Conservation and management of ornamental coral reef wildlife: Successes, shortcomings, and future directions

Laura E. Dee, Stephanie S. Hori, Daniel J. Thornhill

Abstract

Trade in ornamental coral reef wildlife supports a multi-million dollar industry but in some places threatens vulnerable coral reef species and ecosystems due to unsustainable practices and lack of effective regulation. To supply this trade, fishers sometimes deplete fish populations and rely on practices, such as cyanide fishing, that harm coral reef organisms and habitats. The number of countries involved, dispersed fishing localities, and the diversity of species in trade present considerable impediments to conservation and management. For instance, traditional fisheries management techniques such as stock assessments and total catch limits may not be feasible for ornamental fisheries, which are characterized by limited data on population dynamics, stock status, and collection effort, as well as instances of illegal, under-reported, and unregulated fishing. A number of strategies to monitor, regulate, and manage the trade have been implemented with varying efficacy. In order to learn from previous attempts and identify promising approaches, we reviewed selected management practices and regulations from diverse settings, with attention to the effectiveness of each approach. Strategies reviewed include international agreements, marine protected areas, rotational closures, banned-species lists, quotas, cyanide detection, gear restrictions, size limits, licensing and limited entry into the fishery, and regulations on imports. Moratoriums on certain species, no-take reserves, tiered quota systems, and import and export restrictions, among others, provided examples of management successes. Further conservation and management improvements could be achieved through a wider application of successful strategies identified here and utilization of data-limited methods from food fisheries.

Keywords: Aquarium trade, Coral reef conservation, Coral reef fisheries, Ornamental fisheries, Sustainable fisheries management.

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1. Introduction

1.1. The ornamental coral reef wildlife trade and its ecological consequences

The trade in ornamental coral reef wildlife, which includes the aquarium, jewelry, and curio trades, supports a multi-million dollar industry (Grey et al., 2005; Wabnitz et al., 2003); however, collection practices and a lack of effective regulation and management may threaten vulnerable coral reef species (Thornhill, 2012; Tissot et al., 2010). Many species are targeted to supply this trade, primarily based on their size and aesthetics. Examples include brightly-colored juvenile or male fishes; stony corals with attractive skeletons or large, colorful polyps; and mollusks with colorful, ornate shells. The effects of the collection and trade in ornamental wildlife are less studied than other threats to coral reefs – including climate change, ocean acidification, overfishing, and nutrient pollution – in part due to the complexity of the trade, which targets hundreds of fish and invertebrate species (Rhyne et al., 2012; Wabnitz et al., 2003). Nevertheless, collection has reduced certain populations, introduced invasive species, and in rare cases caused localized extirpations (reviewed in Thornhill, 2012). For example, one of the most-studied ornamental species, the yellow tang (Zebrasoma flavescens) in West Hawaii, has declined in abundance (Savaris, 2005; Thorndyke, 2012). For example, one of the most-studied ornamental species, the yellow tang (Zebrasoma flavescens) in West Hawaii, has declined in abundance (Savaris, 2005; Thorndyke, 2012).

Even stony corals (order Scleractinia), the foundation of coral reef ecosystems, are collected. Their collection can reduce coral cover and concomitant ecological changes (Albins and Hixon, 2008; Lesueur et al., 2004). The most prominent example is the introduction of lionfish (Pterois volitans and P. miles) from the Indo-Pacific into the Caribbean and western Atlantic (Betancur et al., 2011). Since the 1990s, lionfish spread along the U.S. east coast and throughout the Caribbean (Betancur et al., 2011). These predators eat large quantities of native fishes resulting in reduced recruitment of Atlantic coral reef fishes, competition with native predators such as grouper, reduction of grazers like surgeonfish and parrotfish, and concomitant ecological changes (Albins and Hixon, 2008; Lesuer and Slattery, 2011).

The broader ecological consequences of collection for the trade are understudied from both fisheries and ecological perspectives. The coral reef wildlife trade targets species ranging from the foundation of coral reefs (e.g., corals and live rock for aquariums and home décor) to top predators (e.g., sharks for teeth, jaws, and other curio items; Grey et al., 2005; Knittweis and Wolff, 2010; Ross, 1984). One concern is that characteristics that make fish and invertebrate species attractive to aquarium enthusiasts can also lead to disproportionate impacts on the reef when these species are removed. For example, hobbyists’ preferences for species that consume algae or parasites could drive reductions of these species on the reef, potentially with trophic effects (e.g., Edwards and Shepherd, 1992; Rhyne et al., 2009; but see Tissot et al., 2004). The diversity of species and complexity of interactions on coral reefs make understanding population dynamics of coral reef wildlife and predicting the ecosystem-level consequences of their removal difficult.

1.2. Management challenges

The coral reef wildlife trade exhibits both notable similarities and differences from other capture fisheries, including characteristics that can impede resource management. Organisms from nearly every trophic level are collected, making identification and monitoring of collected species exceptionally challenging. The life history, demographic, and population data required for traditional stock assessments are typically unavailable (Fujita et al., in press; Honey et al., 2010). Even countries with higher management and enforcement capacity, such as the U.S., generally do not conduct stock assessments for ornamental species. In general, stock assessments for many species in the trade may be difficult because rare species are targeted. For rare species, accurate estimates of population size are difficult to obtain because their probability of detection in surveys is quite low (e.g., see Chadés et al., 2008). It is therefore difficult for managers to monitor populations and reefs, enforce regulations, document catches, and develop accurate population models.

Many locations have few (if any) regulations addressing the coral reef wildlife trade. In countries where regulations exist, enforcement is hindered by inaccurate reporting of landings (e.g., Walsh et al., 2004; Rhyne et al., 2012) and illegal collection (Barber and Pratt, 1997). Similar to issues with trans-boundary fisheries (McWhinnie, 2009), roving collectors are common in Southeast Asian fisheries and have little incentive to protect coral reef resources in a given area, because they may never return to the

A complex supply-chain creates challenges for managing the trade, especially in Southeast Asia. Similar to capture fisheries, many countries supply the trade and animals change hands many times between collection and export with no system to monitor this chain of custody (Amos and Claussen, 2009; Nixon et al., 2012). At each stage of the supply chain, animals from various sources are pooled, so separating sustainably-harvested wildlife from their unsustainable counterparts is difficult (Amos and Claussen, 2009). This supply chain complexity complicates reform in several ways. First, high supply-chain mortality can lead to market inefficiencies and drive overharvesting (Wabnitz et al., 2003). Second, the complex supply chain presents challenges for reducing destructive collection practices, like cyanide fishing, since cyanide is increasingly difficult to detect with time (Mak et al., 2005; but see Vaz et al., 2012). Third, import-documentation requirements are challenging when organisms change hands many times. All of these challenges would benefit from a shorter and more vertically-integrated supply chain (Nixon et al., 2012).

Despite the many similarities between ornamental fisheries and most capture fisheries in coral reefs, several unique characteristics of fisheries that supply the coral reef wildlife trade demand new management approaches and present difficulties (Donaldson, 2013). Two aspects differ greatly:

1. value is per individual rather than by biomass; and
2. for the aquarium trade, animals must remain alive in order to be sold.

