SAVING NEMO:

MARICULTURE AND MARKET-BASED SOLUTIONS TO REFORM THE MARINE ORNAMENTAL TRADE

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List of Abbreviations & Acronyms

ACIAR	Australian Centre for International Agricultural Research
APPA	American Pet Products of America
BCICS	British Columbia Institute for Co-operative Studies
C.A.R.E.	Collected by Artificial Reef Eco-friendly
CBD	Center for Biological Diversity
CCD	Community-Driven Development
CI	Conservation International
CIA	Central Intelligence Agency of the United States
CITES	United Nations Convention on Trade in Endangered Species
CNMI	Commonwealth of the Northern Mariana Islands
CTI	Coral Triangle Initiative
CTSA	Center for Tropical and Subtropical Aquaculture
EIA	Environmental Impact Analysis
ESA	Endangered Species Act of the United States
FAO	Food and Agriculture Organization of the United Nations
GATT	General Agreement on Trade and Tariffs
GIS	Global Information System
LRFF	Live Reef Food Fish
MAC	Marine Aquarium Council
MACTRAQ	Marine Aquarium Trade Coral Reef Monitoring Protocol
MAMTI	Marine Aquarium Market Transformation Initiative
MASNA	Marine Aquarium Society of North America
MERIP	Marine and Environmental Research Institute of Pohnpei
MFMR	Ministry of Fisheries and Marine Resources of the Solomon Islands
MICS	Marshall Islands Conservation Society
MMF	Marshall Islands Mariculture Farm
MPA	Marine Protected Area
NACA	Network of Aquaculture Centers in Asia Pacific
NFA	Papua New Guinea National Fisheries Authority
NGO	Non-Governmental Organization
NOAA	National Oceanic Atmospheric Administration of the United States
OAR	Oceans, Aquariums and Reefs
OFT	Ocean Farm Technologies (LLC)
PCC	Post-larval Capture and Culture
PNG	Papua New Guinea

QR	Quick Response code
RAMSI	Regional Assistance Mission to the Solomon Islands
SCUBA	Self-Containment Underwater Breathing Apparatus
SPC	Secretariat of the Pacific
TERANGI	Indonesian Coral Reef Foundation
TIU	Technical Implementation Units
TNC	The Nature Conservancy
UN	United Nations
UNEP	United Nations Environmental Program
U.S.	United States of America
USD	United States Dollar
U.S. FWS	United States Fish and Wildlife Service
WCMC	World Conservation Monitoring Centre for UNEP
WCS	World Conservation Society
WTO	World Trade Organization
WWF	World Wildlife Fund

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Abstract

The marine ornamental trade for aquaria is currently on an economically and environmentally unsustainable trajectory. Producers in the Coral Triangle often use destructive methods to harvest species in an attempt to meet worldwide demand. In the process, coral reef habitats can be destroyed; additionally, harvested species have a higher mortality in transit, which can contribute to higher retail prices. Producers receive low prices for their catch, motivating overharvesting to increase revenue. We investigated mariculture as an option to alleviate the negative impact to coral reef ecosystems while increasing revenue for producer communities. First, we conducted an economic analysis of United States' demand to provide recommendations for domestic economic interventions that might increase sustainability throughout the supply chain. Second, we created a guidance document for non-governmental organizations interested in sustainable aquaculture to benefit producer livelihoods. Our analysis indicated that a novel combination of post-larval capture and culture (PCC) and offshore grow-out using Micropod™ technology could provide a sustainable alternative to wild capture. We conducted a cost-feasibility assessment of this method and determined under which market scenarios producers could make a profit. We concluded that community-based mariculture can become a viable option for increasing the sustainability of the trade.

Executive Summary

Introduction

The marine ornamental trade is on an unsustainable path due to ecologically destructive fishing practices and overfishing on coral reefs. Over 80% of traded marine ornamentals originate from the Coral Triangle, and both producer communities and the delicate reef ecosystems are at risk because of this unsustainable trade (Wood, 2001). Many fishermen use harmful chemicals such as cyanide and dynamite to catch ornamental fish, because it is a fast and easy way to catch multiple fish at once. However, cyanide essentially poisons the fish, leading to extremely high mortality rates in the supply chain. Additionally, these destructive methods can have devastating, effects on coral reefs in the form of physical destruction from chemical use and poor practices and the depletion of species from overharvesting.

Figure 1. Map of the Coral Triangle. Coral Triangle boundary source: Coral Geographic (Green & Mous, 2008).

A number of solutions have been proposed to address these problems. Mariculture, a form of aquaculture, may alleviate issues facing both producer communities in the Coral Triangle and precious coral reef ecosystems. There are many forms of mariculture, including full-cycle breeding and growing operations, post-larval capture and culture, and both on-land and offshore facilities. While some ornamental species have been successfully cultured by commercial operations, many others have only been successfully cultured in a laboratory setting and others species have yet to be cultured in any setting.

