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Early Culture Trials and an Overview on U.S. Marine Ornamental Species Trade

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Abstract

Ornamental aquarium fishes have been traded globally for centuries. In the last few decades, the trade in marine species has expanded to over 40 countries supplying tropical and temperate marine life for both public and private aquariums. Accurate trade data covering the diversity and magnitude of species are elusive. The poor record keeping by both exporting and importing nations hinders efforts to understand the trade and its implications on marine ecosystems. We provide an overview of a multi-year data set that catalogs the imports of marine aquarium fishes and invertebrates into the United States. Further, we examine the history of marine ornamental aquaculture and assess constraints and bottlenecks to commercial production. We demonstrate that pelagic larval duration (PLD), economics, and regulatory actions are constraints to commercial production, while selective breeding and alternative species are production opportunities. Aquaculture can provide environmental benefits by reducing collecting pressure on highly traded species, but may carry economic and environmental risks, such as livelihood displacement and increasing the number of tankbusters in trade.

Keywords *Invasive marine species; larval bottlenecks; pelagic larval duration (PLD); risks and benefits of aquaculture; www.aquariumtradedata.org*

4.1 Introduction

Ornamental fishes and invertebrates have captivated humans for hundreds of years. Ornamental fishkeeping originated in the 10th century in Asia (i.e., China and Japan) followed by the western cultural centers of Turkey and the Roman Empire. The proliferation of ornamental fishkeeping is closely tied to the keeping of fishes for food. For example, brightly colored food carp were likely pulled from ponds as novelties, and became the predecessors of the modern day goldfish. By the late 16th century, ornamental fishkeeping quickly spread across the globe by sailors, who marketed goldfish in

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addition to the spices and other commodities they traded. By the early 1600s and late 1800s, ornamental fish keeping caught on in Europe and the United States, respectively (Brunner, 2005). During this time, especially in Europe, interest in the natural world (e.g., naturalist cabinets) grew substantially, and the keeping of marine organisms in aquaria became the spotlight of the naturalist movement. In London England, Phillip Henry Gosse published the handbook *The Aquarium* (Gosse, 1856), and his private interests soon culminated in the opening of several public marine aquariums, most notably the London Fish House (Brunner, 2005). Over the last few centuries, advances in filtration technology have increased the ability to keep and breed a variety of marine species, which has catalyzed not only a growing understanding of natural history and an increased popularity of fish keeping but also the potential to negatively impact aquatic ecosystems that support the rapidly growing marine ornamental hobby. In recent times, aquaculture of marine ornamental species has been touted as a solution to the sometimes environmentally destructive collection and over-harvesting of marine species for aquaria.

Robust analytical assessments of the risks and benefits of ornamental fish aquaculture and the aquarium industry are rare (see Tlusty, 2002). Any analytical study must understand the trade in aquarium fishes, its history, and the history of aquaculture. Here we provide an overview of the marine ornamental trade, a new data resource for studying the trade, and a brief history of marine ornamental fish culture. We explore life history bottlenecks, regulatory constraints, and opportunities for the aquaculture production of species, and explore the potential pitfalls of increasing the number of small juvenile stages of large reef fishes available to the trade through increased aquaculture capacity. Finally, we conclude by re-examining and updating the risks and benefits of marine ornamental aquaculture.

4.2 Import Data and the Marine Aquarium Trade

The ornamental fish hobby is extremely large, although the true magnitude of this industry is unknown. While survey data indicate that 79 million individual aquatic animals are held by hobbyists in the U.S., it is estimated that 190 million aquarium fishes, both freshwater and marine, are imported into the U.S. yearly (AVMA, 2007). Between 1.5 and 2 million people worldwide are believed to keep marine aquaria. The trade in live marine animals is a global multi-million dollar industry, worth an estimated 200–330 million USD annually, and operating throughout the tropics (Wabnitz *et al.*, 2003). Estimates have placed the total number of marine fish species in the global trade between 1,471 (Global Marine Aquarium Database, GMAD) to 2,300 (Rhyne *et al.*, 2012a; Rhyne *et al.*, 2015) with the best estimate of annual global trade ranging between 20 and 24 million marine individuals (Wabnitz *et al.*, 2003). Wood (2001) placed the total global annual marine catch ranging between 14 million to over 30 million fishes with the caveat that a number of assumptions have been made in reaching these figures, so they should be treated with caution. Rhyne & Tlusty (2012) demonstrated that both technology and health of the wider economy has the potential to greatly impact the marine aquarium trade.

Increasing the sustainability of the ornamental fish industry should be considered a primary initiative ("low hanging fruit") for retailers and the entire industry transport chain (Tlusty *et al.*, 2013; Rhyne *et al.*, 2014). Increasing the sustainability of the ornamental supply chain can only come through a more thorough understanding of the magnitude of the trade (Amos & Claussen, 2009). Yet we currently lack a clear picture of the number of species and individuals in the marine aquarium trade. This is primarily a result of insufficient tracking of the global trade of marine animals, which stems from a lack of a standardized data collection format. Some countries use general categories of trade data (e.g., the Marine Aquarium Tropical Fish (MATF) designation by the U.S.), whereas other countries log the weights of shipped product (e.g., livestock and water weight by the Philippines), and yet still other countries record no data at all. A crucial first step toward a more sustainable ornamental fish industry is to assess the magnitude and biodiversity of imports for major consuming countries. The United States is a natural starting place for this analysis given that it alone is purported to account for about 50% of the trade in marine ornamental fishes (U.S. Coral Reef Task Force, 2000). Once country-specific trade assessments (both imports and exports) are completed, other germane issues including understanding and improving shipping quality and animal survival can be tackled, leading to environmental (less fishing effort as fewer fishes need to be supplied to the trade) and socio-economic benefits of this trade.

The lack of a standardized trade collection system is compounded by the fact that, even in the U.S. where multiple sources of trade data exist, trade data collection systems were not all intended for general wildlife trade monitoring. For example, endangered species are monitored by compulsory wildlife trade data maintained under federal mandates for species listed by the Convention on the International Trade in Endangered Species (CITES). Unfortunately, previous studies have demonstrated that CITES records can be inaccurate, incomplete, or insufficient (Bickford *et al.*, 2011; Blundell & Mascia, 2005). Listed species (namely stony corals, giant clams, and seahorses) comprise a small proportion of the total ornamental aquatic animal trade, and only a few studies (Smith *et al.*, 2008, 2009) have attempted to quantify the movement of non-CITES-listed aquarium species from source to market. Alternatively, U.S.-based studies have primarily relied on another data management system, the Law Enforcement Management Information Systems (LEMIS) as maintained by the United States Fish and Wildlife Services (USFWS). The USFWS is charged with inspection of wildlife shipments and maintains species-specific data only for CITES species per LEMIS requirements. Non-CITES-listed fish and invertebrate species are only listed with general codes (e.g., non-CITES marine fishes are coded as MATF – Marine Aquarium Tropical Fish). Thus while CITES-listed species are monitored and can be studied (Rhyne *et al.*, 2012b; Foster *et al.*, 2016), this general coding provides no information on volume, species diversity, or trade pathways (Smith *et al.*, 2009), and hence non-CITES-listed species are not easily assessed. This dichotomy results in a data void, and there is a great need to develop a data resource that encompasses all species in the wildlife trade regardless of CITES listing status.

The lack of specific data systems for recording all species exported and imported for the wildlife trade raises two critical questions: First, how can importing and exporting governments monitor the industry effectively? Second, how should sustainability be encouraged given the paucity of data? As coastal managers scrutinize practices of the live animal trade, including efforts to reduce risks from introductions and diseases, the gap between the need for accurate accounts of trade data and the current monitoring methods are ever increasing (Bickford *et al.*, 2011).

4.2.1 Reducing the Data Deficiency

To more accurately benchmark the size of the marine ornamental trade, Rhyne *et al.* (2012a) catalogued shipping invoice data for an entire year and compared the invoices to official shipment declarations for a single country of import (the U.S.). This analysis provided the first account of volume, biodiversity, and trade pathways of marine fish species beyond the limited coverage of information provided by volunteer reporting systems (i.e., Global Marine Aquarium Database, Wabnitz *et al.*, 2003).