Furthermore, collection of aquarium fishes differs from harvesting food fishes. It often targets juveniles, affecting the population’s age structure, and brightly-colored males, potentially skewing the sex ratios of the population.

1.3. Objective

Overcoming barriers to effective management and regulation is daunting given that trade includes over 1800 species of fish, hundreds of species of coral, over 500 species of other invertebrates, and live rock (Rhyne et al., 2012; Wabnitz et al., 2003;). Exports emerge from at least 45 countries while imports largely go to the U.S. (~64%), the E.U. (~14%), and Japan (~7%) (Tissot et al., 2010; Wabnitz et al., 2003). Our objective is to identify successful regulation and management approaches that could potentially be replicated elsewhere by reviewing select management practices around the world. For purposes of this discussion, we consider regulations to be a set of codified rules established to govern the trade, and management to be the implementation and enforcement of various conservation and fisheries measures, including regulations. This paper does not attempt to comprehensively review management effectiveness in each country involved in the ornamental coral reef wildlife trade; instead, it highlights the range of management techniques currently used or with potential to manage the trade. We first examine the application of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to govern the coral reef wildlife trade on an international-level (Section 3.1). Second, we review the laws, management practices, and fisheries management plans used for ornamental fisheries in exporting and importing countries (Section 3.2). We conclude by highlighting strategies that have been used successfully in other data-limited capture fisheries that may hold promise if they were applied to ornamental fisheries (Section 4).

2. Materials and methods

We reviewed the available peer-reviewed and grey scientific literature, as well as government websites and reports, on regulations and management practices by locality for the ornamental coral reef wildlife trade. The review focused primarily on practices within the aquarium trade, over other ornamental trade sectors (e.g., curios), because much of available conservation and management literature is on this topic. Literature was compiled primarily from online databases and search engines, including Web of Science (thomsonreuters.com/web-of-science), Google Scholar (scholar.google.com), PubMed (ncbi.nlm.nih.gov/pubmed), and Science Direct (sciencedirect.com). Search terms included some combination of the terms wildlife trade, aquarium trade, curio trade, or ornamental fisheries with country names, management practices, and names of the most heavily-traded species (as noted in Rhyne et al., 2012; Wabnitz et al., 2003; Wood, 2001). These sources were supplemented by more targeted searches for papers identified during the search process (e.g., from the references of another paper or report), suggestions from colleagues, and informal interviews with management practitioners, conservationists, and academics (see acknowledgements).

Countries that lacked source information were subsequently excluded from this review despite their contributions to the supply of coral reef wildlife (e.g., Mexico, Cook Islands, Solomon Islands, and Taiwan). Additional countries were excluded because no post-1996 source documentation was located (e.g., Samoa and the Cook Islands). Haiti was the one exception; it was maintained despite few sources on its practices due to its importance as an exporting country (Rhyne et al., 2012). This resulted in a broad review of existing management practices based on international agreements, the practices of three major wildlife importers (the U.S., European Union, and Australia), and the practices of 18 wildlife-exporting nations, states, and territories (Australia, Bahamas, Eritrea, Fiji, Haiti, Indonesia, Kiribati, Maldives, Philippines, Sri Lanka, Papua New Guinea, the Kingdom of Tonga, U.S.-Florida, U.S.-Guam, U.S.-Hawaii, U.S.-Puerto Rico, Vanuatu, and Vietnam).

Because this review examines international, national, and regional regulations and management, inevitably local and non-governmental organization (NGO) efforts have been overlooked. For example, during the Marine Aquarium Market Transformation Initiative within the Philippines, some villages developed total allowable catches for ornamental fish species and restricted fishing permits to villagers (D. Ochavilla, personal communication). Additionally, in both Indonesia and the Philippines, several villages developed fisheries management plans in conjunction with NGO partnerships, though these plans were not implemented at the national level. Due to length constraints, such local initiatives are not covered here.

3. Results and discussion

3.1. International agreements regulating the trade

Several international treaties and governing bodies set the foundation for nations to regulate harvesting of marine species (Table 1; Fidelman et al., 2012), yet few have been applied to the trade in coral reef species. The primary international mechanism regulating the coral reef wildlife trade is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), an agreement among 175 countries (CITES, 2012). Since 1975, CITES has aimed to ensure that the international trade in wildlife does not threaten species with extinction or endangerment. The species covered by CITES are listed in three Appendices,
Table 1
International agreements and guidelines, as well as U.S., E.U., and Australian regulations, related to the trade in coral reef wildlife.

<table>
<thead>
<tr>
<th>Year</th>
<th>Law or regulation</th>
<th>Target</th>
<th>Mechanisms and limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948</td>
<td>International Union for Conservation Nature Red List of Threatened Species</td>
<td>Conservation</td>
<td>Inventory on conservation status and extinction risk for species. Provides scientific advice, but lacks regulatory authority (IUCN, 2012; Vagelli, 2008)</td>
</tr>
<tr>
<td>1973</td>
<td>Convention on International Trade in Endangered Species</td>
<td>Trade</td>
<td>Restricts international trade in listed species. Protects only a few species in the trade and the process for listing additional species is cumbersome (Bruckner, 2001; Tissot et al., 2010)</td>
</tr>
<tr>
<td>1992</td>
<td>Agenda 21 and the Rio Declaration on Sustainable Development</td>
<td>Fisheries</td>
<td>Provides criteria for sustainable management of marine resources, funding mechanisms, and technology transfer to developing countries, but funding arrangements and technology transfers have not been widely implemented to facilitate sustainability (Dodds et al., 2012)</td>
</tr>
<tr>
<td>1993</td>
<td>Convention on Biological Diversity</td>
<td>Fisheries</td>
<td>International collaborative agreement to promote biodiversity conservation and sustainable resource use. The US, the largest consumer of coral reef wildlife, is not a member (Smith et al., 2008).</td>
</tr>
<tr>
<td>1995</td>
<td>World Trade Organization regulations</td>
<td>Trade</td>
<td>Restrictions on international trade among member nations. There is little enforcement on imports for the aquarium trade and inaccurate identifying/labeling/recordings of ornamental species imported into the US (Rhine et al., 2012; Smith et al., 2008).</td>
</tr>
<tr>
<td>1997</td>
<td>European Community Veterinary Controls</td>
<td>Trade</td>
<td>Requirements for species-level information and veterinary inspection of imports. Requires proof of quarantine and animal welfare measures as well as adherence to CITES. It requires no additional administrative burden for traders but possibly duplicates efforts of the Annex D of the WTR.</td>
</tr>
<tr>
<td>1997</td>
<td>Wildlife Trade Regulation EC 338/97</td>
<td>Trade</td>
<td>Acts as supplement to CITES, with importing countries held partly responsible for reporting violations. Creates dataset of CITES-listed species entering the EU (Annex D). More stringent than CITES, but lacks standardized protocols for collecting and managing information. The implementation of this regulation and its integration with CITES requirements varies across countries (Jones, 2008).</td>
</tr>
<tr>
<td>2000</td>
<td>Civil Asset Forfeiture Reform Act</td>
<td>Trade</td>
<td>Government authority to confiscate illegal assets. Dependent on the Lacey Act; burden of proof shifted to government (Thorson and Wold, 2010).</td>
</tr>
<tr>
<td>1999</td>
<td>Fisheries Management Act of 1991</td>
<td>Fisheries</td>
<td>Established the Australian Fisheries Management Authority to oversee fishing zones.</td>
</tr>
<tr>
<td>1999</td>
<td>Environmental Protection and Biodiversity Conservation Act</td>
<td>Fisheries/Trade</td>
<td>List of acceptable species for import and only allows live fish from approved countries (Morrissey et al., 2011).</td>
</tr>
</tbody>
</table>

Corresponding to the level of protection (Kinch and Teitelbaum, 2008):

- **Appendix I** provides the highest level of protection to species threatened with extinction and vulnerable to international trade. It strictly prohibits all international trade for commercial purposes. For instance, the hawksbill turtle (*Eretmochelys imbricata*) is listed on Appendix I, prohibiting all international trade in this species for jewelry and luxury items.