Other solutions attempted in the past include certification schemes for sustainably harvested fish, educational campaigns for producer campaigns to shift away from bad practices, and trade restrictions at both the U.S. and international level. While all the proposed solutions have potential to improve the trade, none have had any long-term success. The certification scheme was overly complex and too difficult to implement. Many NGOs have attempted to teach better practices to collector communities, but they tend to revert back to old techniques as soon as the NGOs pull out. Finally, legislation has been proposed to further protect coral reef ecosystems and certain ornamental species, but they have failed to gain political support.

To explore these potential solutions, we divided our analyses into two parts. First, we conducted an analysis of potential U.S. economic solutions to motivate sustainable practices in the Coral Triangle and throughout the supply chain. Second, we outlined the factors that determined the economic, social, and environmental feasibility of a mariculture operation start-up for producer communities in the Coral Triangle, and we provided scenarios by which this can be done.

Economic Analysis

Economic inefficiency in the trade is a major driver of environmental unsustainability, contributing to overharvesting, poor practices, and producer poverty. We looked for opportunities to intervene in the market that might create incentives for more sustainable practices, while ensuring profit for retailers and quality products for consumers. Specifically, we analyzed the potential for three diverse classes of solutions: a mandatory warranty that could create incentives for better harvest practices, a price premium fueled by an increased willingness to pay for tank-bred fish versus wild-caught fish, and the extent to which aquaculture businesses could become competitive in the market if they used a direct market contract.

Warranty

We investigated the potential for a warranty on fish both to protect consumers from buying moribund fish and to motivate retailers to purchase fish from more sustainable sources. These measures would improve sustainability throughout the supply chain. Using a stated preference approach, we conducted a consumer survey of marine fish aquarists in the U.S. The survey included data on fish mortality in home aquaria, years of consumer's aquaria experience, and willingness to pay for a warranty. Based on our survey results, we discovered that in the current market for every dollar a customer spent on fish today, a store can expect to make an additional $0.39 in sales to replace fish that have died. Additionally, we discovered that approximately 80% of the fish mortality in home aquaria can be attributed to poor practices in the supply chain, not customer error. Under current practices, stores have been making significant profits from selling impaired fish to unaware customers.

Our warranty analysis supports implementing a mandatory warranty to protect customers from purchasing damaged fish. The primary motive of the warranty, however, would be to provide stores with an incentive to purchase from only the suppliers that do not use harmful collection or handling practices throughout the supply chain. Our analysis showed that if a mandatory warranty was implemented and the supply chain was not reformed, on average stores would lose 11.7% of their current profits. By reforming the supply chain under a mandatory warranty, stores could earn 5.33% more than they are currently earning today. Under a mandatory warranty, stores have a significant financial incentive to look into the practices of their suppliers and ensure that changes are made to improve the health of the fish, and eventually the overall sustainability of the trade. Therefore, we can recommend a mandatory warranty as an effective market-based solution to protect customers and to improve the sustainability of the marine aquarium trade.

Willingness to pay for tank-bred fish

We looked at willingness to pay for tank-bred fish versus wild-caught fish for consumers in the U.S. This analysis determined the increase in price that retailers could charge for a tank-bred fish, and how much more an aquaculture business might need to produce their fish and still remain competitive in the market. A stated preference survey of consumers in the U.S. determined the percent increase in price for tank-bred fish that would maximize profit. We found that a markup of 25%-30% would provide retailers with the greatest gain in revenue – a 25.6% increase. A retailer could successfully place a price premium of 30% on its tank-bred fish, and this extra revenue could resonate through the supply chain and increase profits for aquaculture operations.

Market contracts

We conducted a supply chain analysis and incorporated price data at various points along the supply chain from collectors to retailers and determined the price markups at each step. We also estimated shipping costs for various fish species. Using this information, we calculated the highest price that aquaculture producers could sell their fish and remain competitive in the market under the following scenarios: current market conditions, if retailers placed a price premium on tank-bred fish, and if producers entered in a direct market contract with either a wholesaler or a retailer in the U.S. We found that under current market conditions, an aquaculture operation would have to produce fish at an average of $0.54 per fish to compete successfully in the market. If retailers placed a 30% price premium on tank-bred fish, the competitive producer price would increase to $1.04 per fish. Under a market contract with a wholesaler, an aquaculture operation could sell their fish for $3.29 each, and this price would increase to $7.39 if they contracted with a retailer. Under the most favorable market scenario, a direct market contract with a retailer who also places a 30% price premium on tank-bred fish, an aquaculture operation could sell its fish for an average price of $10.10 each. We recommend implementing either a 30% premium or a market contract (or both) in order to give aquaculture a significant competitive advantage in the trade.