The methods used to analyze trade invoices have been described by Rhyne *et al.* (2012a; 2015), and are briefly summarized here. To evaluate the diversity of non-CITES-listed aquarium species imported to the U.S., shipment declarations and attached commercial invoices containing MATF from four full years (2005, 2008, 2009, and 2011) were reviewed. Only fishes were recorded in 2005, and invertebrates were added to the dataset in 2008, 2009, and 2011. While 35,000 invoices contained MATF in the LEMIS database during this period, not all of these invoices were recovered and, of those recovered, not all contained aquarium species. Therefore, only about 29,000 shipment declarations and associated invoices containing MATF were recovered. Invoices were assessed at face value, as it was impossible to control incorrect information on invoices (or if the invoice was missing). Shipping information, species, and quantities from the shipping declarations and invoices were cataloged into a database. As reported by Rhyne *et al.* (2012a), two methods of data input were utilized: manual entry and automated optical character recognition (OCR). Species names were verified using World Register of Marine Species (WoRMS), FishBase, and the primary literature. Taxonomic information for species listed on invoices with junior synonymies were corrected. When species were listed under common names not isolated to a single species, or when genera- or family-level listings could not be resolved, species were listed as unknown. Taxonomic error was reduced by comparing species listed on invoices and in the database to geographic distribution records. Listings with obvious geographic mismatches were listed as “unknown”.

Here we focus on major trade flows of fishes and invertebrates entering the U.S. In addition to the data presented in this chapter, we have developed an online platform where users can interact and query data (http://www.aquariumtradedata.org/). This online resource was developed to help anyone interested in the marine aquarium trade understand the trade with species-specific data from four years of import data.

4.2.2 General Trends in the Trade of Marine Aquarium Species

In 2005, 11 million marine fishes representing 1,802 species were imported into the U.S. About 5% of these fishes were unidentifiable to species level (e.g., listed as “assorted spp.” on invoices, Rhyne *et al.*, 2012a). The total number of marine fishes imported into the U.S. decreased each subsequent year in the database. In 2008, 8.2 million total fishes representing 1,788 species were imported. In 2009 and 2011, 7.1 and 6.9 million marine fishes were imported, respectively. While in any given year no more than 1,802 species were imported, 2,278 different species were imported across the four years (Table 4.1).

The trade in marine invertebrates demonstrated a similar import trend as marine fishes. The number of individuals and species of invertebrates imported into the U.S. was greatest in 2008 (4.3 million individuals representing 545 species) and relatively

Table 4.1 Summary of invoice data for marine aquarium fishes and invertebrates imported into the United States across four years. No. (M) is millions of individuals imported as calculated from invoice data, ΔLEMIS is the difference (%) of between the number of fish as recorded from the USFWS LEMIS data and that of the invoice data (where a negative number indicates the LEMIS value is greater), Sp. is number of species imported, and % Sp. is percentage of individuals imported identifiable to species level.

	Fishes				Invertebrates		
Year	No. (M)	ΔLEMIS	Sp.	% Sp.	No. (M)	Sp.	% Sp.
2005	11.0	−30.2	1802	95.1	–	–	–
2008	8.2	−28.0	1788	97.4	4.3	545	73.4
2009	7.1	−39.7	1780	96.7	3.7	537	73.1
2011	6.9	−40.5	1798	96.7	3.7	535	72.2
Total unique			*2278*			*724*	

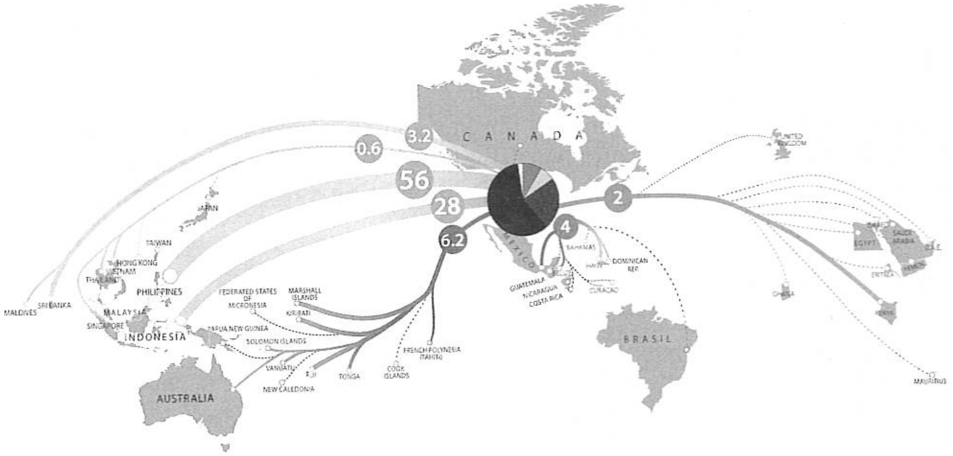

Figure 4.1 Trade flow of marine aquarium fishes from source nations to the United States. Numbers on lines represent percent total import. Pie chart within the United States represents ports of entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW). (*See insert for color representation of the figure.*)

similar in 2009 and 2011 (3.7 million individuals and 537 and 535 species, respectively). The total number of species imported over the three years (724 species) was greater than the number of species imported in any one year (545 species). While marine invertebrate import trends were similar to those of marine fishes, relatively fewer invertebrates than fishes were identified to the species level (72.9 vs. 97.0%) (Table 4.1).

During the four years assessed, 45 countries exported marine fishes to the U.S. The Philippines exported on average about 56% of the total volume of marine fishes (Figure 4.1). The 37% decrease in the total number of fish imported by the U.S. across the years was mirrored in the number of fishes coming from the Philippines and

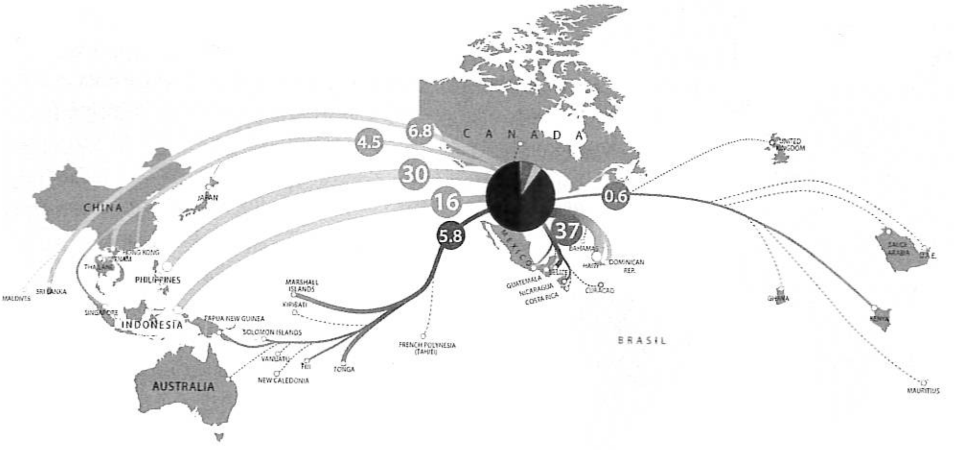

Figure 4.2 Trade flow of marine aquarium invertebrates from source nations to the United States. Numbers on lines represent percent total import. Pie chart within the United States represents ports of entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW). (*See insert for color representation of the figure.*)

Indonesia. Sri Lanka (representing the third ranked country of export) remained consistent across the four years, whilst fourth ranked Haiti decreased exports by nearly 50% over the four assessed years, with the larger drop being a result of the global decline compounded by the 2010 earthquake.

