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A Review of the Papua New Guinea Marine Aquarium Fishery

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Abstract

The marine aquarium trade is characterised by numerous source countries that collect a diversity of coral reef associated fishes and invertebrates primarily destined for private and public aquaria worldwide. While aquaculture accounts for a few species entering the trade, the bulk of diversity must still be collected from wild populations. With most organisms being sourced from economically marginalised countries in the Indo-Pacific region, the marine aquarium trade has potential to offer a sustainable livelihood opportunity to the custodians of these source habitats. However, in the absence of appropriate management, unsustainable practices can flourish, including use of anaesthetising chemicals (i.e., sodium cyanide) and physical reef damage to collect organisms. In order for long-term benefits of the marine aquarium trade to be accrued by local custodians, effective management systems must be in place.

The marine aquarium fishery of Papua New Guinea (PNG) first opened in 2008 and was relatively short lived, closing in 2012. The fishery operated under both a government funded consultancy (2008-2010) and a private commercial entity (2011-2012). Since then, no further commercial exports of marine aquarium organisms have occurred. The apparent lack of viability in this fishery has not yet been evaluated. It is uncertain to what extent government management, operator practices, or consumer attitudes impacted the viability of initial operations. This thesis examines those factors anticipated to impact on the viability of marine aquarium fishery operations within PNG and extends these findings to marine aquarium fisheries at a regional and global level.

The existing system of management, encompassing spatial restrictions of fishing effort, limited entry through licensing, gear restrictions, bans on destructive fishing methods, and species-specific Total Allowable Catches (TACs) for 369 species created an unsustainable management burden bourne by the fishery. The collection practices of the PNG fishery were found to be highly selective, collecting fishes disproportionate to their availability (i.e., TAC), rendering many of the established species-specific TACs obsolete. Specifically, 53.2 % (n = 142) of fish species and 87.3 % (n = 89) of invertebrate species with assigned TACs were never collected by the commercial fishery in 2011-2012. A further 124 fish species were collected in the absence of assigned TACs. Of the fish and invertebrate species collected, only three fish species (*Amphiprion percula*, *Paracanthurus hepatus*, and *Hemiscyllium hallstromi*) were found to merit species-specific TACs. By narrowing the focus of species-specific management to those species actually requiring such management attention this refinement of TAC use will reduce the management burden posed by the fishery.

The selectivity of the marine aquarium fishery was found to extend beyond species to specific colour morphs of species. This was true for two of the most collected species, *A. percula* and *Premnas biaculeatus*. The export price of rare colour morphs was found to increase with decreasing natural abundance ($y = 4.73x^{-0.53}$, $R^2 = 0.97$), but were well below the value-for-rarity threshold ($y = 4.21x^{-1.00}$) derived from the price of regular morphs. This suggests the observed targeted exploitation of rare clownfish morphs in the PNG fishery was a less profitable fishing strategy than opportunistic exploitation, where fishes are collected by random encounters.

Supply-chain losses attributed to both quality control rejections and mortality were high in 2010. Quality control rejections accounted for a supply-chain loss of 24.2 % of fishes and 11.5 % of non-CITES invertebrates. Among the accepted catch, a mortality of 27.3 % of fishes and 30.6 % of invertebrates occurred prior to export. Where losses occur after purchasing organisms from fishers, this comes as an economic loss to the exporting operator. The loss of one out of every three purchased organisms would have greatly impacted on the economic viability of the fishery. This finding also raises concern over the accuracy of trade data (i.e., export invoices) to accurately monitor exploitation of the trade and raises ethical concerns in regards to humanitarian standards for the treatment of animals.

In the absence of prior reviews of practice, the PNG marketing approach of “sustainability” appears to have engendered consumer support for PNG marine aquarium fishery products. In an online survey, consumers were found to show preference for buying a PNG fish over fish sourced from Vietnam, Indonesia, or the Philippines. However, consumers were more likely to purchase fish independently certified for themes of environmentally sustainable, industry best practice, or revenue supporting indigenous fishers compared to purchasing fish from any of the specific countries included in the survey. This suggests consumers want product information validated by a trustworthy third-party. At a global scale, there is minimal evidence that media influences consumer demand, with consumer demand appearing to be more dependent on global economy and advancements in captive husbandry technology.

The viability of the marine aquarium trade in PNG appears to have been largely hindered by supply chain losses. While this was empirically evaluated in 2010, there appears to have been little improvement within the fishery as export invoices underestimated catch by 29.3 % in 2012. As such, a direct comparison of the PNG fishery is made to a long-running Fijian supply chain. This identifies areas requiring improvement for better viability of future marine aquarium trade operations in PNG. The research contained within this Thesis is likely to be of interest to PNG, regional marine aquarium fisheries, and the global marine aquarium community.

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Chapter 1
General introduction

1.1 The marine aquarium trade

Every year, millions of marine organisms are removed from the world's coral reefs and associated habitats and funnelled into supply chains that deliver them to more than two million homes and public aquaria worldwide (Wabnitz et al. 2003; Rhyne et al., 2017). This trade of live marine organisms for captive confinement in aquaria is known as the marine aquarium trade and is classified as both an exotic pet trade and wildlife trade. Extraction of live organisms for this trade primarily occurs from biodiverse coral reefs within the Indo-Pacific region (Wabnitz et al., 2003; Rhyne et al., 2017). The most recent estimates suggest that the trade encompasses over 2,200 fish species, 550 non-CITES invertebrates, and numerous species of CITES listed Tridacninae and Scleractinia (Rhyne et al., 2017). While aquaculture sources supply the trade with a few species (Moorhead and Zeng, 2010; Olivotto et al., 2011; Militz, 2017), the limitations of captive production necessitate the bulk of biodiversity traded to be sourced from wild populations.

Organisms in the trade are primarily intended for use as exotic pets, though marine aquaria are also maintained as a symbol of prestige, as therapeutic furniture, or for educational purposes (Militz, 2017). As a result of these intentions, the marine aquarium trade is classed as a luxury good (Wabnitz et al., 2003; Rhyne et al., 2012a,b; Militz, 2017) and this is reflected by the economic wealth of the primary consumers of aquarium products: United States (US), Europe, Japan, and Australia.

1.1.1 Collection

Aquarium organism collection techniques are varied in style and methodology, often reflecting local habitat conditions and available materials. Most of the marine organisms traded require use of free diving or compressed air in the form of hookah or scuba to collect, the exception being species with intertidal habitats. Species associated with subtidal habitats can be collected using traps, although most species are collected with a compliment of hand nets, barrier nets, and a 'herding' stick (Pyle, 1993). Most nets used in the collection of aquarium fish are constructed of fine-mesh monofilament line with an eye-hole size generally less than 19 mm. The small mesh size is essential to avoid small-bodied fish "gilling" themselves on the net and to minimise abrasion leading to fin or body damages (Yeeting, 2010).

Net collection is often achieved by strategically placing a barrier net along a natural ingress along the substrate. The target fish are then herded towards the barrier net using the 'herding' stick and hand nets (Pyle, 1993). Once fish are trapped in the pocket of the barrier net, they are removed by hand or with use of the hand net. Where fishes are collected at depth there is need to relieve pressure in the swim bladder as the fishes ascend to the surface. This is often done using a hypodermic needle inserted directly into swim bladder, either upon capturing the fish or once returned to the surface (Munday et al., 2015).

This method of collection requires a level of skill and experience (Pyle, 1993). Alternative methods of collection involve environmentally destructive techniques. These include the use of some anaesthetising agents (e.g., sodium cyanide) to stun fish allowing for increased ease of capture (Rubec et al., 2001). The wide dispersal of the anaesthetising agent can kill non-target fishes and sessile invertebrates within the vicinity (Wabnitz et al., 2003). Exposure to sodium cyanide can also result in physiological impairment causing mortality post-collection (Hall and Bellwood, 1995; Rubec and Cruz, 2005). Other low-skill, but environmentally destructive techniques used in the collection of aquarium fish encompass physical reef damage. For example, the target fish is chased into living coral which is removed from the reef and smashed apart on board a fishing vessel (Kinch, 2004). This method can allow for a high catch-per-unit-effort of schooling fish species.

The collection of invertebrates is less physically demanding (Rhyne et al., 2009), typically encompassing walking intertidal areas at low tide and collecting organisms by hand. Collection of corals (Scleractinia) also extends to free diving or scuba to chisel colonies away from the reef (Wabnitz et al., 2003). Collected organisms may be held within floating surface containers or on board the fishing vessel until collection activities conclude.

1.1.2 Supply chains

The sources of origin for most marine aquarium organisms are coral reefs and associated habitats. Thus, supply chains all begin with fishers in the water collecting the organisms. Following collection, fishers transport organisms to one of several locations: (1) an export facility, (2) holding substation, or (3) middlemen buyer. Supply chains can become quite multifarious where fishers transport their catch to holding substations before sale to middlemen buyers (Fig. 1.1). In some cases, organisms may pass through a series of middlemen before reaching an export facility (Wabnitz et al., 2003; Schmidt and Kunzmann, 2005). In other cases, the fisher may sell the catch directly to an export facility (Schwerdtner Máñez et al., 2014). Given the necessity for products to be transported long distances by air freight, the end destination within source countries is almost always an export facility (i.e. the exporter).

The export facility collates catch from fishers and/or middlemen buyers to fill orders from overseas importing companies (i.e. the importer). Organisms are typically held for a couple days at export facilities to ensure their good health and to allow them to purge their digestive tracts 24 h before shipping. This is necessary to minimise fouling of shipment water while in transit. Individual organisms are placed in bags filled with seawater and oxygen to sustain them for a 12 to 48 h journey.

Once arrived at the importer, the organisms are unpacked and acclimated to the import holding facility. Here organisms are similarly held before transport to retail or online vendors. The retail outlets or online vendors deal directly with consumers, the final end point for most supply chains (Fig. 1.1).

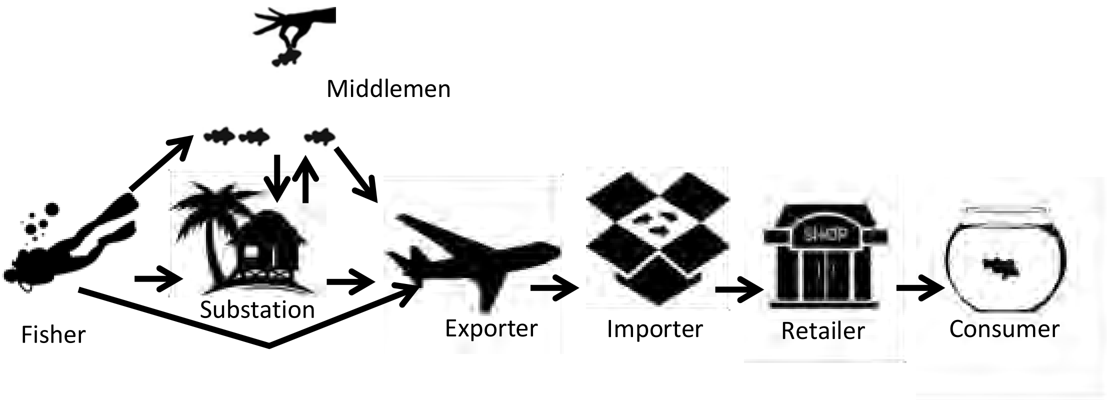

Figure 1.1: Supply chain stages in the international marine aquarium trade.

1.1.3 Factors influencing product demand

There is compelling evidence that demand for marine aquarium organisms fluctuates in response to numerous factors. Global economics appears to have a large impact on consumption of luxury goods (Ariely, 2009), and the marine aquarium trade is no exception (Rhyne et al., 2017). Other factors influencing product demand include advancements in home aquaria technology (Rhyne and Tlusty, 2012). Developments in aquarium lighting and filtration systems presented cost-affordable options for maintaining photosynthetic organisms that coincided with an increase in demand for such organisms at the turn of the century (Wabnitz et al., 2003; Rhyne and Tlusty, 2012). More recently, developments in "nano" aquarium technology have seen a rise in popularity of smaller office or desktop aquaria that coincide with a decline in the quantities of live rock and live sand traded (Rhyne and Tlusty, 2012). The popularity of specific organisms appears to be independent of larger trends, with demand fluctuating suddenly for certain organisms (Rhyne et al., 2009). Public and digital media have frequently been implicated in "fuelling" demand for certain species (Rhyne et al., 2012b; McClenachan et al., 2012), though empirical evaluations of such claims are lacking.

1.2 The Papua New Guinea marine aquarium fishery

Documentation of the Papua New Guinea (PNG) marine aquarium fishery began with PNG becoming a sovereign nation in 1975. Aquarium industry activities occurring prior to this, when PNG was a recognised territory of Australia, are not documented with the National Fisheries Authority (NFA). The NFA is the statutory authority established to manage fisheries in PNG.

1.2.1 Scoping studies and early proposals

Initial scoping into the viability of establishing marine aquarium trade operations within PNG commenced in 1989 (Perino, 1990). The PNG Department of Fisheries and Marine Resources had requested the South Pacific Forum Fisheries Agency to conduct an assessment of the potential for promoting live exports of fishes to international aquarium markets. This report identified a high diversity and abundance of marine organisms of interest to marine aquarium markets but found several major impediments to development. This included seasonal restrictions to fishing activity due to strong trade winds six months of the year and limited reef habitat around the country’s only international airport in Port Moresby. The establishment of fishery operations in other regions of the country was found to be greatly limited by high domestic freight costs and poor road access. Further restraints to development included potential for reef access conflicts due to PNG’s system of reef tenure and customary law (Cinner, 2005), disproportionally high international freight rates compared to other countries supplying aquarium markets, and restrictions on foreign investment in fishing activities within PNG (Perino, 1990). The report also detailed several guidelines regarding the necessary governmental management required to regulate and maintain a sustainable marine aquarium fishery.

Following this initial review, interest in establishing a marine aquarium fishery in PNG lay dormant until nearly two decades later. The NFA commissioned EcoEZ Inc., a US consulting company, in May 2007 to conduct a contemporary assessment of marine resources of interest to the marine aquarium trade (Yeeting and Batty, 2010). This project became known as the Papua New Guinea Sustainable Marine Aquarium Resources Trade (PNGSMART) and was given a six week budget of US$ 41,000 (Yeeting and Batty, 2010). Forty sites around the Port Moresby area of Central Province were surveyed to assess diversity and abundance of fish and invertebrate species of potential value to the marine aquarium trade. The surveys identified 191 target fish species and 28 non-CITES listed invertebrate species suitable for the aquarium trade (Ruz, 2007).

1.2.2 SEASMART programme

Following the initial resource assessment by EcoEZ Inc., a one year technical services contract of PGK 3.5 million (US$ 1.3 million) was then awarded to EcoEZ Inc. Commencing in January

2008, this funding was used to launch the Sea Sustainable Marine Aquarium Resources Trade (SeaSmart) program with the objective of providing technical and management services for the development of a marine aquarium trade in PNG. Further funding was allocated to the program extending activities till end of 2010 by which point PGK 15 million (US$ 5.4 million) had been invested by the NFA. The program deliverables, as specified in the contractual arrangements with NFA, and progress against these deliverables have been reviewed by Yeeting and Batty (2010) and are summarised in Appendix A.

The SeaSmart program led to the country's first export of marine organisms for the aquarium trade in 2008. A total of 52 exports, mainly destined for the US, occured under the project between 2008 and 2010. This encompassed 67,598 live organisms with a value of US$ 161,453. Assessing the percentage of the US market share captured by the PNG fishery in 2008 - 2009 indicates that 0.1 % of fishes and 0.1 % of invertebrates imported into the US were sourced from PNG (Rhyne et al., 2017). Compared to other countries, the PNG fishery ranked 18th out of 34 countries supplying fishes to the US market in 2009, based on total quantity traded (Rhyne et al., 2017). This defines the PNG fishery as relatively small volume, though larger than many of the other Pacific island nations (i.e., Cook Islands, Federated States of Micronesia, New Caledonia, and Tonga).

Over the course of development, EcoEZ Inc. engaged eight villages in fish collection for the marine aquarium trade. These villages were all in the Central Province bordering the PNG capital of Port Moresby and included Fishermen Island, Roku, Pari, Gaire, Tarauama, Gabagaba, Keapara, and Kouderika (Schwerdtner Máñez et al., 2014). Collected organisms were held at villages until visited by an EcoEZ Inc. agent to review and purchase the catch. Purchased organisms were transported by road and/or boat to a centrally located export facility in Port Moresby that relied on recirculating technology to maintain organisms. From this location organisms were packaged and shipped overseas.

The conclusion of the SeaSmart program ended with much resentment between EcoEZ Inc. and the NFA. Legal disputes between both parties occurred over contractual deliverables and a withholding of funds (Yeeting and Batty, 2010). The absence of an affable exit strategy between both parties led to a disarray of research assets. Much of the collected data concerning collection activities and exports lodged within the NFA archives are incomplete. This has limited the study periods over which formal research assessments can be conducted on the PNG fishery, while active between 2008 and 2010 (Schwerdtner Máñez et al., 2014).

It is also unclear what impact the government funding had on fishery performance. Given the substantial investment into fisher training and education, trade monitoring, and fishery management through the SeaSmart program, the fishery's performance should have been optimal, though this funding would have also shielded the fishery from ever experiencing real market conditions (Schwerdtner Máñez et al., 2014).

1.2.3 EcoAquariums Papua New Guinea Ltd.

Following advice from the formal review of the SeaSmart program (Yeeting and Batty, 2010), the NFA pursued further developments of the marine aquarium industry with a private investor. In 2011, the NFA issued a one-year trial license to EcoAquariums Papua New Guinea Ltd., a company founded by two former employees of the SeaSmart program. EcoAquariums focused its activities on Fisherman Island where a new, simpler holding facility was built using equipment sourced from the SeaSmart program. The island location of the facility allowed for direct collection of organisms, avoiding the need for village-based holding. This further reduced the duration of the supply chain from the SeaSmart program and eliminated transportation expenses from village collection stations to the export station. The ocean-side location of the EcoAquariums facility allowed direct access to a seawater source to operate flow-through holding systems.

Fishing activities were largely restricted to the Fishermen's Island Fishery Management Area (FMA) established by the SeaSmart program. According to collection records, 32 fishers were involved with the collection of organisms for EcoAquariums. Collection records were made publicly available via the company website (www.ecoaquariumspng.com) and export invoices were lodged with the NFA as part of licensing conditions. Under the one-year trial licence a total of 11,946 live organisms were exported with value of US$ 59,262, according to export invoices. Following the conclusion of the trial licence, EcoAquariums ceased operations because of economic non-viability (Dandava-Oli et al., 2013).

1.3 Research needs

There is a clear lack of transparency in the marine aquarium trade. This has prohibited an understanding of optimal practices relating to collection and supply of marine aquarium organisms to market. Industry may understandably fear persecution or loss of sales from data indicative of poor practices entering the public domain, leading to hesitation in disclosing information (Rubec and Cruz, 2005). Further, the view that such information is proprietary and disclosure of practices may engender competition from other operators is also known to persist (Rubec and Cruz, 2005).

Most information related to the marine aquarium trade has been sourced from mandatory reporting. This largely encompasses data extracted from trade invoices and lodged with the exporting or importing country's government (Rhyne et al., 2012a,b, 2017; Okemwa et al., 2016; Prakash et al., 2017). However, trade data is inherently limited in its capacity to monitor exploitation. For example, collected organisms lost before a point of sale are unreported on trade invoices. This leaves potential for catches of marine aquarium organisms to differ greatly from exports (Schmidt and Kunzmann, 2005). Management recommendations made for countries operating marine aquarium fisheries on the basis of trade data are hindered by the lack the knowledge in their accuracy disparity. Identifying the accuracy of trade invoices is therefore an immediate research need in this discipline.

Available trade data suggest that marine aquarium fisheries are highly selective. This is evidenced from only a few species comprising the bulk of trade, by quantity (Wabnitz et al., 2003; Rhyne et al., 2017). However, given that trade may be unreflective of collection and the natural abundance of species available to fisheries is often not evaluated, it has not been possible to empirically evaluate if collection practices are indeed selective. Given that selective collection practices have clear implications for management, such as with aggregate catch quotas (Dee et al., 2014), it is surprising that this facet has not received prior research attention.

Lack of transparency in the marine aquarium trade may influence consumer purchase decisions. In the absence of transparency, consumers often make purchases with minimal knowledge of the practices employed to bring organisms to market. While it has been established that consumers would like more information regarding potential purchases at a point of sale (Murray and Watson, 2014), it remains unclear how consumers want this information delivered. Information can be delivered in the form of providing the collection location and collection practices employed in bring an organism to market or in the form of certification schemes that encompass such information into their standards. Given that a number of socio-economic barriers prevent industry reform within source countries (Erdmann, 2001; Rubec et al., 2001), consumer oriented approaches are an appealing option (Dykman, 2012). However, in order for consumer oriented approaches to be successful, consumers must favourably purchase products representative of a high industry standard. The extent to which consumers care or are willing to support such products has not been evaluated in the current market climate.

In the context of the PNG marine aquarium fishery, more simplistic research needs are observed. Since the end of marine aquarium trade activities in 2012 a formal review of industry and management performance has not been undertaken. It is unclear to what extent the viability of a marine aquarium trade in PNG was impinged by the operating companies' performance or managerial restraints (Section 1.1.1). The appropriateness of prior management practices is of great importance given that the NFA is still drafting a formal Marine Aquarium Management Plan by which to regulate future industry activities (Dandava-Oli et al., 2013).

1.4 Statement of organization

The overall objective of this thesis was to review the practices (managerial and operational) of the Papua New Guinea marine aquarium fishery. This objective is addressed through the format of Thesis-by-Publication. Each chapter represents a succinct study that has either been published, submitted, or is in preparation for submission. The status of each chapter at the time of thesis submission is indicated via footnotes associated with the chapter titles. The progression of the research presented reflects logical divisions that do not necessarily correspond with publication date.

Chapters 2 and 3 focus on the selective nature of the PNG marine aquarium fishery. This starts with an examination of selectivity at the species level (Chapter 2). Further population studies of unique species morphs allow selectivity of the marine aquarium trade to be examined at a within-species level (Chapter 3) for the first time. The implications of the reported selectively are discussed in relation to the appropriateness of current fishery management.

Chapters 4, 5, and 6 focus on supply chain losses along the PNG marine aquarium supply chain. This starts with a comprehensive examination of quality control rejections (Chapter 4) followed by examination of supply chain mortality (Chapter 5) of fishes. Supply chain losses of invertebrates are presented in Chapter 6. The implications of supply chain losses are discussed in relation to the appropriateness of the fishery's practices and the use of trade data to monitor exploitation.

Chapter 7 focuses on the potential for consumer driven approaches to improve practices in the marine aquarium trade. The need for consumer driven approaches is discussed in relation to the socio-economic barriers to industry reform that are addressed in Chapters 2 - 6.

Chapter 8 focuses on the potential for media driven consumption to occur in the marine aquarium trade. The many benefits of the marine aquarium trade to economically marginalised communities like PNG are discussed in relation to the rise of emotive environmental activism perpetuated by media.

The research outputs of Chapters 2 – 8 are brought together by way of a concluding synthesis in the General Discussion (Chapter 9). The outcomes of the research undertaken during this study are cross-evaluated with the research needs addressed above (Section 1.3) and the means by which these outcomes could be applied in the discipline are discussed. Finally, potential directions for future research in this field are identified.

Chapter 2
Selectivity of the Papua New Guinea Marine Aquarium Fishery[1]

Abstract
The Papua New Guinea (PNG) marine aquarium fishery is unusual in that a total allowable catch (TAC) structure of management was enforced from the fishery's inception in 2008. Species-specific TACs, based on stock assessments conducted prior to the commencement of fishing, were established for 267 fish species and 102 invertebrate species presumed to be collected within the fishery. We analysed the selectivity of the PNG fishery in 2012 and found a large portion (200 species) of the available fish diversity was "weakly" to "strongly avoided". This manifested in 53.2 % (n = 142) of fish species and 87.3 % (n = 89) of invertebrate species with TACs never being collected in 2012. Of those species collected with assigned TACs, 76.8 % (n = 96) of fish species catches and all invertebrate species catches never exceeded 1 % of their TACs. Catches of only seven fish species exceeded 10 % of their assigned TACs. Collection records also identified 124 fish species collected in the absence of species-specific TACs. Unbiased recursive partitioning is used to examine ecological attributes of these species to help identify flaws in the methods used for initial TAC assignment. On the basis of our results, we suggest refining the role species-specific TACs play in the management of this fishery to optimise managerial resources. Considerable time, effort and resources were expended toward developing species-specific TACs for this fishery. The lessons learned from this approach to marine aquarium fishery management are likely to be of interest and value to PNG, other developing island nations, and marine aquarium fisheries globally.

2.1 Introduction
The marine aquarium trade differs fundamentally from other capture fisheries, but shares characteristics that can impede resource management. The difficulties of managing marine aquarium fisheries reflect the diversity of species traded. Globally, marine aquarium fisheries encompass more than 2,200 unique species with 45 countries known to export anywhere from three to 1,320 species (Rhyne et al., 2017). The life-history, demographic, and population data required for traditional stock assessments are typically unavailable for traded species (Honey et al., 2010; Fujita et al., 2014), and a lack of institutional capacity and enforcement are often cited as impediments to management (Dee et al., 2014; Fujita et al., 2014). The use of catch limits is a tenet of traditional fisheries management (Karagiannakos, 1996; Chu, 2009; Poos et al., 2010); however, the feasibility of this technique for marine aquarium fisheries is questionable, given the aforementioned limitations (Dee et al., 2014).

[1] Submitted as: Militz, T.A., Kinch, J., Schoeman, D.S., Southgate, P.C., in review. Use of total allowable catch to regulate the highly selective Papua New Guinea marine aquarium fishery. *Marine Policy*

Total allowable catch (TAC) is an annual quota or catch limit for a fishery that is often set using stock assessments. TAC can be used as a management technique for specific species or groups of organisms collected within marine aquarium fisheries (Dee et al., 2014). Depending on the information available for the species being assigned a TAC, the calculation of the TAC may involve complex population models or set as a percentage of the estimated standing stock of the target species. Where no information is available on the stock status, TACs are often based on historic export quantities or set at what is presumed to be a precautionary level (Saleem and Islam, 2008).

The use of TAC in marine aquarium fishery management is most commonly employed for live coral and live rock (Dee et al., 2014), but use of species-specific TACs to manage fish collection is limited. Notable exceptions include Vanuatu implementing a TAC for the flame angelfish (*Centropyge loriculus*) in 2008 (Kinch and Teitelbaum, 2009; VDF, 2009), Kiribati implementing a TAC for *C. loriculus* in 2010 (Wabnitz, pers. comm.), and the Maldives implementing TACs for 66 species (Saleem and Islam, 2008). These TACs being based on the quantity of individuals traded. In all of these cases, use of TACs came after prior establishment of the respective marine aquarium fishery, preventing stock assessments being conducted before exploitation began.

The Papua New Guinea (PNG) marine aquarium fishery is unusual in that a TAC structure of management was enforced from the fishery's inception in 2008 (Schwerdtner Máñez et al., 2014). Species-specific TACs, based on stock assessments conducted prior to the start of the fishery, were established for 267 fish species and 102 invertebrate species presumed to be collected within the fishery. However, the necessity of this resource-intense component of PNG's fishery management strategy has not been evaluated against actual performance of the fishery.

Marine aquarium fisheries are typified by export of a few species that comprise the bulk of individuals traded (Wabnitz et al., 2003; Rhyne et al., 2017). For imports into the United States (U.S.), the single most-imported species averaged 37 % for fishes and 63 % for invertebrates of the total species quantity exported from each of the 45 countries supplying the marine aquarium trade (Rhyne et al., 2017). The PNG marine aquarium fishery has been shown to behave similarly, with evidence that the majority of collections (Chapter 4), accepted catch (Chapter 5), and exports destined for the U.S. (Rhyne et al., 2017) were characterised by a small portion of the available diversity. This suggests that the PNG fishery was selective of the species being collected and that only a limited number of species may merit continual monitoring through species-specific TACs.

The aim of this study is to evaluate the selective nature of the PNG marine aquarium fishery and examine the effectiveness of the TAC component of fishery management. Refinement of the existing TAC structure is then discussed in relation to optimising the allocation of managerial resources. This is done using an entire year of fishery collection and export records.

2.2 Material and Methods

2.2.1 Study Fishery

Papua New Guinea comprises the eastern part of the island of New Guinea and a number of smaller islands in the Indo-Western Pacific region. In 2007, the National Fisheries Authority (NFA) contracted a U.S.-based consulting firm, EcoEZ Inc., to provide an assessment of marine resources with value to the marine aquarium trade. This consultancy subsequently developed into a three-year project to develop a sustainable marine aquarium fishery. This was followed by investment from the private sector in 2011, with the NFA granting a one-year trial license to EcoAquariums Papua New Guinea Ltd. (hereafter EcoAquariums). While collection and export activities occurred under EcoEZ Inc. between 2008 and 2010, this was part of the government funded consultancy and did not take place under real market conditions (Schwerdtner Máñez et al., 2014). On this basis, the effectiveness of the TAC system of management is assessed only in relation to the commercial activities of EcoAquariums between 2011 and 2012.

2.2.2 Data Collection

Collection and export records for PNG's marine aquarium fishery were obtained from the NFA. As a condition of licensing, EcoAquariums provided the NFA with a copy of all collection records and export invoices. Collection records came from the EcoAquariums tracking database where each collected specimen was assigned a unique identification number (Schwerdtner Máñez et al., 2014). Collection records and export invoices were taken at face value, as misinformation could not be corrected. However, corrections were made when species names were misspelled or the listed name was a junior synonym of a valid species. Validity of scientific names was confirmed using the World Register of Marine Species (WoRMS, 2017).

TACs were set for individual fish and invertebrate species within the marine aquarium fishery management area (FMA) at Fishermen Island (9°32′00″S, 147°3′38″E). This FMA defined the spatial unit around Fishermen Island in which EcoAquariums' collection activities for the fishery were permitted. The species-specific TACs were set by the NFA with guidance from EcoEZ Inc. in 2008, prior to the PNG marine aquarium fishery first becoming active (Chapter 4;

Schwerdtner Máñez et al., 2014). The TACs for invertebrates were set at 10 % of the estimated population size, while the TACs for fishes were calculated from the estimated population size and an estimate of natural mortality derived from FiSAT software (EcoEZ Inc., 2008). Population parameters were estimated using underwater visual surveys at 40 sites within the 26 km^2 FMA (EcoEZ Inc., 2008). TACs were to be valid for 12 calendar months with re-assessment, by means of underwater visual surveys, advised to occur within six months after expiration of the previous TAC. Where species were collected in the absence of a TAC, a TAC was to be set at the next annual reassessment (EcoEZ Inc., 2008).

Collection and export records were supplemented with biological information extracted from FishBase (Froese and Pauly, 2016) that may have influenced the assignment of a TAC to a given species. The fields collected from FishBase included minimum depth, maximum length, nocturnality, and IUCN Redlist status for each species. To determine whether a species was nocturnal or not, the available biological information was examined. We accepted both direct statements of "nocturnal" and descriptions indicative of nocturnal behaviour as nocturnal. We also characterised each fish species as being a known or unknown marine aquarium commodity. All species listed in the marine aquarium database aquariumtradedata.org (Rhyne et al., 2017) were species taken to be known aquarium commodities.

2.2.3 Data Analysis

Collection records indicate that 0.7 % (n = 111) of the fishery's catch was sourced outside the Fishermen Island FMA; this catch was omitted from all analyses concerning TAC and selectivity of the fishery. The proportion of TAC collected was determined by the number of individuals reported to be collected as a proportion of the assigned TAC to each species. Only fishes were examined further, given the limited numbers and diversity of invertebrates collected. It was not possible to assess relationships between the proportion of a fish's TAC collected and potential predictor variables of interest (i.e., quantity of individuals collected, quantity of individuals exported, and mean export price) using parametric models, given the preponderance of zeros, and the extreme right skew in the distributions of all variables. Instead, we constructed a conditional inference tree, using unbiased recursive partitioning according to the ctree function in the R package *partykit* (Hothorn and Zeileis, 2015), to determine whether quantity of individuals collected, quantity of individuals exported, and mean export price (2012 US$) significantly predicted the proportion of the TAC collected for each species. This analysis relies on a permutation-based significance test to select predictor variables, and does not make assumptions as to the distribution of either the predictor or the response variables. Only significant ($P \leq 0.05$, with Bonferroni's correction) splits were considered. Unbiased recursive partitioning was also utilised to assess whether minimum depth, maximum length, nocturnaility, or aquarium commodity status could predict the assignment of TAC to a species.

To determine which fishes were being selectively collected, we used the electivity or selection index (*E*) of Jacobs (1974):

$$E = (U_i - A_i) / ((U_i + A_i) - (2 \times U_i \times A_i)),$$

where U_i is the proportion of collections accounted for by a given fish species *i* and A_i is the proportion of fishery availability (i.e., the TAC) attributed to the given fish species *i*. *E* is therefore defined as the relative difference between collection and availability of a species, and it gives an indication of the relative selection pressure on each fish species, with the value of *E* ranging from −1 to +1. Interpretation of *E* values is presented in Table 2.1.

Table 2.1: Interpretation of selection index (*E*) values as taken from Gordon (1989).

E values	contextual interpretation
–1 to –0.5	strong avoidance
–0.49 to –0.1	weak avoidance
–0.09 to 0.09	neutrality
0.1 to 0.49	weak selection
0.5 to 1.0	strong selection

2.3 Results

2.3.1 Collection and Export

Collection records indicate that a total of 14,615 individual fishes and 93 invertebrates were collected within the PNG fishery for the license period spanning November 2011 to November 2012 (hereafter 2012). Records were able to identify, by quantity, 99.1 % of collected fishes and 88.2 % of collected invertebrates to species. There were, however, disparities between the reported number of organisms collected within the fishery and the reported number of organisms exported. The number of fishes exported was 70.7 % (n = 10,329) of the number of fishes collected, while over five times (542 %, n = 504) as many invertebrates were exported than collected. By quantity, fishes accounted for the vast majority of the trade when considering both collection (> 99 %) and export (> 95 %) records.

In addition to the discrepancy in the quantity of fishes collected and exported, the total number of identifiable fish species collected (n = 243) exceeded the number of species exported (n = 195). Eight fish species were exported without any record of their collection, indicating the PNG fishery presumably collected a total of 251 species. The most commonly collected and exported species were *Amphiprion percula* and *Paracanthurus hepatus*, which together accounted for 45.8 % of fish collections and 49.7 % of fish exports (Fig. 2.1). The majority of collections and exports were represented by a small portion of species diversity, this trend being more pronounced in exports (Fig. 2.2).

2.3.2 Total Allowable Catch

TACs were set for 267 fish species and 102 invertebrate species within the Fishermen Island FMA. When considering both collection and export records, no species was found to have catches or exports that exceeded their TAC. Only 46.8 % (*n* = 125) of fish species and 12.7 % (*n* = 13) of invertebrate species with TACs were actually collected within the Fishermen Island FMA in 2012. Of the 125 fish species with TACs that were collected, catches of only seven species (5.6 %) exceeded 10 % of their TACs (Table 2.2); catches of the majority (76.8 %, *n* = 96) of fish species did not exceed 1 % of their TACs. Collection of invertebrate species never exceeded 1 % of their TACs.

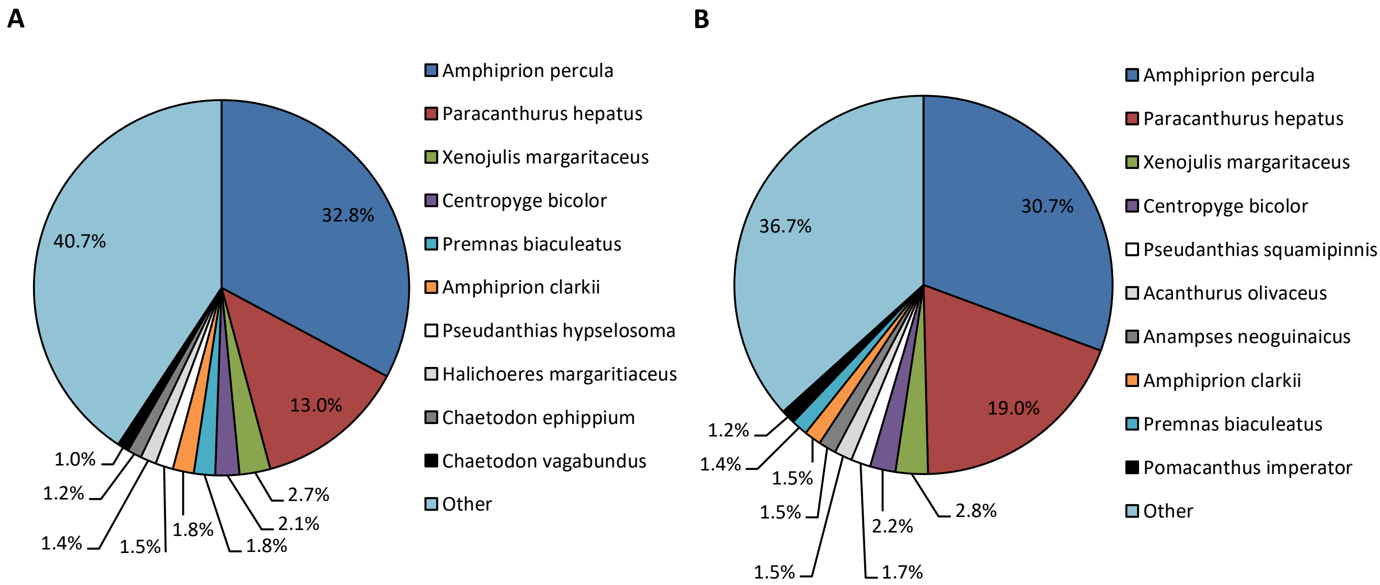

Figure 2.1: Top ten marine aquarium fish species (A) collected and (B) exported from Papua New Guinea in 2012. Species common to both charts are presented in matching colours. Use of greyscale indicates species were not common to both charts.