Producer-side Mariculture Feasibility Study

Our client, Olazul, assists coastal communities in transitioning towards sustainable livelihoods. Due to the issues related to the wildlife collection and trade, stakeholders in the trade have directed greater attention towards aquaculture. We explored possible aquaculture methods that would not harm coral reefs and would be feasible for low-income producers. Unfortunately, a very small percentage of marine species can be bred in captivity. The process is incredibly complex and expensive due to the amount of quality care necessary to rear marine ornamentals. Considering the barriers to full-cycle mariculture, we recommend a post-larval capture and culture (PCC) technique in combination with a unique grow-out operation using an open-ocean cage called the Micropod™. We analyzed the technological, social, political, and economic feasibility of implementing this system in producer communities in the Coral Triangle.

Technical considerations
PCC is an aquaculture method that requires fewer resources than full-cycle aquaculture. PCC works by capturing marine fish during their pelagic post-larval stage and then culturing them in a controlled environment. This method takes advantage of the large quantities of fish larvae moving from the open ocean towards reef habitats. Since high natural mortality occurs during the post-larval stage, collecting a portion of larvae will minimally affect the long-term population. Past PCC operations have required expensive on-land facilities. Open-ocean containment systems originally developed for the food fish industry may provide a feasible alternative.

Legal considerations
Despite the presence of a strong legal framework supporting aquaculture at the national level, enforcement varies by region. The Coral Triangle Initiative (CTI) and member-states' individual laws are generally conducive to new marine ornamental ventures. CTI is a multilateral agreement between the six nations in the Coral Triangle (Indonesia, the Philippines, Malaysia, the Solomon Islands, Papua New Guinea, and Timor-Leste) designed to encourage responsible stewardship of coral reefs and their surrounding ecosystems while ensuring economic stability of the communities who utilize their resources. National laws vary, and even those are rarely enforced uniformly. Regional laws and customs frequently take precedence over official stated regulations, so we advise any potential investors to investigate local laws and customs in locations they consider for mariculture operations.

Political stability
Political stability is a complex issue that defies quantitative assessment, but is an important factor to potential investors and varies widely between the different countries of the Coral Triangle. We used a combination of Polity Fragility scores and information from the CIA World Factbook to assess which countries were most politically and socially stable and thus safe and attractive to new business ventures. We found that Indonesia, the Philippines, and Malaysia are currently the most stable and best suited to attract outside investments. The Solomon Islands currently host at least one successful partnership with a U.S.-based mariculture operation and has potential to host more. Papua New Guinea and Timor-Leste could be excellent sites in the future, but are currently politically and socially unstable, and are therefore less attractive options for start-up mariculture operations.

Business considerations
The limitations of the trade, in combination with the technical limitations of mariculture production, impose constraints on potential business models for mariculture in producer communities. We found that the major considerations for the feasibility of a mariculture business include: funding, market share security, and identification of a willing entrepreneur. Market contracts should be arranged between producers and retailers because they would increase the percentage of profits that producers receive. Market contracts could be coupled with guarantees of sustainable production practices and, consequently, fish health if retailers were to implement a warranty program.

Social considerations
We suggest a cooperative production model as a way of ensuring equitable distribution of income across the community. This would simultaneously increase the accountability and transparency of a mariculture operation in a given producer community in the Coral Triangle. Cooperative models need to address community dynamics and gender roles. On-the-ground knowledge and experience is necessary to inform an NGO on how to appropriately incorporate the current community and livelihood structure into the business structure of a mariculture venture.

Cost-Feasibility Analysis

A direct contract with a retailer and a price premium would provide the highest annual returns, however considering the large volume of retailers compared to the number of wholesalers, this might not be a realistic option. In contrast, a direct contract with a wholesaler would likely be easier and still make a profit within 10 years. The price premium would not be as crucial as the direct contract. The recommend the best and realistic option would be a direct contract with a wholesaler along with a price premium.

Conclusions

We addressed the complex problem of trade in ornamental marine species by considering both economic variables in U.S. demand and technical, legal, political, social, and business variables in producer communities in the Coral Triangle. Our economic analysis showed three possible market-based solutions to increase the sustainability of the trade: implementation of warrantees for U.S. consumers, price premiums for tank-bred fish, and direct market contracts. Our producer-side analysis concluded that producer communities, coupled with support from an agency with funding and expertise, could successfully implement a mariculture operation using PCC and Micropod™ technology.

Project Background

Problem Statement

The harvest of marine organisms from coral reefs for the aquarium trade provides income for coastal communities around the world. Global trade in marine ornamental fish accounts for about 28-44 million USD per year (Bruckner, 2006), with the United States accounting for approximately 80% of imports from over 40 countries (Wood, 2001). Most collectors use unsustainable extraction methods, which deplete the same resources the communities depend on. These practices stem from high mortality in transit and lack of equipment and motivation for sustainable collection. Today, collector communities - and by extension the entire industry - face significant environmental and economic challenges. The trade needs sustainable methods of harvest, collection, and transport in order to remain viable into the future.

Many current harvesting methods of coral reef species devastate both reef ecosystems and wildlife. Collectors use explosives and cyanide to extract fish, methods that result in extensive reef damage and high mortality rates of collected fish (McManus & Reyes, 1997). These unsustainable collection methods deplete both fish populations and the corals that provide habitat for target species at rates that will eventually lead to population collapse (Timotius et al., 2009). Additionally, gross inefficiency in the supply chain causes high mortality as fish travel toward the end consumer. To compensate for the high mortality rates throughout the supply chain, many more fish are harvested than are demanded, which results in severe overfishing.