A total of 38 countries exported invertebrates to the U.S. across the three years assessed (27 countries in 2008, 2009; 28 countries in 2011, Figure 4.2). The total number of exported individuals declined by 14% over the three years. The Philippines (3.6 million), Haiti (3.1 million), and Indonesia (1.8 million) exported the greatest number of individual invertebrates over the three years. The Philippines increased the total number of individuals exported by 24% between 2008 and 2011, while Haiti decreased exports by 48% between 2008 and 2011 (again, likely due to the massive earthquake in Haiti in 2010). The total number of individual invertebrates exported by Indonesia remained consistent across the three years; and Indonesia also exported the greatest number of species (413). The Philippines and Sri Lanka exported the second and third greatest number of species (Figure 4.2).

The top 20 species of marine fishes imported by the U.S. accounted for approximately 52% of the total volume of marine fishes imported (identified to the species level, Figure 4.3), and remained surprisingly consistent over the three years assessed. Specifically, the top 20 marine fish species list from 2008 and 2009 are identical, and, in 2011, the single difference was *Valenciennea strigata* replacing *Gramma loreto* as the 20th rank. The top seven marine fish species were consistent across all years, and represented nearly 33% of the total marine fish imports. The most popular species, *Chromis viridis* was consistently greater than 10% of total marine fish imports per year, and originated from between 13 to 16 countries yearly. The only other species of marine fish sourced from an equivalent number of countries was *Paracanthurus hepatus*, which originated from approximately 15 countries per year.

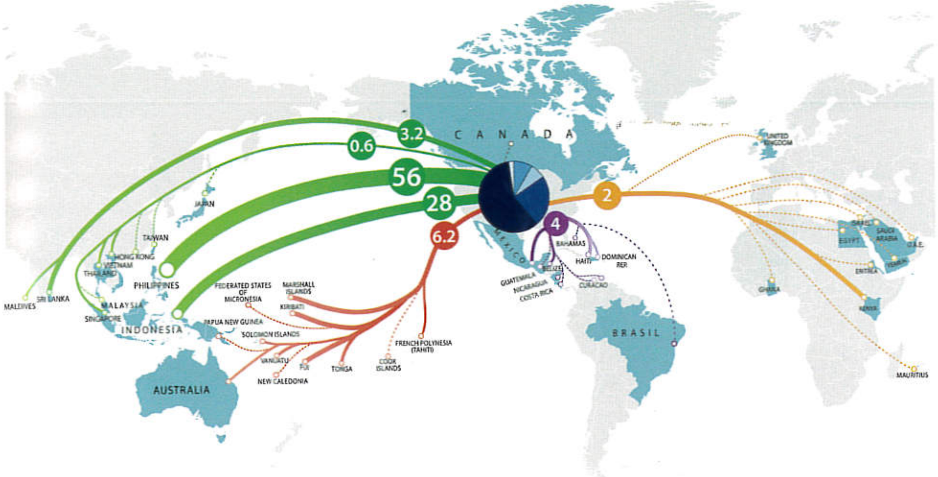

Figure 4.1 Trade flow of marine aquarium fishes from source nations to the United States. Numbers on lines represent percent total import. Pie chart within the United States represents ports of entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW).

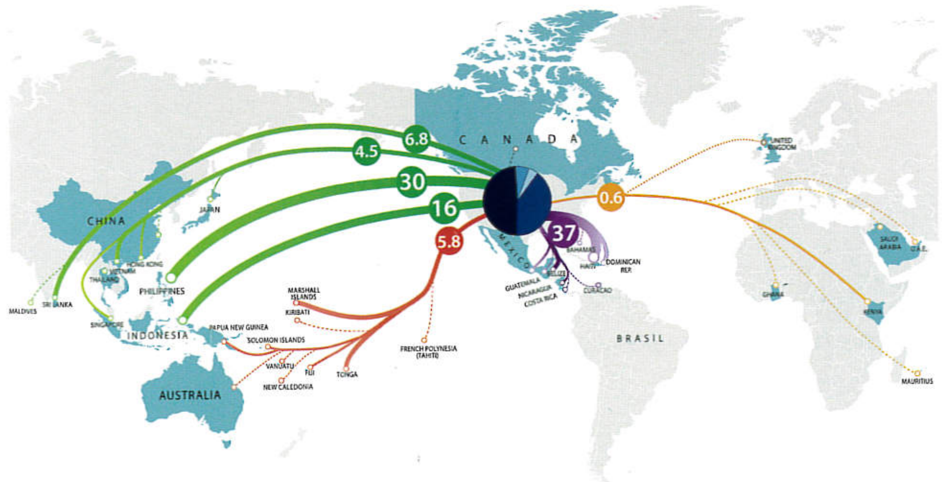

Figure 4.2 Trade flow of marine aquarium invertebrates from source nations to the United States. Numbers on lines represent percent total import. Pie chart within the United States represents ports of entry (with the Midwest starting at 0 degrees, and clockwise, NE, SE, SW and NW).

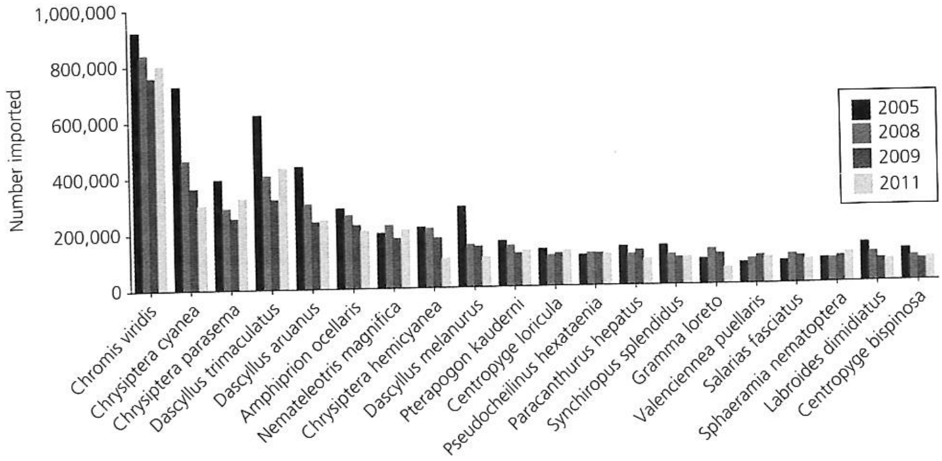

Figure 4.3 Top 20 marine aquarium fish species imported into the United States across four years. Dataset generated from www.AquariumTradeData.org.

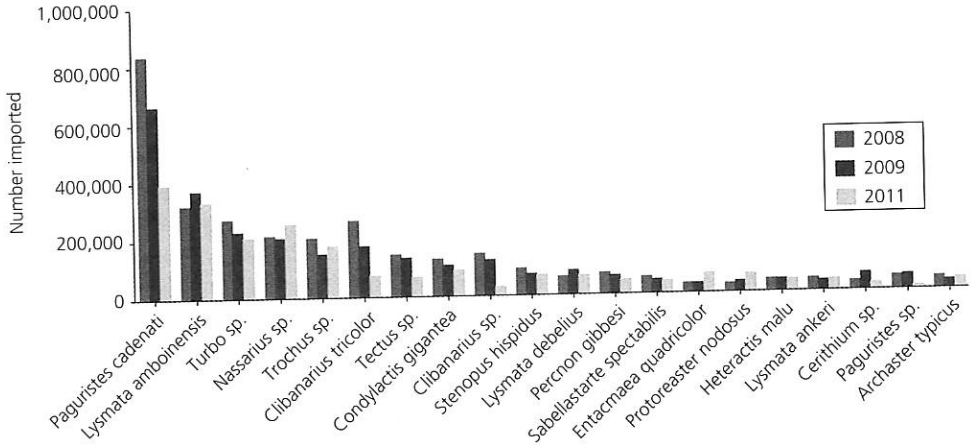

Figure 4.4 Top 20 marine aquarium invertebrate species imported into the United States across four years. Dataset generated from www.AquariumTradeData.org.

In contrast, the top 20 invertebrate species imported by the U.S. represented approximately 75% of the total volume of marine invertebrate imports (identified to the species level, Figure 4.4). Only the top two species (*Paguristes cadenati* and *Lysmata amboinensis*) were in an identically-ranked position among years. In all, 25 marine invertebrate species were represented in the top 20 list across the three years.