Unbiased recursive partitioning revealed that collection quantity, export quantity, and mean export price were poor predictors of the proportion of TAC collected for a given species, the model produced (Fig. 2.3) had a predictive accuracy of only 53.2 %. Figure 2.3 illustrates significant ($P < 0.05$) splits among the assessed variables (nodes 1-5 and 8) predicting the proportion of TAC collected among species (nodes 6-7 and 9-13). Export quantity showed a significant split at an export quantity of 121 individuals ($P < 0.001$): export quantities > 121 individuals identified species that had a high proportion of their TACs collected ($\bar{x} = 0.23$, M = 0.06, range = < 0.01 – 0.85). Species being exported at quantities of 53 – 121 specimens had the next-highest proportions of TAC exported ($\overline{x}$ = 0.05, M = 0.02, range = < 0.01 – 0.22). Further refinement of the model for species with lower export quantities did identify additional significant splits, but these accounted for only a very small fraction of the variation in the proportion of TAC collected among species ($\overline{x}$ = 0.002, M = 0, range = < 0.01 – 0.04).

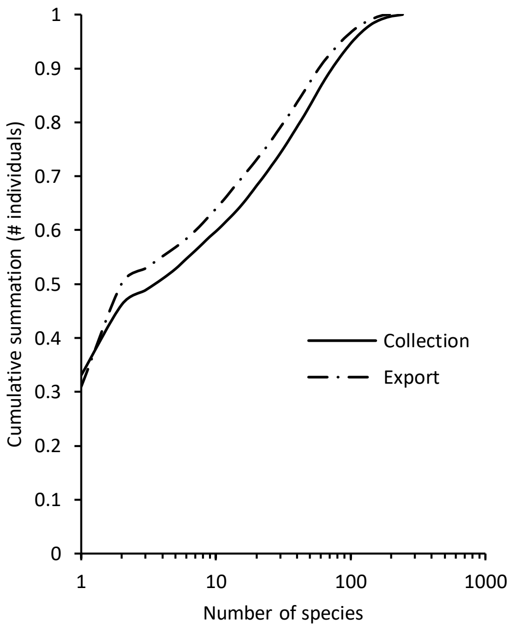

Figure 2.2: The cumulative summation of the number of fishes collected and exported from the Papua New Guinea marine aquarium fishery by rank order of species. The majority of collections and exports are represented by a small portion of species diversity, this trend being more pronounced in exports.

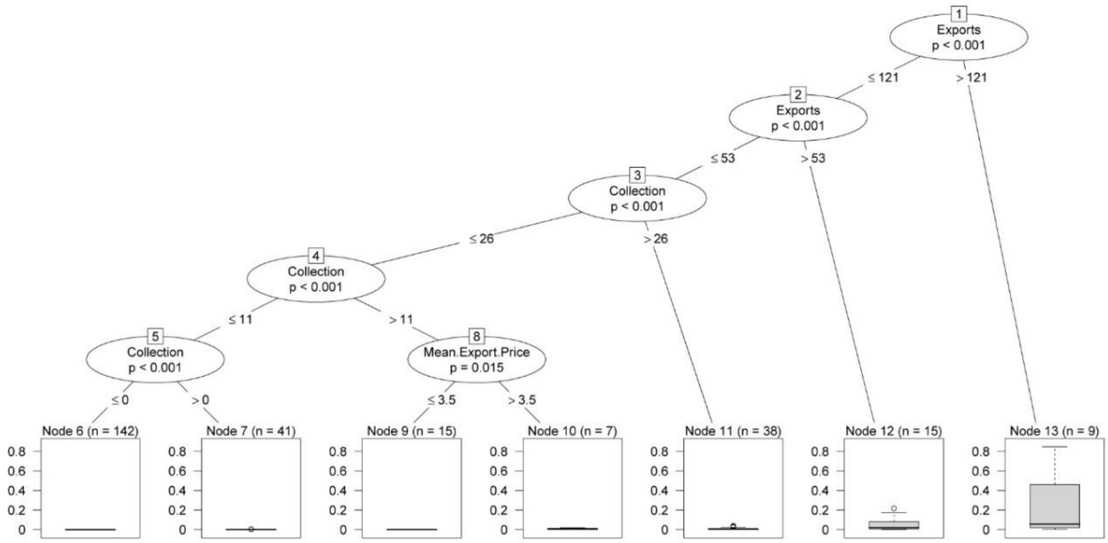

Figure 2.3: Conditional inference tree of proportion of total allowable catch collected for a given species as explained by collection quantity, export quantity, and mean export price.

A total of 124 fish species were reported to be either collected or exported in the absence of an assigned TAC. This encompassed 14.6 % (*n* = 2096) of all identifiable fishes collected within the Fishermen Island FMA (*n* = 14,380). Among the species collected without an assigned TAC was *Xenojulis margaritaceus*, the third most-collected and exported species from the fishery (Fig. 2.1). All other species collected without a TAC comprised < 1 % of collections from the Fishermen Island FMA. Unbiased recursive partitioning revealed that fishes collected or exported in the absence of a TAC could be predicted (69.6 % accuracy) by their nocturnality and maximum length (Fig. 2.4). The first node separated those species reported to be nocturnal in behaviour from others ($P = 0.006$); 51.1 % of nocturnal species collected lacked a TAC. Further separation of assigned TACs for species not identified as nocturnal was achieved by maximum adult length ($P = 0.043$), with species larger than 60 cm being twice as likely (56.0 % without TAC) to be without a TAC as species smaller than 60 cm (27.1 % without TAC). Minimum depth and whether a species was a known marine aquarium commodity were not significant factors in predicting assignment of TACs. The proportion of species known to be marine aquarium commodities was statistically indistinguishable between those species collected without a TAC (89.5 %) and those with an assigned TAC (89.7 %; $\chi^2 = 0.004$, $P = 0.95$).

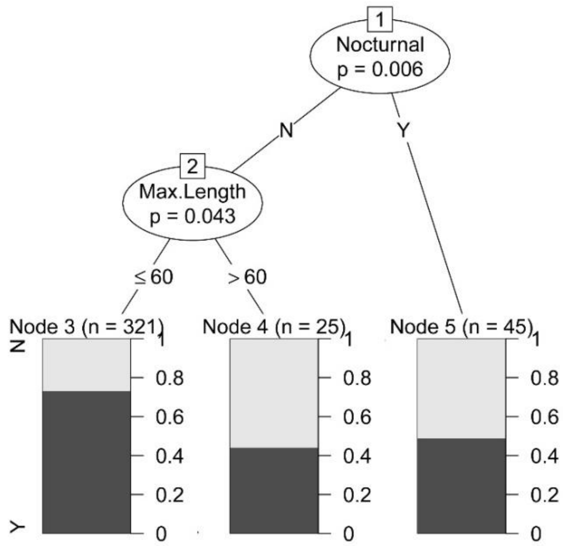

Figure 2.4: Conditional inference tree exploring whether fishes had been assigned a TAC (dark shading) or not (light shading). Predictor variables include characteristics potentially impacting on assignment of TACs (maximum length, minimum depth, nocturnality, and whether a species was a known aquarium commodity).

2.3.3 Selective Collection

Collection effort was not evenly distributed among the 267 fish species with TACs. Jacob's (1974) selection indices indicated that 176 species (65.9 %) were strongly avoided, 24 species (9.0 %) were weakly avoided, 7 species (2.6 %) were neutral, 27 species (10.1 %) were weakly selected, and 33 species (12.4 %) were strongly selected. Of the fish species strongly avoided, 142 had an *E* value of –1, indicating that while these species were available to the fishery, they were never collected. By contrast, those species identified as being strongly selected encompassed all species that had ≥ 0.8 % of their TAC collected. A complete list of all species strongly selected for by the PNG marine aquarium fishery is presented in Table 2.2.

Table 2.2: All species strongly selected for the Papua New Guinea marine aquarium fishery. Species are presented with their selection index (*E*), percentage of TAC collected, mean export price (2012 US$), and IUCN Redlist status. Shaded rows identify species with "vulnerable" Redlist status.

Species	*E*	% of TAC collected	Mean export price	IUCN status
Amphiprion percula	1.00	84.8	5.74	NE
Pomacanthus imperator	0.99	58.2	20.65	LC
Paracanthurus hepatus	0.99	46.1	4.30	LC
Amphiprion polymnus	0.98	21.7	5.02	NE
Acanthurus triostegus	0.98	17.5	2.38	LC
Chaetodon ephippium	0.97	13.3	3.83	LC
Acanthurus olivaceus	0.96	11.1	4.14	LC
Salarias fasciatus	0.95	8.8	3.25	LC
Chelmon rostratus	0.95	7.8	3.96	LC
Premnas biaculeatus	0.93	5.5	9.75	NE
Coris gaimard	0.89	3.8	4.42	LC
Amphiprion melanopus	0.89	3.7	3.00	NE
Pervagor janthinosoma	0.87	3.2	5.00	LC
Amphiprion clarkii	0.85	2.6	4.58	NE
Halichoeres margaritiaceus	0.84	2.5	4.00	LC
Canthigaster papua	0.84	2.5	4.19	LC
Chaetodon ulietensis	0.83	2.3	3.59	LC
Pseudanthias hypselosoma	0.82	2.1	3.02	NE
Chaetodon rafflesii	0.82	2.1	1.44	LC
Macropharyngodon meleagris	0.81	2.0	3.82	LC
Halichoeres argus	0.80	1.9	2.78	LC
Centropyge bicolor	0.79	1.8	3.36	LC
Arothron hispidus	0.78	1.8	6.14	LC
Chaetodon trifasciatus	0.76	1.6	2.97	LC
Parupeneus cyclostomus	0.76	1.6	3.57	NE
Hemiscyllium hallstromi	0.73	1.4	43.33	VU
Ostorhinchus hoevenii	0.69	1.2	1.86	NE
Chaetodon auriga	0.67	1.1	2.33	LC
Chaetodon plebeius	0.65	1.0	3.08	LC
Pygoplites diacanthus	0.64	1.0	13.08	LC
Zebrasoma veliferum	0.59	0.8	3.52	LC
Siganus doliatus	0.59	0.8	2.79	NE

Abbreviations: NE = not evaluated; LC = least concern; VU = vulnerable

2.4 Discussion

2.4.1 Assignment of TACs

While the effort invested into establishing species-specific TACs for the PNG marine aquarium fishery is laudable, this effort was largely misplaced: more than half of the species with TACs were never collected within the fishery and half of the fish species actually collected did not have TACs. We suspect this error was due to both a limited capacity to accurately predict which species were going to be collected within the fishery and detectability limitations of the underwater visual surveys used for initial stock assessments.

Given the high diversity of species demanded by the marine aquarium trade (Wabnitz et al., 2003; Rhyne et al., 2017) it is understandably difficult to preemptively identify which species will actually be collected under commercial constraints, and how demand might change through time. A large array of factors such as biogeography, local stock abundance, catchability of stock, connectivity to the market, market demand, market competition, and even public media can govern whether a certain species will be collected and exported from a given fishery (Chapter 8; Wabnitz et al., 2003; Rhyne et al., 2012a). Given that industry expertise was enlisted in the form of a consulting firm, employing ex-Marine Aquarium Council staff, to establish the initial TACs, it is unlikely that predictive accuracy in establishing TACs for species could have been improved. Our results indicate the majority of species assigned TACs were known marine aquarium commodities. Predictive accuracy in this industry is likely to be a constraint in all cases where TACs are established before the start of commercial fishing, this limitation making argument for adaptive management of marine aquarium fisheries.

The use of underwater visual surveys to identify species of commercial interest to the marine aquarium fishery would be inherently limited by survey effort. Given that the marine aquarium trade demands organisms from different habitats (varying in reef zone and depth), behaviours (including diurnal, nocturnal, and crepuscular species) and niches (Chapter 7; Wabnitz et al., 2003; Rhyne et al., 2017), it is logistically difficult to ensure that surveys can encompass the full diversity of organisms demanded by the marine aquarium trade. Additionally, there are basic limitations in the detection capacity of underwater visual surveys that could result in erroneous stock estimates or fail to detect species altogether (Jennings and Polunin, 1995; Kulbicki and Sarramégna, 1999; Willis, 2001; Edgar et al., 2004; Williams et al., 2006). This facet is clearly illustrated by our results, which indicate that nocturnal species are less likely to have an assigned TAC than other species. Because their probability of detection in surveys is quite low, accurate estimates of stock abundance are particularly difficult to obtain for cryptic or scarce species (Willis, 2001; Chadés et al., 2008). These limitations of the stock assessment method employed make it inherently difficult to both predict which species will be target prior to commercial fishing and to set sustainable TACs.

Failure to assign a TAC to the majority of larger species in this study (i.e., maximum lengths exceeding 60 cm) is understandable. Roughly half of the surveyed consumers of marine aquarium fishes own aquaria with quantities less than 400 L (Chapter 7), limiting the export demand for large fishes to a niche market. The small quantity of exports (< 1 % of exports) for fishes with maximum lengths exceeding 60 cm confirms this notion. Species that grow exceptionally large are of questionable aquarium suitability and a contributing factor to the establishment of invasive species where fish, out-growing the confines of an aquarium, are released into waterways (Holmberg et al., 2015). Excluding fishes with the capacity to quickly outgrow the confines of marine aquaria may have been deliberate based on the PNG marketing approach of sustainability (Yeeting and Batty, 2010; Dandava-Oli et al., 2013). However, failure to assign a TAC does not appear to have prevented or restricted exports of a species in practice.

2.4.2 Management Value of TACs

Given the difficulties associated with prior identification of species that will be collected on commencement of commercial fishing, it is worth addressing the management value of species-specific TACs. While the use of a TAC management approach has been a successful management component of single-species fisheries in some instances (Hilborn et al., 2005), there are numerous instances where this approach fails to achieve fishery sustainability (Karagiannakos, 1996; Swain and Chouinard, 2008; Poos et al., 2010).

To ensure sustainability, regular reviews of TACs need to be carried out to assess whether existing limits on collection are sustainable. This is particularly challenging with coral reef fishes given the capacity for populations to fluctuate in response to varying recruitment (Walsh, 1987; Williams et al., 2009; Saenz-Agudelo et al., 2012) and environmental disturbances (Syms and Jones, 2000; Munday, 2004). With the PNG marine aquarium fishery exposed to commercial collection for only a single year, it is uncertain whether the set TACs would have ensured long-term sustainability of the species collected. Despite no species being collected in excess of their assigned TAC, anecdotal evidence from fishers indicated declining abundance of the most frequently collected species, *A. percula* and *P. hepatus*, within the FMA (Dandava-Oli et al., 2013; Schwerdtner Máñez et al., 2014). Ensuring the appropriateness of TACs over time is necessary to ensure ecological sustainability of the resource and economic sustainability of the fishery. This ongoing monitoring of the TACs requires further investment of resources. The sheer magnitude of resources required to re-assess the 369 established TACs may explain why no re-assessment was done while the fishery was active (Schwerdtner Máñez et al., 2014).

Despite the existence of species-specific TACs, the absence of a TAC was not a determining factor in whether a fish species could be collected within the PNG marine aquarium fishery. This is shown by the 124 fish species that were collected without TACs, together accounting for half of the fish species collected within the fishery. It can be expected that new species of interest to the aquarium trade will be discovered by emerging marine aquarium fisheries and the need for adaptive management was factored into the original TAC management system. Species of interest could be collected in the absence of an assigned TAC but were to be surveyed during the next annual reassessment of TACs for assignment of a species-specific TAC (EcoEZ Inc., 2008). However, this protocol was not adhered to, with nearly a quarter (22.6 %) of the fish species collected without TACs in 2012 having been previously collected in 2008 and 2009 (Rhyne et al., 2017). This and the failure to conduct annual reassessments (Schwerdtner Máñez et al., 2014) calls into the question the capacity for the NFA to effectively monitor and implement the existing TAC component of the fishery management strategy.

Even for the majority of species collected with TACs, the justification to invest resources to continually conduct stock assessments, undertake the analyses necessary to set TACs, and review the sustainability of the TACs is lacking. In the PNG fishery, no invertebrate species with a TAC was ever collected at levels in excess of 1 % of their TAC. Three quarters of fishes with a TAC were never collected at levels in excess of 1 % of their TAC and 94.4 % were never collected at levels in excess of 10 % of their TAC. For the vast majority of collected species, this indicates no imminent threat of over-exploitation by the marine aquarium fishery, negating the value of continually conducting stock assessments and managing the collection of these species through TACs. The lack of justification to manage all collected species with TACs is also exemplified in an economic sense, given the high management investment relative to fishery revenue. In 2012, the PNG marine aquarium fishery had an export value of roughly US$ $60,000 in organisms, while the cost of staff salaries alone for the fishery's Resource Assessment and Management Officers employed at this time was US$ 28,000 per annum (NFA *pers. comm.*). Where future marine aquarium fishery activities extend beyond Fishermen Island, the difficulty of maintaining effective species-specific TACs will increase in scale. This may further increase management costs relative to fishery revenue, suggesting a timely need to optimise managerial investment for this fishery.

In other marine aquarium fisheries, stock assessments and scientifically-set TACs remain underutilised (Dee et al., 2014). The limited application of these management techniques is largely due to paucities of data, institutional capacity, and resources. The marine aquarium fishery of the Maldives is the only comparable example of a marine aquarium fishery managed with TACs for all species collected. Saleem and Islam (2008) report the use of TACs to be effective, though economic and ecological sustainability of this approach has yet to be reported. The TACs were implemented well after the country's marine aquarium fishery was established, with TACs being based on export data and general information on species abundance (Saleem and Islam, 2008). The Maldives marine aquarium fishery has an export value ten times (US$ $590,530 in 2007) the value of the PNG fishery with 66 species managed by species-specific TACs and a further 71 species managed by an aggregate TAC (Saleem and Islam, 2008). In contrast, the smaller PNG fishery attempted to manage 369 species with species-specific TACs.

This equates to five times the management effort despite a tenth of the return from the PNG fishery. This comparison further emphasises a need to rationalise the PNG fishery management approach, with respect to TACs.

2.4.3 Refining the role of TACs

Following the EcoAquariums one-year trial licence, the PNG marine aquarium fishery has remained closed. This has provided an opportunity for PNG's fishery management agency, the NFA, to review their initial approach to managing the marine aquarium fishery. Use of species-specific TACs as a management approach to marine aquarium fisheries has historically been discounted on the basis that the resources required are generally limited among the developing island nations that supply the trade (Dee et al., 2014; Fujita et al., 2014). Our study shows that even when the necessary resources were invested, there was limited value in the use of species-specific TACs as applied for managing the emerging PNG marine aquarium fishery.

The use of TACs was only one component of the management system employed to manage the PNG marine aquarium fishery. Management was also achieved through regulating the number of commercial operators by requiring the attainment of a license from the NFA (i.e. restricted entry), restricting collection activities to FMAs (i.e. spatial management), gear restrictions, bans on anaesthetising chemicals, and prohibition of destructive collection techniques (Chapter 4; Dee et al., 2014; Schwerdtner Máñez et al., 2014). This management framework already mitigates many of the potential risks posed by marine aquarium collection in other fisheries (Dee et al., 2014). Hawaii and Australia are both successful examples of how spatial management, in the absence of species-specific TACs for fishes, can achieve a level of sustainability that has allowed these marine aquarium fish fisheries to persist for decades (DEEDI, 2009; Williams et al., 2009; Stevenson et al., 2013). The capacity for recruit replenishment (Christie et al., 2010; Saenz-Agudelo et al., 2011, 2012) and adult spillover (Russ and Alcala, 1996; Abesamis and Russ, 2005) from unfished areas are well-known benefits associated with spatial restriction in fishing effort. However, the success of spatial resource management requires compliant fishers (Edgar et al., 2014).

We acknowledge that compliance is likely to break down if saleable catch declines within FMAs, given the socio-economic pressures facing fishers in PNG (Filer, 2004; Macintyre and Foale, 2004; Kinch, 2008b). Enforcement is an immediate countermeasure to compliance, but most fishers use personal boats, canoes, or swim from shore to access fishing grounds (Schwerdtner Máñez et al., 2014) hindering easy identification of aquarium fishing vessels. Further, most marine aquarium fishers in PNG also fish for food and, given the overlap of many marine aquarium species with subsistence fishery species (Chapter 4; Schwerdtner Máñez et al., 2014), it may not always be possible to discern whether collection is occurring specifically for the marine aquarium trade.

These impediments to spatial enforcement necessitate absolute restrictions to fishing effort where excessive exploitation has potential to result in declines of both the resource as well as market price in the marine aquarium trade (Teitelbaum et al., 2010), both aspects with potential to impair the socio-economic well-being of fishers. While a TAC is often viewed as a potential management option with regard to mitigating ecological consequences of the marine aquarium trade (Dee et al., 2014; Fujita et al., 2014), the potential value of a TAC includes managing supply of a particular organism to maintain market prices. For these reasons, we do not suggest removal of the TAC component of management entirely, but do advise refining the role that TAC plays in managing the PNG marine aquarium fishery.

We see immediate merit in the use of TACs to regulate three species on the basis of minimising ecological impacts and maintaining market price: (1) *A. percula*, (2) *P. hepatus*, and (3) *Hemiscyllium hallstromi*. Our selectivity analysis revealed *A. percula* to be the most selected fish species by the fishery with 84.8 % of its TAC being collected in 2012. Overfishing populations of clownfishes (Amphiprioninae) has been documented to occur in the Philippines (Shuman et al., 2005) and Indonesia (Madduppa et al., 2014), both regions with minimal effective fishery management (Dee et al., 2014). Furthermore, Amphiprioninae have been attributed a "high" vulnerability category for over-exploitation by the aquarium trade in productivity susceptibility analysis (Fujita et al., 2014). Given the economic importance of this species to the PNG fishery, there is a clear need to maintain harvest of this species at sustainable levels to ensure economic viability of trade and income accrued by fishers.

Our justification for *P. hepatus* similarly arises from the relatively high proportion of TAC collected (46.1 %), quantity exported, and economic importance to the PNG fishery. Chapter 8 of this thesis reviews the risks posed by marine aquarium fishing for this species which encompass a potential for media-driven consumption, environmentally destructive collection techniques, and monetary incentives for targeted exploitation. While productivity susceptibility analysis attributed only a "low" vulnerability for over-exploitation by the marine aquarium trade (Fujita et al., 2014), there are examples of over-exploited stocks as a consequence of aquarium collecting (Thornhill, 2012). We are also mindful that fishers have already perceived a reduction in stock abundance of *P. hepatus,* as well as *A. percula* (Dandava-Oli et al., 2013; Schwerdtner Máñez et al., 2014). The prescription of species-specific management for these species could also help nullify tensions between fishers and the NFA concerning effective resource management (Bennett et al., 2001).

Lastly, we recommend a species-specific TAC for *H. hallstromi*, given this species is endemic to PNG, is listed as vulnerable by the IUCN Redlist (Dudgeon et al., 2016), was highly selected for by the fishery, and was the most valuable species exported. *H. hallstromi* was the only highly selected species with an IUCN listing exceeding least concern or not evaluated. For these reasons we also think it would be prudent to not collect this species until allocation of a species-specific TAC based on a sound understanding of the species biology and sitribution is acquired. Overexploitation of an already vulnerable species by the aquarium trade poses the risk of substantial negative media attention (e.g. Kolm and Berglund, 2003) that could derail PNG's marketing approach that is based on sustainability (Yeeting and Batty, 2010). While only 17 individuals were collected in 2012, we note collection and export quantities of *H. hallstromi* were much higher for the PNG fishery between 2008 and 2010, exceeding 260 individuals (Chapter 4; Rhyne et al., 2017). Further, the information gathered in establishing a TAC (including population demographics) for *H. hallstromi* would be of value to the larger aim of conserving this vulnerable species.

We note that *Pomacanthus imperator* had a higher proportion of its TAC collected than *P. hepatus*, but we do not feel this species merits assignment of a TAC. The larger adult size of *P. imperator* (maximum length 40 cm) indicates a portion of the adult spawning biomass will be of little interest to the marine aquarium trade. A review of online vendors offering *P. imperator* for sale indicates that the largest commercially available size is 28 cm (liveaquaria.com; bluezooaquatics.com; saltwaterfish.com; petco.com). Given the high freight costs in delivering PNG marine organisms to markets (Kinch, 2008a) relative to those for other countries supplying the trade with *P. imperator* (Rhyne et al., 2017), there is further economic disincentive to export large *P. imperator* from PNG. In contrast, nearly the full size range *A. percula* and *P. hepatus*, both smaller species than *P. imperator*, are offered for sale by the same commercial vendors.

By restricting species-specific TACs to three species we anticipate that the cost efficiency and feasibility of management for the PNG fishery will be greatly improved. Given that the existing TACs were never re-assessed, we hope that by reducing the number of species requiring reassessment that such reassessments will actually occur. This refinement in the use of species-specific TACs will help eliminate the management burden imposed by an expanding fishery. As new species are discovered or collected within the fishery, we advise the employment of data-limited assessments (Dee et al., 2014; Fujita et al., 2014) prior to consideration of a species-specific TAC. A productivity susceptibility analysis, as suggested by Fujita et al. (2014), could help identify species at potential risk from over-exploitation. Once a marine aquarium fishery becomes established within PNG (> 3 years of operation), export records can serve as a useful tool to identify species meriting management concern (DEEDI, 2009), particularly to detect shifts in market demand (Chapter 8; Rhyne et al., 2012a). The value of this approach was confirmed with our unbiased recursive partitioning model showing the quantity of exports could effectively identify those species with the greatest proportion of their TAC collected.

2.4.4 Conclusions

Marine aquarium fisheries have long been assumed to be selective of the species they collect (Andrews, 1990; Ochavillo et al., 2004). Our study quantitatively confirms that collection within PNG was highly selective of only a limited portion of the available diversity. Given that many Pacific marine aquarium fisheries are similar to PNG in that only a few species comprise the bulk of exports (Rhyne et al., 2017), we anticipate collection to be highly selective elsewhere. This attribute of collection suggests the vast majority of marine species available to and collected within the PNG fishery were typically avoided. This negates the necessity of allocating species-specific management to all species collected or of potential interest to the fishery.

The assignment of TACs to species never collected within the commercial fishery, and the failure to assign TACs to nearly half of collected species emphasise the difficulty in establishing species-specific TACs for an emerging fishery. From an initial scope of more than 369 species managed by species-specific TACs, we identified only three species meriting such directed management. Focusing on these three species aims to rationalise management investment relative to the size of the industry and to increase the likelihood that reviews of TACs would actually be conducted. With the PNG marine aquarium fishery likely to resume in the near future (Dandava-Oli et al., 2013), the current cessation of fishery operations provides an opportune time for a refinement of a management approach. The information presented here could be utilised for finalising draft versions of PNG's Marine Aquarium Trade Management Plan, as done elsewhere (Kinch and Teitelbaum, 2009; VDF, 2009).

Considerable time, effort and resources were expended toward developing species-specific TACs for the PNG marine aquarium fishery. The lessons learned from this approach to marine aquarium fishery management are likely to be of interest and value to PNG, other developing island nations, and marine aquarium fisheries globally.

Chapter 3

Natural rarity places clownfish colour morphs at risk of targeted and opportunistic exploitation in a marine aquarium fishery [2]

Abstract

As fish stocks become depleted, exploitation eventually fails to be cost-efficient. However, species or morphs of species can suffer from continual exploitation if their rarity results in increased value, justifying the cost-efficiency of targeted or opportunistic exploitation. The trade in coral reef fishes for public and private aquaria is an industry in which naturally rare species and rare morphs of species command high prices. Here we investigate the relationship between price and the natural prevalence of colour morphs of two in demand clownfish species using a localised case study. The export prices for clownfish colour morphs increased with decreasing frequency of occurrence ($y = 4.73x^{-0.53}$, $R^2 = 0.97$), but price increase was inversely less than the observed reduction in frequency. This rendered all the studied morphs at risk of opportunistic exploitation. Using ecological data, we also demonstrate how this increased value can subject rare clownfish colour morphs with aggregated distributions to targeted exploitation. These findings are discussed in relation to the broader marine aquarium trade, identifying taxa potentially at risk from rarity-fuelled exploitation and addressing potential management strategies.

3.1 Introduction

Exploitation of live organisms is a potential threat to biodiversity and ecosystem resilience (Rosser and Mainka, 2002; Bellwood et al., 2004), with numerous extinction pathways attributed to exploitation (Clark, 1973; Dulvy et al., 2003; Courchamp et al., 2006; Branch et al., 2013). This may seem paradoxical as basic economic theory suggests that the point at which it is no longer economically efficient to exploit a species will precede ecological extinction (Courchamp et al., 2006; Grafton et al., 2007). As population abundance decreases it becomes more difficult, and therefore more costly, to exploit the remainder of the population. Where cost of exploitation exceeds the financial return, exploitation generally stops until a point in time when the species has recovered in abundance to make exploitation cost-effective again. However, naturally less abundant species or morphs of species could suffer from continual exploitation if this rarity makes them more attractive to consumers (Courchamp et al., 2006; Hall et al., 2008).

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The trade of wild coral reef fishes for public and private aquaria ownership is an expanding industry worldwide (Wabnitz et al. 2003; Leal et al. 2016). Consumer demand exists for particular species known to be suited to life in captivity and deemed to be aesthetically pleasing (Chapter 7; Murray and Watson, 2014). A segment of the marketplace also ascribes importance to the rarity of traded fishes (Chapter 7), and price premiums are associated with both the natural and perceived rarity of species and morphs of species (Dulvy et al., 2003; Rhyne et al., 2012a).

To satisfy consumer demand, marine aquarium fisheries operate in a manner that promotes targeted exploitation (Branch et al., 2013). Fishers generally target a limited range of species in comparison to the available biodiversity (Stevenson et al., 2011). This selectivity is best demonstrated by the limited number of species that comprise the bulk of organisms exported from nearly all source countries supplying the trade (Wabnitz et al., 2003; Rhyne et al., 2012b). Targeted exploitation is not restricted to abundant species and may extend to rare species if their value exceeds the bioeconomic equilibrium (Gordon, 1954), when profitability is similar among alternative targets.

Even if the value of rare taxa is below the bioeconomic equilibrium, exploitation may still occur opportunistically if the rare taxa have relatively higher value and overlap in distribution with targeted taxa. This mode of opportunistic exploitation allows for continued exploitation of rare taxa past the point at which targeted exploitation would no longer remain economically efficient (Branch et al., 2013). Evidence of opportunistic exploitation among small-scale tropical fisheries (Purcell et al., 2013; Branch et al., 2013) would suggest this fishing strategy to be employed within marine aquarium fisheries.

Resource managers must recognise scarce taxa at risk from targeted and opportunistic exploitation given already small population sizes predispose such taxa to local and/or global extinctions (Dulvy et al., 2003). There is particular interest in evaluating the potential for rare morphs of commonly traded taxa to be at risk, given that cryptic species are frequently traded prior to scientific evaluation (e.g., Tea and Gill, 2016) and disproportionate exploitation of morphs could have negative repercussions for genetic diversity within populations (Drew et al., 2008, 2010).

For this reason, our study combines economic and ecological data to evaluate whether colour morphs of two fish species commonly exploited for the marine aquarium trade could be at risk from targeted and/or opportunistic exploitation. This is done using the marine aquarium fishery of Papua New Guinea (PNG) as a case study. Our evaluation extends into discussion of intervention strategies for the marine aquarium trade that seek to minimise the desirability of rare taxa from having negative repercussions on resource sustainability.

3.2 Material and methods

Two licensed companies engaged in the collection and export of marine aquarium fishes within PNG between 2008 and 2012, with only a single export company operating at any point in time. As a condition of export licensing, export invoices were lodged with the National Fisheries Authority of PNG. Export invoices itemised the export price of individual fishes and the invoices used in our study, dated from 2011 to 2012, also differentiated the sale of colour morphs of two species of clownfishes (Pomacentridae), *Amphiprion percula* and *Premnas biaculeatus*. Morphs of *A. percula* were categorised as regular, melanistic, or aberrant while morphs of *P. biaculeatus* could be grouped as regular or aberrant. Melanistic morphs refer to melanin-induced pigmentation that darkens the fish's body (Militz et al., 2016) while aberrant morphs refer to variations in stripe patterning that include the addition or absence of stripes (Allen, 1972; Fautin and Allen, 1997). The export prices of regular morphs were compared to melanistic and aberrant morphs for each species using one- and two-sample *t*-tests in the *R* statistical package.

Natural clownfish populations were assessed for morph prevalence within the Kavieng lagoonal system of New Ireland Province, PNG (Fig. 3.1) as per Militz et al. (2016). This site was chosen on the basis that it had no prior history of exploitation for the marine aquarium trade and is a proposed site for future aquarium fishery operations within the country (Dandava-Oli et al., 2013). The lagoonal system also reflects a high level of habitat diversity (Hamilton et al., 2009), making it an ideal location for evaluating habitat dependency in marine taxa (Militz et al., 2015; Militz et al., 2016). Populations of *A. percula* and *P. biaculeatus* were assessed over a cumulative 50 km of shallow-water habitat within the lagoonal system. Where the target species were observed, individual fish were classified according to which morph category best described them, using the definitions provided by Militz et al. (2016) to differentiate melanistic morphs. Personnel previously active in the PNG aquarium fishery confirmed the definitions were comparable to commercial morph categories used by the fishery. The population frequencies of the different morph categories were compared using two-proportions *z*-tests in *R*. Unbiased recursive partitioning using the ctree function in the *R* package *partykit* (Hothorn and Zeileis, 2015) was conducted to determine if variation among reefs, surrounding habitats (fine sediment, loose rubble, solid rock, and live coral), or depth were spatial predictors of morph prevalence.

The natural frequency of each morph was modelled against actual export prices as an exponential function (i.e., $\log_{10}$ transforming both the response and predictor variables in the model of export price as a function of frequency) using the linear model function in *R*. All prices are reported as 2012 U.S. dollars.

3.3 Results

Export invoices showed a total of 10,329 individual fishes exported for the marine aquarium trade from PNG during the study period, with 99.1 % identified to species level. *Amphiprion percula* and *P. biaculeatus* were amongst the first (n = 3,166) and ninth (n = 145) most exported species, respectively, together accounting for 32.1 % of exports.

Only a single aberrant *A. percula* morph was reported on export invoices with a price of $30.00, which was several times greater than the mean export price of regular *A. percula* ($5.36 ± 0.02, $t_{(2,2979)}$= -1127.67, $P < 0.01$). The export prices of melanistic *A. percula* morphs were also significantly higher ($11.03 ± 0.34) than the prices of regular morphs ($t_{(2,185)}$= 16.81, $P < 0.01$). The export prices of *P. biaculeatus* were more than five times higher for aberrant morphs ($23.78 ± 5.30) than for regular morphs ($4.66 ± 0.09, $t_{(2,35)}$= 3.61, P < 0.01). The price premiums of two aberrant *P. biaculeatus* morphs ($150.00 each) rendered these individual fish the highest value export from the PNG marine aquarium fishery.

Morph frequency was assessed within the Kavieng lagoonal system with a sample size of 1,068 for *A. percula* and 1,343 for *P. biaculeatus*. Aberrant *A. percula* morphs were found to account for 2.3 % of fish in the surveyed population, being less frequently encountered than melanistic morphs (19.7 %; χ^2 = 161.9, $P < 0.01$) and regular morphs (78.0 %; χ^2 = 1936.9, $P < 0.01$). Unbiased recursive partitioning was unable to detect any significant variation in morph frequency across the surveyed spatial scales ($P > 0.05$).

Melanistic *A. percula* morphs (19.7 %) were also less frequently encountered than regular morphs (78.0 %; χ^2 = 1336.4, $P < 0.01$). Melanistic morphs were unevenly distributed within the population, showing significant variation among reefs, water depths, and surrounding habitats (Fig. 3.2). Melanistic morphs were most frequently observed in shallow water habitats of the lagoon's interior (Node 7, Fig. 3.2) where a cluster of five reefs (reefs 16, 17, 19, 20, and 21 in Fig. 3.1) accounted for 53.3 % (n =210) of all melanistic morphs surveyed within the lagoonal system. Within the shallow water habitats, melanistic morphs were more frequently associated with rocky or fine sediment habitats (Node 10, Fig. 3.2).

Aberrant morphs of *P. biaculeatus* were less frequently encountered (7.3 %) than regular morphs of the species (92.7 %; $\chi^2 = 1955.8$, $P < 0.01$). Unbiased recursive partition was unable to detect any significant variation in morph frequency across the surveyed spatial scales ($P > 0.05$).

There was an inverse relationship between morph frequency and export price ($y = 4.60x^{-0.51}$, $R^2 = 0.43$), but the mean price increase was inversely less than the observed reduction in morph frequency (Fig. 3.3). Only 12 individual fishes (two aberrant *P. biaculeatus* and ten melanistic *A. percula*), representing 5.4 % of the trade in rare morphs ($n = 222$), had export prices in excess of prices based on relative frequency (Fig. 3.3).