The last several years have seen considerable effort to introduce collectors to more sustainable methods. Some supplier countries developed legislation to regulate coral species export and restrict destructive fishing practices, but the lack of government resources, coupled with the nature of collection, make enforcement of such laws extremely difficult. Nations in the Coral Triangle have extensive coastlines and large reef areas and lack the law enforcement capabilities to monitor harvest practices. In order to be successful, a solution will have to be feasible in both scope and implementation. Furthermore, this solution must result in competitive prices for collectors and create an incentive to change practices.

The uncertain effect of ornamental trade regulations on the U.S. market poses another challenge for the trade. Demand for luxury goods are highly elastic, which could result in dramatic drops in demand if U.S. import laws change or prices for fish increase, either as a result of international accord or a change in domestic policy. There is considerable pressure from environmental groups to tighten import laws and bolster enforcement capabilities. As the biggest global importer, the U.S. can significantly affect the industry through policy towards more sustainable collection requirements (Tissot et al., 2010). Despite intended positive ecological effects, these policy changes could negatively affect collectors on the other end of the supply chain. If a new U.S. import policy requires different collection methods, then small collectors who are not equipped to upgrade their methods or prepared to do so could lose their source of income (Rubec et al., 2001). Implementing an alternate, sustainable method of production may provide environmental and economic security by ensuring that there will still be corals and reef fish to collect if regulations change, and that communities will not lose their source of income to larger scale and better-equipped collectors.

Aquaculture may alleviate many of the issues faced by producer communities in the Coral Triangle and can help protect coral reef ecosystems. However, aquaculture for marine aquaria, while promising, is still relevantly in its infancy (Reef Culture Technology, 2012). Of the roughly 2,000 marine ornamental species traded globally, less than 200 have ever been cultured (Hayes, 2009). Aquaculture is defined by the FAO as "the farming of aquatic organisms including fish, molluscs, crustaceans, corals and other invertebrates, and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated" (1997). When "the cultivation of the end product takes place in seawater," aquaculture is typically referred to as "mariculture" (FAO, 2012). Mariculture is a rapidly growing industry, and many nations are developing legislation and policies that promote its development.

United States policy

Current United States legislation includes very little regulation and infrastructure to manage the marine ornamentals trade. The Lacey Act states that trade in any species protected by domestic, international, or tribal law is prohibited (United States Fish and Wildlife Service [U.S. FWS], 2011). The United States Fish and Wildlife Service has jurisdiction over the trade and import of wildlife, and commercial importers require a permit. Importers must have their shipments inspected at one of the 14 designated U.S. ports (U.S.FWS, 2000), and importation of species listed on either the United States Endangered Species Act (ESA) or the United Nations Convention on Trade in Endangered Species (CITES) is prohibited. Aside from these requirements, no regulation exists to ensure that the supply of fish comes from sustainable sources.

Despite the clear threat facing coral reefs from degradation and overfishing, only a few reef species are listed under either the CITES or the ESA (Endangered Species Act, 2010). Leading domestic and international environmental groups, including Conservation International (CI) and the Center for Biological Diversity (CBD), advocate strong action for coral reef conservation. While the process of legally protecting international species of interest can be politically cumbersome, it is possible that threats to trade from overall biodiversity loss might provide the catalyst for either the U.S. or UN Environmental Program to act. Changes in legislation has been proposed a number of times to both institutions, but thus far has failed to gain widespread support.

The U.S. has coral reefs off the coasts of Hawaii, Florida and a number of Pacific and Caribbean Territories. Current U.S. legislation enables the government to enforce strict conservation laws, including marine protected areas (MPAs), and fund extensive monitoring programs by the National Oceanic Atmospheric Administration (NOAA). In 1998, President Clinton signed Executive Order 13089, forming a Coral Reef Task Force to protect coral reef ecosystems and prevent their degradation. Commercial harvest is still permitted but is strictly regulated.

On the domestic side, the United States can impose standards on imported fishes to require that their harvesting be in compliance with standards similar to those set for domestic marine fishes. Implementation of these standards would require major changes in equipment and practices on the part of the suppliers and increased monitoring by the U.S. to ensure that the more stringent standards are met. Two species of coral are already listed as "threatened" under the ESA, meaning they cannot be harvested, imported, or exported (National Oceanic Atmospheric Administration [NOAA], n.d.). In 2009, the Center for Biological Diversity (CBD) petitioned NOAA to list an additional 83 corals as threatened or endangered and to designate critical habitat for them. The petition is currently under review (FR75-6616). Designating coral as critical habitat does not necessarily mean fish harvesting would be prohibited, but it would be a significant step toward ensuring that harvesting will be done a more cautious and sustainable manner.