These data represent the volume of trade in marine ornamentals recorded as "wild capture" on import declarations. There are occasions where these self-declarations are incorrect (Rhyne *et al.*, 2012b). With the proliferation of aquaculture operations, cultured organisms can be confused with wild-captured organisms, leading to reporting inaccuracies. The most evident examples of this confusion are the stony corals (Rhyne *et al.*, 2012b) and clownfishes. It is currently impossible to accurately determine the number of wild stony corals or clownfishes imported to the U.S. because cultured specimens are often mislabeled as wild products. A comprehensive assessment of the relative risks and benefits of both aquacultured and wild species is required to more accurately discern source trends in trade (Tlusty, 2002; Tlusty *et al.*, 2013; Rhyne *et al.*, 2014).

4.3 Aquaculture for the Marine Aquarium Trade: Bottlenecks and Opportunities

Brief History

Marine ornamental fish aquaculture is likely rooted in the tanks of European aquarium hobbyists, following their first successes as marine fish breeders (Schreiner, 1972; Moe, 2012). Commercial production of marine aquarium fishes in the U.S. began in the 1970s at the Aqualife Research Corporation founded by Martin Moe, followed by the Instant Ocean Hatchery founded by Frank Hoff (Moe, 1997). Moe's and Hoff's ornamental hatcheries demonstrated the feasibility of commercial production and likely served as the catalysts that prompted the prevalence of commercial ornamental aquaculture endeavors today. Moe's and Hoff's early successes were, at least in part, reliant on the growth and development of marine food fish aquaculture, as well as a deeper understanding of the life history and nutritional requirements of marine fishes in general. Perhaps the most important ingredient in the widespread successful culture of marine fishes was the discovery of a suitable live feed that could be cultured in large volumes and was accepted by marine fishes: the rotifers of the genus *Brachionus* (Ito, 1960; Lubzens *et al.*, 1989). While using rotifers as a first-feed for marine fish culture greatly increased the number of species cultivated and the reliability of marine fish culture, rotifers also limited culture success to species with relatively simple larvae (i.e., consume large prey items) and nutritional requirements.

During the 1990s, commercial production of clownfishes, dottybacks, gobies, and other species with short pelagic larval phases increased, as did efforts to rear species with less developed and more demanding larvae (e.g., angelfishes from the family Pomacanthidae). Similar to ancient fish keepers in Asia, once fishes are regularly bred domestically, they can easily be bred for certain colors, shapes, and patterns. By the late 1990s, hatcheries were beginning to offer color morphs that were distinctly different from wild-type fishes, such as the pearl-eyed Clark's clownfish, *Amphiprion clarkii*, and black oynx clownfish, *A. percula*, that quickly became the first "designer" fishes in the marine ornamental fish market. The rapid diversification by selective breeding in clownfish and other marine fishes opened new opportunities for marine ornamental aquaculture (Pedersen, 2014).

Finding the appropriate foods was a critical step to the eventual success of marine fish rearing. Moe and colleagues successfully reared a few families of ornamental species in small numbers on wild plankton (i.e., copepods) (Moe, 1976, 1997; Potthoff *et al.*, 1987). Moe (1997) quickly recognized the superiority of copepods over rotifers for certain species. As demand increased for seahorses and other species of marine fishes proven to be difficult to rear on traditional larval diets (i.e., rotifers and *Artemia*), researchers began developing culture methods for copepods and other live prey (Olivotto *et al.*, 2011). Advancement in copepod nauplii production has provided renewed interest in marine ornamental aquaculture, and has been credited for the development and success of seahorse aquaculture (Payne & Rippingale, 2000; Gardner, 2003) and other more demanding marine aquarium fishes (Shields *et al.*, 2005). Perhaps nowhere is this development more evident than the enormously successful *Centropyge* culture efforts of Reef Culture Technology (RCT) (Baensch, 2014). Similar to the initial successes of the first marine aquarium hatcheries, the successes of the RCT *Centropyge* breeding project has opened the door to future aquaculture possibilities, as well as a wave of challenges on the battleground where life history characteristics, culture technology, and economics converge.

4.4 Constraints and Opportunities for the Commercial Production of Marine Aquarium Species

4.4.1 Life History Characteristics as Constraints to Commercial Production

While clownfishes, cleaner gobies, dottybacks, seahorses, and a limited number of large marine angelfishes (genus *Pomacanthus*) are regularly produced at commercial levels, other fishes such as mandarin dragonets and pygmy angelfishes have not yet sustained regular commercial viability. Variations in commercial viability are usually explained by several life history attributes combined with market forces. The most consistent predictors of commercial success with respect to life history characteristics are (1) larval duration; (2) settlement size; and (3) live feed requirements. Growout duration and spawning mode are important, but minor constraints to commercial development. Most commercially available aquacultured marine aquarium species have a larval duration under 30 days (Figure 4.5). Generally, the cultured Pelagic Larval Duration (cPLD) of marine fish species is often different than the wild Pelagic Larval Duration (wPLD) of a species in its natural habitat. Much of this variation is driven by temperature, paternal identity, and larval nutrition under laboratory conditions (Searcy & Sponaugle, 2000; Green & McCormick, 2005). For example, the literature reports that angelfish species of the genus *Centropyge* have an average wPLD of about 32 days (minimum: 24 days; maximum: 39 days, Thresher & Brothers, 1985). Based on reported wPLD, *Centropyge* should be a strong candidate for commercial culture in the near future; however, the cPLD of many *Centropyge* angelfishes is substantially longer than reports of wPLD (Baensch, 2014). For example, the cPLD for *Paracentropyge venusta* is currently between 95–130 days (K. Brittain pers. comm.), in contrast to a wPLD of only 25 days (Brothers & Thresher, 1985). The discrepancy between cultured and wild PLD indicates larvae quality issues, nutrition deficiencies, or other unknown factors prevent larvae from developing at natural rates. On the other hand, clownfishes and other easily cultured species have a cPLD at or slightly shorter than published wPLD values (Figure 4.5).

Larval size at settlement is positively correlated with larval duration for most reef fishes (Wellington & Victor, 1989). A study of 100 species of damselfishes (family Pomacentridae) found larval duration ranges from 12 to 39 days with settlement size ranging from 6 to 14 mm (Wellington & Victor, 1989). Variation within and among species of the same genera has been demonstrated (Cowen, 1985; Bay *et al.*, 2006). A survey of 100 wrasse species demonstrated a high degree of variation among and within species of labrids (Victor, 1986, Figure 4.5). Reef fish species with long larval durations appear to be capable of delaying settlement and extending their wPLD (Searcy &

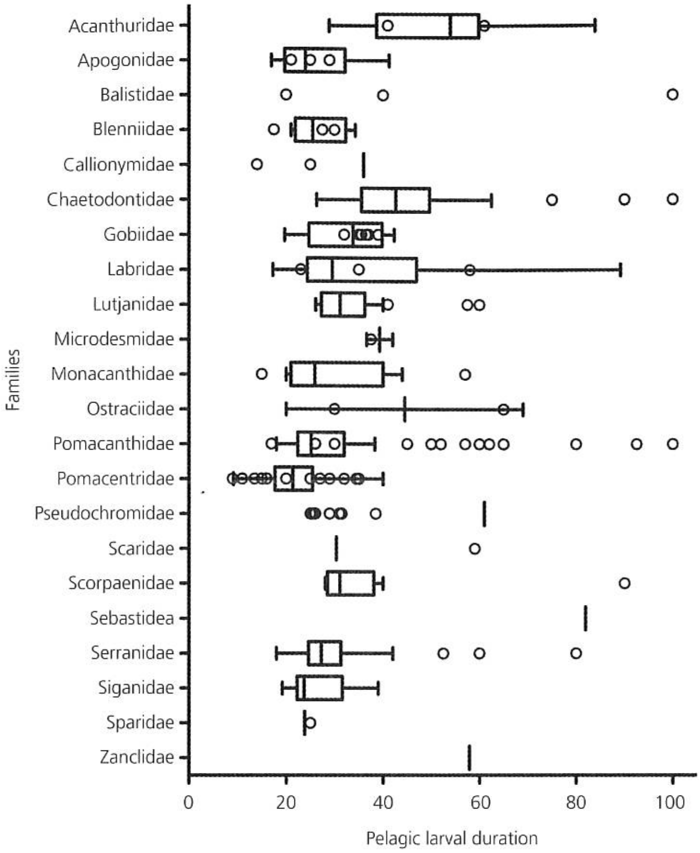

Figure 4.5 Comparison of pelagic larval duration (PLD, days) of marine aquarium fish families. Box-whisker plots represent PLD of wild specimens (wPLD) from the literature, and open circles represent PLD of cultured specimens (cPLD) from the literature and hobbyist publications. Error bars represent minimum and maximum PLD. (See Stier *et al.* and references therein.)