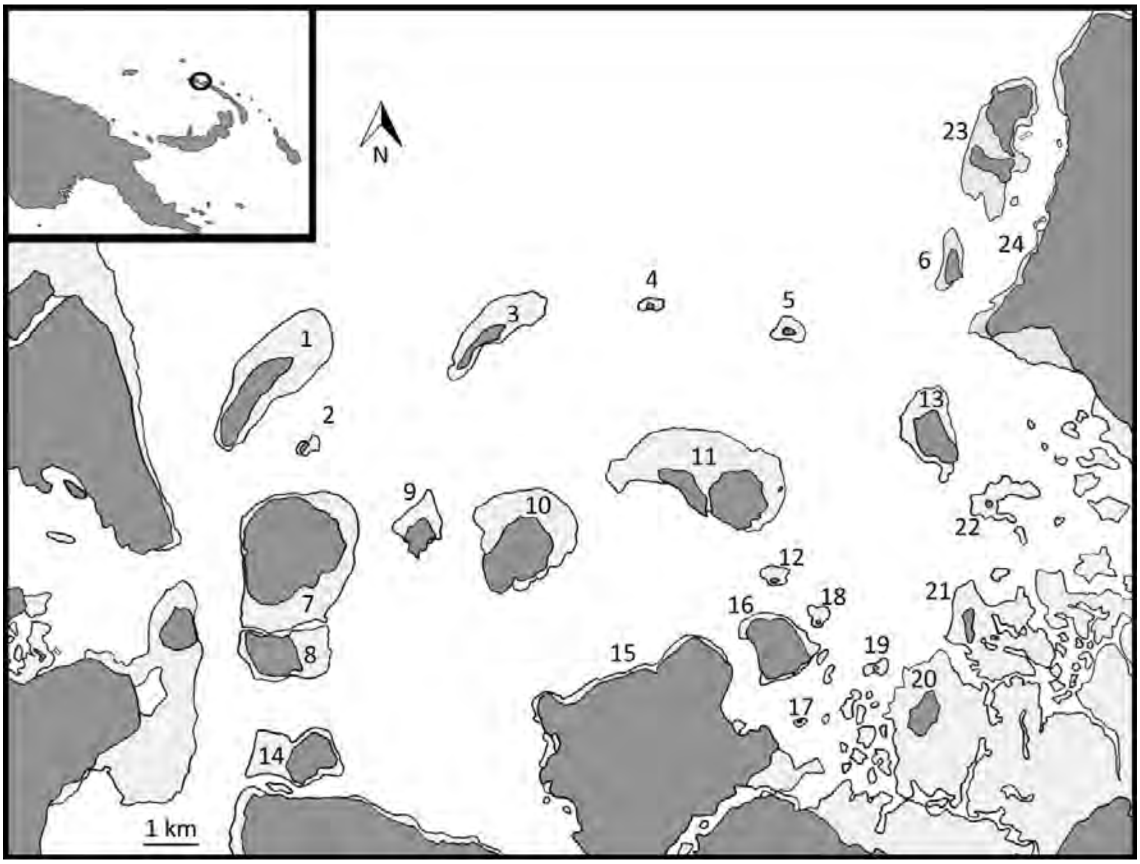

Figure 3.1: Map of the Kavieng lagoonal system (2°36′S, 150°46′E) where numbering identifies surveyed reefs. The *white* areas indicate water, the *dark shaded* areas represent land, and the *light shaded* areas indicate areas with reef development. Top left insert places the lagoonal system (*circled*) in geographical context within Papua New Guinea.

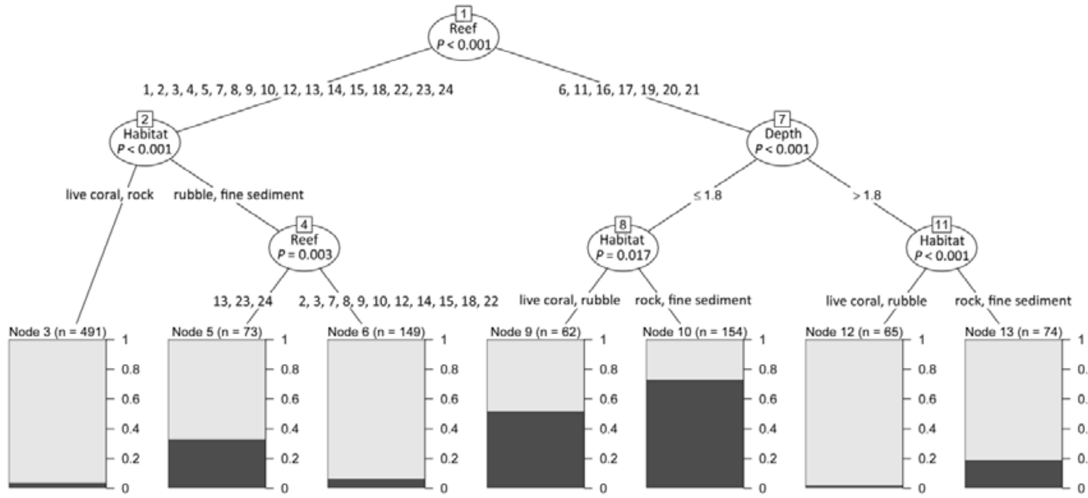

Figure 3.2: Unbiased recursive partitioning of spatial scale variables predicting the distribution of melanistic and regular *A. percula* morphs within the Kavieng lagoonal system. *Dark shading* indicates the proportion of melanistic individuals and *light shading* indicates the proportion of regular individuals at each terminal node. Reef identification numbers correspond to Figure 3.1.

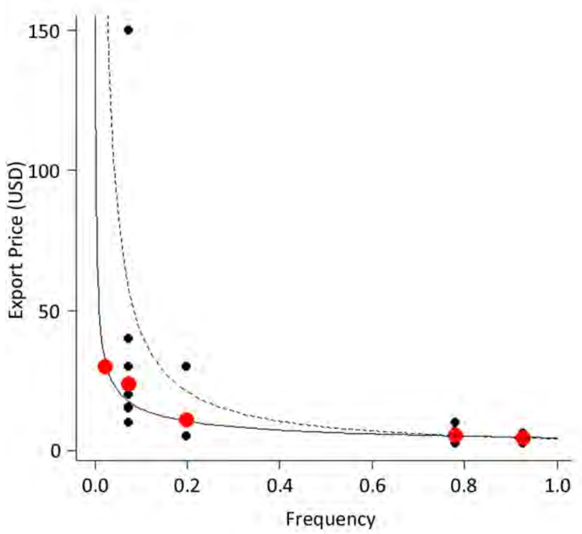

Figure 3.3: The mean export price (*red circles*) and individual export prices (*black circles*) of the different *A. percula* and *P. biaculeatus* colour morphs with respect to their natural frequency in the Kavieng lagoonal system. The solid line represents the exponential function ($y = 4.60x^{-0.51}$) best describing actual export price. The dashed line represents the bioeconomic equilibrium, if export prices were directly proportionate to morph frequency ($y = 4.21x^{-1.00}$).

3.4 Discussion

With the potential for high reward, fishers and exporters are incentivised to exploit melanistic and aberrant *A. percula* and *P. biaculeatus* morphs for the aquarium trade. Our results show export prices increased exponentially with increasing morph rarity for two species of clownfishes. However, the value prescribed to the studied morphs does not reflect an exaggerated value of rarity (Courchamp et al., 2006; Hall et al., 2008), as the increase in value was inversely less than the increase in rarity. This could be taken as evidence that the studied morphs face a reduced likelihood of targeted exploitation in the PNG marine aquarium fishery (Branch et al., 2013). On the basis of random encounters, opportunistic exploitation of the rare clownfish morphs would be a more economically efficient fishing strategy.

This notion holds true for aberrant morphs of both *A. percula* and *P. biaculeatus* which were randomly distributed among their populations across the surveyed spatial scales. Given the random distributions, there is limited scope for fisher knowledge, skill, or gear investment to improve capacity in targeting these portions of the clownfishes' populations. The combination of economic and ecological qualities characterising aberrant *A. percula* and *P. biaculeatus* morphs reduces the scope for these morphs to be at risk of targeted exploitation (Courchamp et al., 2006; Branch et al., 2013). This does not preclude risk-seeking fishers (Kahneman and Tversky, 1979) from irrationally targeting these morphs, but we note risk-seeking behaviours in small-scale fisheries typically characterise only a minority of fishers (Eggert and Lokina, 2007). Rather, the economic and ecological qualities of aberrant *A. percula* and *P. biaculeatus* morphs are more characteristic of taxa at risk from opportunistic exploitation (Branch et al., 2013). In the case of aberrant *P. biaculeatus*, opportunistic exploitation could extend beyond active aquarium fishers to even fishers engaged in subsistence food fishing. Our evidence for this comes from prior operations using mobile phone text-messaging to alert the general populace of cash rewards for the capture of aberrant *P. biaculeatus* morphs (*pers. obs.*).

The non-random spatial distribution of melanistic *A. percula* morphs, in contrast, revealed several locations where melanistic morphs occurred at high prevalence. The frequency of occurrence in shallow water habitats of reefs in the lagoon's interior would justify the economic efficiency of targeted exploitation for fishers with the knowledge and capability to access these locational "hot spots" of melanistic *A. percula* morphs. This would put more than half of the regional melanistic morph population at risk of targeted exploitation (i.e., those individuals within the locational hot spot), while the remainder of the population would be at risk from opportunistic exploitation given the relative high value of this morph.

The adoption of both targeted and opportunistic exploitation strategies by fishers can lead to the unsustainable harvest of taxa (Courchamp et al., 2006; Branch et al., 2013). However, the absence of exaggerated value for rarity among the studied morphs would limit targeted exploitation to locational hot spots of melanistic *A. percula* morphs, and limit depletion to the point of bioeconomic equilibrium (Grafton et al., 2007; Branch et al., 2013). Beyond this, opportunistic exploitation is more likely to be a concern for the PNG fishery. Concern for the unregulated exploitation of aberrant *A. percula* morphs arises from some aberrant individuals having shown noticeable genetic differentiation from other individuals of the species (Litsios et al., 2014). Melanism in clownfishes has also been linked to genetic differences for at least one species (*Amphiprion clarkii*), but at present it is unclear whether colouration alone explains such differences or whether differences represent separate subclades (Litsios et al., 2014).

In addition to concern for a loss of biodiversity, there is value in sustaining this economically valuable resource for the profitability of marine aquarium fisheries. In the PNG fishery, melanistic and aberrant morphs of *A. percula* and *P. biaculeatus* accounted for 5.7 % of the fishery's export value. Globally, both *A. percula* and *P. biaculeatus* are important commodities in the marine aquarium trade being among the 20 most frequently traded species, and being exploited in a number of countries (Wabnitz et al., 2003; Rhyne et al., 2012b). Melanistic and aberrant morphs of *A. percula* and *P. biaculeatus* are known to exist from several other locations, beyond PNG (Allen, 1972; Fautin and Allen, 1997). Given the potential for clownfishes to experience targeted exploitation in other regions (Shuman et al., 2005; Madduppa et al., 2014), opportunistic exploitation of rare morphs likely occurs elsewhere.

Comparative studies evaluating relationships between the natural rarity of taxa and their exploitation are lacking for the marine aquarium trade. We intend for this article to bring a new perspective to how exploitation for the marine aquarium trade targets not only species, but potentially morphs of species as a consequence of increased value being associated with natural rarity. There are numerous polymorphic reef fishes, with a multitude of explanatory factors giving rise to polymorphism. Exploitation of sex-associated (Kodric-Brown, 1998), dietary induced (Whitman et al., 2007), or environmentally elastic morphs (Cortesi et al., 2015) is less of a potential concern than exploitation of naturally rare morphs with a genetic basis (Drew et al., 2008, 2010). Exploitation of the latter has potential to extirpate the resource and reduce genetic diversity of populations.

Useful policy in managing the exploitation of rare taxa involves trade restrictions and shortlists of allowed exports (Courchamp et al., 2006; Branch et al., 2013). For example, PNG has implemented export bans on seven species of birdwing butterflies, as a consequence of their rarity and the global demand from insect collectors (Slone et al., 1997). For the developing marine aquarium industry, shortlists of allowed species and morphs may be more advantageous than imposing bans, as bans are reactionary management that may come too late to avoid depletion of naturally rare taxa (Branch et al., 2013). Shortlists of allowed species and morphs can be coupled with collection limits for further management (Chapter 2; Saleem and Islam 2007; Dee et al., 2014), but trade limits are unlikely to be effective given that disparities between collection and trade can be substantial (Chapters 2, 4, and 6). Additionally, spatially restricting extractive exploitation, as practiced in the PNG fishery previously (Chapters 2, 4, and 6), or the establishment of marine reserves could limit the spatial extent over which opportunistic exploitation occurs (Branch et al., 2013). However, the effectiveness of these policy ideas for mitigating the risks of targeted and opportunistic exploitation is inherently limited without effective monitoring and enforcement.

The harsh reality is that many of the source countries supplying the marine aquarium trade (Wabnitz et al., 2003; Rhyne et al., 2012b; Leal et al., 2016) are economically marginalised and with minimal fishery regulations (Dee et al., 2014). Where regulations do exist, the capacity for enforcement is usually low (Erdmann, 2001). This greatly limits the ability of many countries supplying the marine aquarium trade to adequately protect exploited taxa. The marine aquarium trade's contribution to the endangerment of the Bangaii Cardinalfish, *Pteragogon kauderni*, being a noteworthy example (Vagelli, 2008). For these reasons, we suggest management strategies aiming to reduce consumer demand are likely to be a more effective solution.

Conservation interventions appealing to consumer ethics are likely to be the most effective method in reducing demand for naturally rare taxa in the aquarium trade. Trade surveys reveal consumers desire more information at the point of sale (Murray and Watson, 2014) with consumers indicating preferences for environmentally sustainable livestock collection and supply (Chapter 7). Awareness campaigns portraying the natural rarity of taxa being exploited for the aquarium trade may be successful in this regard. While it can be argued that publishing information on species abundance in the public domain could contribute to rarity-fuelled consumption (Chapter 8; Hall et al., 2008), the importance consumers ascribed to rarity was less prominent than the importance ascribed to environmental sustainability (Chapter 7). Thus, consumer understanding of sustainability risks associated with the exploitation of naturally rare taxa may help curb demand.

An additional management strategy would be to present acceptable alternatives to consumers. Rarity in the marine aquarium trade is largely a product of a skewed and scale-dependent human perspective: a species may be considered rare when portrayed as such by digital media and suppliers, rarely encountered due to difficulties in accessing habitat (i.e., deep-water species), infrequently collected due to limited demand or intolerant of captive conditions (i.e., corallivorous butterflyfish), geographically restricted (i.e., island endemics), or widespread but at low densities (Chapter 8; Hall et al., 2008; Rhyne et al., 2012a). Consumption of only the latter two perceptions of rarity poses risks to the exploited species and exploitation for the aquarium trade has been directly linked to extinction risks for geographically restricted species (e.g., *Pteragogon kauderni*) and reduced abundances of widespread species at low densities (e.g., *Amphiprion ocellaris*) (Shuman et al., 2005; Vagelli, 2008; Madduppa et al., 2014). Industry and social media promotion of naturally abundant, but rarely traded taxa would offer an alternative avenue by which consumers could obtain "rare" taxa that pose a much lower extinction risk to the exploited species.

In the case of rare clownfish morphs, sustainable alternatives such as aquacultural supply could mitigate demand for taxa derived from wild populations (Militz, *in press*). However, aquaculture development in the marine aquarium sector is far from producing the full range of taxa traded in the marine aquarium trade (Militz, *in press*). This indicates that for many naturally rare taxa there will be no acceptable alternatives available to consumers. This is particularly true for taxa that exemplify unique behaviours, perform functional roles in aquaria, or have distinctive appearances (Hall et al., 2008). Demand for rare taxa with these attributes may be less easily shifted with consumer awareness campaigns and should be prioritised in future research assessing rarity-fuelled exploitation for the aquarium trade.

Chapter 4

Fish rejections in the Papua New Guinea marine aquarium supply chain[3]

Abstract

A major difficulty in managing wildlife trade is the reliance on trade data (rather than capture data) to monitor exploitation of wild populations. Collected organisms that die or are rejected before a point of sale often go unreported. For the global marine aquarium trade, identifying the loss of collected fish from rejection, prior to export, is a first step in assessing true collection levels. This study takes a detailed look at fish rejections by buyers before export using the Papua New Guinea marine aquarium fishery as a case study. Utilising collection invoices detailing the species and quantity of fish (Actinopteri and Elasmobranchii) accepted or rejected by the exporting company it was determined that, over a six month period, 24.2 % of the total fish catch reported (*n* = 13,886) was rejected. Of the ten most collected fish families, rejection frequency was highest for the Apogonidae (54.2 %), Chaetodontidae (26.3 %), and Acanthuridae (18.2 %) and lowest for Labridae (6.6 %) and Hemiscylliidae (0.7 %). The most frequently cited reasons for rejection were fin damage (45.6% of cases), undersized fish (21.8 %), and fish deemed too thin (11.1 %). Despite fishers receiving feedback on invoices explaining rejections, there was no improvement in rejection frequencies over time ($r = -0.33$, $P = 0.15$) with weekly rejection frequencies being highly inconsistent (range: 2.8 % to 79.4 %; s = 16. 3 %). These findings suggest that export/ import statistics can greatly underestimate collection for the marine aquarium trade as additional factors such as fisher discards, escapees, post-collection mortalities, and unregulated domestic trade would further contribute to this disparity.

4.1 Introduction

Wildlife trade has evolved into a pivotal concern for both biodiversity conservation and sustainable development. The present century is afflicted with global declines in terrestrial and aquatic ecosystems, spurred by anthropogenic stressors and global climate change (Laurance, 1999; Hughes et al., 2003; Bellwood et al., 2004). Exploitation associated with wildlife trade in the present era is a contentious issue. Sustainably managed wildlife trade can provide income for some of the least economically affluent people (Ferse et al., 2013; Madduppa et al., 2014) though overexploitation of wildlife can be a principal cause of biodiversity loss (Blundell and Mascia, 2005; Thornhill, 2012). Consequently, accurate monitoring of exploitation is critical.

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An inherent flaw in managing the exploitation of wildlife trade is a reliance on trade data, and not capture data, as a proxy variable to monitor impacts of exploitation of wild populations (Blundell and Mascia, 2005). The disparity between collection and trade is largely unknown for most wildlife trades. Collected organisms that die or are rejected before a point of sale often go unreported. Quantifying this unreported loss is a first step in correctly modelling and assessing the real impact of wildlife trade on wild populations.

Like much of the wildlife trade, the marine aquarium trade is largely characterised by international trade statistics (Balboa, 2003; Wabnitz et al., 2003; Rhyne et al., 2012a,b). This trade is responsible for the translocation of millions of marine organisms from their natural habitats to public and private aquaria worldwide (Wabnitz et al., 2003). Current proposals for more accurate monitoring of the marine aquarium trade suggest utilisation of trade invoices as the way forward (Rhyne et al., 2012a). While this is likely to be the most feasible method for countries to monitor the industry, management recommendations made for source countries on the basis of trade data are hindered because trade may be unrepresentative of true collection levels. Prior to commercialised trade, fish may be lost due to fisher discards, quality control rejections by buyers, mortality, escape, and unregulated domestic trade, which can all accentuate the difference between numbers collected and traded. A secondary consequence of escapees, discards, and rejections leading to release is the risk of disease transmission, unnatural gene flow, and establishment of nonindigenous species populations (Tlusty, 2002; Thornhill, 2012; Holmberg et al., 2015). A logical first step in addressing this potential issue is to assess the degree to which these factors may impact a fishery's total catch.

Fish rejections are inevitable in the quality control process of supplying a trade largely built around aesthetics (Wabnitz et al., 2003; Murray and Watson, 2014). Where quality control falters, export of low quality fish can have negative repercussions for all operations in the region (Teitelbaum et al., 2010). While buyer rejections of fish caught by fishers are known to occur within the trade, the proportion of the catch rejected from village-based fisheries has never been empirically evaluated beyond isolated collection events (Kinch, 2004; MAC, 2006). Village-based fisheries dominate the global supply of marine aquarium organisms, with most fish being derived from impoverished countries in the Indo-Western Pacific (Wabnitz et al., 2003; Rhyne et al., 2012b). In this study we quantify the proportion of total catch rejected by buyers, evaluate reasons for rejection, and examine rejection frequencies over time using the entire Papua New Guinea (PNG) marine aquarium fishery as a case study.

4.2 Materials and methods

4.2.1 Study fishery

Papua New Guinea comprises the eastern part of the island of New Guinea and a number of smaller islands in the Indo-Western Pacific and is considered part of the Coral Triangle, a centre of global marine diversity and a hot-spot of endemism. There is a rich tradition of fishing among the coastal and island communities of PNG. Signs of overexploitation of some commercially important marine income generating and food species have increased in recent times, especially in areas close to urban centres (Lock, 1986; Cinner and McClanahan, 2006). As an alternative livelihood option, the PNG National Fishery Authority (NFA) began expressing interest in the marine aquarium trade as early as 1990 (Perino, 1990). However, no commercial action eventuated and it was not until 2007 that interest was reinvigorated when the NFA contracted a US-based consulting firm, EcoEZ Inc., to reassess marine resources with value to the marine aquarium trade. This consultancy subsequently developed into a three year project to develop a sustainable approach to a marine aquarium trade fishery with commercial realisation to be achieved in the third year of the project (Yeeting and Batty, 2010).

Over the course of development, EcoEZ Inc. engaged eight communities in fish collection for the marine aquarium trade. These communities were all in the Central Province bordering the PNG capital of Port Moresby and included Fishermen Island, Roku, Pari, Gaire, Tarauama, Gabagaba, Keapara, and Kouderika. Six of these communities had their own demarcated Fishery Management Areas (FMAs) while the remaining two communities (Pari and Tarauama) had shared access to a single FMA. The FMAs defined the spatial unit in which all collection activities were to occur. Two of the FMAs, Fishermen Island and Keapara Village, were claimed to be certifiable under Marine Aquarium Council (MAC) standards (MAC, 2001b; Yeeting and Batty, 2010).

All fishers were trained in collection and handling practices according to MAC certification standards [MAC, 2001a; Dandava-Oli et al., 2013) and there have been no reports of illegal fishing activity (i.e. use of chemicals or prohibited gear) occurring. Collection of aquarium fish was conducted using snorkel with a compliment of hand, fence, and barrier nets made from fine mesh. Fish were coerced into the fence or barrier nets by the presence of the fisher or with the aid of a ‘tickler’ stick at which point they were scooped up with hand nets and placed into submerged or floating holding containers. Fish were typically targeted as individuals or small groups. At the end of a fishing session, the fish were transported from the fishing grounds by canoe or motorised boat (generally < 10 km) to a holding enclosure, nets suspended from the surface or submerged containers, often close to shore and close to the fisher’s residence. Fish were held live within holding enclosures until purchased by a buyer from the exporting company.

4.2.2 Data collection

Livestock collection operated with orders being given to fishers by the exporting company (EcoEZ Inc.) on a weekly basis. After several days of fishing, a buyer from the exporting company would visit fishers to purchase their catch. Purchasing was done by collating information on the catch and producing a collection invoice for the amount owed to fishers for their catch. Collection invoices detailed the identity and quantity of each fish species (Actinopteri and Elasmobranchii) accepted and/or rejected. Where fish were rejected the reason behind such rejections were often noted to provide fishers with feedback on their catch. This 'catch-to-order' method of fishery organization was perceived as a solution to avoid collecting species in excess of demand and to decrease the quantity of fish rejected by buyers; both problems known from the Indonesian and the Philippine fisheries (MAC, 2006; Reksodihardjo-Lilley and Lilley, 2007; Thornhill, 2012).

The NFA retained an electronic copy of all collection invoices provided to them by EcoEZ Inc. as part of the contracted consultancy. However, records prior to 2010 are largely incomplete and a complete set of collection invoices could only be obtained for a six month period from January 1st 2010 to June 14th 2010 which was analysed in this study (hereafter, the 'study period'). Seven of the eight communities were engaged in fishing during the study period.

4.2.3 Data analysis

All data was transferred into Excel (Version 14). Collection invoices were taken at face value as misinformation could not be corrected for. However, corrections were made when species names were misspelled or listed with only a common name. Scientific names were matched with common names using an NFA-supplied EcoEZ Inc. identification guide. Validity of scientific names was confirmed using the World Register of Marine Species (WoRMS, 2015). For purposes of analysis, all Apogonidae species were grouped as 'Apogonidae spp.' for two reasons: (1) the majority (55.9%) of apogonids could not be identified, accounting for 90.0% of all unidentified species, and (2) due to multiple species sharing the common name 'yellow cardinal' it is plausible those identified on collection invoices were in error. Fish were labelled as 'unknown' where neither a species name nor family could be assigned using the company's identification guide.

At all levels of analysis, rejection frequencies were calculated by the number of fish rejected as a percentage of the total fish catch. In the case of explanations reported for rejections, responses deviated from definitive categories. In an iterative process, all explanations were grouped into eight encompassing categories (Table 4.1). The statistical package S-Plus (Version 8.0) was used to determine 95% confidence intervals for the fishery-wide rejection frequency using the

Agresti-Coull method. Linear regressions were run in S-Plus comparing individual fishers' rejection frequencies against their total catch and to compare rejection frequencies against their catch of two specific fish families. It was necessary to apply a square root transformation to fishers' rejection frequencies to satisfy the assumptions of the linear regression analysis. All invoices were also time sorted by the week in which fishing commenced for a given collection invoice. Weeks were numbered chronologically from the start of the year. A Pearson's correlation analysis was run using S-Plus to determine the nature of an association between time (i.e. fishing week) and rejection frequencies.

Table 4.1: Reasons given for fish rejections and the grouping terms used in this study.

As grouped in this study	Reasons reported on invoice
Too thin	Too thin
Undersized	Too small
Too fat	Too fat
Oversized	Too large
Not ordered	Wrongly Identified Not ordered
Body damage	Bruised Tissue damage Removed scales Bulging eye
Fin damage	Torn fin
Dead	Dead

4.3 Results

4.3.1 Fish collections

Collection invoices made available by the NFA show that a total of 13,892 fish were collected during the study period. Of these 83.6 % could be identified to species whilst 99.9 % were identified to family. The top ten collected families (of the 29 families identified) accounted for 95.8 % of total fish collections while the top ten species (of the 134 species identified) collected accounted for 77.9 % of total fish collections (Fig 4.1). Nearly all (98.5 %) identified fish species collected were species known to be purchased by the exporting company.

Across the entire fishery, 24.2 % (95 % confidence interval: 23.5 to 24.9 %) of the total fish catch was rejected. Rejection frequencies among the most collected families ranged from 54.2 % (Apogonidae) to as low as 0.7 % (Hemiscylliidae; Fig 4.1). Of the top ten most collected species, the butterflyfish, *Chelmon rostratus*, had the highest rejection frequency (29.8 %) while the anthias, *Pseudanthias squamipinnis*, had the lowest (7.0 %; Fig 4.1). Explanations for rejection were recorded for 40.0 % of all rejections (n = 3,360; Fig 4.2). The most common explanations were fish having fin damage (45.6 %) or being undersized (21.8%). Chaetodontidae were particularly prone to fin damage, accounting for 48.6 % of all fin damage cases (n = 613) and comprising 78.0 % of all explained chaetodontid rejections (n = 382; Table 4.2). Rejections due to undersized fish were mostly associated with Pomacentridae, with this family accounting for 56.3 % of all undersized catch (n = 293) and this factor accounted for 41.5 % of explained pomacentrid rejections (n = 398; Table 4.2).

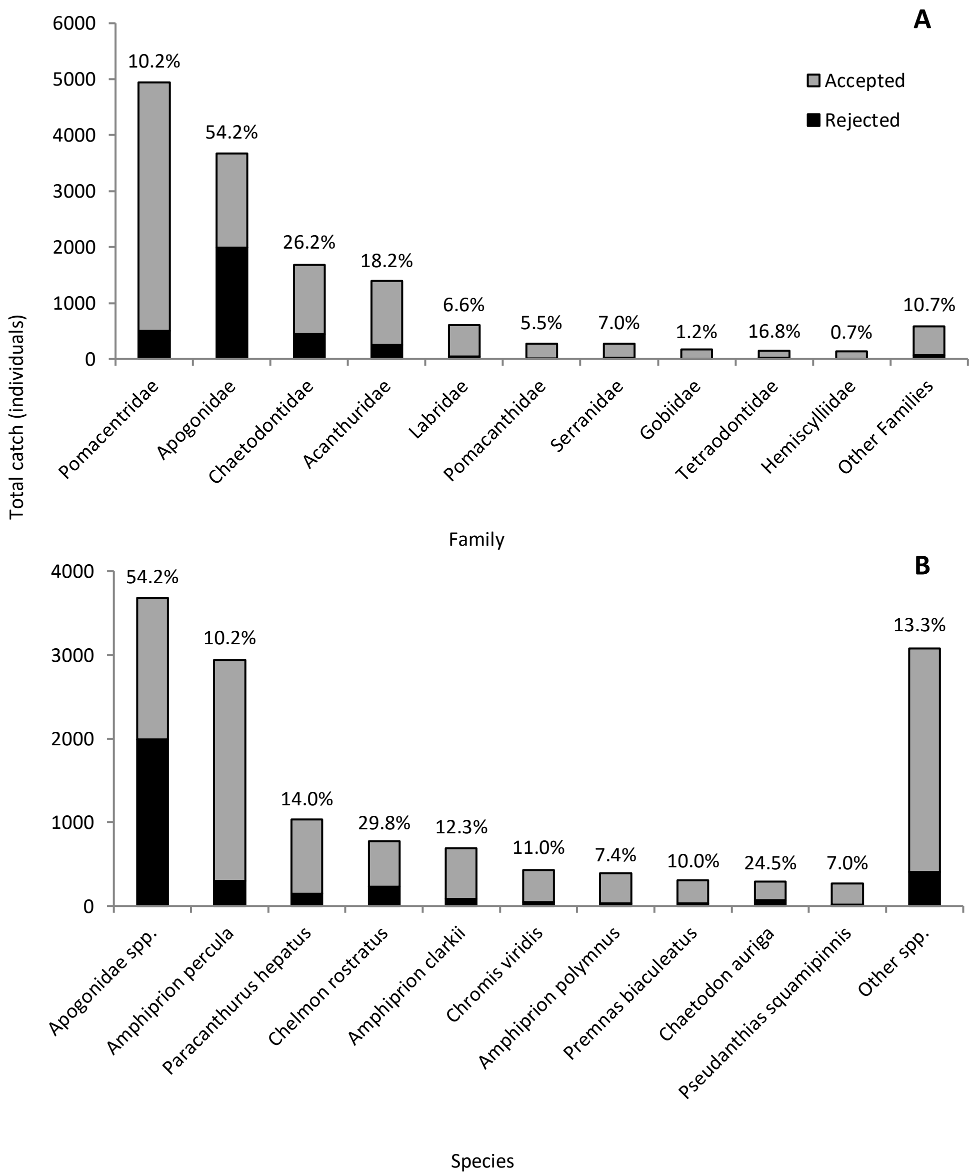

Figure 4.1: Total catch for the most collected fish families (A) and species (B) divided into those fish accepted and rejected by the exporting company. The percentage of catch rejected for a given family or species is presented as superscripts.

4.3.2 Fisher performance

From the total catch, 91.0 % could be attributed to individual fishers; the remaining catch resulted from multiple fishers collaborating or unidentified fishers. A single community, Roku, was responsible for 67.3 % of all rejections despite contributing only 17.6 % of all accepted fish

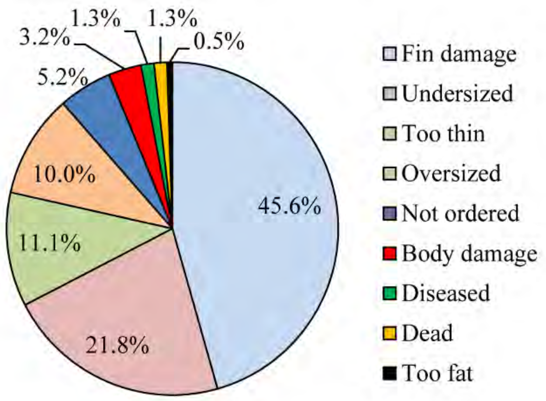

Figure 4.2: Reasons for rejecting individual fish as a percentage of explained rejections.

(Fig. 4.3). One week of fishing at Roku over the study period contributed to 50.1 % of all rejections in the fishery over the study period. However, even when this week is removed from the data set, Roku still had the highest rejection frequency (29.0 % of total catch), which was nearly double that of the village with the next highest rejection frequency (Tarauama: 15.0 %; Fig. 4.3).

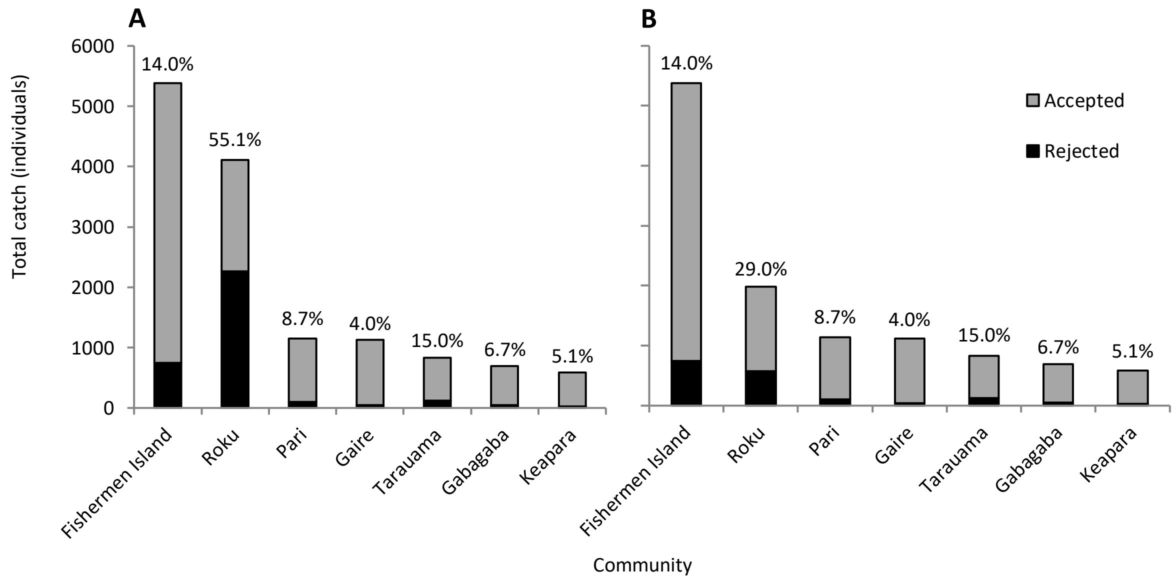

Figure 4.3: Total catch of fish by each community divided into those fish accepted and rejected by the exporting company. The percentage of total catch rejected is presented as superscripts. (A) Presents all data during the study period. (B) Data with one week of fishing at Roku omitted.

The high percentage of rejections at Roku is due to the targeted fish species, with two-thirds (66.1 %) of the accepted catch (n = 1848) from this village being composed of Apogonidae and Chaetodontidae, the highest of any village. These two families of fish accounted for 72.5 % of all rejections in the fishery. There was a significant positive relationship between rejection frequency and a fisher's catch of Apogonidae and Chaetodontidae fishes ($F_{1,56} = 29.55$, $P < 0.001$; Fig. 4.4). The relationship between fishers' rejection frequencies and their catch of Apogonidae and Chaetodontidae explained almost twice the total variation ($R^2 = 0.35$) in rejection frequencies than a relationship with total catch of all fish species ($R^2 = 0.21$, $F_{1,56} = 15.22$, $P < 0.001$; Fig. 4.4). There was no significant correlation between time (i.e. fishing week) and rejection frequency (r = -0.33, $t_{(2)18} = -1.49$, $P = 0.15$) with notable inconsistencies in rejection frequencies between weeks (range: 2.8 % to 79.4 %; s = 16.3 %).

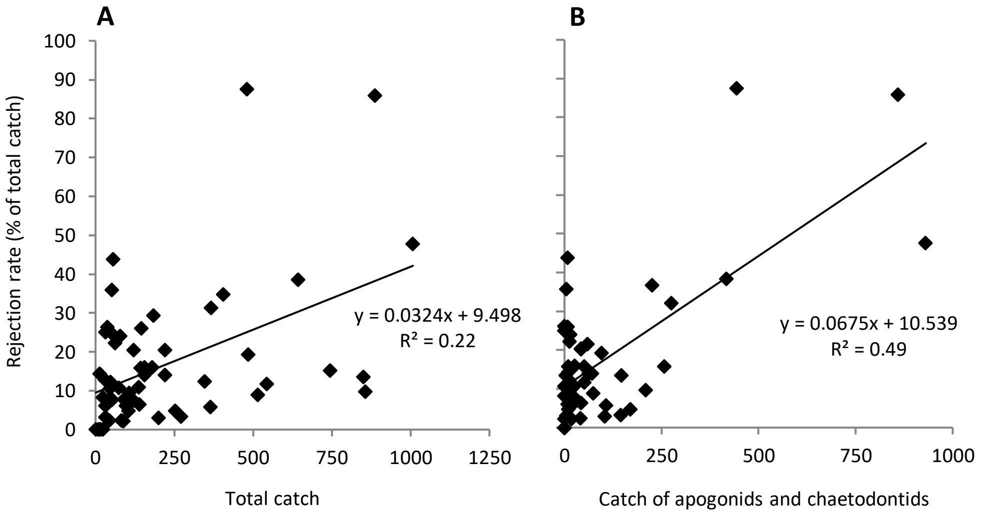

Figure 4.4: Proportion of total catch rejected (square root transformed) plotted against (A) total catch and (B) catch of apogonids and chaetodontids over the study period for individual fishers.

4.4 Discussion

Characterisation of the marine aquarium trade is dominated by international trade statistics (Balboa, 2003; Wabnitz et al., 2003; Rhyne et al., 2012a,b) with proposals for improved monitoring to utilise trade invoices (Rhyne et al., 2012a). While this is likely to be the most feasible method to monitor relative exploitation by the trade, management recommendations made on the basis of export/import data must account for their limitations. Here we show that a minimum of 24.2 % of the total fish catch from the PNG marine aquarium fishery went unreported in export/import invoices during the six month study period. This unreported catch consisted only of rejections at the collection level. The actual difference between collection and export is likely to be even greater when mortalities at the exporting facility and unreported domestic trade are factored in. Those species and villages with the highest rejection frequencies indicate where management considerations are needed most.

4.4.1 Fisher performance

Despite being a relatively new fishery, it is unlikely that fisher inexperience contributed to the results because fishers had already collected a minimum of 31,365 organisms prior to the study period in 2008–2009 (Rhyne et al., 2015). Further, fishers who collected more fish (i.e., had more experience) tended to have higher, rather than lower, rejection frequencies. Widespread use of anaethetising chemicals and environemtnally destructive collection techniques can also be ruled out as a factor contributing to rejections as all fishers were trained according to the MAC certification standards (Dandava-Oli et al., 2013).