- **Appendix II** lists species that are not currently in danger of extinction but are threatened by over-exploitation. Export permits for Appendix II species can be issued by the exporting country only when (a) the Scientific Authority has advised that export will be non-detrimental to the survival of that species or when a Management Authority regulating exports is satisfied that (b) the specimen was not obtained illegally and (c) risk of injury and cruel treatment during transport was minimized for living specimens. Appendix II covers over 30,000 species, including the following coral reef wildlife species: over 2000 hard corals (including all scleractinians), all giant clams (*Tridacna* and *Hippopus* spp.), three species of hammerhead sharks (*Sphyrna* spp.), and all seahorses (*Hippocampus* spp.) (CITES, 2012; Jones, 2008). Although a number of other coral reef species have been proposed for Appendix II listing, for instance red and pink corals (*Corallium* and *Paracorallium* spp.) and the Banggai cardinalfish, these listing proposals were either withdrawn or rejected (Vagelli, 2008).

- **Appendix III** lists species that are protected by at least one member that requests enforcement assistance from other CITES members. In July 2008, China listed four *Corallium* species in CITES Appendix III, adding permit requirements for export of these corals from China (CITES, 2012).
Note that when CITES listed animals are “aquacultured,” or born and reared in captivity, these species move to the next Appendix (e.g., from Appendix I to II). This is done to reflect the generally lower ecological impact of aquaculture compared to wild collection.

Most of the thousands of species involved in trade are not CITES listed (CITES, 2012). The small number of listed species may not be indicative of the status of trade species, since few species in the coral reef wildlife trade have ever been evaluated for extinction risk by the International Union for the Conservation of Nature and CITES authorities (McClenachan et al., 2011), including only one of the top-10 traded aquarium fishes, *Centropyge bicolor* (Table 2). For listed species, the effectiveness of CITES protection has been questioned (Jones, 2008; Tissot et al., 2010). We illustrate these issues through two examples, Banggai cardinalfish and scleractinian corals (Supplemental Text).

### 3.2. Country-level regulations and management

The United Nations Convention on the Law of the Sea established Exclusive Economic Zones (EEZs) that grant coastal countries jurisdiction over their near-shore marine resources and the responsibility to conserve and manage natural resources. Species collected for the aquarium and ornamental trades are almost entirely shallow water, reef-associated species that reside within EEZs (Supplemental Table 1); therefore, countries have greater potential control over the harvest of coral reef wildlife in contrast to the many highly-migratory species targeted by food fisheries. Nations have implemented various measures to protect coral reef species, including marine protected areas (MPAs), harvest regulations (e.g., gear type, permits, quotas), and/or required documentation (e.g., quarantine certification) (Morissey et al., 2011; Smith et al., 2008; Wood, 2001). These laws and initiatives either directly (e.g., species-specific quotas for aquarium fishes) or indirectly (e.g., no-take reserves that protect coral reef habitats and associated wildlife) regulate collection. The success of management regimes and regulations varies greatly. In Sections 3.2.1–3.2.2 and Tables 1, 3 and 4, we highlight examples of strategies adopted by both importing and exporting countries.

Management actions currently or potentially used for ornamental trade species (Table 3):

- **Gear restrictions** are commonly used in both food and ornamental fisheries to either prevent negative impacts on habitats or on non-target species (bycatch). Ornamental fisheries commonly restrict gear usage and fishing methods, including cyanide fishing.
- **Total bans** prohibit collection of certain species, which should allow for populations to recover provided that reproductively-viable populations remain, habitat is protected, and poaching is minimized. For instance, species listed under CITES Appendix I and the Endangered Species Act in the U.S. are banned from trade. Similarly, the Philippines banned collection of giant clams, seahorses, and black and scleractinian corals.
- **Limited effort** programs attempt to control total harvest by limiting overall harvesting effort. In the aquarium trade, effort limitation has only restricted who can fish. Although season restrictions are common in capture fisheries, to our knowledge, they are not widely used in ornamental fisheries.
- **Total allowable catch (TAC)** is an aggregate annual quota for a fishery that is often set using stock assessments – complex population models that determine the status of a fishery and predict how populations will respond to harvest rules. Country-level export quotas, aggregate TACs on the number of fish that can be exported in a given year, are commonly employed by Pacific island nations.
- **Rights-based fisheries management**, sometimes called “catch shares,” refers to fisheries management strategies that allocate exclusive access to a portion of the TAC to individuals or groups of fishers (Costello et al., 2008). Catch share programs establish property rights to an otherwise common-pool or open-access resource, and they also exist in the form of traditional marine tenure (Hilborn et al., 2005). In some ornamental fisheries, property rights are established through exclusive fishing zones for local communities or individuals called **Territorial User Rights Fisheries (TURFs)**.
- **Spatial closures and zoning** aim to protect biodiversity and allow for the recovery of fished species by prohibiting or zoning fishing and other impactful activities in certain areas (e.g., no-take marine reserves and MPAs). Fish replenishment areas (FRAs) in West Hawai‘i specifically prohibit the collection of ornamental fishes (Tissot et al., 2004).
- **Size limits** restrict fishing or collection to a species above or sometimes below a certain size threshold to protect a certain portion of the breeding stock and allow the