Sponaugle, 2000). The literature is ripe with information on the size of newly settled marine fishes and culturists should use natural history data on both settlement size and larval duration before undertaking commercial production efforts for a given family (e.g., labrids, Figure 4.5).

A current focus of the marine ornamental aquaculture industry is on tangs, most notably the yellow tang, *Zebrasoma flavescens*, and the blue hippo tang, *Paracanthurus hepatus*, and butterflyfishes such as the schooling bannerfish, *Heniochus diphreutes*, and millet seed butterflyfish, *Chaetodon miliaris* (http://www.risingtideconservation.org/). Unlike clownfishes, tangs and butterflyfishes have extended wPLD that make commercial culture challenging with current aquaculture bottlenecks. Callan (2016) reported rearing the iconic yellow tang and produced several hundred juveniles with a cPLD around 60 days, a significant improvement from previous reports (Williams, 2014 and Chapter 15 in this book). The correlation between larval size and larval duration suggests that yellow tangs likely settle at 54 days (wPLD) at around 33 mm TL (Basch *et al.*, 2009). Similarly, larvae of the blue hippo tang have a reported wPLD of 37 days and settle at around 30 mm TL (29.8 mm larvae reported by Johnson & Washington, 1987). Talbot (2016) reported the culture of the blue hippo tang in captivity for the first time by the University of Florida Tropical Aquaculture Laboratory (UF TAL) using the culture techniques Callan developed for the yellow tang. The cPLD from this cohort was 42 days (Barden, pers. comm.). While the recent developments of Callan and UF TAL are extremely promising, the life history of these species presents a significant challenge for the commercial production of tangs. Recent success by RCT in closing the life cycle of the schooling bannerfish provides additional contrast between cPLD and potential commercial production in reef fishes. Baensch (2014) reported a cPLD of 100 dph with the larvae settling at about 18 mm TL, which contrasts wPLD of 30 at 18 mm TL. While rearing marine fish species with extended PLDs is within the technical capabilities of some researchers, commercially viable production is still a challenge. Life history characteristics such as PLD and settlement size can be important predictors of commercial success for researchers and other interested parties.

4.4.2 Economic and Regulatory Constraints to Commercial Production

It has been well demonstrated that biological characteristics of marine species can hinder aquaculture production and make commercial production difficult or improbable. Likewise, economic and regulatory constraints can also inhibit the commercial success of a species or entire group of taxa. Here we provide two examples of reef fishes that are easily cultured; however, commercial success is limited due to current economic factors.

The Banggai Cardinalfish

There are few better examples of marine aquarium species that should be commercially produced via aquaculture than the Banggai cardinalfish (BCF), *Pterapogon kauderni*, a mouth brooding and geographically restricted species. Even though BCF is IUCN red listed, it is highly traded, under enormous collection pressure (Yahya *et al.*, 2012), has been over-exploited, and suffers from a high level of supply chain mortality. A commercial supply of aquacultured BCF to address these issues is fleeting (see Chapter 13). The BCF quickly became a popular fish in the aquarium industry after its introduction to the trade (Allen, 1996). When first introduced it was a high valued species, retailing for over 100 USD per specimen. As seen in other aquarium species, BCF volumes increased and the retail price quickly dropped dramatically (Rhyne *et al.*, 2014). Within a few years populations were being overexploited and some have yet to recover (Vagelli, 2011). A recent survey of collection sites continues to indicate evidence of over collection and population declines (Yahya *et al.*, 2012). Yahya *et al.* (2012) noted that while nearly 100,000 fish a year are exported from approved locations, an additional yet unknown number is exported from other areas. While GMAD only indicates small levels of trade in 2001, our data consistently place BCF in the top 20 most imported fishes into the U.S. (Figure 4.3). These data corroborate reports (Talbot *et al.*, 2013) that Indonesia's exports exceed the approved quotas put in place to protect this species. Numerous conservation organizations, scientists, and professional hobbyists have advocated for both trade protection via CITES and an increase in captive breeding efforts (Talbot *et al.*, 2013). To date these efforts have been met with limited success. The key factors inhibiting the wide spread commercial production of BCF are the limited number of eggs produced per spawn (<50) and time to market (4–5 months, Vagelli, 2011) combined with a low market price due to a high influx of low quality wild BCF (Talbot *et al.*, 2013). This combination creates challenges for commercial aquaculture (Tlusty, 2002) as the efficiencies with economy of scale are difficult with pair bonded fish exhibiting low fecundity. Notwithstanding the economic challenges of commercial production of BCF, the recent regulatory environment (listed as threatened under the Endangered Species Act (ESA)) in the U.S. could prohibit the trade of this iconic species (NOAA, 2014). If an ESA listing allows trade in aquaculture fish, but limits the trade of wild caught specimens, then the regulatory environment could be a boom for aquaculture producers. Quotas on CITES-listed species have greatly increased market prices (Rhyne *et al.*, 2012b) and the BCF is a likely candidate for CITES listing. It could also provide an additional challenge for unscrupulous exporters and/or importers that mis-identify wild-caught BCF. Regardless of proposed regulatory measures, a large-scale production (>120,000 fish per year or 75% of the current wild volume imported into the U.S.) of BCF within Thailand appears to have overcome the economy of scale, regardless of the low fecundity of the species (Rhyne, unpublished data), likely due to the cheaper production costs in Southeast Asia. As with other marine aquarium species, trade regulations can be a benefit or be an impediment to aquaculture production.

Mandarin Dragonets

Unlike the mouth brooding and geographically restricted Banggai cardinalfish, mandarin dragonets, *Synchiropus* spp., have a wide geographic distribution and are pelagic spawners. These species are a staple of the marine aquarium trade, consistently ranked in the top 20 marine fish species (Rhyne *et al.*, 2012a, Figure 4.3). Two species represent the vast majority of trade: *Synchiropus splendidus* and *S. picturatus*. Dragonets are marketed as peaceful but delicate reef safe fish, requiring large amounts of live prey to be successfully kept in aquaria. These species suffer high collection related mortality and the fishery has been implicated in skewing population sex ratios (Sadovy *et al.*, 2001). Mandarins often fail to acclimate to captivity or starve in aquariums lacking ample supplies of live feeds. As with many marine fishes in the aquarium industry, increased mortality along the supply chain increase the number of mandarins that need to be collected and sold. Mandarins have been cultured by hobbyists (Sprung, 1989); researchers (Wittenrich *et al.*, 2010); and it was with great fan fair and excitement that Oceans Reefs and Aquariums, Fort Pierce Florida, U.S. produced commercial numbers of both *S. splendidus and S. picturatus* (ORA, 2010; Rhyne, 2010). Given the short larval duration (cPLD of 14–24 days) and high survival, mandarins should be an ideal species for commercial production. However, two factors have greatly impeded commercial production. First, the mandarins are extremely slow growing and require 6 months or longer to reach market size. Second, producers must compete with a large supply of cheaper wild fish. The extended growout time coupled with a large supply of cheaper wild fish yielding relative prices of 60 USD for cultured compared to 25 USD for wild) has limited the commercial success of these iconic species. Like the BCF, large-scale commercial production will likely only occur in countries with more extensive culture methods and cheaper labor forces.