Competition and rivalry between fisher groups targeting aquarium organisms has been reported in Indonesia (Ferse et al., 2013). Where competition for shared resources occurs, resource depletion can be accelerated through a 'tragedy-of-the-commons' scenario (Hardin, 1968), albeit within a collectively owned territory. Interestingly, the shared FMA of Pari and Tarauama did not result in exceptionally high rejection frequencies for either community that would be expected from such a scenario. Rather, the species composition of catches seemed to explain the majority of variation in rejection frequencies for fishers.

Rejections translate to a reduction in sale-per-unit-effort for the fishers as the buyers would only compensate fishers for accepted fish. This method of purchasing catch is commonplace in the trade (Wood, 2001; Kinch, 2004; MAC, 2006; Ferse et al., 2013). The wasted effort in collecting/holding a fish that becomes rejected, however, is not perceived as a disincentive to avoid rejections in the future (MAC, 2006; Reksodihardjo-Lilley and Lilley, 2007; Lilley, 2008). We are not suggesting fishers collected fish indiscriminately as nearly all collected species identified were known to be purchased by the exporter. Rather, the potential for financial gain, coupled with the effort required to isolate a fish for discarding, incentivises retention of fish even if there is only a slight chance of purchase by buyers. For example, in the case of rejections attributed to damaged fish (the most common reason for rejections), it is most likely that damage occurred during collection and/or subsequent handling after the fisher correctly identified suitable species. Damage therefore would only be realised after the point of capture. This presents the fisher with the decision to either discard the fish, potentially benefiting the long term productivity of the fishery (but risk someone else catching it), or retain the fish with the chance that a buyer may accept it. Only the latter option offers potential for an immediate economic return; a strong incentive for fishers in low-income countries like PNG (Foale, 2001; Filer, 2004; Macintyre and Foale, 2004).

Further, the primary reason for buyers to itemise rejected fish and give an explanation for rejection on collection invoices was to provide fishers with continual feedback about their catch. Despite provision of this feedback, fisher performance failed to improve over the duration of the study period. These scenarios highlight how education alone may not achieve alterations in behaviour and suggest that economic incentives/disincentives must be coupled with education to promote change in practice. A reward system such as third party eco-certification (Shuman et al., 2004), where buyers are incentivised to reward fishers and/or villages for low rejection frequencies, may have merit in these circumstances.

4.4.2 Reasons for rejections

Rejection frequencies varied greatly between species and even between families being collected. This limits the capacity for a single rejection value to accurately represent the disparity between collection and export/import statistics. Those families most frequently rejected (i.e. Apogonidae, Chaetodontidae, Acanthuridae) are where the greatest inaccuracies between collection and export/import statistics are likely to occur.

Fin damage was the most cited reason for rejection and a primary cause of rejections for four of the five most collected families. This suggests mitigation of fin damage be made a management priority for the PNG fishery. Predictably, those families characterised by more elaborate and delicate fins (i.e. Chaetodontidae and Acanthuridae) had a greater proportion of rejections attributed to fin damage than families with smaller, compact bodies (i.e. Pomacentridae and Apogonidae). Such damage likely arises from collection where abrasion from netting material damages the soft tissue of the fins or through handling/aggression from co-habiting fish after capture (Reksodihardjo-Lilley and Lilley, 2007; Lilley, 2008). Ensuring fishers use appropriately sized netting (3–28 mm depending on target fish) (Wood, 2001) for collection and isolating aggressive fish during holding would be first steps in reducing the frequency of fin damage rejections.

Oversized and undersized fish are another cause of rejection that occurred at the point of collection. Of the top five fish families, undersized fish were the most cited cause of rejection only for the Pomacentridae. Given the high demand for certain pomacentrids (namely *Amphiprion percula*) fishers may be tempted to collect potentially undersized fish in an attempt to fill orders and increase economic returns (Reksodihardjo-Lilley and Lilley, 2007; Madduppa et al., 2014). Aquarium fishers in Indonesia knowingly collected undersized *Amphiprion* spp. given their ease of capture in the hope that a buyer would accept a portion of the undersized catch (MAC, 2006; Madduppa et al., 2014).

The same logic likely applies to the collection of oversized fish, a primary cause of rejection for the Acanthuridae. These fishes have asymptotic growth curves (Choat and Axe, 1996) with juvenile fish being sought by the aquarium trade (Wabnitz et al., 2003; Kinch, 2004). Where juveniles are limited in supply on the reef due to seasonal recruitment (Doherty et al., 2004; Elizabeth et al., 2014) fishers may be tempted to collect oversized fish. Additionally, Acanthuridae are a target food species in PNG with many aquarium fishers simultaneously engaged in subsistence fishing for income (Schwerdtner Máñez et al., 2014). This suggests that oversized fish may represent catch from food fishing where fishers try to obtain a higher price from aquarium trade buyers before sale at local markets or consumption (Wabnitz et al., 2003; Madduppa et al., 2014).

Fish rejected for being too thin (i.e. Apogonidae), in contrast, is likely to be a consequence of post-capture care during holding where fish are not fed or fed inappropriately resulting in emaciation. A reduction of holding times through more frequent visitation to fishers by buyers, and ensuring buyers are equipping fishers with appropriate fish feeds and knowledge on fish husbandry practices, would help ensure such rejections are minimised.

4.4.3 Ecological consequences

The vast majority of explained rejections in this study involved live fish. The end fate of such fish is uncertain. The most likely scenarios are that rejected fish are returned to the sea, held for an alternative buyer, held until aesthetic impairment improves (for fin damage/body damage cases), eaten, or used as bait in subsistence food fishing. In the case of the PNG fishery, there were no alternative buyers and fishers did not have facilities for holding fish beyond a couple days. This would suggest rejected fish did not find their way into the trade through an alternative route.

Where post-collection rejections result in return of live fish to the sea, either for the purpose of survival or as escaped bait, serious ramifications can result. Rejection due to identifiable disease or body damage (possibly caused by disease) accounted for 4.5% of explained rejections. Pathogenic organisms are known to proliferate under tight holding conditions and with host stress (Bondad-Reantaso et al., 2005; Guo and Woo, 2009), both of which are inherent in the collecting process. Thus, the release of any rejected fish confined for a period of time poses the risk of releasing a fish with amplified levels of disease (Tlusty, 2002). Where fish are released in an area far removed from the point of collection, release can also result in unnatural gene flow and establishment of nonindigenous species (Tlusty, 2002; Thornhill, 2012). This has previously been documented in Indonesia where rejections of the Banggai Cardinalfish, *Pterapogon kauderni*, along the aquarium supply chain have resulted in the establishment of nonindigenous populations (Erdmann and Vagelli, 2001; Vagelli et al., 2009). These risks merit consideration by the regulatory authorities of supply countries and protocols deemed appropriate for dealing with rejected fish communicated to buyers and fishers. Discarding fish likely to be rejected immediately after capture would be the surest way to prevent such risks but places the onus on the fisher to accurately gauge fish of acceptable quality, the socio-economic complications and potential management of which have already been addressed above.

In addition to these risks, the survival of aquarium fishery releases are unknown and difficult to assess (Gutowsky et al., 2015). Average release mortality from a meta-analysis of recreational sport fishing show a mean mortality of 18% across studied species with post-release predation potentially accounting for a further 20% loss (Bartholonew and Bohnsack, 2005). However, the differences in gear used and the biology, ecology, and life history of the target species, limit the applicability of such data to aquarium fisheries. The majority of fish collected in this study and traded globally (i.e. Pomacentridae and Apogonidae) (Wabnitz et al., 2003; Rhyne et al., 2012b) are known to have adult home ranges of a few meters or less (Sale, 1971; Jones, 2007). Releasing these fishes outside of their home range in different habitats may limit their chances of survival (McCormick, 2012). This is expected to be true for habitat dependent fishes like clownfish (Amphiprioninae) which are reliant on host anemones for survival (Elliott and Marsical, 2001). In reality, it is unlikely that many of the rejected fish are returned to their reef of origin. In Indonesia, live rejected fish were thrown back into the sea behind the buyer's facility regardless of origin (MAC, 2006) and this was likewise noted for rejected coral collected for the aquarium trade (Ferse et al., 2013). Until estimates of the proportion of rejected fish returned to sea and their survival are known, it would be advisable that fishery management decisions be made following the precautionary principle and assume rejections are lost from natural populations. To accurately gauge these risks and loss it may be more prudent for fishery management agencies to begin developing policies to monitor collection records rather than trade invoices for species suspected of frequent rejections.

4.4.4 Rejection frequency in the trade

The majority of supply to the marine aquarium trade originates from impoverished countries of similar economic status to PNG (Wabnitz et al., 2013; Rhyne et al., 2012b) and, where fishers face economic pressures, unsustainable practices can flourish (Kinch, 2004; Reksodihardjo-Lilley and Lilley, 2007; Wood, 2001). Operated as 'fish-to-order' with direct supply (i.e. the fisher directly supplies the exporting company) and fishers trained to MAC standards, rejections should have been minimised within the PNG fishery. However, rejection frequencies reported for PNG are higher than any previously reported figure. Prior to this study, quantitative evaluations of rejection frequencies have been limited to brief accounts on collections. Kinch (2004) reported an exporter rejection frequency of 11.6 % (n = 493) for fish collections from Rarumana, Solomon Islands over a four day period in 2004; however the representativeness of this sample is uncertain given the inconsistencies in quality noted by the buyer. Such inconsistencies were also noted in the PNG fishery with weekly rejection frequencies ranging from 2.8% to 79.4% during the study period.

Where middlemen operate in the market chain that facilitate collection from fishers and then on-sell to exporters (Wabnitz et al., 2003; Ferse et al., 2013), quality assessment and rejection occurs on multiple levels within the supply chain (Gonzales and Savaris, 2005). Where the MAC (2006) looked at fish rejection frequencies in Indonesia during supervised fishing trips they found buyers rejected 5.7 % (n = 5,052) and 1.4 % (n = 14,246) during an eight and six day fishing trip, respectively. However, these rejection frequencies were considered low by the collectors and likely only represent preliminary rejections as buyers would then on-sell the catch to an exporter where further, unreported, rejections occur (Reksodihardjo-Lilley and Lilley, 2007). Such supply networks can also limit feedback to fishers on the quality of their catch and what the end market is demanding.

The high rejection frequency reported in this study results from the six month study period allowing the reported inconsistencies to be averaged out. The methodology employed in this study to analyse data routinely collected by buyers would also have negated potential observer effects on fisher performance present in previous studies. It is likely that the rejection frequency observed within the PNG fishery is not unrepresentative of village-based fishing operations in developing countries. Many island nations with marine aquarium fisheries have only a single exporting company (Kinch and Teitelbaum, 2009), eliminating the possibility that rejected fish enter the market through an alternative buyer. Even in Indonesia and the Philippines, where multiple buyers operate in close proximity, fishers generally deal exclusively with a single buyer with strong fisher-buyer relationships being driven by financial and social pressures (MAC, 2006; Ferse et al., 2013). Other aquarium fisheries are also burdened with excessive transportation distances between fishing grounds and place of sale, exceeding hundreds of kilometres (Kinch, 2004; MAC, 2006), suggesting fish are exposed to even greater levels of transport stress than in the current study. However, until comparable data from other marine aquarium fisheries is made available, the authors caution overextrapolation of the results from this case study. Much lower levels of rejection would be expected in fisheries operating in affluent countries or where fishers are directly employed by the exporting company (or self-employed) allowing for increased feedback on catch. In Hawaii, for example, where collectors are typically self-employed, collection discards and mortality following capture were < 1 % of total catch for November 2008 (Stevenson et al., 2011). Quality of the catch was assessed onsite immediately after capture with discards being returned to the sea and no further rejections were reported to occur before sale.

4.4.5 Conclusions

While global monitoring of trade through catch data continues to lack feasibility, case studies demonstrating the difference between exports and collections are needed to translate trade statistics into more accurate representations of fishery catch. Identifying the loss of collected fish through buyer rejections prior to export is one key component in the difference between collection and export statistics. Application of rejection frequencies as a correction tool and undertaking localised studies, as done here, can ground truth in the underestimation of catch and provide a better estimate of overall mortality for aquarium fisheries from trade invoices. In this initial case study, a rejection frequency of one in every four collected fish raises concern about the quantity of unreported catch that may be occurring in other aquarium fisheries. Such concern is further compounded because rejections are one of several factors contributing to the disparity between catch and export statistics. Further research effort aimed at addressing mortality along supply chains and domestic trade within supply countries, would greatly aid determination of the true fishing effort from trade data.

Chapter 5

Fish mortality in the Papua New Guinea marine aquarium supply chain[4]

Abstract

High supply-chain mortality is a major ecological concern for the exotic pet trade as loss of organisms between collection and retail sale causes waste, requiring further organism collection to satisfy market demand. We investigate supply-chain mortality for two enterprises, based in Papua New Guinea (PNG) and the Fiji Islands, engaged in the collection and export of marine aquarium fishes. Mortality was assessed at three stages in the supply-chain: (1) mortalities during transit to export facilities, (2) mortalities at export facilities, and (3) mortalities during transit to an importing enterprise. Cumulative mortality of fishes for this segment of the supply-chain was 0.7% for the Fiji enterprise and 29.9% for the PNG enterprise. This demonstrates that while the marine aquarium trade can operate with high survivorship from exporter to importer, instances of high mortality can still occur within the trade. Mortality was also found to not only vary between enterprises, but also across the three stages in the supply-chain assessed and among fish families and species. We examine the practices employed in the collection, holding, and transport of fishes by the Fiji and PNG enterprises to identify potential factors contributing to the disparity in mortality. The implications of the reported mortalities are discussed in relation to trade monitoring and management practices aimed to improve industry performance.

5.1 Introduction

The present era is experiencing global declines in terrestrial and aquatic ecosystems, spurred by anthropogenic stressors, human population growth, and climate change (Laurance, 1999; Hughes et al., 2003; Bellwood et al., 2003). In this context, exploitation associated with the exotic pet trade is a contentious issue. A sustainably managed pet trade can provide income for some of the most economically marginalized people (Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014) though overexploitation can be a principal cause of biodiversity loss in some localities (Blundell and Mascia, 2005; Thornhill, 2012).

High supply-chain mortality is a major ecological concern in the exotic pet trade (Thornhill, 2012; Ashley et al., 2014; Robinson et al., 2015). Death of organisms between collection and point of sale causes waste and requires further collection to satisfy market demand (Wood, 2001). Lack of appropriate attention to the health and welfare of traded organisms raises further concern regarding the ethical treatment of animals. Although the concept of ethics in live

[4] In preparation: Militz, T.A., Nahacky, T., Kinch, J., Southgate, P.C., in prep. Fish mortality in the marine aquarium trade, from exporter to importer, in two short supply-chain fisheries.

organism trades has been raised (Zhang et al., 2008; Baker et al., 2013), little research has focused on the welfare of organisms as they are moved through supply-chains. Where welfare is severely compromised, mortality can result. Along live organism supply-chains, mortalities can result from inappropriate methods of collection, handling, husbandry, and transportation or inadequate holding facilities.

The marine aquarium trade is responsible for translocating millions of marine fishes from their natural habitats to public and private aquaria worldwide (Wabnitz et al., 2003; Rhyne et al., 2012b). While aquaculture has capacity to supply markets with a few species, the majority of fish species traded are still sourced from wild fisheries (Moorhead and Zeng, 2010). Wild fisheries catch for the marine aquarium trade comes from over forty countries with the majority originating from the Philippines and Indonesia (Wabnitz et al., 2003; Rhyne et al., 2012b). Many of these fisheries operate within developing countries of the Indo-Pacific region (Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014) while primary markets exist in the United States, Europe, and Asia (Wabnitz et al., 2003).

The supply-chains of wild-caught marine aquarium fishes begin in the ocean with collection. Following collection, fishes can take many different routes before ending up at an exporting facility. In short supply-chain fisheries, fishers sell their catch direct to the exporting enterprise (Wabnitz et al., 2003; Kinch, 2004; Schwerdtner Máñez et al., 2014). In other supply-chains, fishes may be passed along an extended supply-chain of middlemen who buy and resell fishes for profit before they eventually reach an export facility (Wabnitz et al., 2003; MAC, 2006). Once stocked into the exporting facility, fishes are held until shipped overseas. Given the vast distances that live fishes travel from their point of origin to market, shipment is entirely reliant on air freight. Fishes are bagged with water and oxygen, then packed into styrofoam boxes before their, typically 12 to 48 h, journey to an importing enterprise (Pyle, 1993; Wabnitz et al., 2003).

Along this supply-chain, estimates of mortality can be in excess of 50% (Rubec, 2005; Schmidt and Kunzmann, 2005; Yan, 2016) while other studies indicate mortality to be less than 10% (Pyle, 1993; Wabnitz and Nahacky, 2014). This disparity is likely a consequence of mortality varying widely among collectors, collection methods, location of the collection site, time spent in holding and transport, and target species. This coupled with a lack of empirical studies on mortality levels of collected fishes can further widen the disparity in mortality estimates. Most mortality estimates for the marine aquarium trade were derived from isolated collection events (Kinch, 2004; Schmidt and Kunzmann, 2005; Wabnitz and Nahacky, 2014), industry interviews (Pyle, 1993; Rubec, 2005), or from undisclosed sources (Yan, 2016). The highest mortality estimates typically feature fisheries with minimal regulation (Dee et al., 2014) and poor capacity for enforcement (Erdmann, 2001; Rubec et al., 2001). Applying mortality levels derived from such fisheries to the aquarium trade at large can be misleading. Several fisheries supplying marine aquarium fishes to market are highly regulated (Dee et al., 2014) and, even within poorly regulated fisheries, exporting enterprises can choose to uphold their own set of operational practices.

There is great value in assessing mortality levels within the marine aquarium trade. This information is necessary to ethically justify the many potential benefits of the trade (Rhyne et al., 2010; OATA, 2016), approximate true levels of exploitation from trade invoices (Chapters 4 and 6), empower consumers to make sustainability conscious purchase decisions (Chapter 7), and direct reformation efforts to where they are most needed in the trade (Thornhill, 2012; Chapter 4). In view of such importance, it is surprising that there is a current lack of transparency or appropriate data collection in the marine aquarium trade concerning mortality levels along supply-chains. In this study, we provide an empirical assessment of fish mortality in the marine aquarium supply-chain, from exporter to importer, based on the Papua New Guinea (PNG) and Fiji Islands marine aquarium fisheries. We further attribute mortality levels to specific fish families and species, identifying those where mortalities are highest. This assessment proves, from collection to importer, that the marine aquarium supply-chain can operate with minimal mortality of traded fishes and that two enterprises characterized by relatively short supply-chains can have vastly different levels of mortality.

5.2 Materials and methods

5.2.1 Fiji Islands study enterprise

Fiji is an archipelago of more than 330 islands in the South Pacific Ocean. The Fijian marine aquarium fishery has operated for over 50 years with collection historically occurring around the main island of Viti Levu with recent extension, in 2013, to Vanua Levu. Aquarium fishing is regulated by a limited number of collector licenses that are restricted to demarcated fishery management areas (FMAs), size limits on fishes, gear restrictions, anti-cyanide laws, and customary tenure of fishing grounds (Dee et al., 2014). There are five companies engaged in marine aquarium fish collecting, with our Fiji enterprise of study, Aquarium Fish (Fiji) Ltd. (AFF), accounting for an estimated 60-90% of the country’s aquarium fish exports on an annual basis. Commencing operation in 1984, AFF engages up to 13 local fishers. In 2004, AFF became fully Marine Aquarium Council (MAC) certified (MAC, 2001a,b), having a company specific Collection Area Management Plan and Company Management Policy Manual.

All fishers were trained in collection and handling practices according to MAC certification standards and there have been no reports of illegal fishing activity (i.e. use of chemicals or prohibited gear) occurring. Collection of aquarium fishes was conducted using both snorkel and SCUBA with a compliment of hand, fence, and barrier nets made from fine mesh. Fishes were coerced into the fence or barrier nets by the presence of the fisher or with the aid of a 'herding' stick. Fishes were then scooped up with hand nets and placed into containers transported underwater by the fisher. Fishes were typically targeted as individuals or small groups. At the end of a fishing session, the fishes are removed from their collection containers and placed into 32 L holding containers on board a company boat. After a series of two to three dives or a period of snorkeling, fishes are transported in a company boat to the export facility (generally < 20 km) and immediately stocked into holding aquaria. Fishers are paid for all fishes received alive, in good health, and appropriate for export.

5.2.2 Papua New Guinea study enterprise

PNG comprises the eastern part of the island of New Guinea and a number of smaller islands in the Indo-Western Pacific. The PNG marine aquarium fishery was first established in 2008 when the National Fisheries Authority (NFA) contracted a US-based consulting firm, EcoEZ Inc., to develop commercial exports of organisms for the global marine aquarium trade. Under contractual arrangements, EcoEZ, was given a three year time frame to establish the fishery with commercial realization to be achieved in the third year (Yeeting and Batty, 2010). Within the time frame of the current study, EcoEZ was the sole marine aquarium exporter based in PNG.

Over the course of development, EcoEZ engaged 44 fishers from eight communities in fish collection for the marine aquarium trade (Schwerdtner Máñez et al., 2014). Collection of aquarium organisms was restricted to demarcated FMAs. Two of the six FMAs were claimed to be certifiable under MAC standards (Yeeting and Batty, 2010).

All fishers were trained in collection and handling practices according to MAC certification standards (Dandava-Oli et al., 2013) and there have been no reports of illegal fishing activity (i.e. use of chemicals or prohibited gear). Collection of aquarium fishes was conducted using snorkel with a compliment of hand, fence, and barrier nets made from fine mesh. Fishes were caught in a manner similar to that described above for the Fiji enterprise and placed into submerged or floating holding containers. At the end of a fishing session, fishes were transported from the fishing grounds by a personally owned canoe or motorized boat (generally < 10 km) to village-based holding enclosures comprised of nets suspended from the surface or submerged containers, often close to shore and close to the fisher's residence. Fishes were held live within holding enclosures until purchased by a buyer from the exporting company. After several days of fishing, a buyer from the exporting company would visit fishers to purchase their catch.

5.2.3 Data collection

Records of fishes collected, facility mortalities, and fishes exported were retained by both companies. For EcoEZ these records were lodged with the NFA as part of the contractual arrangement. The NFA and AFF were contacted in 2015 with a request to supply data pertaining to facility and export mortalities of marine aquarium fishes for one full calendar year within the date range of 2010-2012. This date range was selected to ensure the two enterprises were not cognizant of plans for the current study while collecting data. Data were provided by AFF for the 2012 calendar year. Data was provided by the NFA for the 2010 calendar year, however, missing records required data analysis to be restricted to a six month study period, January 11 to July 22, for which complete records were available.

Records of fish mortalities were collated from facility mortality records and feedback from importers. For both enterprises, fish mortalities at the export facility were divided as facility dead-on-arrival (DOA), encompassing those fishes received at the export facility that had died during transport to the facility, and facility dead-after-arrival (DAA), encompassing those fishes that died after being stocked into the facility but before export. Import DOA was collected where records from importers provided feedback on the number of fishes arriving dead or alive after international shipment. For both enterprises, feedback from importers was only provided for a portion of total exports, all feedback analyzed came from imports into California, United States (USA).

5.2.4 Data analysis

All data were transferred into Excel (Version 14). Records of fish collected, facility mortalities, and fishes exported were taken at face value as misinformation could not be corrected for. Collection and facility mortality records were limited to enterprise-specific common names making it necessary to match scientific names with common names through consultation with AFF and use of identification guides supplied by the NFA. Validity of scientific names was confirmed using the World Register of Marine Species (WoRMS, 2015). Fishes were assigned to family where correct identification to species was not possible. This was necessary for all Apogonidae given multiple species being assigned to a single common name and frequent use of the collative term 'assorted cardinalfish' in the records of both enterprises. Fishes were labelled as ‘unknown’ where neither a species nor family could be assigned using the supplied identification guides.

Over the course of the study periods examined for both enterprises, fishes were continually moving through the supply-chains at different and unknown rates. Additionally, the available data did not allow for tracking of individual fish as they moved through the supply-chains. This made it necessary to assess mortality as the proportional loss of fish at each stage of the supply chain, independently. Mortality was assessed at species and family taxonomic levels, where possible.

For AFF, mortalities were reported at weekly intervals. For EcoEZ, mortalities were reported daily. To evaluate whether mortality demonstrated any significant trend over the study periods, the relationships between weekly or daily mortalities with time were assessed using Spearman’s rank correlation tests in S-Plus (version 8.0). Pearson’s correlation tests were used to assess the relationships between the numbers of fishes collected within a given week and the corresponding facility DOA or DAA. Differences in import DOA between months was assessed for AFF to detect seasonal fluctuation in mortality using PERMANOVA (Primer-E; Version 6.1.13), a univariate alternative to ANOVA (Anderson et al., 2008).

Cumulative mortality was determined by attributing the percentage loss at each stage of the supply-chain to the percentage of surviving fishes. A z-test of proportions conducted in *R* was used to compare the cumulative mortality for each fish species collected in excess of 500 individuals against the collective cumulative mortality for all fish species. This was done separately for EcoEZ and AFF.

5.3 Results

5.3.1 Fiji - overview

For the 2012 calendar year, a total of 200,982 fishes entered AFF’s export facility of which 98.0% were identified to 108 species from 28 families. The top ten fish families held at the export facility accounted for 96.4% of all fishes with the top ten species accounting for 74.1% of all fishes (Figs. 5.1 & 5.2). Fish mortalities that accrued during transport from fishing grounds to the export facility were minimal (0.2%) with the highest facility DOA reported being 1.1% for a batch of 3,308 fishes. Facility DOA had no relationship to the number of fishes collected in any given week ($r = 0.01$, $t_{(2,50)} = 0.08$, $P = 0.94$) nor was there any change in facility DOA over time ($r_s = -0.25$, $z_{(2)} = -1.82$, $P = 0.07$).

Weekly fish mortalities at the export facility ranged from 0% to 0.5% of stock with the 2012 annual facility DAA loss being 0.1%. Facility DAA had no relationship to the number of fishes entering the export facility in any given week (r = 0.08, $t_{(2,50)}$= 0.56, P = 0.58) but was found to decrease slightly over the course of the year (r_s = -0.32, $z_{(2)}$ = -2.25, P = 0.02). Considering facility DOA and DAA together, there was minimal loss at the exporter stage of the aquarium trade supply-chain for AFF with 99.7% for all fishes surviving to the point of export.

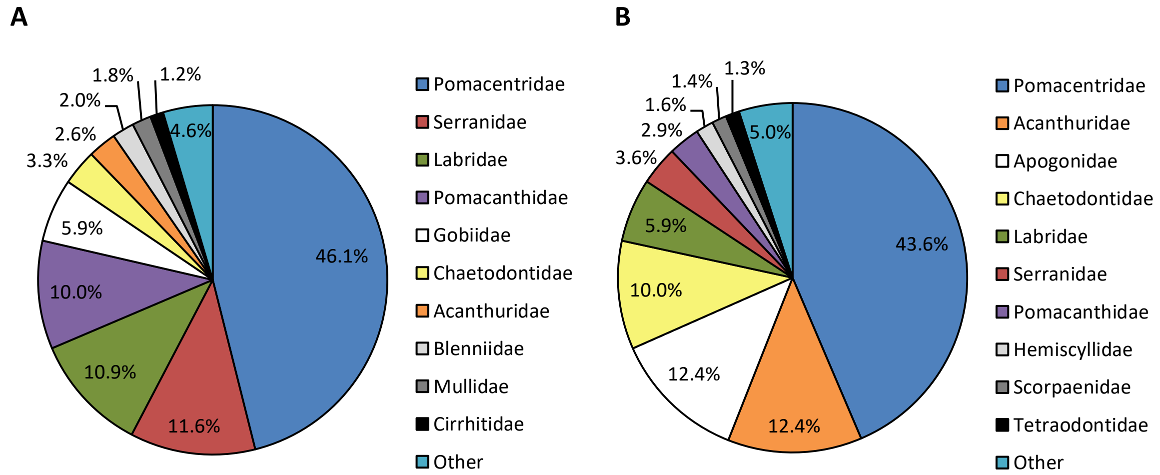

Figure 5.1: Top ten fish families held at the export facilities for the study companies in (A) Fiji and (B) Papua New Guinea. Families common to both companies are presented in color while families unique to each company are in greyscale.

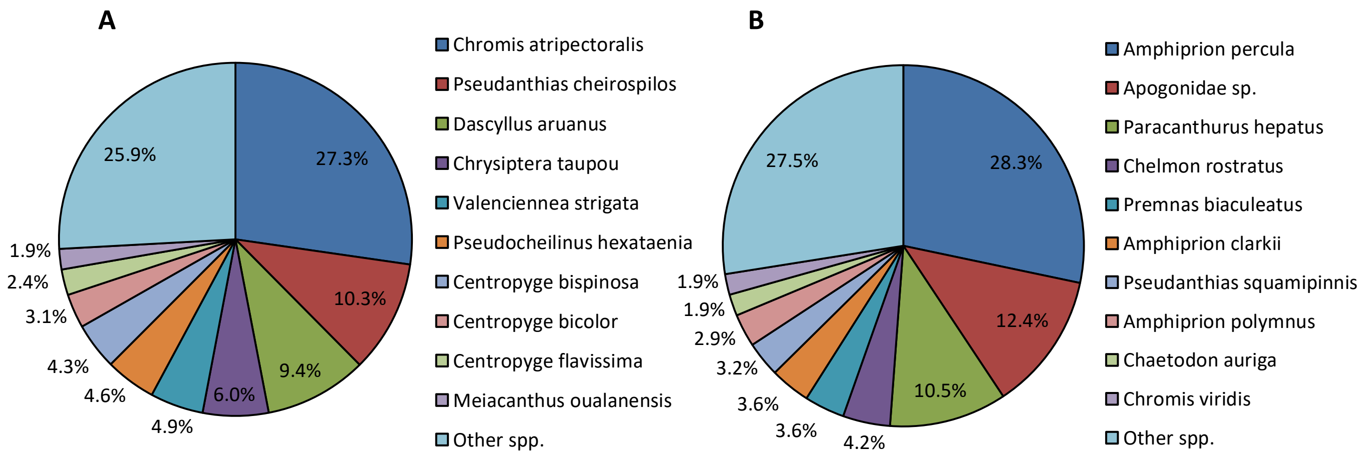

Figure 5.2: Top ten fish species held at the export facilities for the study enterprises in (A) Fiji and (B) Papua New Guinea. None of the top ten fish species were common to both enterprises.

Directly following the exporter stage in the supply-chain, transshipment of fishes to overseas markets occurs. A total of 73 shipments to California, USA contained feedback from importing enterprises regarding survival of fishes during transport, these shipments accounted for 45.1% (*n* = 90,718) of all fishes that entered AFF's export facility. Import DOA ranged from 0% to 5.4% for individual shipments with the 2012 annual import DOA loss being 0.5% of exported fishes. Import DOA loss did not differ significantly between months ($F_{pseudo(11,61)}$=0.74, P=0.65) and was unrelated to the number of fishes in a given shipment (r = 0.05, $t_{(2,71)}$= 0.45, P = 0.65). Considering cumulative facility DOA, facility DAA, import DOA for the Fiji enterprise, total losses from exporter to importer equated to 0.7% of traded fishes.

5.3.2 Papua New Guinea – overview

For the sixth month study period in 2010, a total of 10,526 fishes entered the EcoEZ export facility according to collection records. However, the total number of exported fishes (*n* = 8,307) in combination with the total number of fish mortalities recorded at the export facility (*n* = 3,121) indicates that collection records underestimated the total number of fishes held at the export facility during the study period by 8.6%. On this basis, we assumed the minimum number of fishes at the EcoEZ export facility to be the number of exported fishes plus all facility mortalities (*n* = 11,428). The top ten fish families held by the export facility would then account for 95.0% of all fishes with the top ten species accounting for 72.5% of all fish (Figs. 5.1 & 5.2). Fish mortalities that accrued during transport from village-based holding to the export facility were minimal (0.4%). Based on the smaller sample size of the PNG fishery, it was not possible to assess changes in facility DOA over time or in relation to the number of fishes entering the facility.

Daily records indicate that fish mortalities at the export facility were 26.9% of fishes entering the facility over the sixth month period. Dead fishes were reported on 70.1% of days in the study period (*n* = 191) and the number of mortalities did not change over time (r_s = 0.01, $z_{(2)}$ = 0.11, P = 0.91). Based on the method of data reporting, it was not possible to assess changes in facility DAA as a percentage of facility stock over time or in relation to the number of fishes entering the facility. Considering facility DOA and DAA together, 72.7% of all fishes survived until the point of export.

A total of seven shipments to California, USA contained feedback from importing companies on the survival of fishes during transport, these shipments accounted for 36.8% (*n* = 4,210) of all fishes that entered the EcoEZ export facility and 50.7% of fishes exported during the sixth month period. Of the 4,210 exported fishes, 3.5% were reported as DOA by importers. Considering cumulative facility DOA, facility DAA, import DOA for the PNG enterprise, total loss from exporter to importer equated to 29.9% of traded fishes.

5.3.3 Enterprise comparisons

Facility mortality (inclusive of facility DOA and DAA) for all fish families comprising ≥ 3% of fishes entering either enterprie's facility was assessed (Fig. 5. 3). Among these families, mortality was consistently higher at the EcoEZ export facility. Mortality ranged from 0.1% for the Pomacanthidae to 0.4% for the Pomacentridae at AFF's export facility. In contrast, mortality ranged from 14.1% for the Pomacentridae to 86.4% for the Blenniidae at the EcoEZ export facility. These vast differences in mortality occurred despite both companies having < 1% facility DOA.

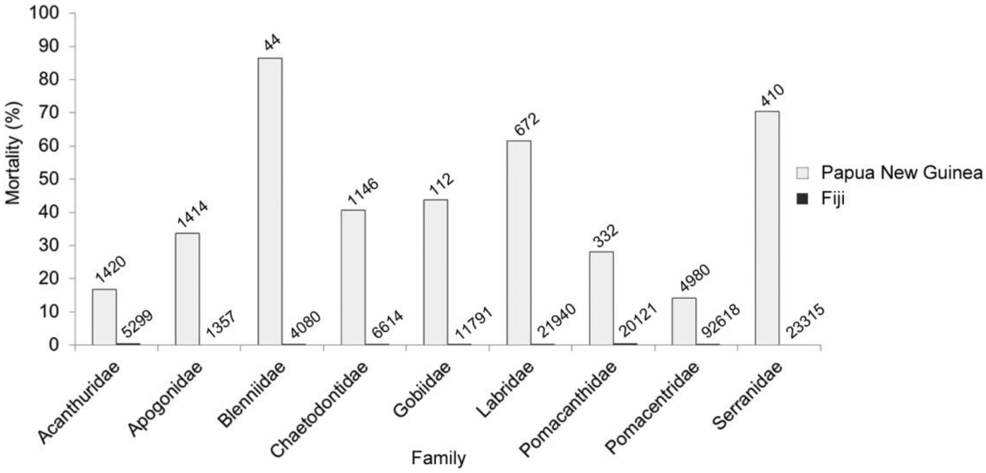

Figure 5.3: Mortality after collection and before export for fish families. Mortality is inclusive of facility dead-on-arrival and facility dead-after-arrival mortalities. Total numbers of fish from which mortality was calculated are presented as superscripts.

Import DOA for all fish families comprising ≥ 3% of fishes entering either enterprise's facility was also assessed (Fig. 5.4). Both companies had the highest import DOA for the Apogonidae: 18.8% (n = 632) for EcoEZ and 4.4% (n = 713) for AFF. However, in the case of AFF, the mortality of apogonids was largely attributed to a single shipment accounting for 80.6% of all mortalities in this family while only accounting for 14.2% of exported individuals.

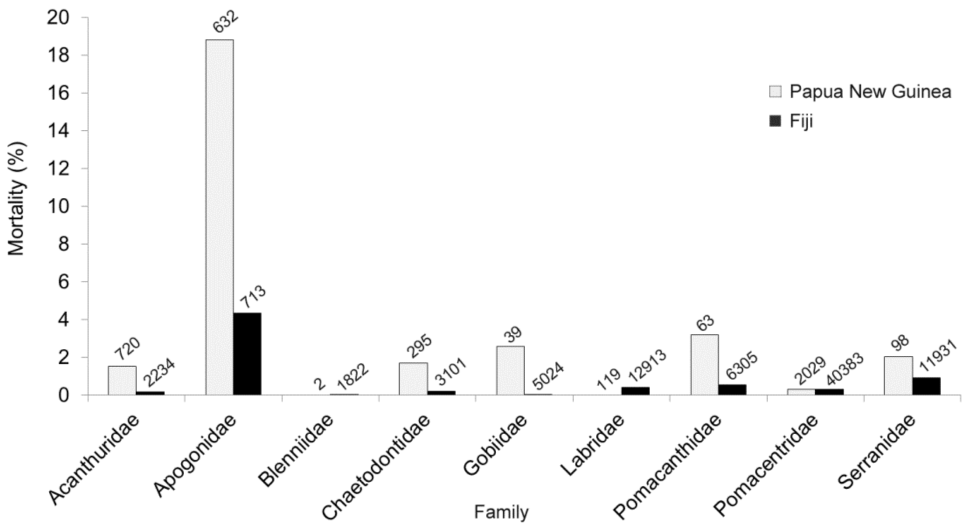

Figure 5.4: Dead-on-arrival mortality for fish families reported by importers in California, USA. Total numbers of fish from which mortality was calculated are presented as superscripts.

The highest cumulative mortalities among fish species from exporter to importer were assessed for all fishes where greater than 500 individuals were collected during the study periods (Fig. 5.5). For AFF only six species were found to have cumulative mortality statistically higher than the collective mortality among all fish species (Fig. 5.5A). For five of the six species (Apogonidae spp., *Luzonichthys waitei*, *Chaetodon pelewensis*, *Synchiropus ocellatus*, and *Coris gaimard*) cumulative mortality was primarily attributed to import DOA while for *Dascyllus aurans* cumulative mortality was largely a factor of facility DOA.