### Table 2

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Common name</th>
<th>Scientific name</th>
<th>IUCN Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquarium</td>
<td>Blue green damsel fish</td>
<td><em>Chromis viridis</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Sapphire devil</td>
<td><em>Chrysiptera cyanea</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Yellow tang</td>
<td><em>Zebrasoma flavescens</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Clown anemone fish</td>
<td><em>Amphiprion ocellaris</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Azure demoiselle</td>
<td><em>Chrysiptera hemiscyana</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Three spot dascyllus</td>
<td><em>Dascyllus trimaculatus</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Blacktail humbug</td>
<td><em>Dascyllus melanarius</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquarium</td>
<td>Australian damsel</td>
<td><em>Pomacentrus australis</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Aquuarium</td>
<td>Goldtail demoiselle</td>
<td><em>Chrysiptera paraseema</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Food</td>
<td>Bicolour angel fish</td>
<td><em>Centropyge bicolor</em></td>
<td>Least Concern</td>
</tr>
<tr>
<td>Food</td>
<td>Anchoveta</td>
<td><em>Engraulis ringens</em></td>
<td>Least Concern</td>
</tr>
<tr>
<td>Food</td>
<td>Alaska pollock</td>
<td><em>Theragra chalcogramma</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Food</td>
<td>Atlantic herring</td>
<td><em>Clupea harengus</em></td>
<td>Least Concern</td>
</tr>
<tr>
<td>Food</td>
<td>Skipjack tuna</td>
<td><em>Katsuwonus pelamis</em></td>
<td>Least Concern</td>
</tr>
<tr>
<td>Food</td>
<td>Chub mackerel</td>
<td><em>Scambus japonicus</em></td>
<td>Least Concern</td>
</tr>
<tr>
<td>Food</td>
<td>Largehead hairtail</td>
<td><em>Trichurus lepturus</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Food</td>
<td>Blue whiting</td>
<td><em>Micromesistes poutassou</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Food</td>
<td>Chilean jack mackerel</td>
<td><em>Trachurus murphyi</em></td>
<td>Data deficient</td>
</tr>
<tr>
<td>Food</td>
<td>Japanese anchovy</td>
<td><em>Engraulis japonicas</em></td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Food</td>
<td>Yellowfin tuna</td>
<td><em>Thunnus albacares</em></td>
<td>Near threatened</td>
</tr>
</tbody>
</table>
population to grow. A 10-cm minimum size limit is often used in seahorse fisheries (Foster and Vincent, 2005).

- National regulations on import/export practices can impose requirements (e.g., documentation, permitting, or quarantine procedures) that can regulate wildlife import, export, and handling practices. These requirements can help control the spread of disease and invasive species as well as the mortality of species in the supply chain. For instance, Australia imposes stringent import requirements (reviewed in Morrissey et al., 2011).

Case studies highlighting the use of these strategies in both exporting and importing countries are presented in Sections 3.2.1 and 3.2.2, respectively.

3.2.1. Exporting nations

3.2.1.1. Indonesia. At the epicenter of coral reef biodiversity, Indonesia has consistently been a top exporter of coral reef wildlife for over 30 years (Rhyne et al., 2012; Wabnitz et al., 2003). Historically Indonesian reefs were open to all extractive uses, but the government has recently attempted to better regulate its natural resources (Amos and Claussen, 2009; Nurhidayah, 2010). The Ministry of Marine Affairs and Fisheries formulates national policy for fisheries management and conducts resource assessments (Dudley and Ghofar, 2006). Management is divided into 11 fisheries management areas and several fisheries groups (Dudley and Ghofar, 2006; CCIF, 2013). Coral reef fish, including ornamental and food fish species, comprise one group (Dudley and Ghofar, 2006). Since the late 1990s, local authorities have been primarily responsible for resource utilization, conservation, and development and implementation of management plans (Dudley and Ghofar, 2006; Fidelman et al., 2012; Nurhidayah, 2010; Timotius et al., 2009).

Management measures for ornamental species include ’business’ licensing systems, a 1985 ban on destructive fishing practices including cyanide fishing, harvest quotas on stony corals, and MPAs (Dudley and Ghofar, 2006; Pet and Pet-Soede, 1999). Despite this range of measures, effective management is stymied on many levels, leading Indonesian fisheries to be described as de facto open access (CCIF, 2013). For example, fish and vessel licensing requirements are not consistently enforced, and small-‐scale fishers are not required to obtain licenses. The prevalence of small-‐scale fishing and the lack of systematic requirements limit the effectiveness of licensing (Dudley and Ghofar, 2006; CCIF, 2013). The ban on cyanide fishing is rarely, if ever, enforced (Pet and Pet-‐Soede, 1999). Implementing management at regional and local scales is challenged by the decentralized governance structure, a lack of enforcement and resource management capacity, and corruption (Amos and Claussen, 2009; CCIF, 2001; Dudley and Ghofar, 2006; Nurhidayah, 2010; Pet and Pet-‐Soede, 1999). This decentralized management ineffectively supervises “roving” collectors – a major source of overharvesting in Indonesia – who commonly travel between different jurisdictions to collect while ignoring collection regulations (Amos and Claussen, 2009; CCIF, 2013; Marine Aquarium Market Transformation Initiative, 2006).

Although there are not harvest quotas for most ornamental species, Indonesia has established collection quotas for many scleractinian corals (Green and Shirley, 1999). Approximately 1 million live coral pieces are permitted for export annually, including a growing number of farmed corals (Wood et al., 2012). The quotas’ efficacy is challenged by weak enforcement and a lack of population data to set total-‐allowable catches (Green and Shirley, 1999). A comparison of the quotas to population assessments indicated that – depending on the targeted genus – 1–96% of available coral populations could be collected thereby allowing for over-‐exploitation of certain corals (Bruckner and Borneman, 2006). Oftentimes there are no size restrictions on collection, allowing for the removal of important demographic groups (Bruckner and Borneman, 2006).

The lack of stock assessments and quotas for the many species leave MPAs as the most widely used measure for coral reef fish conservation in Indonesian (Dudley and Ghofar, 2006). Indonesia maintains a reserve system, including national parks, comprising 2% of Indonesia’s EEZ (World Bank, 2013). MPAs have been shown to be a useful management tool for marine ornamental species (e.g., Tissot et al., 2004), but the presence of MPAs alone does not ensure effective management. For instance, a more extensive MPA system is needed to effectively maintained connectivity in the popular aquarium coral Heliofungia actiniformis (Knittweis et al., 2009) Thus, although Indonesia utilizes management tools ranging from licensing and gear restrictions to quotas and MPAs, various studies have called for additional measures and improvements (Bruckner and Borneman, 2006; Dudley and Ghofar, 2006; Green and Shirley, 1999; Knittweis et al., 2009; Knittweis and Wolf, 2010).

3.2.1.2. The Philippines. The Philippines is another primary exporting nation of ornamental coral reef wildlife, with major source localities in Bataan, Batangas, Bohol, Cebu, Davao, Palawan, and Zambales (Ochavillo et al., 2004; Rhyne et al., 2012). Overall the Philippines supplies the majority – approximately 55% – of the marine aquarium fish imported into the U.S. (Rhyne et al., 2012). The Philippines conducts limited national-‐level fisheries management under the Philippine Fisheries Code. Similar to Indonesia, fisheries management is largely decentralized; Local Government Code of 1991 delegated management authority primarily to barangays or local government units (Gonzales and Savaris, 2005). In most local jurisdictions, there is little management or enforcement capacity and poor data collection (Gonzales and Savaris, 2005; Ochavillo et al., 2004).

Fishers in the Philippines are typically required to have a license or appropriate accreditation to collect coral reef wildlife (Gonzales and Savaris, 2005). However, there are no limits on the total number of licenses (Gonzales and Savaris, 2005), reducing their effectiveness as a management tool to control fishing effort (FAO, 2013). Additionally, roving collectors, who often ignore licensing requirements, make up a sizeable portion of collection activity (Marine Aquarium Market Transformation Initiative, 2006; S. Green, personal communication).