CITES and ESA as Constraints and Opportunities in Aquaculture Production

The Convention on International Trade in Endangered Species of Wild Fauna and Flora is an intentional barrier to international trade, specifically targeting species that have been deemed at an extinction risk because of the trade. The Endangered Species Act (ESA) is a U.S. law that regulates listed species and can prohibit the collection, trade, and commercial sale (defined as *take*) of listed species. Both CITES and ESA provide significant regulatory hurdles for aquaculture producers, but may also provide opportunities by restricting trade to an aquaculture product or capping the trade in wild specimens. Within the marine aquarium industry the most traded CITES-listed species include stony corals (order Scleractinia), giant clams (genus *Tridacna*), and seahorses (genus *Hippocampus*). The CITES treaty member nations have specific rules to permit the commercial trade of captive bred specimens of species listed in CITES – Appendix I (https://cites.org/eng/app/appendices.php). These regulations have proven to be significant barriers to trade in stony corals. A few countries have overcome these challenges by issuing guidelines for aquaculture production (Rhyne *et al.*, 2012b). For example, Indonesia has well documented guidelines (Pasaribu, 2008) for the commercial production of stony corals and supports the export of cultured corals under CITES source code F. Indonesia is actively reducing its export quota for wild corals and intends to supply the coral trade with a 100% aquacultured supply of stony corals. The Solomon Islands, on the other hand, has been producing aquacultured corals for several decades (Lal & Kinch, 2005) but has little to no government support or regulatory method for supporting CITES source code F. Thus, much of the coral shipped as wild product from the Solomon Islands is in fact aquaculture product. Production of corals in countries that have an active coral trade can provide economic and environmental benefits and should be encouraged (Rhyne *et al.*, 2012b). These benefits are threatened by regulatory schemes which are designed to protect wild populations. For example, with the current listing of 20 stony corals on the ESA, the ability to import or export listed species and/or closely related species is in question. If the National Oceanic and Atmospheric Administration (NOAA) limits *take* to cultured specimens for listed species then restrictions on wild specimens could provide a market incentive to increase the value of aquaculture products and would likely increase the production of coral species via aquaculture. NOAA could however limit *take* to domestic production or prohibit the import or export of listed species. These restrictions would greatly inhibit aquaculture production. While hobbyists and researchers have little to worry about (fish tanks will not become illegal), changes in laws and trade regulations will affect commercial aquaculture vendors. The trade as a whole is entering new and uncharted waters. To develop a business, one must invest capital and time into species and, given the current uncertainties, this species may ultimately end up listed as threatened or endangered. Trade in restricted species is a difficult business model. Understanding the regulatory climate both within a country's border and within the global community is now essential to ensure commercial success.

4.5 Risks and Benefits of Aquaculture Production

The continued growth of aquaculture production offers several important benefits, both to end consumers and the reef-side communities (Tlusty, 2002; Rhyne *et al.*, 2014). Capturing these benefits can be difficult and elusive; many aquaculture initiatives are marketed as conservation efforts but fall far short of this goal. Other efforts are focused solely on the production of animals for the aquarium and food industries and have no concerns about the broader conservation issues associated with the aquarium trade. There are enormous conservation benefits that can occur with the commercial aquaculture production of aquarium species, but there are also significant risks (Tlusty, 2004). To ensure the long-term sustainability of the industry, the benefits of aquaculture must balance, if not outweigh the risks. Below we outline the most significant risks and benefits of aquaculture production for the marine aquarium.

4.5.1 Ecological Risk and Aquaculture Production as a Source of Nonindigenous and Invasive Marine Species

The introduction of the pacific lionfish, *Pterois volitans*, into the western Atlantic Ocean has caused environmental damage throughout the Caribbean and subtropical regions of the western Atlantic (Albins & Hixon, 2011). There is little doubt that the source of the founding population of lionfish was from an aquarium hobbyist or aquarium wholesaler in south Florida. The aquarium trade has been a vector for introduced marine fishes in south Florida for decades (García-Berthou, 2007). Most introductions do not rise to the level of an invasion; however, each additional species introduced into Florida or other nonindigenous location is cause for alarm. In response to the lionfish invasion, the Florida Fish and Wildlife Commission imposed a ban on the importation of all species of the genus *Pterois*. Further bans would be expected if additional species were to become established. It is therefore imperative that propagule pressure is reduced. It has been proposed that "*tankbusters*," those species that grow far too large to be housed in a home aquarium, are at the highest risk of being released by hobbyists and therefore experience a higher propagule pressure than other smaller species (Holmberg *et al.*, 2015). Reef fish species often enter the aquarium trade at a small size, and become part of the food trade at a large size. Thus, aquaculture production of food fishes can generate thousands of individuals that can be sold to the aquarium trade as juveniles. Holmberg *et al.* (2015) tested the hypothesis that the desirability of marine tankbusters peaks early in life history by examining retail size and price vs. growth. Five representative internet-based marine ornamental fish vendors were surveyed, and data were gathered on retail size range, life history stage, price, origin, and maximum potential length (according to vendor) for over 700 species and compared size to data in FishBase. With an increasing volume and diversity of tropical marine fishes imported into the U.S., there is astonishing potential for the trade to influence propagule pressure. Given the risk of intentional release by consumers and the implications for propagule pressure, we posit that it is unwise to allow the sale of species that quickly and routinely outgrow their captive environment. Therefore it seems unwise to encourage or support the development of aquaculture technologies for species targeted for the aquarium trade that would easily outgrow hobbyist tanks. We propose that to increase the robustness of any preventive measures, the trade should be fully engaged in the framing of future actions. In order for this to happen, we propose the creation of a multi-stakeholder workgroup to curate a moving whitelist of species with high invasive potential, which would then be voluntarily disallowed (except for permitted activities). Until we have a better understanding of all factors involved in determining invasive potential, we suggest that regulated quotas and caps are not sufficient given that a number of species are seldom traded yet potentially invasive (Holmberg *et al.*, 2015).

4.5.2 Economic Benefits of Aquaculture in Reef Side Communities

The reef-side communities that collect marine ornamental species are fishing communities. They often have few alternate economic opportunities. While opponents of the trade have decried the collection of coral reef fishes as destructive (reviewed in Tissot *et al.*, 2010), these oppositions do not address the corollary *what would be the opportunity cost of closing a fishery*? Species that are collected for a high value at a small size for the ornamental trade are still often fished for food when at a larger size, but will earn a significantly lower economic value for the fisher. Thus, ornamental fisheries need to be managed as a way to create value for coral reef socioeconomic ecosystems. For example, maintaining a relatively low biomass ornamental fishery can allow for managed no fishing zones, ecotourism, and other value-adding activities to derive the maximum benefit to these fragile ecosystems.

4.5.3 Reducing Bottlenecks and Opportunities for Growth

As the marine ornamental aquaculture industry continues to develop, it is essential that industry efforts advance the role of aquaculture as an economic and environmental tool. While innovation cannot be predicted, carefully considering new species to pursue, reducing live feed bottlenecks, and advancing culture technology and life support systems are several critical opportunities for industry growth.

Species Selection

We suggest future ornamental aquaculture efforts focus on species exhibiting high market potential and life history characteristics that lend well to aquaculture. This includes species that are already at market but have limited consumer availability (e.g., the yasha goby, *Stonogobiops yasha*), as well as species that are currently not common in the trade but exhibit strong market potential, such as the purple tailed dottyback, *Pseudochromis luteus* (Kai, 2012), or the DeJong's gramma, *Gramma dejongi* (Victor & Randall, 2010). Additionally, marine ornamental aquaculture can diversify the market for aquaculture products through the hybridization of commonly cultured species (e.g., clownfishes, Pedersen, 2014). Commercial producers should also focus on species that have similar ecological roles in aquaria as natural reefs, with life history characteristic more amendable to aquaculture production (e.g. *Mithraculus forceps* vs. *M. sculptus*, Rhyne *et al.*, 2005). Similarly, researchers should invest in the foxface rabbitfish, *Siganus vulpinus*, as an alternative to tangs. Foxface rabbitfish are attractive, in high demand, and provide the same ecological services to the aquarium as tangs (i.e., algae consumption). However, the foxface rabbitfish has a more reasonable wPLD compared to the yellow tang. While "firsts" and innovations are essential aspects of industry growth, it is important to focus on species with predictive culture success based on life history characteristics and culture history and species currently threatened by the trade (e.g., unsustainable wild harvest).

