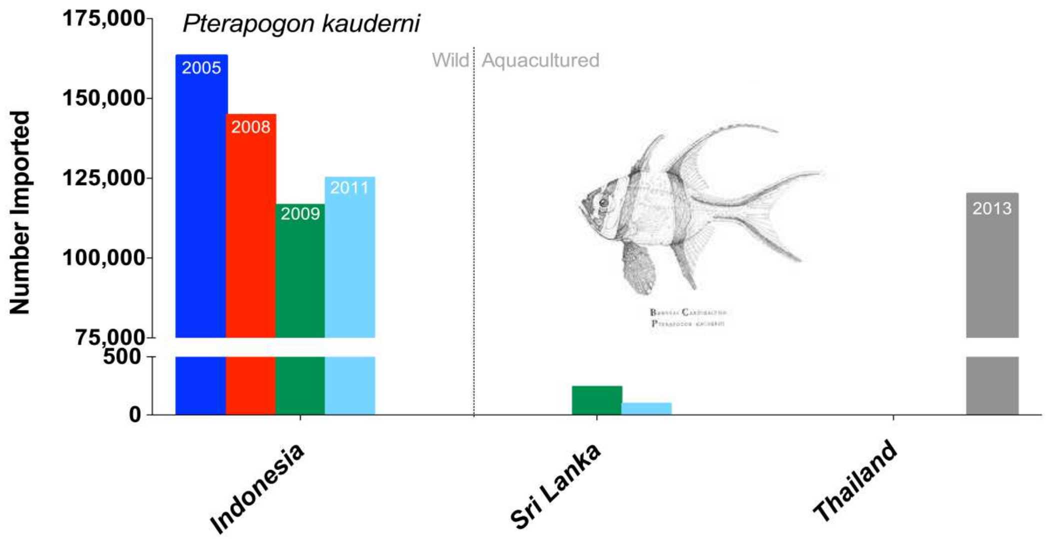

Figure 11. Top countries that exported *Pterapogon kauderni* to the United States in 2005, 2008 2009, and 2011, and 2013. Note: Thailand fish are aquacultured. Artwork by Karen Talbot.

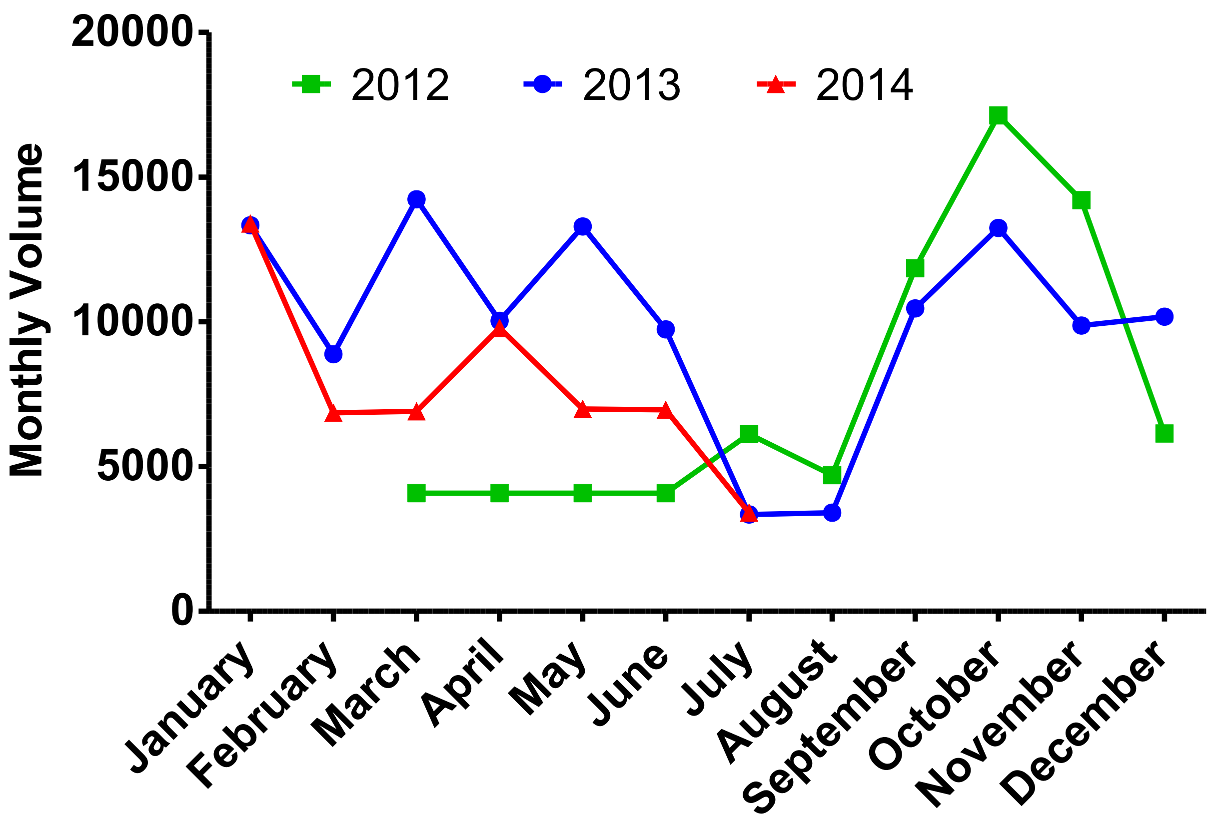

Figure 12. Number of aquacultured *Pterapogon kauderni* exported from the Kingdom of Thailand, imported into Los Angeles California during the past three years.

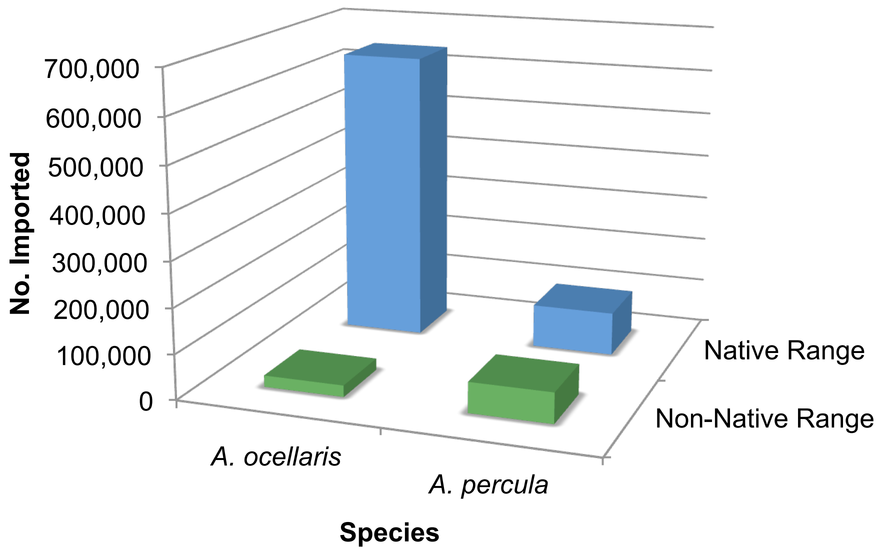

Figure 13. Imports of *Amphiprion ocellaris* and A. *percula* to the US aggreagated over the years 2008, 2009, and 2011. The species were summed over countries of export depending if the country was in the species native or non-native range. All non-native fish are either a) actually native, but of an unknown distribution, b) produced in aquaculture or c) mis-identified as to origin on the shipping invoice.