Beyond licensing of collectors, the Philippines prohibits export of species listed on Appendix II of CITES, including stony corals and seahorses. The stony coral trade was once based primarily on Philippine corals until collection and export was outlawed (Ross, 1984). Commercial collection of stony corals continued for several years, especially in the Cebu region, but the coral trade ultimately dwindled (Ross, 1984). The Philippines also banned trade in giant clams and seahorses following their listing in CITES Appendix II in 1996 and 2002, respectively (Vincent et al., 2011; Wabnitz et al., 2003). For seahorses, exports from the Philippines had ceased by 2006 (Vincent et al., 2011) and recent CITES data indicate a global reduction in the seahorse trade, possibly resulting from the Philippine ban (Evanson et al., 2011). For most species, there are no catch limits, species quotas, size limits, or restocking programs (Gonzales and Savaris, 2005; Ochavillo et al., 2004). Perhaps as a result of the few management measures in place, overfishing of coral reef species is reported (e.g., Ross, 1984; Saddovy et al., 2001; Shuman et al., 2005).

Finally, the Philippines controls exports of coral reef wildlife through a permitting process and limited testing for cyanide in live fish. Although anticyanide laws exist, these bans are commonly unenforced (Ochavillo et al., 2004). In the late 1980s and 1990s, the government and the International Marinelife Alliance jointly
established a set of Cyanide Detection Laboratories (CDL) (Barber and Pratt, 1997; Barber, 1999; Rubec et al., 2001). However, detection of cyanide is technically difficult, and the accuracy of the CDL tests has been questioned (Mak et al., 2005; Bruckner and Roberts, 2008). Currently, there is only one active CDL, so very few exported shipments are tested. Despite this, the recent innovation of a new and more reliable cyanide test, which uses optical fiber technology to detect thiocyanate, may enable the Philippines and others to better control the trade in cyanide-caught fish (Vaz et al., 2012).

3.2.1.3. The Maldives. Since the inception of the Maldives’ aquarium trade in the 1980s, the government has monitored the collection and export of coral reef fish (Edwards and Shepherd, 1992). In 1988, concern over the trade’s sustainability and conflicts with the diving-tourism industry led the government to establish an aggregate export quota of 100,000 coral reef fish and invertebrates per year (Edwards and Shepherd, 1992). Collectors and exporters were required to report the volume of exported coral reef fish to customs officials and fishing was only permitted until the quota was reached (Edwards and Shepherd, 1992). Although this precautionary measure was laudable, it insufficiently protected species from over-exploitation. A combined analysis of export data, field surveys of fish abundance, and rough estimates of Maximum Sustainable Yield concluded that many coral reef species were potentially overexploited by over-collection under this aggregate quota system (Edwards and Shepherd, 1992).

Further management measures were added in response to such concerns, for example a 1997 ban on destructive moxy nets (Edwards and Shepherd, 1992; Saleem and Islam, 2008). Cyanide fishing, although never reported in the Maldives, was also banned (Saleem and Islam, 2008). In 1995 and 1999, twenty-five MPAs were established as no-take reserves (Saleem and Islam, 2008). Still, monitoring and enforcement for these systems were lacking, leading the government to implement a species-specific quota program (Saleem and Islam, 2008; Wood, 2001).

This latest Maldives management system divides fish into three categories or tiers. Category A bans export of 17 species that are considered highly vulnerable (Saleem and Islam, 2008; see Saleem and Adam, 2004 for lists of species in each category). Furthermore, parrotfish, puffer fish, porcupine fishes, eels, giant clams, and hard corals other than Tubipora musica are barred from export under this system (Saleem and Islam, 2008). Chromis viridis, a popular aquarium species (Rhine et al., 2012), is prohibited due to its use as bait for tuna fishing (Saleem and Islam, 2008). The second tier (Category B) includes 66 species managed under species-specific quotas (Saleem and Adam, 2004; Saleem and Islam, 2008). The remaining 71 species (Category C) are managed under a 300,000 organism aggregate quota for the entire country (Saleem and Islam, 2008). The efficacy of the tiered quota system is currently under evaluation by the Marine Research Centre and Marine Conservation Society.

Saleem and Islam (2008) noted the apparent effectiveness of the new system, but also highlighted significant challenges, including weak enforcement, unnecessary bureaucracy, a lack of monitoring officials familiar with exported species, confusion between common and scientific names for exported species, under-reporting of value to avoid purchasing additional licenses, and roving collectors. By incorporating quotas built on data from species-specific stock estimates and export records, the tiered system is superior to the previous open-access system. However, these data are of uncertain reliability and have not been applied to monitor changes in the stocks of collected species or for setting appropriate catch limits (Saleem and Islam, 2008).

3.2.1.4. The Kingdom of Tonga. The Kingdom of Tonga is an active exporter of fish and invertebrates for the ornamental aquarium trade. Tonga uses a licensing system to cap the total number of businesses collecting and exporting coral reef wildlife at five companies (Fisheries Management and Planning Section, 2008; Matoto et al., 1996). On the reef, collectors must adhere to strict gear controls that ban the use of poisons and damaging gear, only allow the use of hand or barrier nets, and restrict the use of scuba diving to authorized collectors (Fisheries Management and Planning Section, 2008). Limiting the spatial extent and amount of collection effort, Tonga confines aquarium fish and invertebrate collection to certain areas and has a blanket quota of 100,000 fish per exporting company annually (Fisheries Management and Planning Section, 2008). This aggregate volume of fish is considered to be a “negligible fraction” of the biomass of targeted species (Matoto et al., 1996), suggesting that collection is largely sustainable. Nevertheless, no stock assessments have been conducted to determine the status of targeted species.

Species that are susceptible to overharvesting may be insufficiently protected under this system, because management is not conducted on a species-by-species basis. Although no quotas are placed on the harvest of invertebrates or soft corals, Tonga prohibits the collection of dead hard corals and live rock. Tonga also requires exporters to provide detailed reports on the volume of animals exported (Marine Aquarium Fishery Management Plan, 2008). This suite of management tools provides Tonga with a relatively-comprehensive management program, particularly for aquarium fishes.

3.2.1.5. Australia. Australia exports wildlife to supply the trade, and this collection is regulated under the national Environmental Protection and Biodiversity Conservation Act of 1999. While allowing the export and trade in wildlife, this Act also places responsibility on state governments to develop fisheries management plans (Department of Primary Industries and Fisheries, 2009). Approximately 50% of collection for the coral reef wildlife trade in Australia occurs in Queensland where three aquarium fisheries operate: the Queensland Marine Aquarium Fish Fishery (MAFF), the Queensland Coral Fishery (QCF), and the Coral Sea Fishery.

The Queensland Government regulates the MAFF and the QCF by restricting destructive gear types and limiting entry through a licensing system, which has not issued new commercial licenses since 1997 (Roelofs and Silcock, 2008). Both fisheries operate in the Great Barrier Reef Marine Park that protects approximately 30% of the available habitat from fishing. The MAFF (48 licenses) employs different combinations of management techniques including catch quotas, bans on certain species, size limits, and seasonal closures (Roelofs, 2008a). For one, MAFF collection rates are compared to sustainability benchmarks based on ecological risk assessments (Roelofs, 2008a; Roelofs and Silcock, 2008).