Live Feed Bottlenecks

While the current culture successes of copepods prompted new waves of cultured marine fishes with more delicate and complex larval requirements, copepod culture refinements (e.g., recirculating culture systems, low-cost production) as well as the production of alternative larval feeds (e.g., larvaceans) is likely needed before the commercial success of many current aquaculture efforts can be realized (i.e., tangs and butterflyfishes). Efforts towards commercially affordable recirculating copepod production systems will increase not only the diversity of copepods (and similar planktonic feeds) produced but also the volume of currently and newly aquacultured species that reach commercially viable scales. Many species of wrasses, tangs, triggerfishes, and other small marine larvae require foods smaller than the current copepod nauplii, and research to close the gap in the early first feeding larvae is still lagging behind efforts to culture these species. While first feeding mortality is still high, many highly desirable species exhibit dietary shifts during development (Llopiz & Cowen, 2009), often moving from copepods to larvaceans and pteropods. Research on suitable alternatives to both larvaceans and pteropods will likely increase development and survival of many coral reef fish larvae.

4.6 Conclusions

Marine ornamental aquaculture is a growing and malleable tool with implications for the sustainability and advancement of the aquarium trade as well as the ecological and socioeconomic wellbeing of coral reefs and associated reef-side communities. There is a strong need to better understand the global marine aquarium trade as a whole, as well as the risks and benefits of a larger aquaculture footprint within the trade. Concurrently, as an industry, the focus should be on the marketability of aquacultured products while decreasing production costs. To do so, collaboration across all facets of the industry is essential.

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References

Albins, M.A. & Hixon, M.A. (2013) Worst case scenario: potential long-term effects of invasive predatory lionfish (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, **96**, 1151–1157.

Allen, G.R. (1996) The king of the cardinalfishes. *Tropical Fish Hobbyist*, **5**, 32–45.

Amos, A.M. & Claussen, J.D. (2009) *Certification as a Conservation Tool in the Marine Aquarium Trade: Challenges to Effectiveness.* Turnstone Consulting and Starling Resources Report.

AVMA, American Veterinary Medical Association. (2007) *U.S. Pet Ownership and Demographics Sourcebook, 2007 Edition*. American Veterinary Medical Association, Schaumburg, Illinois, USA.

Basch, L.V., Eble, J., Zamzow, J., Shafer, D. &Walsh, W.J. (2009) *Recruitment Dynamics and Dispersal of Coral Reef Species in a Network of National Parks and Marine Protected Areas, West Hawai'i Island: Some Preliminary Findings*. NOAA/HRCI Technical Report.

Baensch, F. (2014) The Hawaii larval fish project. *CORAL Magazine*, **March/April 2014**, 64–68.

Bay, L., Buechler, K., Gagliano, M. & Caley, M. (2006) Intraspecific variation in the pelagic larval duration of tropical reef fishes. *Journal of Fish Biology*, **68**, 1206–1214.

Bickford, D., Phelps, J., Webb, E.L., Nijman, V. & Sodhi, N.S. (2011) Boosting CITES through research – response. *Science*, **331**, 857–858.

Blundell, A. & Mascia, M. (2005) Discrepancies in reported levels of international wildlife trade. *Conservation Biology*, **19**, 2020–2025.

Brothers, E.B. & Thresher, R.E. (1985) Pelagic duration, dispersal, and the distribution of Indo–Pacific coral reef fishes. *The Ecology of Coral Reefs*, **3**, 53–69.

Brunner, B. (2005) *The Ocean at Home: An Illustrated History of the Aquarium*. Princeton Architectural Press, Princeton, New York, USA.

Callan, C.K. (2016) Striking Gold – The dream of breeding *Zebrasoma flavescens* comes true in a Hawaii marine lab.*CORAL Magazine*, **January/February 2016**, 36–48.

Cassiano, E.J. (2016) A Regal Beginning.*CORAL Magazine*, **September/October 2016**, 106–113.

Cowen, R.K. (1985) Large scale pattern of recruitment by the labrid, *Semicossyphus pulcher*: causes and implications. *Journal of Marine Research*, **43**, 719–742.

Foster, S., Wiswedel, S. & Vincent, A. (2016) Opportunities and challenges for analysis of wildlife trade using CITES data – seahorses as a case study. *Aquatic Conservation: Marine and Freshwater Ecosystems*, DOI: 10.1002/aqc.2493: n/a–n/a.

García-Berthou, E. (2007) The characteristics of invasive fishes: what has been learned so far? *Journal of Fish Biology*, **71**, 33–55.

Gardner, T. (2003) The copepod/*Artemia* tradeoff in the captive culture of *Hippocampus erectus*, a vulnerable species in lower New York State. In: *Marine Ornamental Species: Collection, Culture, and Conservation* (Cato J.C. & Brown, C.L. eds), pp. 297–303. Iowa State Press and Blackwell Publishing, Ames, Iowa, USA.

Gosse, P.H. (1856) *The Aquarium: An Unveiling of the Wonders of the Deep Sea*. J. Van Voorst, London, UK.

Green, B.S. & McCormick, M.I. (2005) Maternal and paternal effects determine size, growth and performance in larvae of a tropical reef fish. *Marine Ecology Progress Series*, **289**, 263–272.

Holmberg, R.J., Tlusty, M.F., Futoma, E., Kaufman, L., Morris, J.A. & Rhyne, A.L. (2015) The 800-pound grouper in the room: asymptotic body size and invasiveness of marine aquarium fishes. *Marine Policy*, **53**, 7–12.

Ito, T. (1960) On the culture of mixohaline rotifer *Brachionus plicatilis* OF Müller in the sea water. *Report of Faculty of Fisheries, Prefectural University of Mie*, **3**, 708–740.

Johnson, G.D. & Washington, B.B. (1987) Larvae of the Moorish idol, *Zanclus cornutus*, including a comparison with other larval acanthuroids. *Bulletin of Marine Science*, **40**, 494–511.

Kai, T.Y. (2012) The purple tailed *Pseudochromis luteus* is just one of many unknown dottybacks out there. http://reefbuilders.com/2012/03/06/pseudochromis-luteus/ (accessed 26 June 2016).

Lal, P. & Kinch, J. (2005) *Financial assessment of the marine trade of corals in Solomon Islands.* A report prepared for SPREP, FSPI, DFMR.

Llopiz, J.K. & Cowen, R.K. (2009) Variability in the trophic role of coral reef fish larvae in the oceanic plankton. *Marine Ecology Progress Series*, **381**, 259–272.

Lubzens, E., Tandler, A. & Minkoff, G. (1989) Rotifers as food in aquaculture. *Hydrobiologia*, **186**, 387–400.

Moe, M.A. (1976) Rearing Atlantic angelfish. *Marine Aquarist*, **7**, 17–26.

Moe, M.A. (1997) Spawning and rearing the large angelfish *Pomacanthus* sp.. *Aquarium Frontiers*, **5**, 14–24.

Moe, M.A. (2012) The way we were 1973: Breeding the clownfish, *Amphiprion ocellaris. Advanced Aquarist*, **2**, 10–16.

NOAA, National Oceanic and Atmospheric Administration. (2014) *Endangered and Threatened Wildlife and Plants; 12-Month Finding for the Eastern Taiwan Strait Indo-Pacific Humpback Dolphin, Dusky Sea Snake, Banggai Cardinalfish, Harrisson's Dogfish, and Three Corals Under the Endangered Species Act.* Federal Register **79 FR 74953**.

Olivotto, I., Planas, M., Simões, N., Holt, G.J., Calado, R. (2011) Advances in breeding and rearing marine ornamentals. *Journal of World Aquaculture Society*, **42**, 135–166.

ORA, Ocean Reefs and Aquariums. (2010) *Ocean Reefs and Aquariums [ORA] Announces Captive Bred Mandarins.* In: Press Release: http://glassbox-design.com/2010/ora-mandarin-goby-captive-bred/ (accessed 26 June 2016).