The U.S. has a legal precedent for creating international standards, found in the Dolphin-Safe Tuna Initiative of the 1980s and 90s, which has lowered dolphin mortality from tuna fishing by 98% since 1990. There were significant policy issues to overcome before such an action could be implemented, including fishing industry lobbies and potential international trade agreement violations.

The U.S. attempted to impose an embargo on several countries as a part of the Dolphin-Safe Tuna Initiative, refusing to import tuna from countries who did not take steps to eliminate dolphin by-catch. However, the World Trade Organization (WTO) struck the embargo down for being contrary to General Agreement on Trade and Tariffs (GATT) (Skilton, 1993). In the end, the U.S. had to withdraw the embargo and rely on a "Dolphin-Safe" labeling scheme, which eventually had tremendous success in reducing demand for tuna caught using destructive practices. The lesson from this example is that unilateral policy action by the U.S., if it even occurs, may not hold up in the international arena. To be successful, a solution will have to include both legislative and market-based approaches.

International conservation policy represents a parallel track to that of the U.S. While there appears to be widespread support for adding protective measures to coral reefs, the last meeting of the governing bodies of CITES in 2010 voted against imposing trade regulations on additional species other than corals (Environmental News Service, 2010). At this meeting, the U.S. advocated more stringent regulations, citing international trade as the greatest threat to coral reef ecosystems. Both U.S. policy and CITES face intense commercial lobbying to eliminate or relax trade regulations, along with the threat of the WTO striking down any regulations that are passed. The WTO can preempt decisions made by UNEP, so policy-makers must tread carefully before restricting global trade. If the change in the marine ornamental industry is going to come from top-down legislation, success will depend on a concerted push by environmental and trade groups, along with a balance of regulation that encourages rather than inhibits trade.

Impact on coral reef ecosystems

Despite the lack of nutrients in the ambient waters, coral reefs have very high density and diversity of species and are considered biological hotspots. They provide a wide array of ecosystem benefits such as fisheries, tourism, and act as coastal barriers against strong wave action (Wabnitz et al., 2003). Although habitat-forming corals are able to support a diverse and abundant biome, these delicate ecosystems have rapidly degraded worldwide over the past century due to anthropogenic activities. While a great deal of emphasis has been placed on damage to the reef ecosystem from the food fish industry, less is known about impacts from the ornamental aquarium trade. However, the practices of ornamental fish harvesting have been shown to be detrimental to reef health (Wabnitz et al., 2003).

Main Ecological Impacts of the Aquarium Trade:
(Adapted from Wabnitz et al., 2003)

- Chemicals affecting organisms' health
  - Sodium cyanide and quinaldine most utilized
  - High mortality rates for fish and invertebrates
  - Harm to both target and non-target species
  - Exposure damage to highly susceptible corals
  - Loss of zooxanthellae ("Bleaching")
  - Coral death at high doses
- Habitat Damage
  - Breaking off of coral pieces
  - Boat anchoring
  - Nets caught on coral
- Overfishing
  - Depletion of wild stocks
  - Large decreases in abundance

  - Decreases in biodiversity
  - Alteration of community structure
- Negative effects on the food web and trophic levels
  - Invasive Species from accidental and intentional release
  - Often robust populations that outcompete natives
  - Disease introduction

The most immediate negative impacts of ornamental aquarium harvesting relate to harmful practices such as cyanide use and the physical destruction of coral reef habitat. Sodium cyanide, used to stun target species, can affect both target and non-target species, decreasing their health and increasing the probability of mortality (Wabnitz et al., 2003). Coral can be especially vulnerable to even low doses of cyanide. Intermittent but concentrated doses of sodium cyanide may have a range of effects on coral – from some zooxanthellae loss at low doses, to most or all zooxanthellae loss (signifying a "bleaching event") at medium doses, and coral death at the highest doses (Jones & Stevens, 1997). Unfortunately, while the effects of these harmful practices are apparent, collectors commonly use cyanide in underdeveloped locations where both education and fishery management enforcement are limited (Wabnitz et al., 2003).

Overharvesting of coral reef ornamentals poses another threat to the coral reef ecosystem. Ornamental reef fish experience similar overharvesting effects as reef food fish. Direct effects on the ecosystem include decreased species abundance, and indirect effects (such as distorting community structure) are extremely likely. Often, fishing practices are nondiscriminatory, and collectors harvest large quantities of many different fish species at a time (UNEP-WCMC, 2008). Collectors also target high-demand species, which are usually rare, endemic species (Wabnitz et al., 2003). Juveniles are also targeted since they tend to be more colorful and easier to transport than adults (Bruckner, 2005). Harvesting juveniles can result in fewer individuals left in the population to reach reproductive maturity. Males are also often preferred over females due to their coloration, which also can lead to decreased birth rates in populations. Both nondiscriminatory and species-targeted methods of collection increase the probability of significantly and permanently altering community structure around coral reefs.