The QCF (59 licenses), also state managed and regulated, is primarily managed under the Policy for the Management of the Coral Fishery (Department of Primary Industries and Fisheries, 2009). Management under this policy includes a total allowable commercial catch (TACC) of 200 tonnes, separated into 140 tonnes for ornamental corals (coral skeletons of acroporids and pocilloporids collected alive and dried for ornamental purposes) and live rock. The remaining 60 tonnes is allocated to “specialty coral” (hard and soft coral and anemone species taken for live aquaria). The smaller TACC for specialty coral recognizes that these species may not be as highly productive as other ornamental coral species (but see Jones, 2011). PMS and risk assessments also monitor the status of this fisheries (Roelofs, 2008b).

The adjacent Coral Sea Fishery (with 2 licenses) falls under the jurisdiction of the Australian Fisheries Management Authority and includes the collection of marine fishes and limited collection of live rock (Australian Fisheries Management Authority, 2011). Collection is monitored and compared to tiers of precautionary catch
thresholds. Management responses are initiated when the thresholds are reached.

3.2.1.6. The United States: Hawaii and Florida. The U.S. states of Hawaii and Florida and territories of Puerto Rico and Guam supply the coral reef wildlife trade. Each location has adopted different management measures for their fish and invertebrate fisheries (Table 3). Here, we focus on the management practices adopted in Hawaii and Florida.

3.2.1.6.1. Spatial management in Hawaii. The Hawaiian aquarium fishery has grown substantially over its 50-year history into the state’s second-largest inshore fishery. Annually, the fishery lands over 708,800 animals, but the total catch is underestimated due to under-reporting (Walsh et al., 2004). Collection is concentrated on several species, particularly yellow tang, with the top-10 species comprising ~73% of the annual aquarium-fish catch (Walsh et al., 2004). Since 1953, the government of Hawaii has restricted collection gear to small nets and traps. Today, permits are available to anyone for a small fee. The collection of stony corals, however, is illegal.

Since as early as 1970, collection has reduced the abundances of target species (Tissot and Hallacher, 2003; Tissot et al., 2004). The volume of fishes taken from Hawaiian reefs has generated public concern about the long-term sustainability of the ornamental reef fish collection (Tissot and Hallacher, 2003; Capitini et al., 2004). In response, in 1973 the Hawaii Division of Fish and Game required fishers to file catch reports, yet the number of permits issued and fish caught continued to increase over time (Walsh et al., 2004). Increasing fish collection along with growing public awareness of population declines intensified conflicts between the tourism industry – the largest economic driver in Hawaii – and the aquarium fishery (Capitini et al., 2004), including an unsuccessful attempt to ban the aquarium fishery in 1997–1998 (Hawai’i Department of Land and Natural Resources, 2010). Efforts for a statewide ban continue today (Miller, 2012). As an alternative measure, Hawaii implemented Fish Replenishment Areas (FRAs) in 2000 – the first no-take zones specifically targeting aquarium collection – to protect aquarium-fish populations and reduce user conflicts (see Capitini et al., 2004 for details on FRAs establishment). The FRAs, combined with existing MPAs, protect 35.2% of the Kona coast from aquarium fish collection (Tissot et al., 2004; Williams et al., 2009).

From an ecological perspective, the abundance of some targeted species increased within FRAs, but the stock size of these species may not have increased overall. Within the FRAs, 8 out of the top-10 targeted populations appear to be recovering, with 4 species exhibiting statistically-significant increases in abundance (e.g., yellow tang, Hawai’i Department of Land and Natural Resources, 2010; Williams et al., 2009). Some adult fish have spilled over into areas adjacent to the FRA boundaries (Williams et al., 2009) and larval fish are dispersing from the FRAs into the collection zones (Christie et al., 2010). The effectiveness of the FRAs varies among sites (see Ortiz and Tissot, 2008). Outside of the FRAs, collection is now concentrated in the remaining open areas, collection effort remains high, and there are no catch limits (Stevenson and Adams, 2003). Since FRAs were established, overall populations of yellow tang have continued to decline (Williams et al., 2009). For management outside of FRAs, the West Hawai’i Fisheries Management council recommended developing a ‘white list’ of 25-aquarium species that can be collected (Hawai’i Department of Land and Natural Resources, 2010). Ornamental fisheries in Hawaii do not employ catch limits, weakening the effectiveness of the licensing and the FRAs at controlling effort.

Elsewhere in the Waikiki-Diamondhead Fisheries Management Area of Oahu, periodic closures have been attempted to protect reef fish from overharvesting (i.e., Williams et al., 2006). These periodic closures temporarily increased the population of many species, including yellow tang, but fish populations declined dramatically when areas were open for harvesting (Williams et al., 2006).

3.2.1.6.2. Effort and catch controls in Florida. The Florida Keys supports a multi-species ornamental fishery, primarily targeting invertebrates, which has grown in size and impact since 1987 (Rhyne et al., 2009). While Hawaii implemented spatial management through its FRAs, Florida regulates the commercial harvest of ornamental species through licensing requirements, allowable gear types, and harvest restrictions including quotas, closed seasons or areas, size limits, and bans on certain species (Larkin et al., 2001; Larkin and Adams, 2003). Most notably, the state controls collection of ornamental invertebrates by limiting the number of available harvest licenses for both commercial and recreational collectors, including a 1998 moratorium on new licenses (Larkin and Adams, 2003). By limiting entry into the fishery, this cap attempts to reduce collection effort and overharvesting while generating profits for permit holders. For aquarium fishes, Florida employs several management strategies to regulate collection (e.g., daily catch limits as well as minimum and maximum size limits for butterfly and angelfishes) (Larkin et al., 2001; Wood, 2001).

For invertebrates, this limited-entry program restricts the number of participants, but it does not limit catch volume or collection effort (Rhyne et al., 2009). These licenses allow fishers to collect most species unrestrictedly – with the exception of long-spine sea urchins (Diadema antillarum), Bahama starfish (Oreaster reticulatus), sea fans (Gorgonia flabellum and G. ventailina), stony corals (Scleractinia), and fire corals (Millepora spp.) (Larkin et al., 2001). In the absence of catch limits, the limited entry program has not reduced fishing pressure or collection effort, because the majority of collection is done by a minority (~40%) of permit holders (Larkin and Adams, 2003; Rhyne et al., 2009). Catch landings and the number of targeted species have actually increased since the program’s implementation (Rhyne et al., 2009).

Several ornamental species also have daily bag limits that control the volume of the species (both fishes or invertebrates) caught by both commercial and recreational fishers. However, these bag limits are not set based on an overall TAC for the season or on stock assessments. Setting TACs for this fishery would be challenging for several reasons: the fishery targets multiple species, no stock assessments exist, catch landings are underreported despite Florida law requiring reporting, and fishing effort, such as the quantity of gear and time spent collecting, is not reported or measured (Rhyne et al., 2009).

3.2.2. Importing nations

3.2.2.1. United States. The United States accounts for the majority (~64%) of the global market for marine aquarium fish and other coral reef wildlife (Tissot et al., 2010). The U.S. Fish and Wildlife Service is responsible for documenting the volume and abundance of live wildlife imports at U.S. ports of entry, but the volume and diversity of trade makes this monitoring challenging (Rhyne et al., 2012; Smith et al., 2008; Tissot et al., 2010). Three federal laws – the Lacey Act, the Endangered Species Act, and the Magnuson-Stevens Fishery Conservation and Management Act – are the primary legal protections for coral reef wildlife entering the U.S. (Smith et al., 2008; Tissot et al., 2010).