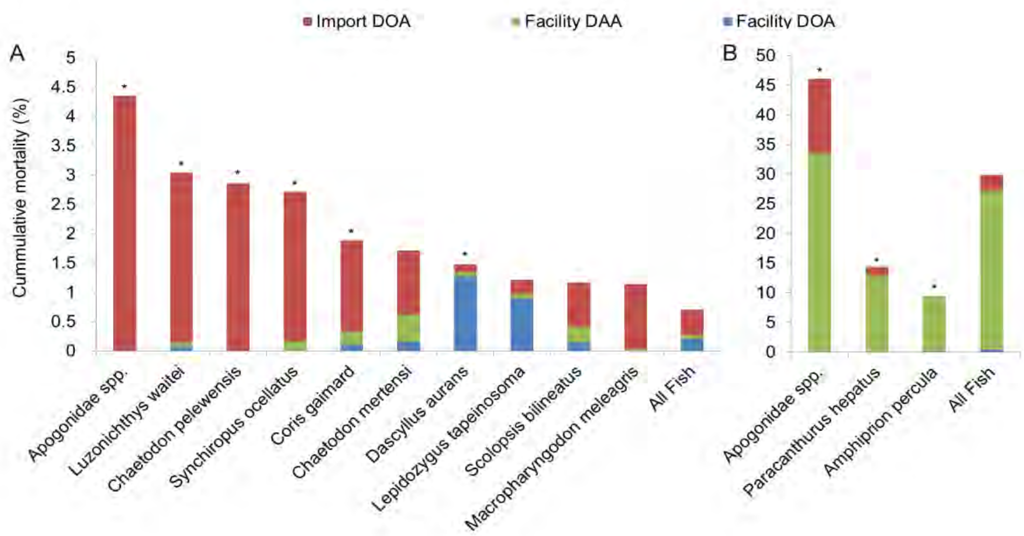

Figure 5.5: Highest cumulative mortalities among fish species from exporter to importer for (A) Fiji and (B) Papua New Guinea enterprises. Only species where greater than 500 individuals were collected during the study periods were considered. * denotes statistical difference from "All Fish".

Given the small size of the PNG fishery, only *Amphiprion percula, Paracanthurus hepatus*, and unidentified apogonids were traded in excess of 500 individuals (Fig. 5.5b). For these species facility DAA was the primary source of mortality as it was collectively among all fish species. The cumulative mortality from exporter to importer was highest for Apogonidae spp. (46.1%) with mortality of *P. hepatus* (14.3%) and *A. percula* (9.4%) being far less than the collective mortality (29.9%) for all fishes traded by EcoEZ.

5.4 Discussion

5.4.1 Differences between enterprises

Mortality in the marine aquarium supply-chain begins with how fishes are initially collected. Hand and barrier nets of stretch-eye (6 – 25 mm) monofilament mesh are utilized to minimize net abrasion and fin damage or entanglement of fishes targeted for collection (Pyle, 1993). Strategic placement of nets allows fishers to coerce target fishes into nets using a ‘herding’ stick, eliminating a need for anesthetizing chemicals (Pyle, 1993). When fishes are collected at depth, venting a fish’s swim bladder, underwater or at the surface, eliminates mortalities known to be associated with barotrauma (Munday et al., 2015). These methods of collecting fishes for the marine aquarium trade have been documented since the 1970s (Straughan, 1973; Jonklaas, 1975) and continue to be validated in recent times (Munday et al., 2015). Post-collection transport to an export facility ideally occurs the same day fishes are caught, minimizing overall transport time and acclimation events before export. This method of collection and transport matches the operating procedures of AFF, and with facility DOA and DAA of < 1%, this study further validates such collection methods as best practice.

EcoEZ similarly adhered to net-only collections and employed a fishing depth limit of 5 m, limiting the likelihood of barotrauma for collected fishes (Wilde, 2009). In contrast to AFF, collected fishes were transported to village-based holding enclosures until visited by staff from the export facility to purchase the catch. This practice often added several days to the length of time between collection and arrival at the export facility. While minimal mortality occurred among fishes transported back to the export facility, the facility DAA accounted for more than a quarter of all fishes. We propose three factors, potentially in combination, that could explain the high facility DAA experienced by EcoEZ:

(1) Village-based holding enclosures. Accumulated stress, from holding and inferior husbandry at village-based holding enclosures, may have resulted in ‘delayed mortalities’ occurring at the export facility. In Indonesian supply-chains, the occurrence of high facility DAA, relative to facility DOA, has been attributed to a lower level of care employed at regional substations in

conjunction with stress from cyanide exposure during capture (Schmidt and Kunzmann, 2005). Where cyanide fishing can be eliminated as a possible stressor, the practice of using village-based holding can still result in a high proportion of the catch being of inferior quality (Chapter 4; Kinch, 2004). EcoEZ was found to reject 24.2% of fishes from village-based holding enclosures in 2010, with rejections related to physical damage or emaciation potentially attributed to an inadequacy of husbandry and facilities (Chapter 4). Improper husbandry associated with stress and starvation can be lethal (Hall and Bellwood, 1995). While village-based holding enclosures typically only held fishes for a maximum of 3-4 d within the PNG fishery, this coupled with the stress of having to acclimate to the export facility would be less ideal than directly transporting fishes to the export facility. The care in handling and husbandry provided at village-based holding enclosures lacking company staff will inevitably be inferior to that in the export facility, under constant control from operational managers (Schmidt and Kunzmann, 2005).

(2) Lack of commercial incentive. Aquarium Fish (Fiji) Ltd. was a self-funded business where the managers, who were also the proprietors, relied on enterprise performance and reputation to maintain their income stream. In contrast, EcoEZ was a consulting firm funded by the NFA, whereby managers were paid a set salary and inevitably aware that their involvement with the fishery would cease with the conclusion of the contracted consultancy. Thus, for EcoEZ, there would be a lack of direct commercial incentives to minimize mortality among the managerial team.

(3) Inexperience. At the time of this study, the marine aquarium fishery of PNG was in its third year of operation with the EcoEZ export facility only recently established. This is in stark contrast to AFF’s history of 32 years in operation. However, we argue inexperience, while plausible, is unlikely to explain EcoEZ’s high facility DAA alone. Our argument stems from EcoEZ employing ex-MAC staff members to manage fishery operations, our own analysis failing to show any improvements in facility DAA at EcoEZ’s exporter facility over the six month study period, and other marine aquarium export enterprises demonstrating the capacity to achieve < 1% facility DAA within three years of exporting fishes for the marine aquarium trade (Wabnitz and Nahacky, 2014).

Excluding these three factors, most other characteristics were similar between EcoEZ and AFF. Both companies employed local fishers, had well-equipped exporting facilities, and collection was organized in response to specific orders thereby minimizing time fishes spent in the export facility.

In general, fishes are held at export facilities a couple days before shipping. This ensures collected fishes are healthy and allows fishes to purge their digestive system to avoid fouling of water in transit. Immediately prior to export, fishes are placed in a plastic bag containing seawater, inflated with pure oxygen, and packed in styrofoam containers for air-freight shipment. Packed in this manner, fishes will usually remain healthy for 24 – 48 h (Pyle, 1993; 19, Lian et al., 2003). Using such methods, AFF was able to achieve 0.5% import DOA loss for total transit times of 24 h, from export facility to import facility. The import DOA of EcoEZ was higher (3.5%) despite similar transport times of around 24 h. Given transit times for both companies were well within industry norms and similar in length, transport time is unlikely to account for the higher import DOA of EcoEZ. Feedback from importers identified inconsistency in packaging as an ongoing problem for EcoEZ. Where fishes are packed with too little water, carbon dioxide and ammonia in the transport water reaches higher concentrations, increasing acidity. This has been linked to severe stress and post-shipment mortality in aquarium fishes (Lian et al., 2003). Surplus water is also disadvantageous as the importing enterprise bears the cost of shipment and, thus, there is economic pressure to minimize the water weight of shipments. Negotiating this compromise may have led to the reported inconsistencies in EcoEZ exports. The high facility DAA is also evidence of stressful conditions prior to export which may have contributed to losses during transit.

The absence of monthly differences in import DOA for AFF implicates an absence of seasonality in transit mortality for shipments to California, USA. Further, there was no apparent relationship between the number of fishes collected within a given week and facility DOA or DAA suggesting the capacity of export facilities used by AFF to adequately accommodate fluctuations in fish biomass among weeks.

5.4.2 Losses among families and species

Consistent to both EcoEZ and AFF, Apogonidae had the highest cumulative mortality among the fish species traded. The reasons for this are unclear. In comparison to other reef fishes, apogonids do not have particularly high metabolic rates and are hypoxia tolerant; signs of agitation or loss of balance do not occur until oxygen saturation drops below 7 -12% for studied species (Nilsson and Östlund-Nilsson, 2003). When packed correctly, dissolved oxygen concentrations within transport water tend to increase over time (Chow et al., 1994) and it is highly unlikely oxygen concentrations would become limiting for apogonids at levels necessary to induce agitation. Rather the mortality of cardinalfishes may be a factor of limited tolerance to seawater acidity or elevated levels of ammonia, both characteristics of transport water after transit (Chow et al., 1994; Lian et al., 2003). The possibility of this should be investigated further for Apogonidae. For EcoEZ, which had a large component of Apogonidae mortality attributed to their export facility DAA, stress accrued during collection may also be a contributing factor. The large number of Apogonidae rejections in the PNG fishery following collection supports this theory (Chapter 4).

While it remains unresolved why mortality was highest among Apogonidae spp., the results of our study indicate additional care may need to be invested in the packaging of Apogonidae. The same would apply to *Luzonichthys waitei*, *Chaetodon pelewensis*, *Synchiropus ocellatus*, and *Coris gaimard* which all experienced the majority of mortality during transit. In Hawaii, Chaetodontidae and Pomacanthidae are noted to be more prone to mortality given their soft-bodies (Stevenson et al., 2011). However, no species of Pomacanthidae were identified among those species with the highest cumulative mortality despite being the fourth most collected family for AFF. Longer term studies are needed to determine if annual cumulative mortality is consistent for the species identified above or whether cumulative mortality varies among species between years.

5.4.3 Mortality in the marine aquarium trade

At present, most available information on fish mortality in the marine aquarium trade is more than a decade old (Pyle, 1993; Kinch, 2004; Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005] or older (Wood, 1985). The last decade has seen momentous improvements in equipment and technology for captive care of marine organisms (Rhyne et al., 2014) with both exporting facilities and knowledge of captive husbandry becoming increasingly more advanced. Our study demonstrates that while some enterprises are capable of achieving mortality levels far below historically reported figures, there are still enterprises that validate the occurrence of high mortality in the trade.

In an analysis of 2,576 fishes moving through an Indonesian supply-chain, Schmidt and Kunzman (2005) reported mortality to range between 10 – 40% for individual shipments with losses inclusive of injured fishes culled in the quality control process raising mortality to 24 – 51%. This assessment was based on a supply-chain encompassing middlemen suppliers and roving collectors supplying fishes to a regional sub-station before further transport to a central exporting facility. The authors noted fishes could take days to weeks to move through this supply-chain from the point of collection to export.

In contrast to this Indonesian example, our study examined mortality in short supply-chain fisheries. However, we argue that industry terminology of ‘short supply-chain’ can be taken as a misnomer based on our results. Taken at face value, our study would indicate mortality can vary dramatically even among short supply-chains. Current notions of short supply-chains are largely restricted to an economic sense, where a shortened supply chain refers to the absence of middlemen (Sadovy, 2002; Wabnitz et al., 2003; Kinch, 2004; Schwerdtner Máñez et al., 2014). In our study, a key difference between the two enterprises' short supply-chains was incorporation of village-based holding of fishes in the PNG fishery. This increased both the number of acclimation events fishes experienced and the elapsed time between collection and export. We argue a distinction within short supply-chain fisheries needs to be made delineating short supply-chains with same-day-facility-arrival (SDFA) and those without. This ensures future comparisons between fisheries or enterprises accounts for the variability in practices among short supply-chains, such as village-based holding and trans-shipping, among others. Considering our results in this light, we see a tiered increase in mortality from a short supply-chain with SDFA (i.e. AFF) to short supply-chains without SDFA (i.e. EcoEZ), with mortality becoming highest where combinations of middlemen and substations lengthen the chain in both the number of operators and elapsed time from collection to export (i.e.Schmidt and Kunzmann, 2005).

Aquarium Fish (Fiji) Ltd., operating with a short supply-chain and practicing SDFA for collected fishes, achieved mortality < 1% from point of collection to import. For this enterprise, fishes would take less than one week to move through the supply-chain from collection to export. Short supply-chains practicing SDFA characterize the majority of enterprises supplying marine aquarium fishes from the Pacific Islands (Kinch and Teitelbaum, 2009) and may explain why historical accounts of supply-chain mortality for this region (Pyle, 1993) have been substantially lower than reported elsewhere (Vallejo, 1997; Sadovy, 2002; Rubec and Cruz, 2005). In a 2014 review of the marine aquarium supply-chain operating in the Federated States of Micronesia, Wabnitz and Nahacky (2014) determined facility DOA to be < 1% over a three day observation period. Facility DAA determined from random visits to the exporting facility were never in excess of 1% and importer records indicated 1.4% import DOA. This suggests the low mortality reported by AFF is unlikely to be an anomaly within the trade, but rather the low mortality achieved by AFF is being replicated by other short supply, SDFA enterprises.

Where longer supply-chains occur, higher mortality is typically reported (Vallejo, 1997; Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005). The higher mortality within the PNG supply-chain fits this trend being intermediate in length and complexity between AFF and the Indonesian supply-chain examined by Schmidt and Kunzman (2005). The cumulative mortality reported for EcoEZ in this study (29.9%) is likely an underestimation of total mortality from collection to import. Our study encompasses export facility DOA to import DOA. Given that

EcoEZ employed village-based holding, mortalities known to occur at villages (Chapter 4), would encompass a pre-facility DOA loss not accounted for in the current study. Given the financial resources, staff and fisher training, and absence of middlemen, mortalities should have been minimized within the PNG fishery. Where fisheries do not have access to the same compliment of resources and engage a series of middlemen, it is not unreasonable to accept supply-chain mortality may still reach levels as high as reported by Schmidt and Kunzmann (2005).

5.4.4 Cross-industry comparisons

Where organisms perish along the supply-chain of exotic pet trades, further organisms have to be collected to meet demand at the end market (Wood, 2001) impacting on the social, economic, and environmental sustainability. For fishes this encompasses the freshwater and marine aquarium trades, but also applies to the other organisms in the exotic pet trade. A study on the international trade of live animals indicate import DOA levels to be 5.38% for amphibians, 3.50% for arthropods, 2.90% for reptiles, 1.36% for birds, and 0.84% for mammals (Schutz, 2003). This puts the import DOA reported in our study in context with exotic pet trades at large, indicating both new (i.e. PNG) and established (i.e. Fiji) enterprises supplying the marine aquarium trade can achieve comparable import DOA levels. In the case of AFF, cumulative mortality (i.e. facility DOA, facility DAA, and import DOA) was less than import DOA alone for most traded animals.

For freshwater aquarium fish consignments, the industry standard for warranty is 5% import DOA; that is, exporters are expected to compensate customers for losses exceeding this standard (Lian et al., 2003). Simulated 40 h shipments of guppies, *Poecilia reticulate*, found mean import DOA to be 2.6%, ranging from 0% to 9.9% for individual bags of fish. However, this study utilized captive-bred guppies and fish were not exposed to stressors involved in collection and transport to exporting facilities. In actual practice, mortality in the freshwater aquarium trade can vary as widely as reported for the marine aquarium trade. In tracking 10,500 cardinal tetras from collection in Brazil until import into the United Kingdom, Dowd (2003) reported mortality from collection to be < 1% with a transport mortality during transport of 0.15%. More general assessments of the freshwater aquarium trade indicate mortality before export to be around 30% with a further 40% loss during transport (Monticini, 2010). Similar to our study for the marine aquarium trade, occurrences of high mortality still occur in the freshwater trade, as well. Following discussions with fishers, mortality for wild harvest of saratoga, *Scleropages jardinii*, within PNG for the freshwater aquarium trade was estimated to be 10% to 50% of all collected fish before export (Kinch and Burgess, 2009).

5.4.5 Implications for trade monitoring

The marine aquarium trade is largely characterized by international trade statistics (Wabnitz et al., 2003; Rhyne et al., 2012b). Current proposals for more accurate monitoring of the marine aquarium trade suggest utilization of trade invoices as the way forward (Rhyne et al., 2012b). While this is likely to be the most feasible method for countries to monitor the industry, management recommendations made for source countries on the basis of trade data are hindered because trade may be unrepresentative of true collection levels (Chapter 4). Prior to commercialized trade, fishes may be lost due to fisher discards, quality control rejections by buyers, mortality, escape, and unregulated domestic trade, which can all accentuate the difference between numbers collected and traded. The disparity between collection and trade is largely unknown for most aquarium fisheries.

Our study demonstrates that a reliance on international trade data would greatly underestimate collection of marine aquarium fishes within the PNG fishery. Export invoices failed to account for 27.3% of collected fishes that were DOA or DAA at EcoEZ's export facility. This loss coupled with a large proportion of the total fisher catch (24.3%) known to be discarded within the PNG fishery prior to arrival at the export facility (Chapter 4) indicates export invoices may account for less than 50% of the PNG fishery's collection of marine aquarium fish species. The capacity to use a single correction factor to more accurately assess collection from trade data is hindered by the variability in mortality (this study) and discards (Chapter 4) between species. In contrast to the PNG fishery, the loss of fishes following collection until import was less than 1% for AFF, suggesting a high degree of similarity between collection and export records.

With loss of collected fishes varying between enterprises and the species collected by those enterprises, there is increasing evidence that the capacity for trade data to accurately predict collection is limited to enterprise-specific case studies. However, the feasibility of enterprise-specific case studies for the entire trade would be an insurmountable task; for example, more than 40 enterprises operate among the Pacific Islands alone (Kinch and Teitelbaum, 2009). Further assessing the tendency for pre-export losses to be reflective of supply-chain characterization may allow generalizations to be formed increasing the predictive accuracy of trade data. This avenue as an alternative to enterprise-specific case studies may be found to improve the predictive accuracy of trade data with the lowest research investment and should be viewed as a potential compromise.

5.4.6 Management

There is a current lack of data collection and/or transparency in the marine aquarium trade surrounding loss within supply-chains. This is evidenced from the limited accounts of mortality within the trade and even fewer empirical evaluations of mortality. Industry may understandably fear persecution or loss of sales from such data entering the public domain, leading to hesitation in disclosing accurate information (Rubec and Cruz, 2005). In some cases, documentation of mortalities along the supply-chain may simply not occur. Even where enterprises wish to keep knowledge of mortality as proprietary information, the proprietors must realize lack of evidence is not evidence of absence. Rather, the absence of mortality can only be taken as fact where detailed records of mortality show this to be true.

To some extent management of mortality is self-regulating. Where fishes die within exporting facilities, this comes at an economic loss to the exporter who purchased the fishes. Where fishes die upon import, this generally comes at an economic loss to the importer. Given economic loss is incurred when fishes die, there is strong economic incentive to minimize mortality for participants within the supply-chain. Where high levels of mortality occur, operations would cease to be economically feasible and collapse. High mortality would have been a considerable factor contributing to the reported lack of financial viability of EcoEZ (Schwerdtner Máñez et al., 2014; Dandava-Oli et al., 2013), which ceased operations in PNG at the end of 2010. In some cases, lack of education, inappropriate facilities, social-economic pressures, and/or lack of alternative employment obscures potential for improvement (Ferse et al., 2013). Fisheries subjected to such pressures are most in need of reform efforts. However, identifying fisheries with high levels of supply-chain mortality to direct reform is also hindered by the lack of data discussed above.

Importing companies may be naïve to mortality occurring before export and inadvertently support enterprises with high pre-export mortality with purchases. Considering import DOA of EcoEZ was within industry standards (Lian et al., 2003) there would be little reason to suspect high pre-export mortality. On this basis, import enterprises are also incentivized to demand data transparency from suppliers as pre-export stressors are known to impact on fishes survival all the way up the supply-chain to the end customer (Rubec et al., 2001).

A certification scheme empowering consumer choice at the end market has the potential to financially reward enterprises with low pre-export mortality through economic incentives (Chapter 6). We advocate the potential role for international trade associations comprised of industry participants to develop the framework for self-regulation. This may initially only succeed at regional levels where industry has expressed interest in cooperating to create proper market incentives associated with higher standards of practice (Kinch and Teitelbaum, 2009; Chapter 6).

5.4.7 Conclusions

This study presents the first detailed empirical assessment of mortality within the marine aquarium supply-chain. Previous estimates of mortality were found to greatly overestimate supply-chain mortality in the case of AFF; however, the operations of EcoEZ indicate high morality can still occur within the trade. As the marine aquarium trade comes under increasing scrutiny by conservation-focused organizations and government regulators (Thornhill, 2012; Chapter 7) trade operators would be incentivized to disclose operational performance to avoid stereotyping industry performance (i.e. Pyle, 1993; Rubec and Cruz, 2005; Yan, 2016). Our study demonstrates adherence to short supply-chain organization, practicing SDFA, is one method for trade operators to minimize loss at the collection and export stages of the marine aquarium trade. Quantifying mortality beyond import at wholesale facilities and retail outlets would be necessary to approximate loss for the entire marine aquarium trade from reef to retail and would be a logical direction for future research.

Chapter 6

Supply-chain loss of non-CITES marine invertebrates within the Papua New Guinea marine aquarium trade[5]

Abstract

A major difficulty in managing wildlife trade is the reliance on trade data to monitor exploitation of wild populations. Collected organisms that die or are rejected before the point of sale often go unreported. For the global marine aquarium trade, identifying supply-chain losses of collected organisms is a first step in assessing true collection levels. This study takes a detailed look at fishery rejections and mortality of non-CITES marine invertebrates (Asteroidea, Gastropoda, Malacostraca, Ophiuroidea) along the Papua New Guinea marine aquarium supply-chain, from fisher to importer. Utilising collection invoices, mortality records, and feedback from importers it was determined that, over a six month period, 38.6 % of the total invertebrate catch (n = 13,299) was lost before export. Supply-chain losses were divided among invertebrates rejected in the quality control process (11.5 %) and mortality of the accepted catch in transit to, and during holding at, an export facility (30.6 %). A further 0.3 % died while in transit to importers. Supply-chain losses are quantified for the ten most collected species which accounted for 96.4 % of collections. Quality control rejections (n = 1,533) were primarily (83.2 %) explained by fishers offering oversized invertebrates for sale. We examine how this is attributed to the socio-economic position of fishers. This case study underscores the fact that low import mortality may mask large losses along supply-chains prior to export and further exemplifies the limitations of trade data to accurately monitor exploitation.

6.1 Introduction

The present era is experiencing global declines in terrestrial and aquatic ecosystems as a consequence of anthropogenic stressors, human population growth, and climate change (Laurance, 1999; Hughes et al., 2003; Bellwood et al., 2004). Exploitation associated with wildlife trade is a contentious issue in this context and has engendered social conflict worldwide (Chapter 8). Sustainably managed wildlife trade can provide income for some of the least economically affluent people (Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014) although overexploitation of wildlife can threaten conservation (Blundell and Mascia, 2005; Thornhill, 2012). Consequently, there is a growing need to accurately monitor the exploitation of wildlife.

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A difficulty in managing the exploitation of wildlife trade is often a reliance on trade data, and not capture data, as a proxy variable to monitor exploitation of wild populations (Blundell and Mascia, 2005). The disparity between collection and trade is largely unknown for most wildlife trades. Collected organisms that die or are rejected before a point of sale often go unreported. Quantifying this unreported loss is a first step towards correctly modelling and assessing the potential impacts of wildlife trade on populations.

Like much of the wildlife trade, the marine aquarium trade is largely characterised by international trade statistics (Balboa, 2003; Wabnitz et al., 2003; Rhyne et al., 2017). This trade is responsible for the translocation of millions of marine organisms from their natural habitats to public and private aquaria worldwide (Wabnitz et al., 2003, Rhyne et al., 2017). Among the organisms traded are around 550 species of non-CITES invertebrates, traded in excess of 3.5 million individuals annually (Rhyne et al., 2017). Current proposals for more accurate monitoring of the marine aquarium trade suggest utilisation of trade invoices as the way forward (Rhyne et al., 2012b). While this is likely to be the most feasible method for countries to monitor the industry, management recommendations made for source countries on the basis of trade data are hindered because trade may be unrepresentative of true collection levels (Chapters 4 and 5). Prior to commercialised trade, organisms may be lost due to fisher discards, quality control rejections by buyers, mortality, escape, and unregulated domestic trade, which can all accentuate the difference between numbers collected and traded (Chapters 4 and 5). A logical first step in addressing this issue is to assess the degree to which these factors may impact a fishery's catch.

Rejections of catch are inevitable in the quality control process of supplying a trade largely built around aesthetics (Chapter 7; Wabnitz et al., 2003). Where quality control falters, export of low quality organisms can have negative repercussions for all operators in the region (Teitelbaum et al., 2010). While quality control rejections of fishes and corals (Scleractinia) collected by fishers are known to occur along marine aquarium supply-chains (Chapter 4; Kinch, 2004; MAC, 2006; Riksodihardjo-Lilley and Lilley, 2007; Ferse et al., 2013), there are no reports on rejections among the diversity of non-CITES invertebrates traded.

There is a similar paucity of information on mortality of non-CITES invertebrates along marine aquarium supply-chains. High supply-chain mortality is a major ecological concern in wildlife trades (Thornhill, 2012; Ashley et al., 2014; Robinson et al., 2015). Death of organisms between collection and point of sale causes waste and requires further collection to satisfy market demand (Wood, 2001). The mortality of fishes along marine aquarium supply-chains varies widely both among species and supply-chains (Chapter 5; Pyle, 1993; Rubec and Cruz, 2005;

Schmidt and Kunzmann, 2005; Yan, 2016). Whether similar variability occurs among invertebrates has yet to be determined.

There is great value in assessing loss along live organism supply-chains attributed to rejections and mortality. In addition to approximating true levels of exploitation from trade invoices (Chapters 4 and 5), this information is necessary to ethically justify the many potential benefits of the trade (Chapter 8; OATA, 2016), empower consumers to make sustainability conscious purchase decisions (Chapter 7; Murray and Watson, 2014), and direct reformation efforts to where they are most needed in the trade (Chapters 4 and 5; Thornhill, 2012). In view of such importance, it is surprising that there is a current lack of data collection or research in the marine aquarium trade concerning losses along supply-chains.

In this study, we provide an empirical assessment of non-CITES invertebrate (Asteroidea, Gastropoda, Malacostraca, and Ophiuroidea) losses due to both quality control rejections and mortality, from fisher to importer, along the Papua New Guinea (PNG) marine aquarium supply-chain. We further attribute rejections and mortality to specific invertebrate classes and species, identifying those where losses were highest. The implications of our results as they relate to monitoring exploitation, improving fishery practice, and mitigating ecological consequences are discussed.

6.2 Materials and methods

6.2.1 Study fishery

Papua New Guinea comprises the eastern part of the island of New Guinea and a number of smaller islands in the Indo-Western Pacific region. The PNG marine aquarium fishery was first established in 2008 when the National Fisheries Authority (NFA) contracted a US-based consulting firm, EcoEZ Inc., to develop commercial exports of organisms for the global marine aquarium trade. Under contractual arrangements, EcoEZ, was given a three year time frame to establish the fishery with commercial realisation to be achieved in the third year (Yeeting and Batty, 2010). Within the time frame of the current study, EcoEZ was the sole marine aquarium exporter based in PNG.

Over the course of development, EcoEZ engaged eight communities in collection activities for the marine aquarium trade. These communities were all in the Central Province bordering the PNG capital of Port Moresby and included Fishermen Island, Roku, Pari, Gaire, Tarauama, Gabagaba, Keapara, and Kouderika. Six of these communities had their own demarcated Fishery Management Areas (FMAs) while the remaining two communities (Pari and Tarauama) had shared access to a single FMA. The FMAs defined the spatial unit in which all collection activities were to occur. Two of the FMAs, Fishermen Island and Keapara Village, were claimed to be certifiable under Marine Aquarium Council (MAC) standards (MAC, 2001b; Yeeting and Batty, 2010).

All fishers were trained in collection and handling practices according to MAC certification standards (MAC, 2001a; Dandava-Oli et al., 2013) and collection of invertebrate species is reported to have been done entirely by hand (Schwerdtner Máñez et al., 2014). Collection activities were conducted from personally owned motorised boats, canoes, or via shore access to collecting areas (Schwerdtner Máñez et al., 2014). Following collection, organisms were transported to holding enclosures, nets suspended from the surface, submerged containers, or pens, often close to shore and close to the fisher's residence. Organisms were held live within holding enclosures until purchased by an agent from the exporting company.

6.2.2 Data collection

Records of non-CITES invertebrates collected, facility mortalities, and exports were obtained from the NFA for a six month period, January 11 to June 20, in 2010. Records of invertebrate rejections were collated from collection invoices similar to Chapter 4. In short, livestock collection operated with orders being given to fishers by EcoEZ on a weekly basis. After several days of collecting, an agent from EcoEZ would visit fishers to purchase their catch. Purchasing was done by collating information on the catch and producing a collection invoice for the amount owed to fishers for their catch. Collection invoices detailed the identity and quantity of each organism accepted and/or rejected. Where organisms were rejected, the reasons behind such rejections were often noted to provide fishers with feedback on their catch.

Records of invertebrate mortalities were collated from facility mortality records and feedback from importers similar to Chapter 5. In short, invertebrate mortalities at the export facility were divided as facility dead-on-arrival (DOA), encompassing those invertebrates received at the export facility that had died during transport to the facility, and facility dead-after-arrival (DAA), encompassing those that died after being stocked into the facility but before export. Import DOA was collected where records from importers provided feedback on the number of invertebrates arriving dead or alive after international shipment. Feedback from importers was only provided for a portion of total exports, all feedback analysed came from imports into California, United States (US).

6.2.3 Data analysis

All data were transferred into Excel (Version 14). All records and invoices were taken at face value as misinformation could not be corrected. However, corrections were made when species names were misspelled or listed with only a common name. Scientific names were matched with common names using an NFA-supplied EcoEZ identification guide. Validity of scientific names was confirmed using the World Register of Marine Species (WoRMS, 2016). For purposes of analysis, data for the starfishes, *Fromia indica* and *Fromia milleporella*, are treated as a single species (*F. indica*/*milleporella*) given both species were associated with the same common name.

At all levels of analysis, rejection frequencies were calculated by the number of invertebrates rejected as a percentage of the total invertebrate catch. In the case of explanations reported for rejections, responses deviated from definitive categories. In an iterative process, all explanations were grouped into seven categories: (1) not ordered, (2) too small, (3) too large, (4) too thin, (5) damaged, (6) diseased, and (7) dead.

Mortality was calculated as a proportion of loss from the total population size present at each stage in the supply-chain. A χ^2-test was used to compare rejection frequencies for the 10 most collected invertebrate species against the collective rejection frequency among all invertebrates over the study period. The same analysis was repeated for assessing cumulative mortality over the study period. This was done to identify taxa particularly prone to rejection or mortality, relative to all invertebrates traded. To evaluate whether the export facility demonstrated any significant trend in daily losses of invertebrates over the study period, the relationship between mortalities, reported daily, and time was assessed using a Spearman's rank correlation test.

6.3 Results

6.3.1 Invertebrate collections and rejections

Collections of non-CITES invertebrates during the study period (n = 13,299) encompassed 56.6 % Asteroidea, 40.3% Gastropoda, 1.8% Malacostraca, 1.0% Ophiuroidea, and 0.3 % of unidentified "miscellaneous" invertebrates, by volume. These collections included 20 identifiable invertebrate species accounting for 98.9 % of collections. Invertebrates identified to genus accounted for 99.7 % of collections. The ten most collected invertebrate species accounted for 96.4% of collections (Fig. 6.1).

Across the fishery, 11.5 % (n = 1,533) of collected invertebrates were rejected by company agents during the study period. Rejection frequencies for the most collected species were quite varied (Fig. 6.1), ranging from 0.4 % for *F. indica/milleporella* to 30.4 % for the starfish, *Nardoa novaecaledoniae*.

Explanations were given for 71.9 % of rejections made. Overwhelmingly, the most frequent cause of rejection was the collected invertebrate being oversized (83.2 %). Damaged organisms accounted for 12.7 % of invertebrate rejections while 0.7 % were attributed to disease (Fig. 6.2). Fishers were found to even offer dead organisms for sale, which accounted for 1.4 % of rejections (Fig. 6.2).

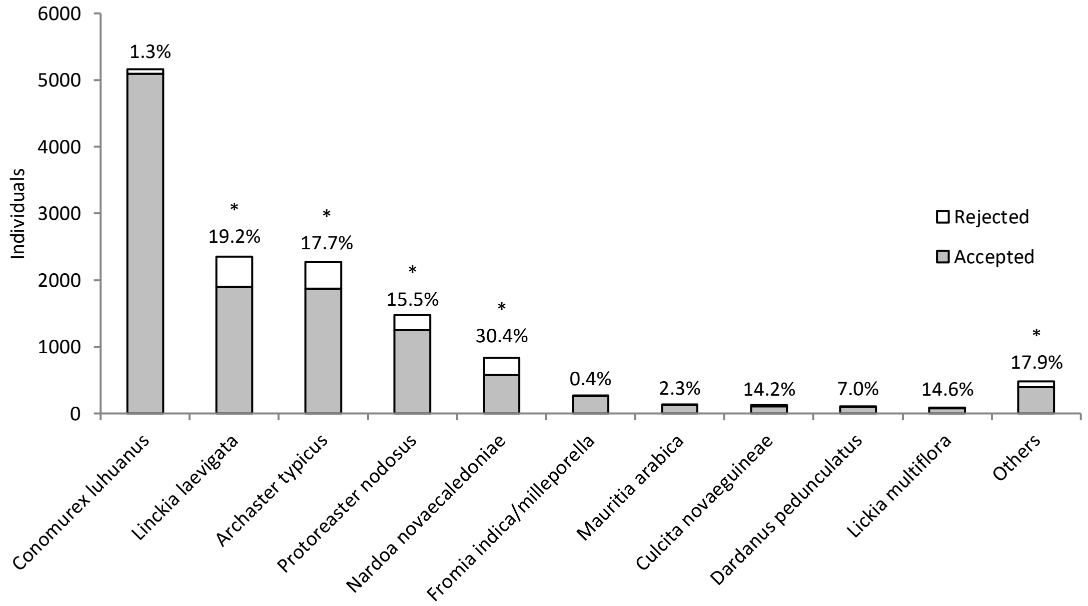

Figure 6.1: Collections of non-CITES invertebrates by the Papua New Guinea marine aquarium fishery. Collections are broken down into accepted and rejected catch. Asterisks (*) indicates statistically higher rejection frequency than observed among all invertebrates (11.5 %).

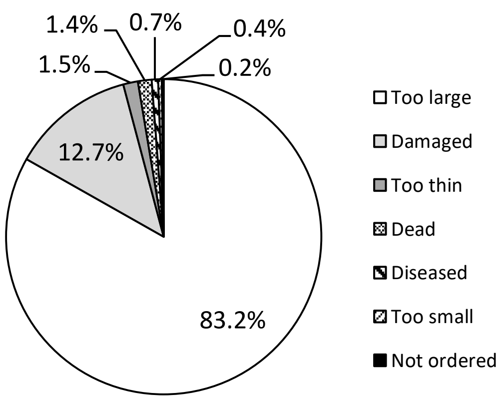

Figure 6.2: Reasons cited for rejecting catch of non-CITES invertebrates in the Papua New Guinea marine aquarium fishery.

6.3.2 Invertebrate exports and mortality

For the sixth month study period, a total of 11,766 invertebrates entered the EcoEZ export facility (i.e. accepted catch) according to collection records. However, the total number of exported invertebrates (n = 9,241) in combination with the total number of invertebrate mortalities recorded at the export facility (*n* = 4,064) indicates that collection records underestimated the total number of invertebrates held at the export facility during the study period by 13.1 %. On this basis, we assumed the minimum number of invertebrates at the EcoEZ export facility to be the number of exported invertebrates plus all facility mortalities (*n* = 13,307).

Invertebrate mortalities that accrued during transport from village-based holding to the export facility were minimal (< 0.1 %). During holding at the export facility invertebrate mortalities reached their highest point along the supply-chain with 30.5 % mortality. Dead invertebrates were reported on 61.5 % of days in the study period (*n* = 161) and the number of mortalities was found to increase over time ($r_s = 0.24$, $z = 2.42$, $P = 0.02$, $n = 99$). Among the ten most collected species, facility mortality was highest for the anemone hermit crab, *Dardanus pedunculatus* (98.6 %), and lowest among the starfish, *Linckia multiflora* (10.9 %; Fig. 6.3). Considering facility DOA and DAA together, 69.4 % of accepted invertebrate catch survived until export.

Feedback from importers was available for 51.9 % (*n* = 4,800) of invertebrate exports, by volume. During transit a further 0.3 % loss occurred, this loss being most prevalent among *L. multiflora* (9.9 %; Fig. 6.3).