Overharvesting reef species alters community structure directly, but the aquarium trade can also affect the coral reef ecosystem by distorting biological relationships (UNEP-WCMC, 2008). Coral reefs have some of the most intricate interspecific relationships including mutualistic, symbiotic, competitive, and predatory (Bellwood, Hughes, Folke, & Nystrom, 2004). One very important symbiotic relationship is that between coral polyps and zooxanthellae: coral polyps provide habitat for photosynthetic zooxanthellae, which in turn provide much of the primary productivity that supports the coral ecosystem. Many species rely on the corals simply as a habitat, while others, such as *Chaetodon* spp. need live corals as a food source. Altered community structure and phase shifts, such as a shift from live coral to algae-dominant habitats, can result when key members of trophic groups are harvested without consideration for the food web and community interactions. Herbivores, which experience the greatest demand for aquarium collection, play an essential role in stemming algal growth. Other important trophic groups that hold high value in the aquarium market include planktivores (e.g., *Chromis* spp.), corallivores (coral-eating species) (*Chaetodon* spp.), piscivores (*Epinephelus* spp.), and cleaner fishes (*Gobiosoma* spp.) (Bruckner, 2005).

Mutualistic relationships in particular are vulnerable to unrestrained harvesting. Cleaner species such as some *Gobiosoma* spp. and *Labroides* spp. remove ectoparasites and dead tissue from client fishes (Grutter, 1999), and the overall health of the reef community may suffer if cleaner species are removed. The effects of interfering with co-dependent species was also observed in overexploited sites in the Philippines, where one study found 80% of the reduction in anemone fish could be attributed to the low density of anemones (Shuman, Hodgson, & Ambrose, 2004). Scientists have only recently begun to understand some of the complex biological relationships, and research may not be able to keep up with unsustainable fishing practices.

Predicting the effects of collection on community structure is difficult due to the diverse and complicated life histories of marine species. Unlike freshwater species, marine organisms often have complex life stages such as a pelagic larval stage or sequential hermaphroditism (Adams, Mapstone, Russ, & Davies, 2000; UNEP-WCMC, 2008). These life histories can vary from species to species and often are controlled by environmental signals such as season, moonlight, and tides. For many wrasses and groupers, community structure is determined by the absence or presence of the dominant sex (most often the largest individual in the local population). If collection practices cause the largest individuals to be removed from an area, a shift in size classes can occur and the population composition for the entire reef can be altered. In essence, harvesting juvenile or mature coral reef species without knowledge of their specific life histories can easily lead to overall shifts in size, age, sex, and species.

The effects of the aquarium trade on coral reef ecosystems are difficult to predict due to the lack of knowledge on the actual status of reef ecosystems. High species diversity, complex biological interactions, and a variety of remote locations create serious obstacles to gathering accurate and robust data. This challenge only adds to the urgent call for gathering more information and developing more accurate models to compensate for current lack of data. One of the greatest challenges for the aquarium trade, however, is moving forward and developing sustainable management strategies despite these many scientific uncertainties.

Current socioeconomic state of producers in the Coral Triangle

In order to reform the coral reef wildlife trade in the Coral Triangle, it is crucial to understand the socioeconomic context of this issue. Management strategies for artisanal fisheries often fail if the local socioeconomic characteristics of the community are not taken into consideration (Allison & Ellis, 2001). A solution that improves the ecological and economic sustainability of the coral reef aquarium trade should therefore consider the socioeconomic conditions of collectors in the Coral Triangle.

Indonesia and the Philippines are the two largest contributors to the Coral Triangle ornamental producer industry, and government practices in each country do not effectively regulate the coral reef aquarium wildlife harvest. Indonesia has a free access policy toward fisheries (CCIF, 2001), which results in a large number of fishermen fighting to catch fewer and fewer fish on already degraded coral reefs. The Philippines employ more community-based fishery management strategies than Indonesia (CCIF, 2001), which may increase their chances of maintaining sustainable coral reef ecosystems over time. Unfortunately, corruption is widespread throughout the Coral Triangle at many levels of society, and government control over this issue is weak (EC Prep Project, 2004). At this point, government attempts to implement policy to improve the ornamental wildlife trade will not experience success without improved enforcement from a national to a local scale.

Collectors in the Coral Triangle generally live in poverty. These people often have low levels of education and live in poor villages without reliable fresh water supplies or sufficient sanitation services (EC Prep Project, 2004). The middlemen, who supply collectors with fishing equipment and transport the fish to exporters, are not much better off, but they usually have a little education and minimal business skills in addition to collecting experience (Reksodihardjo-Lilley & Lilley, 2007). Despite these advantages, middlemen generally live under the same conditions as the collectors. Basic living needs in Indonesia cost about IDR 800,000 per month (90 USD), which is more than many collectors earn (EC Prep Project, 2004). Some collectors work in the marine ornamental trade full time, and some use this trade as a second job to earn extra money in order to send children to school, to purchase non-essential foods like milk, or to pay for medical bills (EC Prep Project, 2004). Collectors commonly use unsafe collecting practices that pose a risk to their health. Boats are generally poorly maintained and often break down. There is usually no safety equipment on board (MAMTI, 2006). Many collectors do not own typical snorkeling equipment, and some create their own fins out of pieces of plywood, plastic, or even palm leaves (MAMTI, 2006). "Hookah diving," a common practice in collecting ornamental fish, supplies air to divers using an unsafe, low throughput air compressor (MAMTI, 2006). This lack of proper diving and safety equipment greatly increases the risk of injury for collectors. For example, in the Banggai Archipelago, Indonesia, reports show that collectors suffer from skin diseases, ear damage, the bends, and decompression sickness; health care is inadequate and generally not available to the poor (EC Prep Project, 2004).