Under the Endangered Species Act (ESA), the U.S. currently safeguards two coral species, Acropora palmata, and A. cervicornis, with 66 additional species under consideration for listing at the time of this writing. The ESA requires the conservation of listed species, including protection of critical habitat as well as prohibition of interstate and foreign commerce. States, including Hawaii and Florida, prohibit most collection of stony corals; however, imports of most coral species are allowed.
The Lacey Act bans the importation of organisms collected in violation of the laws of the source country. Cyanide fishing is banned in most countries, and therefore importation of wildlife caught with cyanide is unlawful. Nonetheless, importation of fishes captured using cyanide continues due to a lack of enforcement in source countries and the difficulty of detecting cyanide in fishes (Bruckner and Roberts, 2008). Cyanide is rapidly metabolized – meaning that detection is technically difficult and time sensitive (reviewed in Mak et al., 2005) – thereby hindering the application of the Lacey Act. However, a recently developed cyanide detection method may overcome these challenges (Vaz et al., 2012). The utility of the Lacey act in promoting global coral wildlife conservation is constrained by the environmental laws of the source countries.

A second provision of the Lacey Act prohibits knowingly allowing any wild animal or bird to be imported under inhumane or unhealthy conditions. Practices that cause high supply-chain mortality appear to be prohibited under this provision; however, the Lacey Act is not invoked because demonstrating that an importer knowingly permitted a violation to occur is difficult. Additionally, the provision has not been interpreted to include imports of fish or other coral reef wildlife species.

The Magnuson-Stevens Act in part aims to conserve and manage fishery resources in federal waters, focusing primarily on food fisheries. Although coral reef wildlife is collected from federal waters, domestic harvesting for ornamental uses occurs primarily in state jurisdictions, outside of the scope of the Magnuson-Stevens Act. The Act regulates some precious coral species. Effective January 30, 2012, a rule was issued for the collection of “aquarium trade species” in federal waters of the Caribbean. However, this rule has not been fully implemented and does not specify which species are included, so its effectiveness remains to be determined.

3.2.2.2. Countries of the European Union. Countries of the European Union (E.U.) are second only to the U.S. as importers of coral reef wildlife (Tissot et al., 2010; Wood, 2001). The E.U. established high regulatory standards for customs procedures, animal welfare, and invasive species (European Commission, 2010; Wood, 2001). The E.U. requires adherence to CITES regulations, membership in the World Organization for Animal Health, and that exporters provide proof of quarantine measures (European Commission, 2010). Wildlife Trade Regulation EC 338/97 supplements CITES by allowing importing countries to question trade sustainability from the source country and further enables an E.U. Scientific Review Group (SRG) to investigate (Jones, 2008; Kinch and Teitelbaum, 2008). A negative SRG ruling can ban imports from that country (Jones, 2008).

The SRG has significant power to protect marine aquarium wildlife that “have a high mortality rate during transport and are unlikely to survive in captivity for a considerable proportion of their life span” (European Commission, 2010). In 1998 and 2000, the SRG temporarily suspended imports for 25 coral species from Indonesia until data demonstrating sustainable management were provided (Bruckner and Borneman, 2006). Since then, additional reviews have been conducted and new wildlife import suspensions imposed on other species and countries (e.g., E.U., 2011). Such suspensions enable importing countries to play a more proactive and precautionary role in coral reef conservation. The global benefit of this legislation is limited, however, because other

Table 3
The presence and absence of various management strategies in 18 exporting countries, states, and territories. “X” denotes a management strategy that has been implemented in a location for multiple groups of species. “NA” indicates no record of the management strategy being planned or implemented in these countries in the literature reviewed here. Given the wide diversity of species targeted by the trade, management often differs across groups of species within a country or territory. “X” refers to management that only applies to corals and live rock. “X” refers to management that only applies to fishes. “X” refers to management that only applies to ornamental invertebrates other than corals. In other places, management actions were only applied to 1 species, which was noted when the information was available. The quality, quantity, and availability of information differed dramatically across regions. “X” refers to management for which the information may be outdated (such as outdated stock assessments). “NA” denotes no information or insufficient or unreliable/conflicting information to score a particular category.

<table>
<thead>
<tr>
<th>Producing country or territory</th>
<th>Size of fishery</th>
<th>Fishery management plan</th>
<th>Fisheries: Barriers to entry</th>
<th>Fisheries: Regulating commercial collection methods</th>
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<tr>
<td></td>
<td>Relative size</td>
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<td>License or permit required</td>
<td>Limited licenses for individual species</td>
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<td>X</td>
<td>X</td>
<td>1 species</td>
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<tr>
<td>Vietnam</td>
<td>Large</td>
<td>No</td>
<td>NA</td>
<td>NA</td>
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major importers, particularly the U.S. and Japan, have less restrictive rules on imports (Tissot et al., 2010).

3.2.2.3. Australia. Australia has been one of the most successful in regulating and managing the coral reef wildlife import trade (CCIF, 2001; Wood, 2001). Australia utilizes stringent quarantine and anti-invasive species regulations to monitor the import and domestic transportation of coral reef wildlife. These measures include a list of species permitted for trade, called a “whitelist,” created under the 1999 Environment Protection and Biodiversity

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<table>
<thead>
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<th>Property rights</th>
<th>Species protection</th>
<th>Ecosystem protection</th>
<th>Trade standards</th>
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<td>Territorial user right fisheries&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Individual transferenceable quotas</td>
<td>Trade Restrictions (export inspection, quarantine laws)</td>
<td>Bans or laws prohibiting catch of endangered species</td>
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<sup>a</sup> A. Roelofs (2008a, 2008b), personal communication and Australian Fisheries Management Authority (2011).
<sup>b</sup> FAO (2009).
<sup>c</sup> J. Comley, personal communication, Manoa (2008) and Teh et al. (2009).
<sup>e</sup> Beta et al. (2005).
<sup>f</sup> Saleem and Adam (2004) and Saleem and Islam (2008).
<sup>g</sup> Saleem and Adam (2004), Gonzales and Savaris (2005), Ochavilla et al. (2004) and S. Green, personal communication.
<sup>j</sup> Marine Aquarium Fishery Management Plan (2008).
<sup>k</sup> Larkin et al. (2001) and Larkin and Adam (2003).
<sup>l</sup> Brazil et al. (2005) and Walsh et al. (2004).
<sup>m</sup> D. Ochavilla, personal communication and WPRFMC (2005).
<sup>o</sup> Kinch and Tettelbaum (2008), SPC (2009) and Vanuatu Fisheries Management Plan of 2009.
<sup>p</sup> Rhyne et al. (2012) and Wood (2001); Small $\leq$50,000 specimens exported annually (value $<100,000 USD); medium = 50,000–100,000 exported specimens ($150,000 USD); large = 100,000–200,000 exported specimens ($300,000 USD); very large $\geq$200,000 specimens exported ($>300,000 USD).
<sup>q</sup> EDF (2012).
<sup>r</sup> Wood (2007).