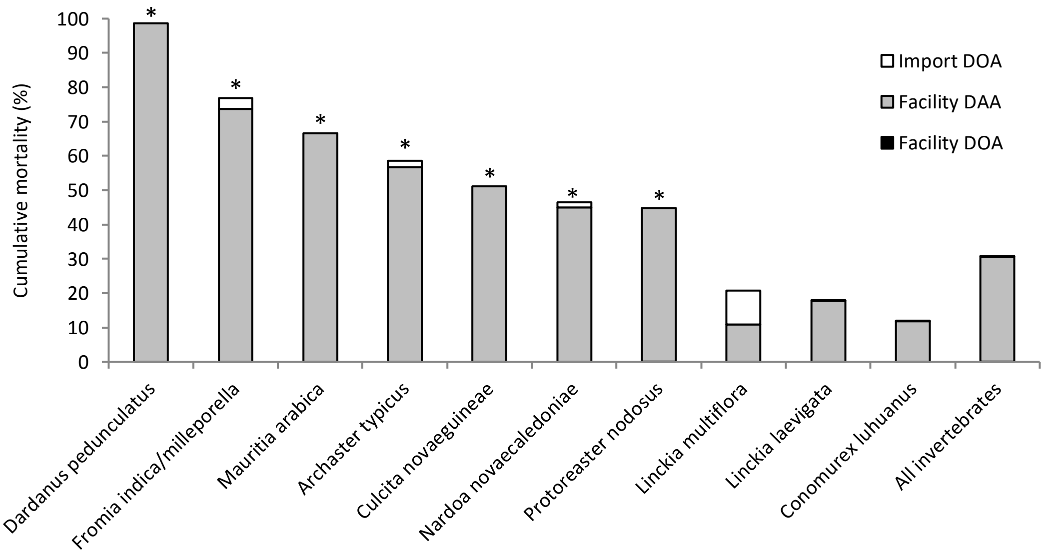

Figure 6.3: Cumulative mortality for the most collected non-CITES invertebrate species along the Papua New Guinea marine aquarium supply-chain. Mortality encompasses facility DOA, facility DAA, and import DOA starting from the point organisms were purchased from fishers. Asterisks (*) indicate statistically higher mortality than observed across all invertebrates.

6.4 Discussion

Characterisation of the marine aquarium trade is dominated by international trade statistics (Balboa, 2003; Wabnitz et al., 2003; Rhyne et al., 2012b) with proposals for improved monitoring to utilise trade invoices (Rhyne et al., 2012b, 2017). While this remains the most feasible method to monitor relative exploitation for the trade at a large scale, management recommendations made on the basis of export/import data must account for their limitations. Here we show that a minimum of 38.6 % of the total non-CITES invertebrate catch from the PNG marine aquarium fishery went unreported in export/import invoices during the six month study period. This unreported catch consisted of both rejections and pre-export mortality. The actual difference between collection and export is likely to be even greater when unreported domestic trade is factored in.

6.4.1 Invertebrate rejections

Quality control rejections of fishes is known to occur in the marine aquarium trade, having been observed in Indonesia (Schmidt and Kunzmann, 2005; MAC, 2006), the Philippines (MAC, 2006), the Solomon Islands (Kinch, 2004), and Papua New Guinea (Chapter 4). Reports on quality control rejections of invertebrates, however, are lacking. Ferse et al. (2013) noted a "high amount" of corals (Scleractinia) brought to traders by fishers ended up being rejected, though frequency of rejection remained unquantified. As the first empirical assessment of invertebrate rejections within the aquarium trade, we show that 11.5 % of collected invertebrates were rejected within the PNG marine aquarium fishery.

Despite being a relatively new fishery, it is unlikely that fisher inexperience contributed to the results because fishers had already collected a minimum of 8,659 invertebrates prior to the study period in 2008–2009 (Rhyne et al., 2017). Widespread use of inappropriate collection techniques can also be ruled out as a major factor contributing to rejections as all fishers were trained according to the MAC certification standards and most invertebrate collection was known to occur by hand (Dandava-Oli et al., 2013; Schwerdtner Máñez et al., 2014).

Rejection frequencies varied among species and even among classes collected. This limits the capacity for a single rejection value to accurately represent the disparity between collection and export/import statistics. Most rejections were associated with starfishes (Asteroidea) in comparison to snails (Gastropoda), brittlestars (Ophiuroidea), and crustaceans (Malacostraca). This most likely occurred because the maximum size obtained by several collected Asteroidea exceeds what can be feasibly shipped or is demanded in the trade. For example, the most frequently rejected invertebrates were *N. novaecaledoniae* and the starfish, *Linckia laevigata*, which can have individual arms lengths exceeding 16 and 13 cm, respectively (de Loriol, 1891;

Yamaguchi, 1977). In contrast, the least rejected species, *F. indica/milleporella* both have a maximum diameter of around 15 cm (liveaquaria.com).

The vast majority of explained rejections in this study involved live invertebrates. The end fate of such invertebrates is uncertain. The most likely scenarios are that rejected invertebrates were returned to the sea, held for an alternative buyer, held until aesthetic impairment improves (for damaged organisms), or eaten. It is unlikely invertebrates rejected in the PNG fishery entered the trade through an alternative route as there were no alternative buyers and fishers did not have facilities for holding organisms beyond a couple days.

Most of the collected invertebrates (Fig. 6.1) are not known to be consumed locally within PNG. The exception is *C. luhuanus* which is a collected in both subsistence and market fishing (Poiner and Catterall, 1988; Kinch, 2003). However, minimal rejections occurred for this species, suggesting the vast majority of rejections were returned to sea. Compared to fish rejections, the release of invertebrates back into the sea is less precarious. Most invertebrates collected by the PNG fishery are motile habitat generalists typically found close to shore (Yamaguchi, 1977; Poiner and Catterall., 1988; Bos et al., 2008). The release of the rejected invertebrates from shore, as is commonly done with fishery rejections (MAC, 2006; Ferse et al., 2013), is unlikely to impair survival to the same extent as fishes (Chapter 4) or scleractinian coral (Ferse et al., 2013). There was also a lower level of rejections attributed to disease among invertebrates compared to fishes (4.5 %; Chapter 4). However, this is not to discount concern where diseased invertebrates are returned to the sea, given the potential for disease transmission (Mrugala et al., 2014). Agents visiting fishers should be tasked with ensuring proper euthanasia and disposal of diseased organisms.

Rejections translate to a reduction in sale-per-unit-effort for the fishers as company agents would only compensate fishers for accepted invertebrates. This method of purchasing catch is commonplace in the trade (Wood, 2001; Kinch, 2004; MAC, 2006; Ferse et al., 2013; Schwerdtner Máñez et al., 2014). The wasted effort in collecting/holding an invertebrate that becomes rejected, however, is not perceived as a disincentive to avoid rejections in the future (MAC, 2006; Reksodihardjo-Lilley and Lilley, 2007; Lilley, 2008; Chapter 4). We are not suggesting fishers collected invertebrates indiscriminately as only 0.2 % of rejections were on account of organisms not being ordered by the exporter. Rather, the potential for financial gain incentivises collection of an invertebrate even if there is only a slight chance of purchase by company agents. For example, in the case of rejections attributed to oversized invertebrates (the most common reason for rejections), fishers encountering a potentially oversized invertebrate are faced with the decision to either pass over the specimen, potentially benefiting the long term productivity of the fishery (but risk someone else catching it), or retain the specimen with the chance that a buyer may accept it. Only the latter option offers potential for an immediate economic return; a strong incentive for fishers in low-income countries like PNG (Foale, 2001; Filer, 2004; Macintyre and Foale, 2004).

We feel that economic incentives or disincentives are necessary to reduce rejection frequencies of organisms in economically marginalised communities. Results in Chapter 4 showed that fish rejections within the PNG marine aquarium fishery failed to improve even where fishers were provided continual feedback about their catch. This, in combination with the socio-economic pressures discussed above, can be taken as evidence that education alone may not achieve alterations in behaviour. Third party certification schemes that financially reward fishers for improving performance have merit in evoking behavioural change in these scenarios (Chapter 7).

6.4.2 Invertebrate mortality

Invertebrate mortality within the PNG supply-chain primarily occurred during holding at the export facility. This was true for all species, with the lowest facility DAA reported for a species being > 10 %. It is difficult to attribute mortality to specific practices of the exporting company retrospectively. A lack of appropriate facilities and husbandry for village-based holding was thought to explain the high facility DAA (26.9 %) among fishes along the same supply-chain (Chapter 5). Poor conditions within villages may result in delayed mortality occurring at the export facility. The occurrence of high facility DAA, relative to facility DOA, along Indonesian supply-chains was attributed to a lower level of care employed at regional substations in conjunction with stress from cyanide exposure during capture (Schmidt and Kunzmann, 2005). While village-based holding enclosures typically only held fishes for a maximum of 3-4 days within the PNG fishery, this coupled with the stress of having to acclimate to the export facility (with potentially different water chemistry) would be less ideal than directly transporting fishes to the export facility. The care in handling and husbandry provided at village-based holding enclosures lacking company staff will inevitably be inferior to that in the export facility, under constant control from operational managers (Schmidt and Kunzmann, 2005).

It is also possible the high facility DAA was attributed to disease. Symptoms of disease were identified among collected stock, leading to 0.7 % of rejections. There would have been potential for accepted organisms, held in confinement with diseased species, to transport pathogens to the export facility (Guo and Woo, 2009). Given minimal available information on Asteroidea pathogens (Hewson et al., 2014), that Asteroidea accounted for 76.0 % of pre-export mortalities, and that common prophylactic measures to control disease within fishes (e.g. hyposalinity, chemicals) are often harmful to invertebrates (Bassleer, 2000), pathogen outbreaks would be particularly difficult to identify and treat. Instances of mass mortality were noted to occur, with daily mortalities exceeding 100 individuals on twelve separate occasions during the study period.

The import DOA reported for invertebrates within the PNG supply-chain was well below mortality typified in wildlife supply chains. In a study of over 7 million animals moving through the international wildlife trade, Schütz (2003) found import DOA to be 0.84 % for Mammalia, 1.36 % for Aves, 2.90 % for Reptilia, 5.28 % for Amphibia, 0.88 % for Actinopterygii, 2.86 % for Anthozoa, 3.50 % for Arthropoda, and 0.85 % for Bivalvia. For all animal groups, mortality was statistically higher for non-CITES listed species.

Importing companies may be naïve to mortality occurring before export and inadvertently support enterprises with high pre-export mortality with purchases. Considering import DOA of invertebrates was lower than previously reported for fishes (Wabnitz and Nahacky, 2014) and for other wildlife in pet trades (Schütz, 2003) there would be little reason to suspect high pre-export mortality. On this basis, import companies are also incentivised to demand data transparency from suppliers as pre-export stressors are known to impact on organism survival further along the supply-chain (Rubec et al., 2001; Schütz, 2003;).

6.4.3 Supply-chain losses in the marine aquarium trade

Supply-chain losses greatly hinder the capacity for trade invoices to be used as a proxy variable for monitoring exploitation in the marine aquarium trade. However, it appears that collection records are also limited in their capacity to accurately reflect true collection. Our study showed collection records underestimated the quantity of invertebrates moving through the export facility by 13.1 %. However, this is a drastic improvement in accuracy compared to the 38.6 % underestimate afforded by trade invoices. As individual cohorts of collected organisms were not tracked through the PNG supply-chain it is difficult to determine the cause of inaccuracy with collection records. When working with collection records small inaccuracies can be expected given the transitory nature of export stations.

As a solution to questionable accuracy or the absence of collection records (such as for the PNG fishery over 2008 and 2009), the best approach for monitoring exploitation is likely to be use of trade invoices corrected by the proportion of supply-chain loss known to occur. Applying this method to existing data on US imports of invertebrates originating from PNG (Rhyne et al., 2017), this would indicate an estimated 3,783 and 10,319 invertebrates were collected in 2008 and 2009, respectively, to supply the US market. A refinement of this approach, for greater clarity, would be to conduct such analyses at a class or species level, using class- or species-specific corrections. As more research surrounding other sources of supply-chain loss (i.e. domestic trade) and the fate of rejected organisms (i.e. post-rejection survival) becomes available, this can be used to further improve models. Such desktop approaches are likely to be more economically feasible than direct assessments of exploitation, such as field surveys, given the diversity of species traded and limited managerial resources available to many of the countries supplying the marine aquarium trade (Dee et al., 2014; Fujita et al., 2014).

The majority of supply to the marine aquarium trade originates from impoverished countries of similar economic status to PNG (Wabnitz et al., 2013; Rhyne et al., 2017) and, where fishers face economic pressures, unsustainable practices can flourish (Kinch, 2004; Reksodihardjo-Lilley and Lilley, 2007; Ferse et al., 2013; Madduppa et al., 2014). Operated as ‘fish-to-order’ with direct supply (i.e. the fisher directly supplies the exporting company) and fishers trained to MAC standards, supply-chain losses should have been minimised within the PNG fishery. However, high cumulative loss reported in our study is indicative of a poorly performing supply-chain.

As supply-chain losses of non-CITES invertebrates have not been reported within the marine aquarium trade, the only comparable commodity is marine fishes. Wabnitz and Nahacky (2014) determined facility DOA to be < 1% along a supply-chain operating in the Federated States of Micronesia. Facility DAA did not exceed 1% and importer records indicated 1.4% import DOA. This supply-chain had operated for a similar period of time (3 years) to our PNG supply-chain at the time of study. More general estimates of mortality among supply-chains operating in the Pacific, following informal consultations, suggest that mortality is less than 10% (Pyle, 1993). Where environmentally destructive collection techniques (i.e. sodium cyanide) and poor handing practices occur, reports on supply-chain losses are indeed higher, sometimes exceeding 50 % (Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005).

There is growing evidence that the PNG fishery performed poorly under the management of EcoEZ. Over the same time period as our current study, 24.2 % of collected fishes were reported to be rejected (Chapter 4) with a further 29.9 % loss of accepted fishes attributed to mortality (Chapter 5). A direct comparison to a Fijian supply-chain, with 0.7 % mortality, further suggests less than effective management (Chapter 5). The use of government subsidies, equivalent to US$ 5 million, allowed the PNG fishery to remain active in the absence of commercial constraints (Chapter 5; Yeeting and Batty, 2010; Schwerdtner Máñez et al., 2014) leaving little financial incentive to improve supply-chain performance. The failure of government support to improve both short- and long-term performance of commercial food fisheries has been well documented (Munro and Sumaila, 2002; OECD, 2006). With the increasing evidence of a poorly performing PNG supply-chain (this study; Chapters 4 and 5) the value of government financial support for establishing or improving aquarium fishery performance can also be questioned.

6.4.4 Conclusions

Monitoring exploitation associated with the marine aquarium trade is a complex issue due to the numerous countries participating in both the export and import of a diversity of organisms. Use of catch data to monitor the trade currently lacks feasibility and, even when reported, the accuracy is questionable (as seen in this study). With real-time monitoring of trade invoices currently within reach (Rhyne et al., 2017), case studies demonstrating the difference between trade and collection will help translate trade data into more accurate representations of fishery catch. Identifying the loss of collected organisms due to rejections and mortality prior to export is one key component in the difference between collection and export data. Application of supply-chain losses as a proportional correction tool and undertaking localised studies, as done here, can provide a better estimate of the overall catch for aquarium fisheries from trade invoices.

For invertebrates, this initial case study shows a large disparity between collection and trade can exist. Future case studies will need to examine invertebrate loss among long-running, commercially successful supply-chains before extrapolating these findings beyond the PNG marine aquarium fishery. There is growing evidence that government funded aquarium trade operations underperform when compared to private commercial operations (Chapters 4 and 5). However, numerous reports of high supply-chain losses (Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005; Yan, 2016) suggest the persistence of poor performing operators in other countries. As the marine aquarium trade is subject to increasing public scrutiny (Chapter 8), stakeholders are strongly incentivised to support sustainable and ethical supply-chains (Chapter 7). Identification of such supply-chains remains dubious until greater transparency in industry performance can be achieved.

Chapter 7

A consumer driven approach to improving the Papua New Guinea marine aquarium fishery[6]

Abstract

Certification schemes are a component of sustainable industry development that can help empower consumers to support environmentally friendly and ethical commodities with their purchase decisions. At present, there is no unified certification scheme within the marine aquarium trade, limiting the capacity for consumers to differentiate sustainable products from others. To assess the extent to which consumers show preference for certified marine aquarium fishes (Teleostei) in the current market climate, an online survey of 510 marine aquarium consumers was conducted over a six month period to determine how certification schemes, presented under different themes, would influence their buying decisions when compared to other attributes of potential importance. Using a Likert five point scale, it was determined that consumers placed significantly higher importance on a certification theme of industry best practice (3.99 ± 0.05) than themes of environmental sustainability (3.77 ± 0.05) or supporting indigenous fishers (3.36 ± 0.06; $F_{pseudo(14,7141)}$=212.08, $P < 0.01$). The only surveyed attributes of greater importance than industry best practice certification were a fish's health (4.81 ± 0.06), aquarium suitability (4.56 ± 0.03), and the fish species (4.21 ± 0.04). A high percentage of surveyed consumers were willing to pay a price premium for fishes that were certified under the themes of environmental sustainability (90.5%), adherence to industry best practice (91.0%), and supporting indigenous fishers (82.6%).This indicates potential for the absorption of the costs of implementing certification schemes by exporters, wholesalers, and retailers. Further analysis revealed consumer predispositions towards certain certification themes that may be helpful in establishing consumer confidence in future industry certification schemes.

7.1 Introduction

Sustainable development is now a well-established business concept (Wynne, 1994; Lubin and Esty, 2010; Lorenz and Veenhoff, 2013; Lawley et al., 2016) though not without problems (Carrier, 2010; Büsher et al., 2012; Sampson et al., 2015). Certification schemes are often a component of sustainable development ideals designed to inform consumers about the processes involved in the supply of a particular commodity and in so doing, empower them to improve industry through their purchase decisions (Teisl et al., 2002; Leadbitter and Ward, 2007). Well known global schemes include the Forest Stewardship Council (FSC) and the Marine Stewardship Council (MSC), which use the willingness of consumers to pay a premium for

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certified commodities to promote and expand environmentally sustainable and socially ethical modes of production of timber and seafood, respectively. For some MSC-certified fisheries, certification has been associated with economic benefits to fishers (Stemle et al., 2016) and environmental improvements occurring as a result of fishery certification (Gutiérrez et al., 2012; Martin et al., 2012). However, implementation of certification does not necessarily guarantee socio-economic or environmental improvement for a fishery (Jacquet et al., 2010; Tlusty, 2012; Bush et al., 2013; Christian et al., 2013) and much remains to be learned in increasing the potential for certification to evoke positive change.

The marine aquarium industry represents an ideal market for a similar type of certification programme (reviewed in Dykman, 2012). This industry collects millions of live marine fishes from their natural habitats, primarily from developing countries in the Indo-Pacific region, for the purpose of stocking public and private aquaria worldwide, with major markets in the United States, Europe, Australia, and Asia (Wabnitz et al., 2003; Rhyne et al., 2012b). Although aquaculture and post-larval capture and culture supply markets with a small number of species (Moorhead and Zeng, 2010; Olivotto et al., 2011), the majority of marine aquarium fishes are still collected from the wild. Sustainably managed marine aquarium fisheries can provide income for some of the most economically marginalized people (Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014) and offer an alternative to more environmentally destructive livelihood activities (Wabnitz et al., 2003). Conversely, overexploitation of marine aquarium fishes can result in localised stock depletions and inflame social conflict between stakeholders (Yeeting and Pakoa, 2005; Chapter 8). Defining what is unsustainably harvested in many cases is easier than defining what is sustainably harvested, as there are clear data on declining stock trends and use of environmentally destructive collection practices involving anaesthetising chemicals (i.e. cyanide) or physical reef damage (Kolm and Berglund, 2003; Wabnitz et al., 2003; Kinch, 2004; Shuman et al., 2005; Reksodihardjo-Lilley and Lilley, 2007; Thornhill, 2012). Post-collection handling, holding, and transport to end markets creates further environmental and ethical concerns prompted by high percentages of rejected catch, establishment of nonindigenous fish populations, and supply-chain mortality (Erdmann and Vagelli, 2001; Schmidt and Kunzmann, 2005; Holmberg et al., 2015; Chapter 4). While efforts have been made and continue to be made to reform the trade through government regulation from within some source countries, capacity for enforcement is often weak (Erdmann, 2001; Wood, 2001; Ferse et al., 2013). Further, education alone is often not enough to initiate change at the supply end of the fishery due to socio-economic pressures that require maximizing immediate financial returns (Rubec et al., 2001; Ferse et al., 2013; Chapter 4).

With the present century being afflicted with global declines in aquatic ecosystems, spurred by anthropogenic stressors and global climate change (Hughes et al., 2003; Bellwood et al., 2004), both the environmental and social impacts of the marine aquarium trade are matters of increasing concern. The potential impacts of the marine aquarium trade on coral reefs have come under increasing scrutiny by NGOs and government regulators given the high-profile nature of the trade (Thornhill, 2012; Chapter 8). However, not all avenues of marine fishes supply pose environmental or ethical concerns, as some supply lines and fisheries are both internally and externally regulated to the best available science (Lovell and Tumuri, 1999; Roelofs and Silcock, 2008; Dee et al., 2014; Rossiter and Levine, 2014).

This leaves consumers as a potential target audience to evoke change in the industry. The market for marine aquarium organisms represents a generally unified, better educated and more informed segment of society (Alencastro et al., 2004; Shuman et al., 2004). The understanding of environmental issues exhibited by the majority of consumers in the aquarium trade (Alencastro et al., 2004; Murray and Watson, 2014) enables links between certification schemes and associated environmental and social benefits to be more easily achieved. Consumers are also incentivised to support certification schemes where, in addition to environmental and/or social benefits, the certified fishes are likely to be in better condition and may have improved survival in captivity (Hall and Bellwood, 1995; Rubec et al., 2001). In order for consumers to play a role in improving the marine aquarium industry with their purchase choices, consumers must first be able to differentiate the practices involved in bringing collected fishes to market.

At present, there is no unified certification scheme for marine aquarium fishes. The past failure of a certification system set up by the Marine Aquarium Council (MAC) (reviewed in Mathews-Amos and Claussen, 2009), as well as the presence of a number of company specific 'eco-labels', is likely to have caused confusion and decreased confidence towards certification schemes among consumers. While prior studies have proposed a certification scheme established with government support as the most effective way to move towards well managed marine aquarium fisheries (Murray and Watson, 2014), the extent to which consumers show preference for certified fishes in the current market climate remains uncertain.

In this paper, we questioned consumers regarding certification schemes that relate to aspects of regulating industry practice, concerning fishes (Teleostei), in the marine aquarium trade. Here we address certification in accordance with three major themes: (1) environmental sustainability, (2) revenue supporting indigenous fishers, and (3) industry best practice for fish handling and husbandry. Given that the effectiveness of any certification scheme depends on consumer acceptance, marine aquarium consumers (i.e. hobbyists) were surveyed on the importance of certification and how these three themes might impact their buying decisions compared to other attributes of potential importance. We then explore how insights from our study could contribute towards the design and implementation of industry-wide certification schemes.

7.2 Material and methods

7.2.1 Survey Design and Distribution

Informal consultations with various industry stakeholders (incl. fishers, exporters, retailers, consumers, government, and aquarium industry consultants) led to the development of a cross-sectional survey to evaluate the perceived importance and willingness of consumers to purchase fishes certified with respect to the three major themes addressed above. Use of broad certification themes was given preference over clearly defined certification standards to more accurately reflect the realities of certification marketing. While this approach runs the risk that surveyed consumers respond to a different set of perceptions than what the certification may specifically entail, the reality of certification marketing is that consumers are rarely presented with complete information that defines the specifics of a certification scheme at a point of sale (Lawley et al., 2016); further, the presentation of specifics in their entirety runs the risk of cognitive overload (Wells et al., 2011). This approach also ensures the results obtained from the survey reflect attitudes towards certification as a principle rather than reflect attitudes towards the specifics of the certification schemes, for which the majority of consumers are unlikely to be adequately equipped to judge the scientific appropriateness (Lawley et al., 2016).

Survey development was done through online survey design software (surveymonkey.com). Eleven questions from a variety of formats were utilised; including multiple choice, Likert-type scales, and open ended response (see supplementary material online for survey). Two marine aquarium suppliers and an anthropologist, formerly employed by the MAC, pre-tested the survey before it was disseminated, to evaluate clarity and appropriateness for consumers.

The survey was accompanied by a cover letter explaining the research objectives under the pretext of what attributes were most important to consumers when purchasing a marine fish. Themes of sustainability, eco-certification, or certification schemes in general were omitted from the cover letter and advertising statements for the survey to prevent preconditioning of respondents. A statement of confidentiality and a request to provide electronic consent in the form of a yes/no question accompanied the survey. Incentive for completing the survey was offered by highlighting that results would facilitate knowledge sharing between consumers and suppliers of the marine aquarium trade.

Distribution of the survey was done entirely online, given the lack of effectiveness of hard copy surveys reported by previous studies (Murray and Watson, 2014). A web link to the survey was advertised through Coral Magazine's official website (reef2rainforest.com) and shared with various aquarium news groups on the social media platform Facebook, Inc. The capacity for respondents to 'share' and independently distribute the survey link via Facebook, Inc. allowed for snowball sampling to take effect. Facebook, Inc. analytics indicate over 20,000 users of the social media platform had viewed the survey's advertisement. Cookies were used to prohibit multiple responses from the same computer as a preventative against multiple survey completions from a single respondent. The survey was left active for a period of six months from July 16th 2015 to January 1st 2016.

7.2.2 Data Analysis

Valid survey responses were defined as respondents who provided electronic consent, indicated they owned at least one or more marine aquaria, and provided a volumetric assessment of their largest aquarium. This was to ensure a level of certainty that the analysed respondents were participants and, therefore, consumers of marine aquarium products. Data entries were also scanned for 'troll responses' which is a growing concern for computer-mediated communication (Hardaker, 2010; Buckels et al., 2014). Only one response was removed from the data set on this pretext, due to illogical responses to open ended questions. All other responses were taken at face value, as misinformation could not be corrected for. Where respondents passed criteria for analysis but failed to provide answers to particular questions they were omitted from all analyses involving those questions. For this reason, the number of valid responses (n) is noted for all comparisons.

In an iterative process, demographic information was handled by grouping respondents into geographical regions. Respondents were identified to come from four major regions: the United States, Australia, Europe, and other countries. Responses for the volume of a respondent's largest aquarium, which were reported in either imperial gallons or metric litres, were all converted to litres. Where consumers were asked about the typical price they would be willing to pay for a marine fish they were asked to report in the currency used by their country of reported aquaria residence. The financial database OANDA (Oanda.com) was used to convert reported currencies to US$ using exchange rates from the date of survey implementation. Responses to scaling questions on likelihood and importance were converted to numerical, integer responses (Table 7.1).

Differences in importance, likelihood of purchase, and willingness to pay a percent premium for the surveyed attributes of a marine fish were independently analysed using permutational multivariate analysis of variance (PERMANOVA) based on Euclidean distances with Primer 6 (Version 6.1.13) and PERMANOVA+ (Version 1.0.3) statistical package. The surveyed attributes were treated as fixed-factors for analysis. PERMANOVA was also utilised for cross-question comparisons, such as defining responses specific to a particular consumer demographic. Where statistical differences were detected in the main effects term, pairwise comparisons were run. Monte Carlo *P*-values (P_{MC}) were accepted for pairwise comparisons where the number of unique permutations was less than 100 as recommended by Anderson et al. (2008). For all analyses using PERMANOVA computation, 9,999 permutations were run to produce the distance-based pseudo-*F* (F_{pseudo}) or pseudo-*t* (t_{pseudo}) statistics.

Table 7.1: Likert-type scales used in the survey to determine level of importance and likelihood with their associated numerical score.

Level of Importance	Likelihood
1 – not at all important	1 – very unlikely
2 – slightly important	2 – unlikely
3 – moderately important	3 – somewhat unlikely
4 – very important	4 – neither likely or unlikely
5 – extremely important	5 – somewhat likely
	6 – likely
	7 – very likely

Relationships between ranked responses (i.e. importance and likelihood) were derived using Spearman's rank correlation tests in the S-Plus (Version 8.0) statistical package. Comparisons between unranked, numeric responses (i.e. typical purchase price and percent premium willing to pay) showed violation of normality and Spearman's rank correlation was used as a non-parametric test of the relationship between these variables.

7.3 Results

7.3.1 Respondent Demographics

A total of 510 respondents passed the criteria for analysis. The majority of respondents were from the United States (61.0 %) followed by Australia (19.8 %), Europe (13.7 %), and other countries (5.5 %). Respondents identified as generally having three or fewer marine aquaria (80.0 %) with 47.8 % of respondents' largest aquarium being less than 400 L (range 23 to 98,421 L). Aquaria were most commonly identified as "reef aquaria with fish" (87.6 %) followed by "fish-only with live rock" aquaria (9.9 %) with the remainder being "fish-only" aquaria (2.5 %). Respondents were quite varied in the frequency at which they made a new fish purchases with 5.1 % purchasing weekly, 16.4 % purchasing monthly, 41.9 % purchasing several times a year, 27.9 % purchasing once or twice a year, and 8.7 % purchasing less than once a year.

7.3.2 Importance and Likelihood

The single most important attribute when purchasing a fish was health (4.81 ± 0.02, n = 477; Fig. 7.1). This was followed by aquarium suitability (4.56 ± 0.03, n = 479) and species (4.21 ± 0.04, n = 478), which all had a mean level of importance between "very" and "extremely" important. Most other attributes had a mean level of importance between "moderately" and "very" important with the exception of location caught (2.94 ± 0.06, n = 477), rarity (2.39 ± 0.06, n = 478), and whether a fish was wild-caught (2.13 ± 0.06, n = 475), which were "slightly" to "moderately" important for consumers. Respondents indicated certification under the theme of industry best practice was significantly more important (3.99 ± 0.05, n = 475) than certification under the themes of environmental sustainability (3.77 ± 0.05, n = 478) or supporting indigenous fishers (3.36 ± 0.06, n = 0.06; Fig. 7.1).

Respondents indicated they would be "likely" to "very likely" to purchase a fish if they were informed that fish was caught without chemicals (6.22 ± 0.06, n = 440), certified under the theme of industry best practice (6.15 ± 0.06, n = 441), or certified under the theme of environmental sustainability (6.15 ± 0.06, n = 438; Fig. 7.2). Respondents were less likely to purchase a fish from a company or country that formally regulates the aquarium trade (5.85 ± 0.06, n = 440) or certified under the theme of supporting indigenous fishers (5.70 ± 0.07, n = 437). In all cases, provision of knowledge on certification or fishery regulation resulted in a significantly greater likelihood of fish purchase than informing respondents of the fish's country of origin (Fig. 7.2).

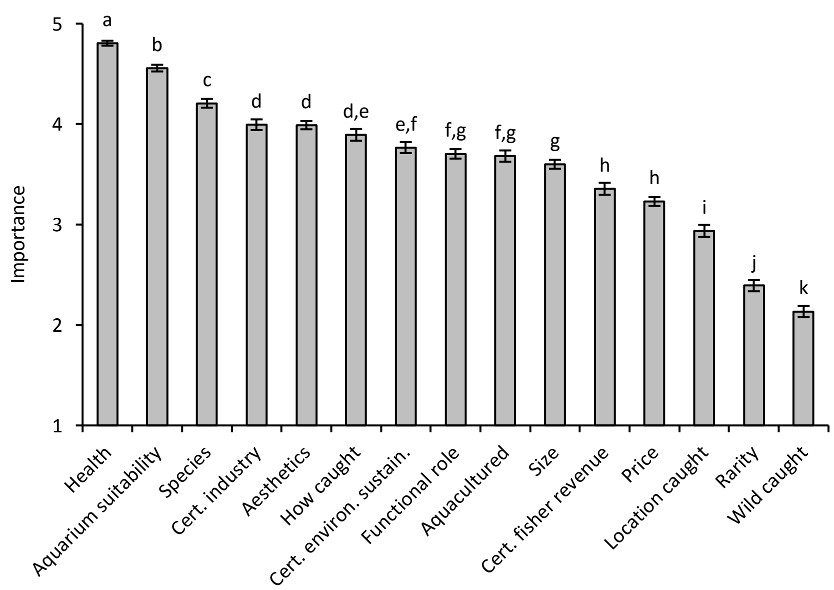

Figure 7.1: Mean (±SE) level of importance for the surveyed attributes when purchasing a marine aquarium fish. Different superscripts denote statistical significance ($F_{pseudo(14,7141)}$= 212.08, P < 0.01). Abbreviations: certified – fish handling and husbandry meet industry standards (cert. industry); certified – environmentally sustainable commodity (cert. environ. sustain.); the functional role that fish will play in

an aquarium (functional role); certified – revenue goes back to indigenous fishers and communities (cert. fisher revenue).

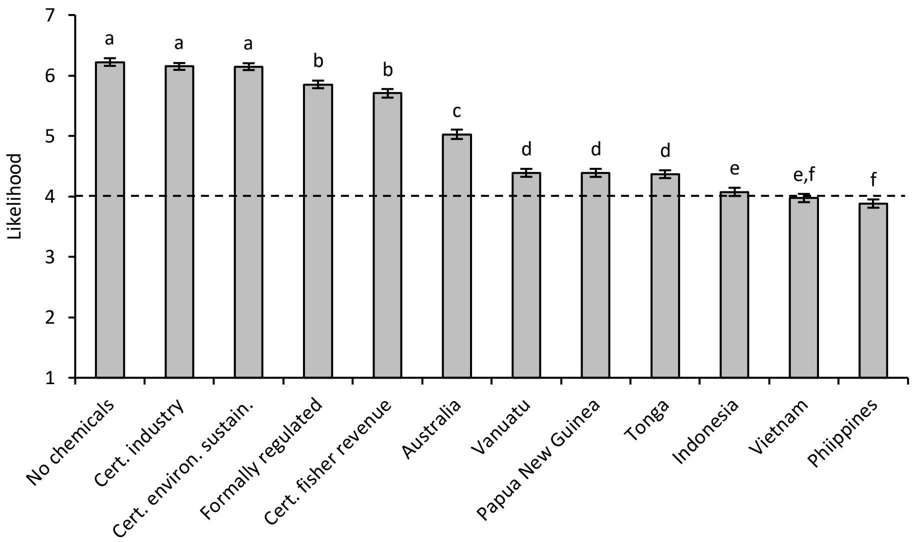

Figure 7.2: Mean (±SE) likelihood of purchasing a marine aquarium fish when given select information about that fish. Dashed line indicates neutral likelihood where scores below the line represent a negative likelihood (i.e. unlikely) and scores above the line represent positive likelihood (i.e. likely). Countries refer to place of fish origin. Different superscripts denote statistical significance ($F_{pseudo(11,5263)}$= 201.05, P < 0.01). Abbreviations: collected from a company/country that does not use chemicals in collection (no chemicals); certified – fish handling and husbandry meet industry standards (cert. industry); certified – environmentally sustainable commodity (cert. environ. sustain.); collected from a company/country that formally regulates aquarium collecting (formally regulated); certified – revenue goes back to indigenous fishers and communities (cert. fisher revenue).

Comparisons were conducted between the likelihood of purchasing a marine aquarium fish from a particular country and likelihood of purchasing a fish from a company/country with specific management practices (Table 7.2). This was also done with respect to the surveyed certification themes. Likelihood of purchase associated with a company or country that formally regulates aquarium collecting showed positive correlations with all countries, and the strength of these correlations generally increased with increasing management status of the exporting country (Table 7.2, 7.3). Despite all countries surveyed having bans on cyanide use (Table 7.3), respondents' likelihood to purchase a fish from Indonesia, Vietnam, or the Philippines was not positively correlated with respondents' likelihood to purchase a fish caught without chemicals (Table 7.2). Respondents' likelihood to purchase a fish from Vietnam, Indonesia, and the Philippines had the strongest association with respondents' likelihood to purchase a fish certified to support indigenous fishers (Table 7.2). For the other certification themes, environmental sustainability and industry best practice, there was no relationship between the likelihood of purchasing a certified fish and purchasing a fish from these three countries (Table 7.2).

Table 7.2: Spearman's rank correlation coefficients (r_s) between the likelihood of purchasing a marine aquarium fish from a particular country and the likelihood of purchasing a fish from a company/country with the stated management/certification. The highest r_s in each management/certification category is bolded and the sample size (*n*) is presented in parentheses.

Exporting Country	Formally regulates aquarium collecting	Does not use chemicals in collection	Certified to support indigenous fishers	Certified for environmentally sustainable practices	Certified to meet fish handling and husbandry industry standards
Indonesia	0.10*$_{(440)}$	0.04$_{(440)}$	0.16*$_{(437)}$	0.06$_{(438)}$	0.03$_{(441)}$
Vietnam	0.10*$_{(439)}$	0.06$_{(439)}$	0.15*$_{(437)}$	0.01$_{(438)}$	-0.02$_{(439)}$
Philippines	0.10*$_{(439)}$	0.03$_{(439)}$	0.17*$_{(437)}$	0.02$_{(438)}$	0.01$_{(439)}$
Papua New Guinea	0.23*$_{(440)}$	0.22*$_{(440)}$	**0.23***$_{(437)}$	0.14*$_{(438)}$	0.11*$_{(441)}$
Vanuatu	0.24*$_{(440)}$	0.21*$_{(440)}$	**0.23***$_{(437)}$	0.15*$_{(438)}$	0.11*$_{(441)}$
Tonga	0.25*$_{(438)}$	0.22*$_{(438)}$	0.21*$_{(437)}$	0.15*$_{(438)}$	0.12*$_{(438)}$
Australia	**0.36***$_{(439)}$	**0.32***$_{(439)}$	0.16*$_{(437)}$	**0.21***$_{(438)}$	**0.21***$_{(439)}$

*denotes statistically significant associations; $P < 0.05$.

Table 7.3: Management strategies for fish collection implemented by the seven exporting countries used for comparison in the survey (see Table 7.2). Data derived from Dee et al. (2014). "NA" denotes no information or insufficient or unreliable/conflicting information to score a particular category.