The aquarium trade's current supply chain structure perpetuates socioeconomic hardship for producers. Collectors do not receive steady wages and instead are paid per fish collected (MAMTI, 2006). Collectors barely earn enough income to meet the daily needs of their families. Furthermore, this payment method encourages collectors to catch as many fish as possible, which puts increased pressure on coral reef ecosystems. Middlemen are often in no better an economic position, as they receive low prices for fish from exporters, who will often withhold payment until their fish are sold to importing countries (Reksodihardjo-Lilley & Lilley, 2007). Under these circumstances, collectors and many middlemen are barely able to make a living. Collectors often fall into a pattern of perpetual debt to middlemen, so that they are never able to make a profit and increase their standard of living. In New Busuanga, the Philippines, middlemen allow collectors to use boats, food, fuel, and cyanide, and then require that the collectors make repayments for the costs of the services. If collectors do not have the money to repay them, the collectors will end up paying the middlemen with the very fish caught using the borrowed provisions (Shuman, Hodgson, & Ambrose, 2004). Collectors in the Philippines also sometimes borrow money from middlemen to support their families; the middlemen often hold them to these debts at extortion-like interest rates (Shuman, Hodgson, & Ambrose, 2004). Once the collectors start borrowing from middlemen, there is little chance that they will ever be able to repay their debt.

In both Indonesia and the Philippines, local reefs are degraded, forcing collectors to "rove" or travel beyond local reefs in hope of making more money. Roving takes days at a time and involves borrowing boats, food, and equipment from suppliers, which decreases profit that collectors would otherwise make from increased effort (MAMTI, 2006). Some middlemen do not accept fish from collectors unless the collectors buy cyanide from them; collectors depend on middlemen for their income and so have no choice but to use cyanide (Wood, 2001). This forced dependence not only affects the collectors but also further exacerbates the pressure put on coral reef ecosystems. As long as these collectors remain in poverty, they have no choice but to continue degrading the coral reefs.

Conservation of coral reefs and the wildlife they sustain is inextricably linked to and dependent on the socioeconomic situation of the people who manage them. Any management strategy that disregards the welfare and livelihoods of collectors will most likely fail. Therefore, any economic solution to improve the sustainability of the coral reef aquarium trade must also lift collectors above their current state of poverty.

Project Significance & Objectives

Sustainability and Our Vision for the Marine Ornamental Trade

In order to structure our research on how to move the marine ornamental trade towards sustainability, it is important to define the vision of the end goal of "sustainability".

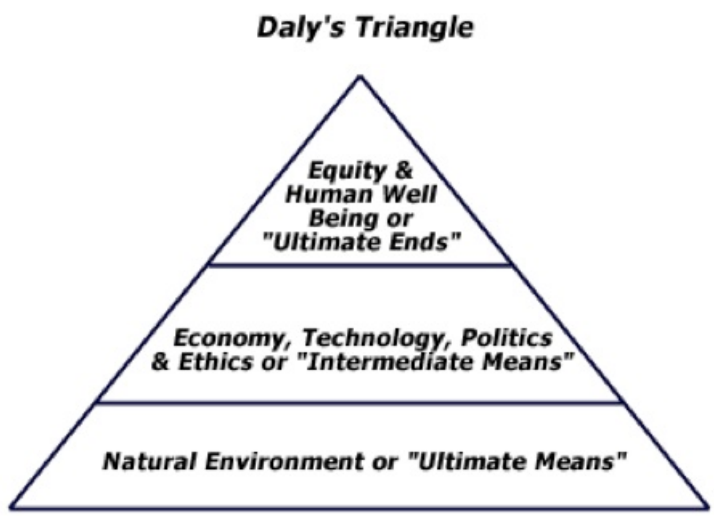


Figure 2: Herman Daly's Model of Sustainability

The Herman Daly Model (above) depicts sustainability in a pyramid with the natural environment as the foundation of the pyramid. In this model, the foundation of natural resources must be maintained and protected in order to have the "intermediate means" of economy, technology, politics, and ethics. It proceeds upward with equity and human well-being as "ultimate ends", and, thus yielding true sustainability.

Our project sought to build upon the strength and clarity of this model. The goal of our project and that of our client's organization (Olazul) was to improve the livelihoods of producer communities (in the Coral Triangle or in developing countries) while protecting coral reef resources and ecosystems, in essence achieving the "ultimate ends" of Daly's Triangle. To do so, our research and analysis sought to understand the state of the first and second tiers of the model, and, in this manner, understand the potential pathways for reform.