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Table 4

Summary of trends in management strategies and regulations employed by 18 exporting countries or territories (Table 3). Regardless of the regulations and strategies in place, the efficacy of any measure depends on enforcement and fishers’ compliance.

- 72% have gear restrictions; 77% ban cyanide use
- Marine Protected Areas represented $\geq$2% of the EEZ<sup>c</sup> for 43% of these countries; however, with the exception of the FRAs in Hawaii, these MPAs were not established for the expressed purpose of conserving ornamental species
- Only 42% had fisheries management plans for ornamentals
- Only 4 areas required any form of stock evaluation or assessment. Assessments for 2 of those countries were outdated. Indonesia only requires stock evaluations for hard corals
- Only Australia employed data-limited stock assessments for fishes
- 33% of the areas have spatial rights-based management
- 27% have size limits for $\geq$1 species with only 22% requiring size limits for fishes
- Of the 12 jurisdictions that prohibit collections of endangered species, these laws apply only to corals in 7 (i.e., no other invertebrates or fish)
- Most areas (78%) require collection permits; less than half of those areas cap available permits
- Most of the reviewed countries are members of CITES (83%) and the WTO (83% members; 11% observers)

<sup>a</sup> World Bank (2013).
Conservation Act (Morrisey et al., 2011). This whitelist has several advantages, including a clearly defined protocol for border inspections to identify permitted species. Australian regulations also require importers to provide extensive documentation, such as permits, risk-assessments, health certificates, and identification of shipments to the species level. Imports must be inspected and quarantined upon entering the country. Because of these requirements, Australia has often served as an example of successful management of imports for the trade (CCIF, 2001; Morrisey et al., 2011).

4. Conclusions

4.1. Alternative approaches and successful practices

Methods such as gear restrictions; entry, size, and catch limits; fishing bans; spatial management; and size limits are commonly used, with mixed success, in this trade (Tables 3 and 4). Voluntary certification approaches, such as the Marine Aquarium Council, have also been attempted, but these programs were not viable (reviewed in Amos and Claussen, 2009). Conversely, stock assessments, scientifically-set TACs, and rights-based fisheries management approaches (e.g., individual transferable quota systems [ITQs] and exclusive fishing zones) remain underutilized. The limited employment of these management techniques is largely due to data, management capacity, and resource limitations (e.g., finances or enforcement and monitoring personnel), as well as a lack of attention to ornamental fisheries. Furthermore, many of these methods likely require modifications in order to be made appropriate for aquarium fisheries.

4.2. Catch limits

TACs set limits on the overall collection of a species or group of species in a given year. Although TACs are not widely utilized, species-specific TACs are currently used in the coral fishery in Australia, whereas aggregate TACs (in the form of export quotas) are used in several island nations including the Maldives and Tonga (Table 3). These aggregate quotas set catch limits at different levels for groups of species, often based on historical levels of export (Sections 3.2.1.3–3.2.1.4). Oftentimes the quotas are not species-specific and insufficient data are available to determine whether fishing effort is currently over or under sustainable levels. Thus, catch limits can be beneficial, they can lead to competition among fishers to fish as quickly as possible, which endangers humans, creates economic inefficiencies, and can have long-term consequences for fish populations (Hilborn et al., 2005).

4.3. Rights-based management

As a type of catch share or rights-based program, ITQs allocate a tradable portion of the annual TAC to an individual or group, thereby incentivizing the long-term maintenance of the fishery (Costello et al., 2008). For instance, transitioning to an ITQ program in Florida would allow the active collectors to “buy out” the inactive collectors to gain a larger share of the total catch, making the fishery more efficient. Nevertheless, establishment of an ecologically- and economically-successful ITQ program requires the TAC to be set appropriately, traditionally through data-intensive stock assessment models. For this reason, the rarity of ITQs and scientifically-set TACs in ornamental fisheries is partially attributable to data and management capacity limitations.

Spatial rights-based management, e.g., TURFs or exclusive community fishing zones, may offer a more promising direction, especially in areas with a history of traditional marine tenure systems (Hilborn et al., 2005). For instance, customary law in Fiji determines access to collection areas, as well as mechanisms for benefit sharing, and enforcement of collection areas (Manoa, 2008). In exchange for access to the resource, marine aquarium operators that collect species within the customary fishing rights areas contribute profits from sales to scholarships for the community (J. Comley, personal communication). Such approaches can improve the socioeconomic benefits of collection to local communities.

4.4. Data-limited stock assessments

Despite the range of management tools available, oftentimes managers must make decisions with limited data about the fishery’s status (Donaldson, 2003; Fujita et al., in press; Honey et al., 2010). Methods to assess data-limited fisheries are emerging to meet this challenge (e.g., Fujita et al., in press; Honey et al., 2010; Wilson et al., 2010). For instance, marine reserves can function as proxies for unfished conditions, thereby providing a relative measure of stock status at local scales (Wilson et al., 2010). This approach, known as the MPA-based decision tree method, compares catch-per-unit-effort and size structure within and outside of reserves as estimates of fishing mortality to calibrate TAC levels. However, the applicability of this approach and others to ornamental fisheries may be limited due to insufficient information on catch and effort trends or the biology of targeted species (Donaldson, 2003; Fujita et al., in press). To address these problems and improve ornamental fisheries management, a tiered approach involving biomass, productivity-susceptibility analysis, and a combination of stock specific and aggregate quotas can be used (Fujita et al., in press). To date, these data-limited methods of fisheries evaluation have not been widely applied to ornamental fisheries, but offer promising tools for future management.

4.5. Other promising directions

Other potential strategies to reform the trade include aquaculture and industry reform. Although out of the scope of this review, which focuses on state, national, and international regulations and management, it is worth noting that aquaculture holds promise for alleviating collection pressure on wild populations (Moorhead and Zeng, 2010; Olivotto et al., 2011). Aquaculture has already reduced the collection of wild fishes and invertebrates, including clownfish, seahorses, tridacnid clams, and several hard corals. These benefits, however, will depend on the extent that the supply of cultured individuals fulfills the market demand.

5. Conclusions

Despite the difficulties in managing the coral reef wildlife trade, some examples of successful management demonstrate that sustainable reform of the trade is possible. Some programs in exporting countries, such as Florida’s moratorium on corals, Hawaii’s FRAs, and the Maldives’ and Tonga’s no-take zones and tiered quota systems, represent steps towards reforming the trade. Similarly, legislation in importing countries, such as the U.E.’s Wildlife Trade Regulation and Australia’s “whitelist,” can also improve the trade’s environmental sustainability by proactively restricting and monitoring imports when there are concerns about the conservation status, disease risk, or invasiveness of certain species. In contrast to the U.S.’s reactionary approach to managing the trade, the precautionary approach adopted by the E.U. and Australia allows importing countries more control and oversight. Examples of regulation and management in the E.U. and Australia highlight promising ways for importing countries to proactively steer the
trade towards sustainability. Different combinations of these management and regulation strategies, in conjunction with emerging data-poor fisheries management approaches, aquaculture, and the other underutilized management tools identified here, offer considerable promise for the future.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.11.025.

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