Exporting country	Fisheries management plan available online	License or permit required	Limited licenses	Quotas for individual species	Size limits	Fishing season or seasonal closure by government	Gear restrictions	Ban on cyanide use
Indonesia	No	No	No	No	No	No	Yes	Yes
Vietnam	No	NA	NA	NA	NA	NA	Yes	Yes
Philippines	No	Yes	No	No	No	No	Yes	Yes
Papua New Guinea	NA	No	No	Yes	Yes	No	Yes	Yes
Vanuatu	Yes	Yes	Yes	1 species	No	No	Yes	Yes
Tonga	Yes	Yes	Yes	No	No	No	Yes	Yes
Australia	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

Respondents showed a much higher likelihood to pay more for a healthier fish than for any of the other surveyed attributes (6.49 ± 0.04, $n = 427$; Fig. 7.3). There was a similar likelihood of paying more for a fish caught without chemicals (5.98 ± 0.06, $n = 424$), a fish certified under the theme of industry best practice (5.93 ± 0.06, $n = 427$), and a fish certified under the theme of environmental sustainability (5.85 ± 0.06, $n = 425$). The only attributes for which respondents were unlikely to pay more were a fish of wild-caught origin (when the alternative was an aquacultured fish) (3.17 ± 0.08, $n = 426$) and a smaller fish (3.83 ± 0.08, $n = 428$). Size, in general, had little influence on likelihood to pay more for a particular fish as even a larger fish evoked a mean response (4.28 ± 0.07, $n = 427$) between "neither likely or unlikely" and "somewhat likely".

Respondents were willing to pay a similar price premium for a fish certified under the theme of environmental sustainability (18.65 ± 1.01 %, range: -50 % to 200 %, $n = 416$) as a fish certified under the theme of industry best practice (18.18 ± 1.03 %, range: -50 % to 200 %, $n = 410$). These price premiums were significantly higher than what respondents indicated they were willing to pay for a fish certified under the theme of supporting indigenous fishers (15.37 ± 0.93 %, range: -50 % to 200 %, $n = 413$). These differences are also reflected in the number of respondents unwilling to pay a price premium for a certified fish. Nearly twice (17.4 %) as many respondents were unwilling to pay a price premium (i.e. ≤ 0 %) for a fish certified under the theme of supporting indigenous fishers compared to environmental sustainability (9.5 % of respondents) or industry best practice (9.0 % of respondents).

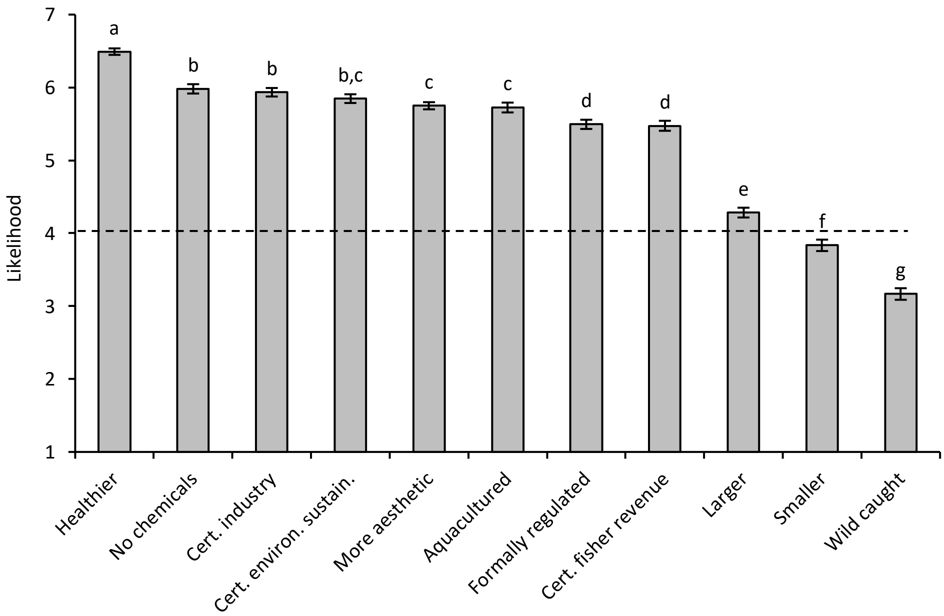

Figure 7.3: Mean (±SE) likelihood of paying a higher price for a marine aquarium fish with the surveyed attributes. Dashed line indicates neutral likelihood where scores below the line represent a negative likelihood (i.e. unlikely) and scores above the line represent positive likelihood (i.e. likely). Different superscripts denote statistical significance ($F_{pseudo(10,4674)}$= 258.65, $P < 0.01$). Abbreviations: collected from a company/country that does not use chemicals in collection (no chemicals); certified – fish handling and husbandry meet industry standards (cert. industry); certified – environmentally sustainable commodity (cert. environ. sustain.); collected from a company/country that formally regulates aquarium collecting (formally regulated); certified – revenue goes back to indigenous fishers and communities (cert. fisher revenue).

There were strong relationships between the importance of a certification theme to a given respondent and the price premium they would be willing to pay for that certification (Table 7.4). The importance of price to a given respondent was found to negatively correlate with the price premium respondents were willing to pay for a certified fish, regardless of certification theme (Table 7.4). However, price importance was independent of the typical price respondents were willing to pay for a fish (r_s= -0.04, n = 475, P = 0.40) and typical purchase price did not correlate with the percentage extra respondents would pay for a certified fish (Table 7.4). We also found that the frequency at which hobbyists make fish purchases was not related to the percentage extra they were willing to pay for a fish certified under the themes of environmental sustainability (PERMANOVA: $F_{pseudo(4,409)}$= 1.90, P = 0.10), supporting indigenous fishers (PERMANOVA: $F_{pseudo(4.406)}$= 2.25, P = 0.06), or industry best practices (PERMANOVA: $F_{pseudo(4,403)}$= 1.48, P = 0.20).

Table 7.4: Spearman's rank correlation coefficients (rs) between the importance of select attributes when purchasing marine aquarium fish and the percentage extra respondents were willing to pay for certified fishes. The highest Rs in each certification category is bolded and the sample size (n) is presented in parentheses. Abbreviations: certified – fish handling and husbandry meet industry standards (cert. industry); certified – environmentally sustainable commodity (cert. environ. sustain.); certified – revenue goes back to indigenous fishers and communities (cert. fisher revenue).

	Percent extra		
	Cert. environ. sustain.	Cert. fisher revenue	Cert. industry
Importance			
Aesthetics	0.07(416)	0.06(413)	0.07(410)
Functional role	-0.07(416)	-0.03(413)	-0.08(410)
Health	0.08(416)	0.06(413)	0.11*(410)
How caught	0.28*(416)	0.23*(413)	0.28*(410)
Where caught	0.21*(416)	0.16*(413)	0.24*(410)
Price	-0.19*(416)	-0.17*(413)	-0.18*(410)
Wild caught	0.01(416)	-0.02(413)	0.01(410)
Aquacultured	0.31*(416)	0.31*(413)	0.31*(410)
Cert. environ. sustain	**0.41***(416)	0.34*(413)	0.36*(410)
Cert. fisher revenue	0.40*(416)	**0.53***(413)	**0.38***(410)
Cert. industry	0.34*(416)	0.27*(413)	0.35*(410)
Typical Price	0.02(416)	-0.01(413)	0.01(410)

7.4 Discussion

7.4.1 Certification and Consumer Empowerment

In order for consumer-driven change to improve the marine aquarium trade, consumers must first be able to differentiate between the processes involved in the supply of marine aquarium fishes. At present, there is no industry certification scheme to inform consumers of such differences. Therefore, the extent to which a consumer is empowered to promote sustainable practices through their purchasing decisions is limited to knowledge of the fish's country of origin and knowledge of the collecting company's practices or by placing their trust in company-specific eco-labels. This limitation is further dependent on whether such information is available at the time of purchase.

There are over 1,800 marine fish species traded as marine aquarium fishes with more than 60 % of these known to originate from multiple source countries (Rhyne et al., 2012b). Complicating this with the almost forty countries supplying marine aquarium fishes to the United States alone (Wabnitz et al., 2003; Rhyne et al., 2012b), it is unrealistic to expect even sustainability conscious consumers to retain knowledge of each species' distribution and the regulations of each source country. The number of source countries is further compounded by the fact that multiple companies, often with their own set of practices, can operate within a single source country (Kinch and Teitelbaum, 2009). This complexity likely explains why the level of importance consumers attributed to how a fish was caught was significantly higher than the importance attributed to where a fish was caught, despite location having a clear bearing on the regulations according to which an aquarium fishery is managed and, therefore, how fishes are caught (Dee et al., 2014). Indonesia, Vietnam, and the Philippines are among the least regulated aquarium fisheries in the world (Wood, 2001; Dee et al., 2014). However, survey results showed a significant positive association between the likelihood of buying a fish from these three countries and the likelihood of buying a fish from countries that formally regulate aquarium collecting, reflecting contradictory preferences. While our survey is unable to elucidate the causation of this contradiction, it is quite plausible that consumer confusion or lack of knowledge is contributing to this result. Given that past studies showed that the market segment captured by marine aquarium trade surveys tends to be highly involved within the hobby (Alencastro, 2004), we would suggest the average consumer to be in an even greater state of confusion with regards to associating source countries with management practices.

We suggest that implementation of a certification scheme would greatly simplify buying decisions for sustainability conscious consumers by easily allowing identification of the practices involved in sourcing marine aquarium fishes. The survey revealed that consumers were more likely to purchase a fish with a certification status, even when only broadly defined, than from any of the surveyed countries. This preference occurred despite one of the surveyed source countries, Australia, representing a high level of marine aquarium fisheries management and regulation (Wood, 2001; Dee et al., 2014). This suggests that consumers need direct clarification of how a fish was caught and brought to market, either directly or through a certification scheme at the time of purchase, and that extrapolating this information from country of origin is either less preferable or not possible given consumer knowledge of the trade. Consumer demand for more information on marine aquarium fishes at a point of sale (from 97 % of surveyed respondents) has been identified as a sign that awareness is lacking with regards to the origin and collection methods of fishes offered for sale (Murray and Watson, 2014). Certification schemes could provide an opportunity for communicating this information to the consumer at the point of purchase that transcends the generalisations that must be made when limited to knowledge of country of origin. This could further allow for differentiation between marine aquarium fishes originating from within countries empowering consumers to support environmentally and ethically conscious suppliers without discrimination.

Company-specific eco-labels can further complicate the aquarium marketplace by “greenwashing” the industry through proliferation of multiple, competing certification schemes. Other fishery markets are already experiencing this phenomenon resulting in confused or ambivalent consumers (Lawley et al., 2016). In addition to adding to marketplace confusion, company-specific eco-labels and sustainability campaigns implemented without independent assessment can decrease confidence in the credibility of certifications where commodity quality fails to meet consumer expectations. They can also be misleading as such labels are often not explicit in the standards they follow nor subjected to independent auditing of performance against such standards.

7.4.2 Predispositions to Certification

To successfully implement a certification scheme that promotes consumer-driven change to improve the marine aquarium trade, consumers must not only be able to differentiate between marine aquarium fishes but they must also favourably purchase those fishes identified (i.e. certified) as representing industry improvements. Our study demonstrates that the current market climate is highly supportive of certification schemes with the surveyed consumers indicating high importance, likelihood of purchase, and willingness to pay a price premium for fishes identified by such schemes.

In line with previous studies (Alencastro, 2004; Murray and Watson, 2014), price was a relatively unimportant attribute to consumers when purchasing a marine fish. This is a common finding of social studies on luxury good markets (Ariely, 2009). A range of physical characteristics (i.e. health, species, aesthetics, size) and other factors (i.e. aquarium suitability and certification status) were all given higher importance by consumers than price. However, a consumer’s perception of price importance negatively correlated with the premium they were willing to pay for a certified fish. Despite this, there was no correlation between price premium and a consumer’s typical purchase price. This suggests the willingness to pay a premium for a certified fish is not restricted to only those consumers with an inclination to make a greater financial commitment when purchasing a fish. Because a key requirement of consumer-driven change is that the consumer actually purchases the fish in question, it is worth highlighting that the frequency with which surveyed consumers purchased fishes had no relationship with their willingness to pay a price premium. This confirms that the market segment proclaiming support for certification schemes in the marine aquarium industry comprises active consumers who buy fishes over a range of purchase prices and therefore are likely to be disconnected from income brackets.

Alencastro's (2004) MAC certification study suggested that consumers were more supportive of certification for the purpose of environmental sustainability, in the form of reef damage prevention and wild stock sustainability, in preference to healthier specimens of a particular marine fish. More than a decade later, our study suggests the reverse. Consumers favoured attributes relating to increased survival of fish purchases (i.e. health, aquarium suitability) above certification for environmental sustainability or industry best practice. It is unclear if this shift in consumer importance is a result of the current study capturing a different market segment or a change in consumer viewpoints. However, it must be noted that the observed difference in importance between certifications based on industry best practice and environmental sustainability did not translate to a difference in likelihood of purchase, likelihood to pay a higher price, or any difference in willingness to pay a percent premium for these two certification themes.

A lower level of importance was assigned to certification under the theme of supporting indigenous fishers. In this case the reduced importance was directly reflected in a lower likelihood of purchase, a lower likelihood to pay more, and willingness to pay a lower percent premium compared to the alternative certification schemes. It is unclear why consumers viewed the provision of support to indigenous fishers as less valuable than industry best practice and environmental sustainability themes, especially when the vast majority of wild-caught marine aquarium fishes originate from developing countries (Wabnitz et al., 2003; Rhyne et al., 2012b). We suspect surveyed consumers, who primarily came from wealthy, developed countries, are unfamiliar with both the socio-economic pressures that drive unstainable fishing practices in the marine aquarium trade (Rubec et al., 2001; Ferse et al., 2013) and the principle drivers of poverty in the Indo-Pacific (Firth, 2007; Shaxson, 2011; Easterly, 2013).

In view of successful implementation of a certification program, it is clear that consumers would be more likely to support certification schemes communicating under the themes of environmental sustainability and industry best practice. These certification schemes would likely garner the greatest consumer support when aiming to achieve an improvement in attributes of marine aquarium fishes perceived as being important to consumers (Fig. 7.1) and those attributes demonstrating strong positive correlations with a willingness to financially support certification schemes (Table 7.4). This would indicate that the aquarium suitability of a fish and how a fish was caught should be information communicated through a future certification scheme. Given that fish health, the most important attribute to consumers, and environmental sustainability both begin with how a fisher collects a fish, it is unlikely improvements will be realised without financially incentivising fishers to change practices for a consumer on the other side of the world. Communicating this to consumers would be necessary to overcome the existing disconnect between social equity and environmental sustainability (Chapter 8).

7.4.3 Implementation of Certification

Targeting consumers to improve industry practice through certification schemes and consumer awareness campaigns has been critiqued on a number of grounds. This includes problems with misinformed consumers, traceability, mislabelling, and difficulties in defining "sustainable" practices, and consumer cynicism over past failures in certification (Jacquet et al., 2010; Ponte, 2012). It must also be noted that favourable attitudes of consumers are not consistently translated into behaviour. The price premiums surveyed consumers indicated they were willing to pay for a certified aquarium fish (15–20 %) were higher than United Kingdom market studies that consistently show consumers willing pay price premiums in the range of 10–15 % for eco-labelled seafood (Roheim et al., 2011; Sogn-Grundvåg et al., 2013; Asche et al., 2015). However, the difference of these results may be attributed to either an ethical purchasing gap between theoretical willingness and actual practice or the difference in products. While an ethical purchasing gap has been widely reported in relation to pro-environmental behaviour (Kollmuss and Agyeman, 2002; Diamantopoulos et al., 2003; Finisterra do Paço and Raposo, 2010) it is unknown to what extent this holds true for luxury goods markets like the marine aquarium trade. This has led to the advocacy of other sustainability interventions, mainly as direct government regulation, including suspension of the trade in aquarium organisms (Wabnitz et al., 2003; Capitini et al., 2004; Saleem and Islam, 2008; Thornhill, 2012). While many of these criticisms are well-founded, it must be accepted that consumer-oriented approaches to sustainability are a significant component of the policy landscape, and are likely to remain so for some time. This coupled with the notoriously weak capacity for enforcement and regulation by the majority of source countries (Erdmann, 2001; Rubec, 2001) and socio-economic pressures creating incentive for fishers to meet consumer demand in order to sell fishes leaves consumer driven sustainability an appealing option to coincide with other initiatives at the government level to direct industry change.

Loss of credibility and consumer cynicism towards the MAC certification scheme reported in the previous decade (Alencastro, 2004) does not appear to have discouraged support for future certification schemes among the surveyed consumers in this study. However, many of the scepticisms facing the MAC certification would likely apply to future certification schemes. This encompasses a lack of consumer confidence in effective monitoring practices throughout the chain of custody, concern that uncertified fishes are being allowed to “cheat” the system and be sold as certified, and the lack of tests (namely field-based cyanide tests; Herz et al., 2016) to ensure standards for improving fish health and chance of survival (Alencastro, 2004; Mathews-Amos and Claussen, 2009). Our study indicated a large portion of consumers were willing to support the idea of certified fishes even when the specifics of certification were withheld from them. This could be interpreted as consumers assigning a measure of trust to the certifying organisation. While trust subjects consumers to the risk of supporting potentially phoney certification schemes, the reality is certified fishes are a credence good that consumers do not have the capacity to evaluate personally and therefore must trust the source claiming the certification standard. Thus, the onus of ensuring the integrity of any certification scheme must be upheld by those implementing the scheme to ensure consumer trust is maintained. Such integrity could only be fostered by implementing a strongly vetted and well monitored certification scheme.

At present, there still appears to be lack of consumer confidence or cynicism towards some supply countries. Despite having bans on cyanide use, the likelihood of consumers to purchase a fish from Indonesia, Vietnam, or the Philippines had no correlations with the likelihood of purchasing a fish known to be caught without chemicals. To combat such criticisms and cynicisms we suggest future certification schemes start by involving companies in countries that consumers demonstrate preconditioned, favourable attitudes towards. Supplying certified fishes from countries already viewed favourably by consumers for a particular certification scheme could help build consumer confidence in the certification label. For example, it was observed that with higher levels of aquarium fishery regulation and management for a given country (Table 7.3), there was a higher likelihood of consumers purchasing a fish certified to be environmentally sustainable or certified to industry best practices from that country. This would suggest initially implementing a certification scheme based on these themes in countries with pre-existing high levels of management would garner the greatest consumer support. This approach would avoid many of the barriers addressed by Mathews-Amos and Claussen (2009) for MAC certification in Indonesia and the Philippines, at least during the initial phase of certification establishment. By focusing a certification scheme that rewards already sustainability-conscientious suppliers, consumers may trigger a shift in market demand that would lead to gradual “ratcheting up” (Cashore et al., 2007) of overall sustainability expectations and performance in the industry.

Given that consumers rely on consistent information, advice and recommendations to remain engaged and avoid becoming misinformed (Leadbitter and Ward, 2007; Parkes et al., 2010) and to ensure long term success of such a scheme, clearly defined certification standards are advised. In this regard, a limitation of our study is the assessment of consumer support for certification at a broad thematic level. A logical next step in gathering the information necessary to ensure consumer acceptance of a certification scheme would be an analysis of why consumers demonstrated preferential support for certifications under the themes of environmental sustainability and industry best practice. This would need to evaluate how closely consumer perceptions of a desired certification would conform to the standards and practices required to achieve such objectives (i.e. environmental sustainability, industry best practice).

7.4.4 Extension to aquaculture

Aquaculture is often seen as a sustainable alternative to wild collection of marine aquarium fishes (Moorhead and Zeng, 2010; Olivotto et al., 2011), but the reality is that current aquaculture technology and research is far from producing the full scope of fish diversity traded (Lindsay et al., 2004; Rhyne et al., 2012b; Militz, *in press*). Even where aquaculture techniques allow for captive production of fishes, the cost of production often renders fishes economically non-viable (Pomeroy and Balboa, 2004; Olivotto et al., 2011). While Alencastro (2004) found consumers preferred cultured fish to MAC certified fish, the present study shows fishes certified under the themes of environmental sustainability or industry best practice to be more important to consumers than whether a fish is from a cultured source (Fig. 7.1). Quality control in the aquaculture sector of marine aquarium fishes has come under criticism with the rise of amateur hobbyist producers supplying the market and offering low quality or ethically contentious fishes (Pedersen, 2014; Militz, *in press*). The drawback of aquaculture extends further, with most marine aquarium aquaculture operations occurring in developed countries (Tlusty, 2002). Support for such operations shifts the economic base away from developing countries supplying the trade with wild-caught marine aquarium fishes; potentially forcing fishers to take up alternative income generating activities that are often more environmentally destructive than marine aquarium organism collection (Tlusty, 2002; Wabnitz et al., 2003; Militz, *in press*). Further, concerns about the supply of wild-caught fishes, such as whether fish handling and husbandry follows industry best practice, whether environmental impacts were minimised, and whether revenue from purchase supports indigenous fishers also apply to the aquaculture sector. This suggests that there may be merit in extending future certification schemes to aquacultural supply companies in addition to wild collection fisheries.

7.4.5 Conclusions

Our results show a strong inclination among consumers to pay a premium for marine aquarium fishes that are certified under environmental and industrial themes. This indicates potential for the absorption of the costs of a global certification scheme by producers, exporters, wholesalers, and retailers. While the results of this study encompass a limited sample of global consumers in the marine aquarium trade, the understanding gained about the preferences of the surveyed consumers can inform management, marketing and trade policies aimed at increasing demand for sustainably sourced (i.e. certified) specimens. Marine aquarium survey respondents are known to be typified by high levels of hobby involvement and exposure to information (Alencastro, 2004). Due to their high use of social media and news sites dedicated to marine aquaria keeping, the demographic that our survey sample represents should be easier, faster, and cheaper to reach with education and promotional efforts on certification and are likely to facilitate further dissemination of information.

As a follow up to our study, future research should examine why consumers demonstrate favourable attitudes towards certifications under the theme of environmental sustainability and industry best practice to help guide development of specific certification scheme objectives. Priority should then be given to studies of market chain economics in the industry that would indicate the actual premium price buyers are willing to pay in practice, and the magnitude of the costs of certification along the remainder of the market chain. It must also be determined if upstream stakeholders such as fishers, exporters, and wholesale distributors would similarly support industry certification schemes and supply certified fishes enabling consumers to make a choice at the end market.

Chapter 8

The influence of popular media on the global demand for marine aquarium organisms[7]

Abstract

Global audiences are increasingly being exposed to digital media with fictitious storylines that draw on animal characters involuntarily entering wildlife trades. An understudied problem in wildlife trade is the potential for motion pictures to influence their audience's desire to become more acquainted, often via acquisition, with animals portrayed in the films. The 2003 Disney motion picture *Finding Nemo* connected audiences with a wildlife trade already commonplace: the marine aquarium trade. In this trade, fisheries supply live coral reef organisms to millions of public and private aquaria worldwide. Here, we examine the perception and reality of *Finding Nemo*'s impact (coined the "Nemo Effect") on the fisheries of the species complex representing the film's primary protagonist "Nemo" (*Amphiprion ocellaris/percula*). Import and export figures show little evidence for fan-based purchases of wild-caught fish immediately (within 1.5 years of release) following the film. We argue that the perceived impact on these species, driven by popular media with an emotive but scientifically uninformed approach to conserving coral reef ecosystems, can be more damaging to the cause of conservation than helpful. This perspective is intended to encourage marine aquarium trade stakeholders to consider the ecological and social repercussions of both media driven consumption and opposition to the trade. Using lessons learned from *Finding Nemo*, we discuss the likely impacts the sequel, *Finding Dory*, will have on wild populations of its protagonist "Dory" (*Paracanthurus hepatus*).

8.1 Introduction

Although coral reefs cover less than 1% of the marine environment, they are considered to be amongst the most biologically rich ecosystems on Earth (McAllister, 1995). The present century is afflicted with global declines in coral reef ecosystems, spurred by anthropogenic stressors of poor watershed management, habitat destruction, global climate change, overfishing and other extractive activities (Bellwood et al., 2004; Hughes et al., 2003). The impact of the marine aquarium trade on coral reef ecosystems in the present era is a contentious issue. A sustainably managed marine aquarium trade has potential to incentivize conservation of marine ecosystems by increasing the perceived value of source habitats to local inhabitants and offer alternatives to more environmentally destructive livelihood opportunities (Tlusty, 2002; Wabnitz et al., 2003; Foale et al., 2016). Further, the global dissemination of marine organisms into more than two million homes and public aquariums worldwide contributes to increased awareness,

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appreciation and understanding of the existence and plight of coral reef ecosystems (Nijman, 2009; Teitelbaum et al., 2010). In some instances fishery supply of organisms for the trade can fuel further declines in reef health through a loss of biodiversity (Ross, 1984; Wabnitz et al., 2003; Rhyne et al., 2009; Knittweis and Wolff, 2010; Thornhill, 2012), overfishing associated with removal of fishes (Kolm and Berglund, 2003; Tissot and Hallacher, 2003; Shuman et al., 2005; Williams et al., 2009), introductions of non-indigenous species and/or diseases (Semmens et al., 2004; Holmberg et al., 2015; Chapter 4), and the use of environmentally destructive fishing practices (Rubec et al., 2001; Kinch, 2004; Mak et al., 2005; MAC 2006; Thornhill, 2012). The effects of the collection and trade in aquarium fishes are less studied than other threats to coral reefs including climate change, ocean acidification, overfishing and nutrient pollution, often due to the complexity of the trade (Dee et al., 2014).

Recently, the role of digital media has been suggested as a potential force for driving conservation efforts in live animal trades and fisheries. Digital media can raise the public profile of charismatic species which then tend to receive increased research effort (Clark and May, 2002), funding (Tisdell and Nantha, 2007) and public popularity (Duarte et al., 2008). However, charisma is a poor predictor of conservation efforts for a given species and the impacts that major motion picture releases have on their featured species are poorly understood. By enhancing the aesthetic value of biodiverse habitats and their associated fauna through motion pictures, this photographically mediated aesthetic fetishisation of organisms may even be counterproductive to achieving overall preservation of biodiversity (Foale et al., 2016). Global audiences are increasingly being exposed to fictitious storylines that draw on animal characters involuntarily entering live animal trades (Table 8.1). While most of the featured animals have husbandry requirements, availability and costs that limit frequent encounter in wildlife trades (e.g. orcas in Free Willy), the Disney animation film *Finding Nemo*, released in May 2003, connected public audiences with pets already commonplace throughout the world: aquarium fishes. Here, we discuss the realized and perceived impacts the release of *Finding Nemo* had on the species represented by the film's primary protagonist. From these findings, we address the possible impact the recent release of the sequel, *Finding Dory*, in June 2016 may have on marine aquarium fisheries.

8.2 Collection and trade pre-*Finding Nemo*

Interest in maintaining live marine organisms for their aesthetic appeal traces back to the 1930s when collection and export for this industry began (Wijesekara and Yakupitiyage, 2001). Starting at a very small scale in Sri Lanka, trade expanded in the 1950s with collections extending to an increasing number of places (e.g. Hawaii and the Philippines; Wood, 2001).

Rapid growth and development of the trade began between 1990 and 1999 with exports of reef organisms showing annual growth of 12–30 per cent (Bruckner, 2001; Wabnitz et al., 2003).

Table 8.1: Films depicting the wildlife trade and their financial success. The engagement of global audiences can be seen in the disparity between U.S. and worldwide gross returns. Sequels proved to be more successful globally than original films in all cases.

Movie	Production Studio	Year of release	U.S. Gross*	World Wide Gross*
Animated				
Finding Nemo	Disney Enterprises	2003	380 843 261	936 743 261
Madagascar	DreamWorks	2005	193 595 521	532 680 671
Rio	Twentieth Century Fox	2011	143 619 809	487 519 809
Rango	Paramount Pictures	2011	123 477 607	245 724 603
Non-animated				
Free Willy	Warner Bros.	1993	77 698 625	153 698 625
Paulie	DreamWorks	1998	27 008 669	NA
Two Brothers	Pathé Renn Production	2004	18 947 630	NA
Sequels				
Madagascar: Escape 2 Africa	DreamWorks	2008	180 010 950	603 900 354
Rio 2	Twentieth Century Fox	2014	131 538 435	500 188 435
Finding Dory	Disney Enterprises	2016	485 684 472	1 024 018 426

*represents gross return presented in 2015 US$. Data obtained from www.imdb.com, accessed on November 1, 2016.

Roughly at the time of *Finding Nemo*'s release, an estimated 1.5 to 2 million people worldwide maintained marine aquaria (Green, 2003), being most prevalent in the United States (US) (Wabnitz et al., 2003). The global value of trade in marine organisms for the aquarium trade was between US$200 and 330 million per year with nearly all of the marine organisms arising from fisheries (Chapman and Fitz-Coy, 1997; Larkin and Degner, 2001). It is estimated that pre-*Finding Nemo* only 1 to 10 per cent of marine aquarium fishes could be captive bred, with less than 1 per cent of the total trade in hard corals being derived from cultured origins (Wabnitz et al., 2003).

Depicting the journey from reef to aquarium, *Finding Nemo* represented more than 1,500 species from 16 families of well-known marine organisms (McClenachan et al., 2012). The primary protagonist of the film, "Nemo," resembled two species of clownfishes with similar appearances, *Amphiprion ocellaris* (Pomacentridae) and *Amphiprion percula* (Pomacentridae). The unique biology of clownfishes, being shallow water, site-attached species in obligatory relationships with anemones, has endeared these fishes to movie fans worldwide but also subjects these fishes to a high risk of overfishing (Shuman et al., 2005; MAC, 2006). Potential local over-exploitation of clownfishes was raised as a concern as early as 1992 (Edwards and Shepherd, 1992), well pre-dating the film. The only study addressing the population-level impacts of collecting marine aquarium organisms before *Finding Nemo* shows that both clownfishes and anemones exhibited significantly lower densities at exploited sites compared to unfished sites in the Philippines (Shuman et al., 2005).

It is also during the pre-*Finding Nemo* era that the aquarium industry became a target of public criticism given the high visibility of marine aquarium products as the trade expanded. Sustainability concerns were raised with regard to destructive collection techniques used, notably in South-East Asia (Wood, 1985; Olivier, 2003). This encompassed the use of sodium cyanide as a stunning agent to aid in the collection of fishes which can damage and kill both target and non-target organisms (Jones and Steven, 1997; Rubec et al., 2001). Additionally, physical reef destruction to access fishes hiding within living coral was known to occur throughout the Indo-Pacific (Kinch, 2004; Thornhill, 2012). Further concerns addressed localized overharvesting of target organisms (Andrews, 1990; Chan and Sadovy, 1998; Wijesekara and Yakupitiyage, 2001; Thornhill, 2012) and high levels of mortality associated with shipping and husbandry practices along some supply chains (Balboa, 2003; Olivier, 2003; Schmidt and Kunzmann, 2005). However, evaluating the extent to which these concerns were validated across the entirety of marine aquarium fisheries is limited given the paucity of data collected on the industry and the lack of biological knowledge (incl. population status) for many of the organisms traded.

8.3 Perception vs. reality post-*Finding Nemo*

8.3.1 Trade data

An understudied problem in wildlife trade is the potential for motion pictures to influence their audience's desire to become more acquainted (via acquisition) with animals portrayed in the films. The Jurassic Park series and the animated televised series Teenage Mutant Ninja Turtles were suggested to be linked with an upsurge of public interest in keeping reptiles as pets (Watson, 1997; Ramsay et al., 2007). Similarly, the suggestion that Harry Potter movies have accelerated India's pet owl trade (BBC, 2010) further implicates either perceived or genuine influence of media productions on consumer driven pet trades.

Finding Nemo differs greatly from the above examples in that the film directly linked its animal characters with its respective pet trade (i.e. the marine aquarium trade). Despite this linkage, *Finding Nemo* appears to have had little immediate impact on US imports of the species complex represented by the film's primary protagonist, *A. ocellaris/percula*. Accredited as the largest importer of marine aquarium fishes, the proportion of the global trade made up by US imports has been estimated to be between 41 % and 80 % (Larkin and Degner, 2001; Wabnitz et al., 2003). Using US import data derived from Rhyne et al. (2015b), the limitations and tabulation of which are discussed by Rhyne et al. (2015a), annual imports of *A.*

ocellaris/percula into the US were found to rise by only 2.0 % between 2000 and 2004 despite a 34.5 % increase in total fish imports over the same time frame according to their models (Fig. 8.1). Relative to other popular fishes, *A. ocellaris* was not imported any more or less frequently, remaining the seventh most imported fish for both 2000 and 2004 while the less imported *A. percula* shifted in ranking from twelfth to the tenth over this time frame. The only time frame after *Finding Nemo*'s release that shows an increase in US imports is in 2005 where imports of *A. ocellaris/percula* were 10.3 % above 2004 imports, despite only a 1.8 % increase in total fish imports (Fig. 8.1). Following this increase, US imports of the *A. ocellaris/percula* species complex consistently declined to the point, that by 2009, imports were less than pre-*Finding Nemo* (i.e. in 2000).

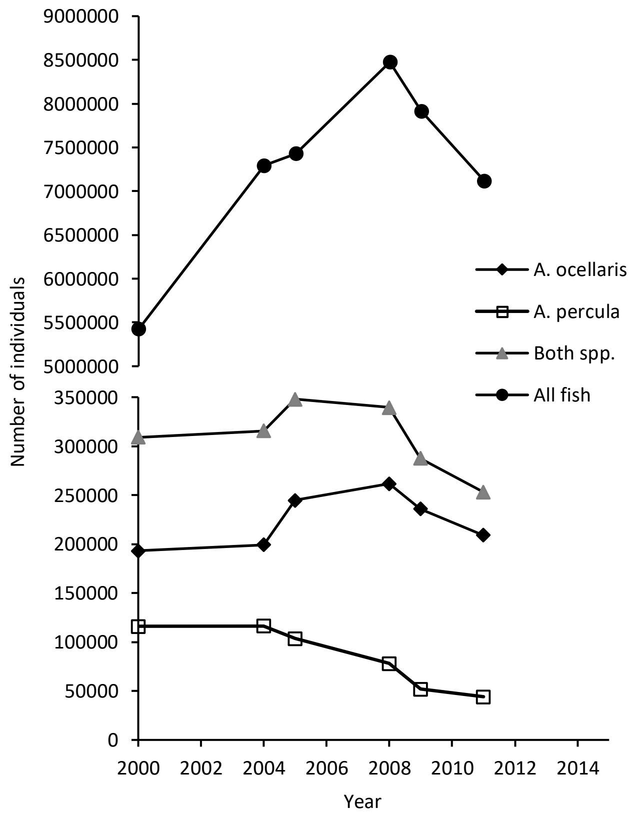

Figure 8.1: U.S. imports of *A. ocellaris* and *A. percula* in comparison to all fish imports. Dashed vertical line identifies the U.S. release of *Finding Nemo* on May 30, 2003. Data extracted from Rhyne et al. (2015b).

Given the global audience of *Finding Nemo*, it is plausible that demand by the global market for aquarium fishes, rather than just the US market, led to increases in wild-harvest of *A. ocellaris/percula*. Global trends, influenced by non-US markets, may not be accurately reflected in the US import data presented above. To examine global trends, the only reliable data currently available are country-specific collection and export records. Examination of collection data for global exports from Marau Sound, Solomon Islands eleven months before and after the release of *Finding Nemo* shows that collections of *A. percula* only increased by 0.9% of the fishery's total catch (Fig. 8.2). At the point of *Finding Nemo*'s release, the Solomon Islands were the largest exporter of A. percula within this species' natural range (Rhyne et al., 2015b). In the Philippines, collection records from January to April 2002 show the catch of *A. ocellaris/percula* was only 2.2 % of the total catch (> 40,000 fishes) (Shuman et al., 2005) while in 2006 less than 1 % of total catch (1,167 fishes) on monitored fishing trips were *A. ocellaris/percula* (MAC, 2006). It must be noted that while the authors of the previous mentioned studies reported on collection of *A. percula* within the Philippines, only *A. ocellaris* is known to occur there (Froese and Pauly, 2015), hence our use of the species complex *A. ocellaris/percula* in this instance.

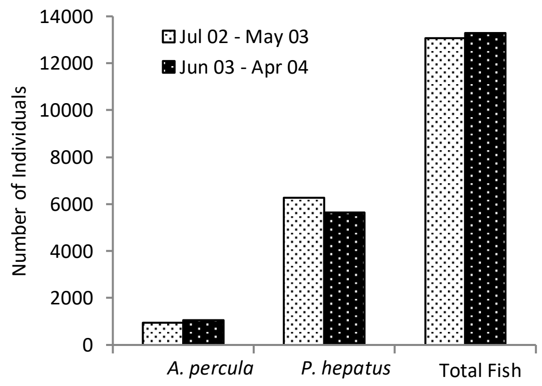

Figure 8.2: Collection records from Marau Sound, Solomon Islands marine aquarium fishery. Total number of individuals collected 11 months before and after the U.S. release of *Finding Nemo* on May 30, 2003. Data from Kinch (2004).

Other sources of collection/export data available prior to 2003 for comparison are restricted to the Global Marine Aquarium Database (GMAD; Wabnitz et al., 2003). Inaccuracies in this data have been identified, being attributed to the nature of voluntary data submissions (Murray et al., 2012; Rhyne et al., 2012b). Exporter data indicate *A. ocellaris* was reported as the most exported species with *A. percula* ranked fourth for years 1997 to 2002 (Wabnitz et al., 2003). This would further suggest the popularity of *A. ocellaris/A. percula* was well established prior to *Finding Nemo* and not solely a direct result of the film.

As an alternative to fisheries, any increase in the demand for *A. ocellaris/percula* following *Finding Nemo* may have been buffered by a supply of fish through domestic aquaculture. While the import data from Rhyne et al. (2015b) are inclusive of both wild-caught and aquacultured fish, it does not account for domestic aquaculture production. Prior to the release of the film, aquaculture operations in the US and United Kingdom were already producing several species of clownfishes (Wabnitz et al., 2003). The US-based aquaculture facility Oceans, Reefs, & Aquariums (ORA) indicated sales of aquacultured *A. ocellaris* rose 25 % following release of the film while the demand for other clownfish species remained consistent (Prosek, 2010). In requesting ORA to substantiate such claims with sales data, the company has remained uncommunicative. It is unclear how representative this anecdotal report from a single facility was for all domestic aquaculture ventures at the time. What is clear is this report led to several studies suggesting wild collection was "fuelled" by the high profile exposure of the aquarium trade by Finding Nemo (see McClenachan et al., 2012; Rhyne et al., 2012b).