Pasaribu, I.H. (2008) *Guiding for Trading Coral Transplantation.* SK.09/IV/Set-3/2008, General Director of Forestry Protection and Natural Conservation.

Payne, M.F. & Rippingale, R. (2000) Rearing West Australian seahorse, *Hippocampus subelongatus*, juveniles on copepod nauplii and enriched *Artemia. Aquaculture*, **188**, 353–361.

Pedersen, M. (2014) New age mutant clownfishes. *CORAL Magazine*, **September/October 2014**, 44–47.

Potthoff, T., Kelley, S., Saksena, V., Moe, M. & Young, F. (1987) Description of larval and juvenile yellowtail damselfish, *Microspathodon chrysurus*, Pomacentridae, and their osteological development. *Bulletin of Marine Science*, **40**, 330–375.

Rhyne, A.L. (2010) The importance of open access in technology transfer for marine ornamental aquaculture: the case of hobbyist-led breeding initiative. *Aquaculture, Aquariums, Conservation & Legislation*, **3**, 269–272.

Rhyne, A.L., Penha-Lopes, G. & Lin, J. (2005) Growth, development, and survival of larval *Mithraculus sculptus* (Lamark) and *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae): economically important marine ornamental crabs. *Aquaculture*, **245**, 183–191.

Rhyne, A.L. & Tlusty, M.F. (2012) Trends in the marine aquarium trade: the influence of global economics and technology. *AACL Bioflux*, **5**, 99–102.

Rhyne, A.L., Tlusty, M.F., Schofield, P.J., Kaufman, L., Morris, J.A., Jr. & Bruckner, A.W. (2012a) Revealing the appetite of the marine aquarium fish trade: the volume and biodiversity of fish imported into the United States. *PLoS ONE*, **7**, e35808.

Rhyne, A.L., Tlusty, M.F. & Kaufman, L. (2012b) Long-term trends of coral imports into the United States indicate future opportunities for ecosystem and societal benefits. *Conservation Letters*, **5**, 478–485.

Rhyne, A.L., Tlusty, M.F. & Kaufman, L. (2014) Is sustainable exploitation of coral reefs possible? A view from the standpoint of the marine aquarium trade. *Current Opinion in Environmental Sustainability*, **7**, 101–107.

Rhyne, A.L., Tlusty, M.F., Szczebak J.T. & Holmberg R.J. (2015) When one code = 2,300 species: Expanding our understanding of the trade in aquatic marine wildlife. *PeerJ PrePrints* **3**, e1447.

Sadovy, Y., Mitcheson, G. & Rasotto, M.B. (2001) Early development of the mandarinfish, *Synchiropus splendidus* (Callionymidae), with notes on its fishery and potential for culture. *Aquarium Sciences and Conservation*, **3**, 253–263.

Schreiner, W. (1972) Breeding report – downfishes. *Marine Aquarist* **3**, 31–33.

Searcy, S.P. & Sponaugle, S. (2000) Variable larval growth in a coral reef fish. *Marine Ecology Progress Series*, **206**, 213–226.

Shields, R.J., Kotani, T., Molnar, A., Marion, K., Kobashigawa, J. & Tang, L. (2005) Intensive cultivation of a subtropical paracalanid copepod, *Parvocalanus* sp., as a prey item for small marine fish larvae. In: *Copepods in Aquaculture* (Lee, C.S., O'Bryan, P.J. & Marcus, N., eds), pp. 209–223. Blackwell Publishing, Oxford, UK.

Smith, K.F., Behrens, M.D., Max, L.M. & Daszak, P. (2008) U.S. drowning in unidentified fishes: scope, implications, and regulation of live fish import. *Conservation Letters*, **1**, 103–109.

Smith, K.F., Behrens, M., Schloegel, L.M., Marano, N., Burgiel, S. & Daszak, P. (2009) Reducing the risks of the wildlife trade. *Science*, **324**, 594–595.

Sprung, J. (1989) Baby mandarin. *Freshwater and Marine Aquarium*, **12**, 20–24.

Stier, A.C., Hein, A.M., Parravicini, V. & Kulbicki, M. (2014) Larval dispersal drives trophic structure across Pacific coral reefs. *Nature Communications*, **5**.

Talbot, R., Pedersen, M., Wittenrich, M.L. & Moe, M. (2013) *Banggai Cardinalfish: A Guide to Captive Care, Breeding, & Natural History*. Reef to Rainforest, Shelburne, Vermont, USA.

Thresher, R.E. & Brothers, E.B. (1985) Reproductive ecology and biogeography of Indo-west Pacific angelfishes (Pisces: Pomacanthidae). *Evolution*, **39**, 878–887.

Tissot, B.N., Best, B.A., Borneman, E.H., Bruckner, A.W., Cooper, C.H., D'Agnes, H., Fitzgerald, T.P., Leland, A., Lieberman, S., Mathews Amos, A., Sumaila, R., Telecky, T.M., McGilvray, F., Plankis, B.J., Rhyne, A.L., Roberts, G., Starkhouse, B. & Stevenson, T.C. (2010) How U.S. ocean policy and market power can reform the coral reef wildlife trade. *Marine Policy*, **34**, 1385–1388.

Tlusty, M.F. (2002) The benefits and risks of aquacultural production for the aquarium trade. *Aquaculture*, **205**, 203–219.

Tlusty, M.F. (2004) Small scale of production does not automatically mean small scale of impact. *OFI Journal*, **46**, 6–9.

Tlusty, M.F., Rhyne, A.L., Kaufman, L., Hutchins, M., Reid, G.M., Andrews, C., Boyle, P., Hemdal, J., McGilvray, F. & Dowd, S. (2013) Opportunities for public aquariums to increase the sustainability of the aquatic animal trade. *Zoo Biology*, **32**, 1–12.

US Coral Reef Task Force. (2000) The National Action Plan to Conserve Coral Reefs. http://coralreef.gov/CRTFAxnPlan9.PDF (accessed 26 June 2016).

Vagelli, A. (2011) *The Banggai Cardinalfish: Natural History, Conservation, and Culture of Pterapogon kauderni*. John Wiley and Sons, New York, USA.

Victor, B.C. (1986) Larval settlement and juvenile mortality in a recruitment–limited coral reef fish population. *Ecological Monographs*, **56**, 145–160.

Victor, B.C. & Randall, J.E. (2010) *Gramma dejongi*, a new basslet (Perciformes: Grammatidae) from Cuba, a sympatric sibling species of *G. loreto*. *Zoological Studies*, **49**, 865–871.

Wabnitz, C., Taylor, M., Green, E. & Razak, T. (2003) *From Ocean to Aquarium: The Global Trade in Marine Ornamental Species*. UNEP-WCMC, Cambridge, UK.

Wellington, G. & Victor, B. (1989) Planktonic larval duration of one hundred species of Pacific and Atlantic damselfishes (Pomacentridae). *Marine Biology*, **101**, 557–567.

Williams, S.C. (2014) Inner workings: Raising yellow tang. *Proceedings of the National Academy of Sciences of the United States of America*, **111**, 9367.

Wittenrich, M.L. (2013) The tang challenge – Inside the global push to rear captive-bred surgeonfishes. *CORAL Magazine*, **10**, 60–68.

Wittenrich, M.L., Baldwin, C.C. & Turingan, R.G. (2010) Larval development of laboratory reared Green Mandarinfish, *Synchiropus splendidus* (Teleostei: Callionymidae). *Aqua*, **16**, 7–18.

Wood, E.M. (2001) *Collection of Coral Reef Fish for Aquariums: Global Trade, Conservation Issues and Management Strategies*. Marine Conservation Society, UK.

Yahya, Y., Mustain, A., Artiawan, N., Reksodihardjo-Lilley, G. & Tlusty, M. (2012) Summary of results of population density surveys of the Banggai cardinalfish in the Banggai Archipelago, Sulawesi, Indonesia, from 2007–2012. *AACL Bioflux*, **5**, 303–308.