A bottleneck in assessing the demand *Finding Nemo* placed on domestic aquaculture is the lack of production information available from industry. Understandably, such data are valued as proprietary information and sales records may not be retained where businesses transfer ownership. Both of these facets were encountered when making requests to industry to provide such records. Data were made available by one US-based aquaculture facility, Reef Propagations Inc., that found sales of *A. ocellaris/percula* declined by 46.8 % between 2002 (17,489 fish) and 2004 (9,302 fish). While sales saw an increase in 2005 (15,799 fish), sales were still 9.7 % below the 2002 volume (Fig. 8.3). This indicates accounts of an increase in supply from domestic aquaculture were not universal across the industry. Where instances of increased supply are reported (as with ORA), such increases may be a result of companies outcompeting their competitors for a greater market share rather than reflecting a greater market demand.

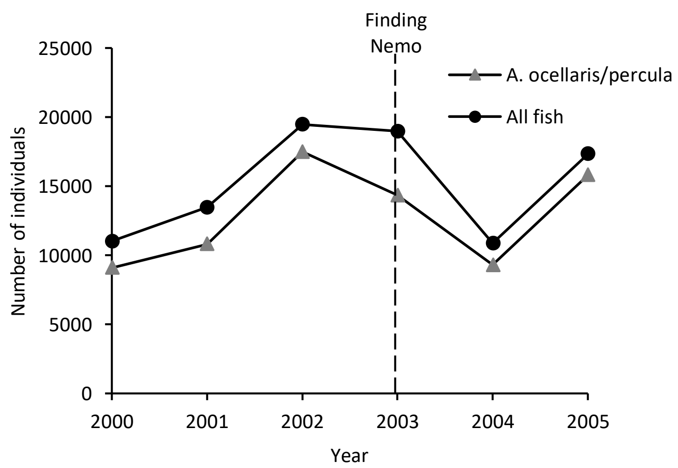

Figure 8.3: Sales of cultured *A. ocellaris/percula* in comparison to all cultured fishes sold by Reef Propagation Inc., a U.S. based marine aquarium aquaculture company. Dashed line identifies the U.S. release of *Finding Nemo* on May 30, 2003.

8.3.2 Popular media perception and effective conservation

Claims that Finding Nemo created an upsurge in consumption of wild-caught *A. ocellaris/percula* (Table 8.2) are in contradiction with the presented data. While increases in imports and collection were reported for *A. ocellaris/percula* seven months after the film (i.e. 2004) these increases were small (≤ 2 %) and had minimal impact on the relative ranking of these species. While lack of growth in a fishery despite increasing demand can be a result of overfishing (Pauly et al., 2005), this is not the case here. *A. percula* imports into the US declined consistently since 2004 (Fig. 8.1) yet conservative estimates suggest only 0.0076 % of the global population of this species are harvested annually (Maison and Graham, 2015). A 2015 assessment found *A. percula* in no danger of over-exploitation throughout its range with the species not warranting inclusion under the US Endangered Species Act (Maison and Graham, 2015). While similar assessment of *A. ocellaris* is unavailable, this species covers a much greater geographical range than *A. percula* with some locations (e.g. Australia) exporting minimal numbers (Rhyne et al., 2015), suggesting over-exploitation is localised where reported to occur (Shuman et al., 2005; Madduppa et al., 2014). Far more substantiating evidence persists that global economic trends and aquarium life-support technology are the main drivers of trends in marine aquarium fisheries (Rhyne and Tlusty, 2012).

Table 8.2: Examples of popular media articles implicating negative environmental impacts and clownfish rarity following the release of *Finding Nemo.*

Publication/Website	Title	Time of Publication
The Guardian	Reefs at risk after Disney film	November 2003
VICE	Stunning Nemo	November 2003
Natural History Magazine	Saving Nemo	March 2004
Independent	'Finding Nemo' pets harm ocean ecology	July 2004
ABC Foreign Correspondent	Vanuatu – Saving Nemo	November 2004

As many coastal regions in the tropics are experiencing a shift away from extractive marine economies towards ecotourism, competition for ocean space and resources is occurring between fisheries and the tourism sector. Social conflict is not unique to the marine aquarium trade, with conflict arising between food fisheries and tourism globally (Bennett et al., 2001; Majanen, 2007; Fabinyi, 2010). Australia (Wabnitz et al., 2003), Fiji (Wabnitz et al., 2003), Vanuatu (Yeeting and Pakoa, 2005), Maldives (Wood, 2001) and Hawaii (Capitini et al., 2004) all have documented cases of conflict between aquarium fishers and the tourism sector. The rise of poorly informed environmental activism has been a leading explanation in the misplaced perception within the tourism sector that aquarium fishing is the primary threat to Hawaiian coral reefs, taking precedence over poor management, land-based development/pollution, invasive species, and other forms of recreational and commercial fishing (Stevenson and Tissot, 2013). The social ramifications of a perceived impact on wild populations due to *Finding Nemo* have engendered increased social conflict between ecotourism industries and marine aquarium fisheries (Yeeting and Pakoa, 2005). Following an article in The Guardian (Fickling, 2003) stating "a booming trade in aquarium fish, sparked by Finding Nemo […] is endangering the wildlife of Vanuatu," the local tour and dive operators' association pressured government authorities to ban the trade. A ban was enacted, but was lifted a few weeks later for legal reasons, and the Vanuatu Fisheries Department was given the urgent task of mediating social conflict between stakeholders (Yeeting and Pakoa, 2005). Vanuatu marine aquarium export records revealed *A. ocellaris/percula* were not collected by the fishery (Grant Norton pers. comm.), which is also confirmed by US import data (Rhyne et al., 2015b), despite Vanuatu being within *A. percula* distribution range (Allen, 1972; Fautin and Allen, 1997). While empirical studies quantitatively demonstrating increased social conflict following the release of the film are lacking, the use of *Finding Nemo* to further emotive but scientifically uninformed conservation agendas in antitrade directed popular media articles cannot be denied (Table 8.2). Such popular media articles (see Table 8.2) make unsubstantiated claims that ignore the process of scientific research.

Antitrade popular media depicting the rarity of clownfishes could, in itself, explain the increase in US imports of *A. ocellaris/percula* that occurred in 2005 (~1.5 years after *Finding Nemo*'s release). Many of the first popular media articles implicating *Finding Nemo* in inducing rarity of clownfishes began circulating the Internet in late 2003 to 2004 (Table 8.2). Hall et al. (2008) explain the potential for perceived rarity to fuel increasing consumer demand, akin to a "limited edition" product. This can be seen in the marine aquarium trade where publicised closure of fishing grounds for the yellow tang (*Zebrasoma flavescens*, Acanthuridae) in Hawaii to create marine protected areas led to a 33 % increase in price despite resulting increases in catch (Tissot et al., 2009). The impact of perceived rarity on demand has also been established in the US live coral trade with price depending more on perceived market abundance rather than actual supply (Rhyne et al., 2012a). In a trade partially governed by a collector's mentality, rarity can fuel demand either through the belief that this is the last chance to obtain a specimen before collection is banned/restricted or if it is believed ownership signifies social status, affluence and prestige (Hall et al., 2008).

While the end goal of such popular media is often to preserve coral reef ecosystems, the fact is this conservation ideology is largely driven by affluent, scientifically educated individuals who tend to privilege abstract intrinsic and aesthetic values of coral reefs over the utilitarian economic value associated with extracting certain species (even when this is perfectly sustainable), which is critical for the livelihoods of the relatively poor custodians of those reefs (Van Helden, 1998; Adams et al., 2004; Foale and Macintyre, 2005; Foale et al., 2016). The intrinsic value placed upon a species for simply existing, perpetuated by media in wealthy countries, is often at odds with ecological importance (Foale and Macintyre, 2005; Foale et al., 2016). There is no evidence that clownfishes or anemones play a pivotal or keystone role in maintaining coral reef ecosystem function or resilience. Anemones are naturally found at low densities in marine protected areas (< 1 per 100 m^2) and, where over-exploited, their functional role is made redundant by other cnidarians (Shuman et al., 2005). However, substantial evidence exists for the ecological importance of fish species targeted for food, particularly given the size at which they are targeted in contrast to aquarium fishes (Bellwood et al., 2004), which is the only alternative livelihood for many marine aquarium fishers (Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014). The capacity for aquarium fish collecting to replace more environmentally destructive income generating activities is particularly true for collection of *A. ocellaris/percula* which is the primary income generating species in many village-based aquarium fisheries (Kinch, 2004; MAC, 2006; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014). The ease of collecting *A. ocellaris/percula* from the soft tissues of a host anemone eliminates the need for sodium cyanide or physical damage to reef structure to facilitate capture for these species (MAC, 2006). Thus, the impact of collecting *A. ocellaris/percula* is limited to the fish and host anemone where the collection occurs.

The economic value placed on clownfishes by coastal people in developing countries is largely a product of and dependent on the aquarium trade. In areas of Papua New Guinea with no history of aquarium fisheries, there are no names in the local languages for clownfishes emphasizing the lack of traditional salience these species have for local people (Foale, 1998; Ross et al., 2011; Cohen et al., 2014). While ecotourism in the form of diving and snorkelling is often proposed as an alternative to aquarium fisheries as a means of bringing value to coral reef resources, the scale of investment and management demands keep such operations out of reach from local entrepreneurs (reviewed in Foale and Macintyre, 2005). Only a minute fraction of revenue generated by such ventures will flow into local communities through employment, reef access fees and purchase of produce. Smaller village-based ecotourism catered towards an "authentic" local experience is often run by locals but only experiences very small returns on investment (Hviding and Bayliss-Smith, 2000). In contrast, the marine aquarium trade provides income to thousands of fishers throughout the Pacific (Wabnitz et al., 2003; MAC, 2006; Ferse et al., 2013; Madduppa et al., 2014; Schwerdtner Máñez et al., 2014).

8.3.3 End-consumers: private and public

The benefits accrued through pet ownership encompass a better understanding of animal physiology and behaviour (Inagaki, 1990; Prokop et al., 2008), more positive attitudes towards wild animals (Prokop and Tunnicliffe, 2010) and greater concern about the welfare of wild animals (Paul and Serpell, 1993). Keeping marine aquarium organisms offers an opportunity for global citizens disconnected from coral reef ecosystems to evoke their own desire to preserve such habitats for the enjoyment of future generations.

The knowledge gleaned from these end-consumers (i.e. hobbyists) of marine aquarium organisms and their contributions to science are often underrepresented. The dissemination of collected knowledge between professional academics and hobbyists in the marine aquarium trade has allowed for significant advances in captive husbandry, culture and understanding of animal biology (Rhyne, 2010). The captive culture of several species of marine aquarium fishes now produced by aquaculture was originally pioneered by home hobbyists (Rhyne, 2010; but see Sweet, 2013, 2014). This work lays the fundamentals for scientific understanding of the early life history of reef species and can be taken to inform both commercial aquaculture development and fisheries management. Aquaculture has potential to reduce pressure on wild stocks and, as alluded to previously, may have buffered any increase in demand for A. ocellaris/percula following the release of Finding Nemo. However, for aquaculture of marine aquarium fishes to be effective in aiding conservation of the source habitats, much work is needed to transition aquaculture development from developed countries to the economically marginalized communities that are custodians of source habitats to avoid a shift in economic base (Tlusty, 2002).

As participants in the marine aquarium trade, public aquariums present a unique opportunity to facilitate research, supply the marine aquarium trade (Cassiano et al., 2015) and educate the general populace on the anthropogenic stressors facing coral reef ecosystems through their displays of live organisms (Tlusty et al., 2013). Public aquariums can have conservation (Hutchins and Conway, 1995), educational and scientific (Falk and Dierking, 2010) impacts on visitors. Given the higher concentration of aquarium hobbyists in attendance at public aquariums, compared to other public spaces, and the large overlap between marine species on exhibit at public aquariums and those species in the trade (Tlusty et al., 2013), public aquariums have an opportunity to directly engage visitors on sustainability as it relates to the trade in live aquarium organisms. Such “consumer driven” approaches are viewed with potential to transform the aquarium trade into a positive conservation force (Marliave et al., 1995; Tlusty et al., 2013), and these benefits need careful consideration by antitrade directed popular media campaigns.

8.4 The New Era of *Finding Dory*

With the recent release of a sequel to *Finding Nemo* occurring globally in June 2016, it is important to consider the potential repercussions arising from its release and strategically document its impact on the trade. The sequel, *Finding Dory*, features "Dory" a look-a- like *Paracanthurus hepatus* (Acanthuridae) as the primary protagonist. The sequels to other animated films featuring the wildlife trade as a motif have done exceptionally well, far exceeding the global success of the original film, and *Finding Dory* has similarly attracted worldwide viewership (Table 8.1). Prior to the film's release, there were already claims in the popular media indicating stocks of *P. hepatus* were inevitability at risk (Adams, 2013).

Such claims are in contrast with market demand for *P. hepatus* following *Finding Nemo* where this species performed a supporting character role to *A. ocellaris*/*percula* in the film. In the year following the film's release (2004), *P. hepatus* imports into the US were 25.4 % lower than they were in 2000 despite overall trade in marine aquarium fishes increasing by 34.5 % (Fig. 8.4). In 2005, imports declined even further to 63.2 % of year 2000 trade levels as did the fish's relative rank which fell from tenth, in 2000, to the fifteenth most imported fish species in 2005 (Rhyne et al., 2015b). The most recent data available (2011) shows ~100,000 individuals are imported annually into the US (Fig. 8.4). In contrast to *A. ocellaris*/*percula*, it is not possible that foreign or unreported domestic aquaculture buffered the demand from wild-harvest as the technologies for *P. hepatus* culture have yet to be developed at a commercial scale.

Should the sequel result in an unexpected increase in demand for *P. hepatus*, there may be some risk posed to the species. *P. hepatus* has an entirely different suite of life-history characteristics from *A. ocellaris*/*percula* that makes it less resilient to fishing (Roelofs, 2008) and less amenable to aquaculture (Moorhead and Zeng, 2010). Negative impacts of marine aquarium collection on *P. hepatus* populations have been suggested for the Seribu Islands, Indonesia and in the Philippines prior to *Finding Nemo* (Thornhill, 2012). A long lifespan and the low natural mortality facing acanthurids (Choat and Axe, 1996) are at odds with removal rates of juvenile *P. hepatus* for the marine aquarium trade. The schooling behaviour and site attachment of juvenile *P. hepatus* to *Acropora* spp. corals facilitate the capture of large numbers of individuals where they occur. In the Solomon Islands, catch per unit effort has been reported in excess of one *P. hepatus* per minute, collection being coupled with environmentally destructive fishing practices (Kinch, 2004). These practices encompass scaring *P. hepatus* deep into the branches of an *Acropora* spp. colony and extracting the entire coral colony from the reef. On the boat, these coral colonies are broken apart to extract the hiding *P. hepatus* juveniles. Such actions subsequently limit the availability of suitable habitat for *P. hepatus* recruits in future generations. While it is laudable that the marine aquarium trade targets juvenile *P. hepatus*

(Kinch, 2004) leaving the spawning biomass of adult populations intact, this can be rendered irrelevant if essential juvenile habitat is lost or recruitment overfishing occurs.

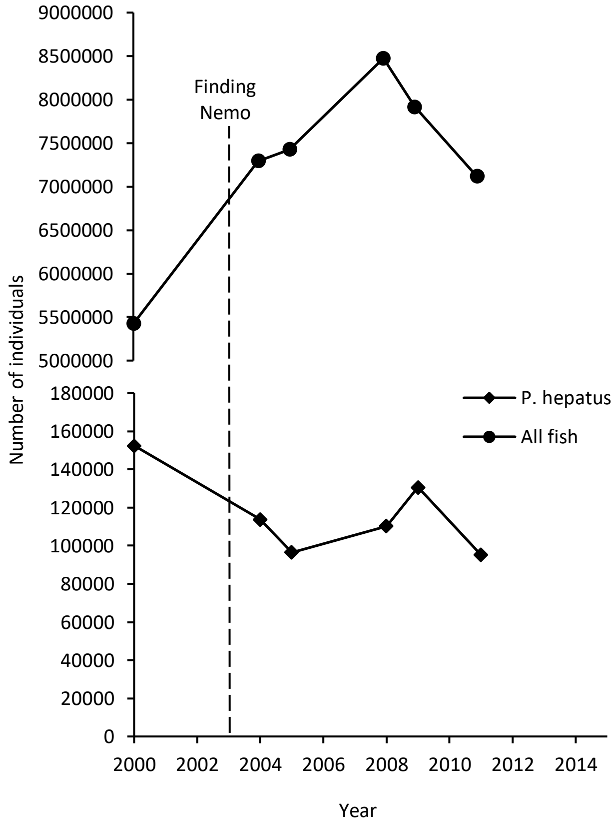

Figure 8.4: U.S. imports of P. hepatus in comparison to all fish imports. Dashed vertical line identifies the U.S. release of Finding Nemo on May 30, 2003. Data extracted from Rhyne et al. (2015b).

While efforts have been made to reform the sustainability of the trade to abolish such destructive fishing practices (e.g. Marine Aquarium Council), the degree to which such fishing methods are still used is unknown, and capacity for enforcement is notoriously weak in most source countries (Dee et al., 2014). In low-income countries, the higher catch value associated with *P. hepatus* compared to *A. percula* (Schwerdtner Máñez et al., 2014) would certainly incentivize fishers to capture this species to meet an increasing demand and could fuel a resurgence of destructive fishing practices. Wild stocks are also simultaneously under pressure from subsistence food fisheries over most of *P. hepatus* geographical distribution. Unlike *A. ocellaris/percula*, the larger adult size of *P. hepatus* makes adult specimens of this species also susceptible to catch for protein (Schwerdtner Máñez et al., 2014).

The capacity to assess the sustainability of exploiting *P. hepatus* for both the food and aquarium fisheries is hindered by the lack of research on this species. The pronounced lack of knowledge is easily exemplified by the comparatively small number of primary research publications on *P.*

hepatus (Fig. 8.5). With the release of *Finding Nemo,* much was already known about *A. ocellaris/percula*, although the same was not true for *P. hepatus* with the release of *Finding Dory*. Most prior research on *P. hepatus* has focused on aspects of the fish's blue pigmentation rather than its ecology, life history, population status, exploitation rates or captive propagation.

While domestic aquaculture may have buffered the demand for wild-caught *A. ocellaris/percula*, a similar scenario is highly unlikely to occur with *P. hepatus* in the immediate future. There is no large-scale commercial aquaculture production of *P. hepatus* to date despite recent research efforts claiming success in culturing this species (Ho et al., 2013; Talbot, 2016). The culture of closely related species has been fraught with difficulties (Cassiano et al., 2015), and commercial production is likely to incur high production costs given the long larval period duration. As an alternative to traditional aquaculture, post-larval capture and culture of *P. hepatus* may supplement supply from fisheries where fish recruiting to reef environments are trapped (via light traps and crest nets) and grown to commercial size *ex situ* (reviewed in Bell et al., 2009). However, the contribution of fish supplied through this method to the trade is unlikely to ever amount to significant quantities given the low number of acanthurids collected by this method and the high proportion of those collected proving to be species of little interest to the aquarium trade (Malpot et al., 2008; Bell et al., 2009).

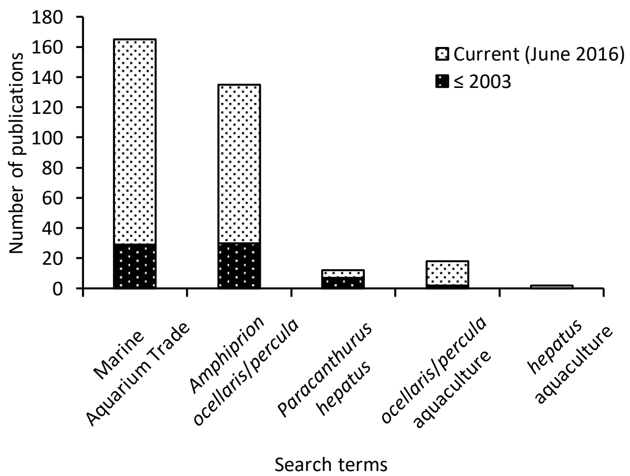

Figure 8.5: Relative research knowledge before *Finding Nemo* (≤ 2003) and *Finding Dory* (June 2016). The number of research papers returned from topic searches on the Web of Science™ from all databases in June 2016 using the indicated search terms. Only results with search terms in the paper's title or abstract of relevance to the topic are included. Searches for *A. ocellaris* and *A. percula* terms were conducted separately and combined.

A further ethical quandary of popularizing *P. hepatus* relates to its suitability to life in captivity. While coral reef fishes most commonly collected for the marine aquarium trade (i.e.

Pomacentridae) are typically site-attached with home ranges of a few metres or less (Chapman and Kramer, 2000; Jones, 2007), the home ranges of acanthurids have been reported to range from 58 m to 5 km (Mazeroll and Montgomery, 1998; Claisse et al., 2011; Claydon et al., 2012; Green et al., 2015). Such home ranges are well in excess of typical home aquaria, with 50 % of marine aquarium hobbyists maintaining aquaria with a capacity of less than 400 L (Alencastro, 2004). The asymptotic growth curve characteristic of acanthurids is also problematic in that juvenile fish, which are most common in the trade (Wabnitz et al., 2003), will quickly reach their adult size within two to four years of age (Choat and Axe, 1996). With the adult size of *P. hepatus* reaching 31 cm length (Froese and Pauly, 2015), this can be particularly problematic where consumers purchase juvenile fish without knowledge of these characteristics. Fish outgrowing the confines of their home aquarium is a driving factor in the release of captive marine aquarium fishes into waterways which has the potential to lead to the establishment of invasive species (Holmberg et al., 2015).

8.5 Conclusions

The perceived impact of *Finding Nemo* still attains public media attention (ABC, 2016; Dengate, 2016) more than a decade after its release. The historical lack of data pertaining to the marine aquarium trade is largely at fault for the inability to quantitatively evaluate such claims until now. Thanks to new sources of publically available data (i.e. Rhyne et al., 2015b), a more quantitative analysis of the popular media claims has been achieved here. While data gaps remain (mainly fishery catch exported to non-US markets), obstructing absolute certainty, the available evidence indicates that the assumed increase in fisheries' catch of *A. ocellaris*/*percula* immediately following the film does not reflect reality.

Finding Dory marks the dawn of new era for the global marine aquarium trade. Scientific and aquarium trade communities are presented with an opportunity to collaborate and quantitatively address the impact of digital media on an economically significant wildlife trade. Evaluating changes in fisheries' catch, assessing the extent to which destructive fishing practices are occurring and establishing estimates of population status for *P. hepatus* should be given the utmost priority to determine whether *Finding Dory* does in fact legitimate any of the ecological concerns we have discussed in this perspective.

The marine aquarium trade offers an opportunity for global citizens disconnected from coral reef ecosystems to evoke their own desire to preserve such habitats for the enjoyment of future generations. We challenge those working towards the preservation of nature to envision strategies that do not place the economic burden of conservation on already economically disadvantaged fishers (as would a closure of aquarium fisheries). More epistemologically aware and less hubristic approaches to biodiversity conservation can be achieved by further educating both consumers and opponents of the trade about the social and economic realities of sustainable development in economically marginalized communities.

Chapter 9

General Discussion

9.1 Summary of aims

This thesis addressed factors affecting the viability of the Papua New Guinea (PNG) marine aquarium fishery. The overall objective of this research was to review the managerial and operational practices of the PNG marine aquarium fishery. This objective was addressed through a number of publications extending these findings to the research needs of the global marine aquarium trade. The research contained within this thesis makes use of all available data pertaining to the PNG marine aquarium fishery not already published elsewhere (e.g., Dandava-Oli et al., 2013; Schwerdtner Máñez et al., 2014). The major outputs of this study and their relevance to PNG and the aquarium trade at large are summarised in Fig. 9.1 and described below.

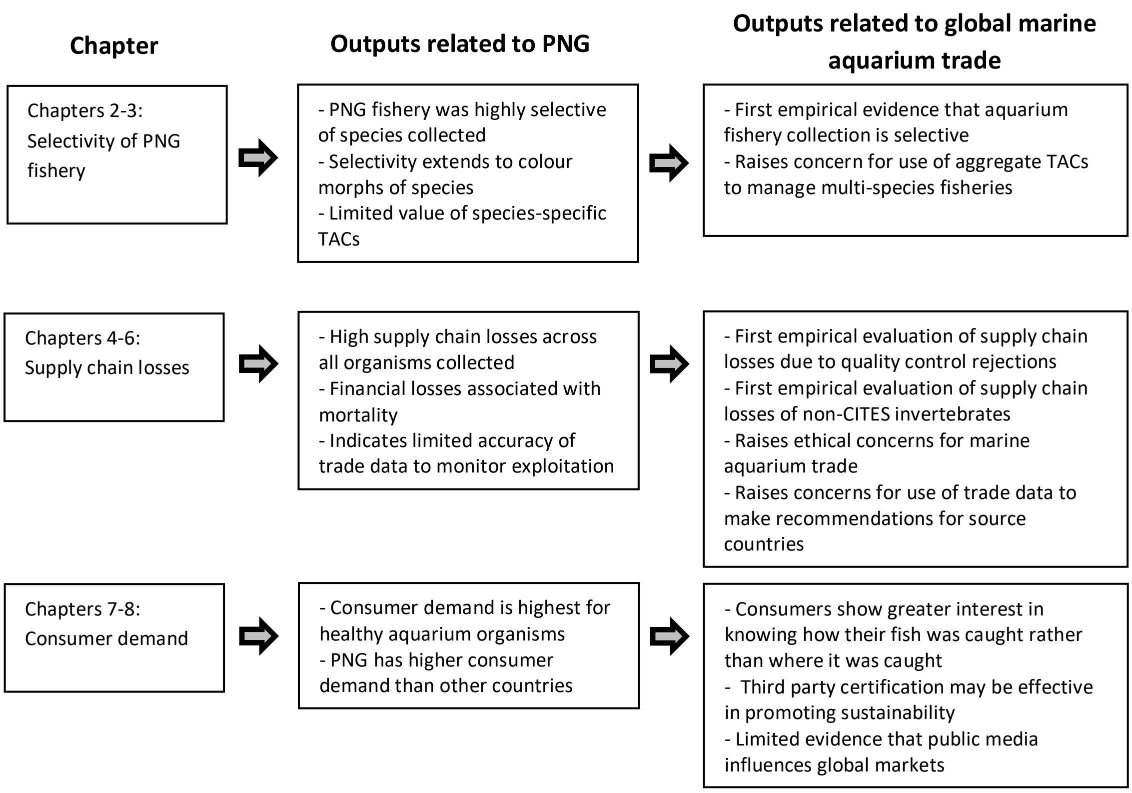

Figure 9.1: Major outputs of this thesis relating to the PNG fishery and global marine aquarium trade.

9.2 Selective nature of aquarium fisheries

The marine aquarium fishery of PNG was found to be highly selective of a limited portion of the available biodiversity (Chapter 2). This selectively was found to occur not only among species but to also extend to colour morphs of highly demanded species (Chapter 3). This research confirms what has long been presumed to occur: collection of marine aquarium organisms is selective and not reflective of their natural abundance (Andrews, 1990; Ochavillo et al., 2004). Given that exports from PNG, where only a few species comprise the bulk of trade (Chapters 2, 5, and 6), were of similar nature to most marine aquarium fisheries (Wabnitz et al., 2003; Rhyne et al., 2017), such selectively is likely to be evidenced elsewhere.

This finding questions the value of aggregate TACs to manage multi-species aquarium fisheries. Aggregate TACs may exacerbate selectivity where fishers try to maximise high value/demanded species composition of the catch limit (Saleem and Islam, 2008). This can lead to overexploitation of targeted species where the aggregate TAC exceeds what is a sustainable harvest limit for those specific species. The high selectivity also indicates that while the marine aquarium fishery encompasses a large diversity of organisms, most of these are typically avoided relative to their natural abundance. This suggests marine aquarium fishers operate as an unprecedented "predator" in marine environments. Fishers target and remove (fishing mortality) species in a highly selective nature that places an emphasis on attributes (see Chapter 7) unrelated to environmental fitness. Further research is needed to identify long-term impacts of this selective fishing on target species.

9.3 Transparency of practice

This research has provided empirical assessment of quality control rejections in the marine aquarium trade for the first time (Chapters 4 & 6). Further, this is the first assessment of supply-chain losses of non-CITES invertebrates in the marine aquarium trade (Chapter 6). This research provides a new standard of industry transparency. While import DOA losses were minimal for fishes and invertebrates, substantial mortality occurred prior to export (Chapters 5 and 6). This may result in importing companies inadvertently supporting poorly operating supply-chains with their patronage. Given that delayed mortalities can result further along supply-chains as a result of inferior husbandry at a single point (Hall and Bellwood, 1995; Rubec and Cruz, 2005), importing companies are incentivised to demand transparency of supplier performance.

Examination of a Fijian supply-chain demonstrated that the marine aquarium trade can operate with close to no mortality for collected fishes but, as shown here for the PNG fishery, high mortality can still occur (Chapter 5). Given that the high mortality in the PNG supply-chain occurred in the absence of destructive fishing techniques, where such practices are employed (Wabnitz et al., 2003) there is concern that mortality may even exceed the levels reported for PNG. There are numerous reports of marine aquarium fisheries being characterised by high mortality and the PNG fishery confirms such claims (Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005; Yan, 2016).

By identifying specific species and families (Chapter 5 and 6) of organisms prone to high mortality along the supply-chain, this research identifies where future research into aquatic organism physiology and transport is needed most. The presented results can be taken to identify model species on which transport and husbandry techniques should be trialled given their apparent susceptibility to inferior practice.

The reported mortality of wildlife also raises ethical concerns regarding the supply of marine aquarium organisms from fisheries (Baker et al., 2013). This case study emphasises a need for greater industry transparency along the full length of supply-chains. While marine aquarium operators may be disinclined to divulge performance data for fear of prosecution or social conflict (Erdmann, 2001), operators must realise the absence of evidence is not evidence of absence. Transparency of practice may actually be one method to avoid unnecessary conflict with other stakeholders of marine resources (see Chapter 8).

9.3 Limitations of trade data

Most information related to the marine aquarium trade has been sourced from mandatory reporting. This largely encompasses data extracted from trade invoices and lodged with the exporting or importing country's government (Rhyne et al., 2012a,b,2017; Okemwa et al., 2016; Prakash et al., 2017). The quantity of organisms collected for the PNG fishery differed greatly from trade data (Chapters 4, 5, and 6) during the government funded SeaSmart program (2008 – 2010). However, the disparity between collection and export quantities persisted in the subsequent, privately-run EcoAquariums export business (2011 – 2012; Chapter 2). Close to 30 % of organisms collected were never exported by EcoAquariums, this likely being attributed to the same sources of supply-chain loss identified for SeaSmart in 2010 (Chapters 4, 5, and 6). Using PNG as a case study, it was found trade data are inherently limited in the capacity to accurately monitor exploitation. Given that high supply-chain losses are known to occur elsewhere (Rubec and Cruz, 2005; Schmidt and Kunzmann, 2005; Yan, 2016) this limitation of trade data is unlikely to be unique to PNG. This is unfortunate given the large, continual resource investments directed towards improvements in trade monitoring (Wabnitz et al., 2003; Rhyne et al., a,b,2017) and emphasises the importance of collection records being monitored and retained by the exporting countries' governments.

9.5 Consumer demand

The lack of transparency along marine aquarium supply-chains currently limits the extent to which customers can make sustainability conscious purchase decisions. Chapter 7 identified consumers placed a high level of importance on leaning how fish were caught at a point-of-sale. Direct explanations of how a fish was caught or certification schemes conveying this information were found to be preferred over information related to where a fish was caught (Chapter 7). There was promising theoretical support for the development of third-party certification schemes as a means of providing more information to consumers at a point of purchase (Chapter 7). Given a number of socio-economic barriers preventing industry reform within source countries (Erdmann, 2001; Rubec et al., 2001) consumer driven approaches are an appealing option to direct industry improvements (Dykman, 2012).

Their also appears to be limited impact of public media on marine aquarium fisheries (Chapter 8). Far more evidence is suggestive that global economy and aquarium husbandry advances govern demand for products traded. The role of public media can play in hindering industry reform was examined and the impact of many anti-trade media campaigns may be negatively affecting effective conservation (Chapter 8).

9.6 Application of research within PNG

In the context of the PNG marine aquarium fishery, this research identified a number of factors hindering the viability of the fishery from both managerial and operational perspectives. From a managerial perspective, the current use of species-specific TACs to manage fishery catch is an excessive management burden for the fishery (Chapter 2). Roughly half of the species assigned TACs were never collected by the fishery over an entire year of operation. Refinement of the use of TACs identified only three species meriting species-specific management. This is likely to reduce the management burden of future fishery operations to a feasible level.

From an operational perspective, high supply-chain losses due to both quality control rejections and mortality would inevitably impact on the economic viability of the fishery (Chapters 4, 5, and 6). This is particularly true given the majority of supply-chain losses occurred after the exporting company purchased organisms from fishers. These losses were substantial compared to a long-running, economically-successful supply-chain in Fiji. This finding questions the value in use of government funding to run marine aquarium fisheries. The lack of commercial incentive to improve performance may have been a contributing factor between 2008 and 2010 that allowed inferior supply-chain practices to persist. This suggests that future marine aquarium fishery activities within PNG be restricted to privately funded entrepreneurs.

From a marketing perspective, consumers generally indicated positive attitudes towards purchasing fish from PNG (Chapter 7). However, this finding was made prior to disclosure of industry performance analysed in this thesis. Future research will need to determine if past-fishery performance will impact on consumer willingness to purchase PNG products in the future. Use of third-party certification may help to improve consumer willingness to buy PNG products. This research also found concern that digital media (i.e., *Finding Nemo* and *Finding Dory*) could drive exploitation of the two most collected fish species in PNG, *Amphiprion percula* and *Paracanthurus hepatus*, appears to be unwarranted (Chapter 8). The use of species-specific management for both *A. percula* and *P. hepatus,* as suggested above, would safeguard against any unexpected rise in consumer demand.

9.6.1 Recommendations for the National Fisheries Authority

With the PNG marine aquarium fishery likely to resume in the near future (Dandava-Oli et al., 2013), the current cessation of fishery operations provides an opportune time for a refinement of a management approach. The information presented here could be utilised for finalising draft versions of PNG's Marine Aquarium Trade Management Plan, as done elsewhere (Kinch and Teitelbaum, 2009; VDF, 2009).

Chapters 2-8 identified a number of recommendations to be incorporated in a Marine Aquarium Trade Management Plan. This includes reducing use of species-specific TACs to three species (*Amphiprion percula, Hemiscyllium hallstromi, Paracanthurus hepatus*) (Chapter 2) and setting an aggregate TAC for rare *Amphiprion* spp. and *Premnas biaculeatus* colour morphs (Chapter 3). In addition to limiting exports of clownfish colour morphs it was advised that the National Fisheries Authority (NFA) communicate the limited financial value in targeted exploitation for these specimens. Such education coupled with fishing limits (i.e., aggregate TAC) should see a reduction in the selective fishing pressure facing these colour morphs and help ensure sustainability of this resource.

Chapters 2, 4, 5, and 6 identified a fishery-wide problem of supply-chain losses along the PNG supply-chain. The recommendations to improve future supply-chain performance would be for the NFA to only extend licensing to experienced marine aquarium trade operators. Allocating government funds to assist in the running of aquarium trade operations may allow poor performance to persist. This suggests future marine aquarium fishery operations should be privately funded to ensure commercial incentive motivates performance. The information obtained from prior government expenditure (i.e., the SeaSmart program) has come at a great expense to the NFA. The synthesis of this information (this thesis; Schwerdtner Máñez et al., 2014) offers the NFA an opportunity to provide future operators unparalleled insight into the challenges of establishing aquarium fishery operations in PNG. This non-monetary governmental support should be given preference over subsidising future marine aquarium fishery activities.

Stipulating the requirement of operators to log both collection and export records with the NFA should be a mandatory component of licensing. While this was done with EcoAquariums, the discrepancy between collection and export records (e.g., invertebrate collection records in Chapter 2) indicates penalties for incorrect reporting should also be incorporated into any resulting Management Plan. Chapter 7 indicated that a PNG marketing approach focusing on PNG as a unique location may be less successful than marketing approaches communicating how fish are brought to market or through third party certification. In view of this finding, PNG fishery managers should support extension of future industry third party certifications to PNG and scientific reviews of performance.

Considerable time, effort and resources were expended toward developing the PNG marine aquarium fishery. It is unfortunate a successful venture has yet to establish within the country. The lessons learned from PNG's approach to marine aquarium fishery management and operational practices employed in past efforts are likely to be of interest and value to PNG, other developing island nations, and marine aquarium fisheries globally.

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Appendix A

Table A.1: Summary of contractual deliverables of the SEASMART program and their status with conclusion of the program in 2010. Please refer to Yeeting and Batty (2010) for a detailed review of the project and the original contracts.

Contracted deliverables	Status with conclusion of program
Marine aquarium resource assessment in Port Moresby area Central Province	Completed (Ruz, 2007)
Develop a draft, national marine aquarium management plan	Incomplete and far from operational
i. Conduct national seminars to support development and adoption of management plan	NA
Provide capacity building through:	
i. Training NFA staff on stock assessment survey methods	Completed
ii. Training NFA staff on models used to estimate stock abundance and Total Allowable Catch (TAC)	Lack of capacity building evident
iii. Extension of activities to local communities	Fisher training conducted; mariculture activities trialled
Establish one Marine Aquarium Council certified trial export facility based in Port Moresby	Completed
Establish two Marine Aquarium Council certified Fishery Management Areas (FMAs) in Central Province	Completed
Develop a function TRADE management software to monitor collection and export of marine aquarium resources	Partially or not accomplished
Establish a marine aquarium trade in PNG with product being exported	Trial exports conducted; no establishment of trade and disregard for commercial viability
Marking and promotion of the PNG 'brand' in the marine aquarium trade	Completed