The natural environment component, and thus the effective resource base of the marine ornamental trade, was understood through a comprehensive literature review of research concerning the state of the marine ornamental fishery in the Coral Triangle. Our analysis, however, was focused on the "intermediate means", specifically the economic implications of reform, as well as the technological potential for reform. Additionally, our deliverables were created in order to provide information on the "intermediates means" in terms of options to achieve improvements in producer livelihoods.

Economic Analysis of the Marine Aquarium Trade

A significant part of our project included examining the current market for the marine ornamental trade and considering changes that could be made in order to promote sustainable practices, either at the producer level in developing countries or at the retail level in the U.S. At the retail level, consumers purchase fish that have been poisoned with cyanide and later die in the consumer's home; the consumer then usually purchases a new fish, which results in additional cost to the consumer and additional profit to the retailer. This situation only perpetuates the unsustainability of the trade, keeping demand for fish high and driving overfishing in producer countries. One solution that has not been previously proposed is legislation that would require stores to carry a warranty protecting consumers from purchasing inferior products. This approach could provide a simple, top-down solution by creating incentives for stores to drive reform in the supply chain through market driven initiatives.

Additionally, we proposed direct market contracts and increased price premiums for captive-raised fish. A direct market contract would ensure that a retailer (and thereby the consumer) deals only with sustainably produced fish, compared to the current market where it is impossible to determine how fish were initially obtained. In addition, a direct market contract would shorten the supply chain and increase the price at which producers can expect to sell fish and remain competitive under current market conditions. A price premium on captive-raised fish could also increase the price at which a mariculture business could competitively produce and sell its fish. If consumers are willing to pay more for captive-raised fish, a price premium on these fish could help to drive the market toward sustainability.

Consumer Survey

Survey design

We designed and distributed a survey to examine consumer preferences and their willingness to pay for marine ornamental fish in the U.S. We investigated preferences such as willingness to pay for a warranty and willingness to pay for captive-raised versus wild-caught fish. We also examined correlations between factors such as experience owning an aquarium, amount of money spent on aquarium fish, and characteristics customers prefer in their retailer or in a new fish.

Using a survey to elicit market characteristics is considered a "stated preference" approach. Unlike a "revealed preference" approach, which examines data based on choices people make in real life, the stated preference approach gathers information by asking people to state what they would do in a hypothetical situation. Both of these approaches have strengths and drawbacks. The stated preference approach is relatively straightforward, as information is obtained simply by asking questions. However, this method can have high uncertainty, as it reflects an isolated, hypothetical situation and may not represent the true choices that are made under the influence of complex, real-life factors. “Revealed preference” studies, on the other hand, take the choices that have been made in the real world and use those data to understand underlying patterns. Unfortunately, this approach can also be very difficult to pursue, because there are so many factors in the real world that have influenced the resulting data. All of this “noise” can distort the data, making it very difficult to analyze effectively.

We explored both stated preference and revealed preference for our investigations. In order to use a revealed preference approach to answer questions about warranties and preference for captive-raised versus wild-caught fish, we would have to use sales data for fish that distinguished whether they were raised in captivity, harvest from the wild, sold with warranties, or sold without warranties. Due to limited availability of such data and the time constraints of the study, we were not able to obtain adequate data necessary to pursue this option. In addition, we found that the available data were influenced by exogenous factors (such as changes in supply unrelated to demand) to the point that we would not be able to reliably determine whether a relationship existed between demand and warranties or between demand and fish origin. Furthermore, sales data alone would not allow us to examine relationships between demand and customer characteristics, such as experience with aquariums or average money spent on aquarium fish. Due to these limitations, we decided to use a stated preference approach for our analysis.

The stated preference method allowed us to collect information specific to our research questions and compare it to certain customer characteristics. In order to minimize the uncertainty and potential error associated with this approach, we followed survey design guidelines as defined by Kolstad (2011) to minimize this issue. A well-designed survey should be developed by the following method: (1) development of a rough draft, (2) review of the draft by an expert or experts, (3) revision of the draft, (4) testing of the second draft of the survey on a small group of people, and (5) revision of the second draft according to results and feedback from the test group. The final survey should then be administered to the participating sample and results are analyzed to understand underlying economic patterns (Kolstad, 2011).

One major consideration in our survey design was to define our sampling frame and target the survey to this audience as well as possible. We chose our sampling frame to be United States residents who purchase marine ornamental fish, since our study specifically focused on U.S. demand in the trade between the U.S. and the Coral Triangle. In order to attract a large enough sample size of this select group of people to take our survey, we created a prize incentive with a chance to win a gift card to an online marine aquarium retailer. We hoped that people who did not own marine aquariums would not be interested in the prize and therefore would decide not to take the survey. In addition to this incentive, we incorporated a few questions at the start of the survey that would exclude respondents who were not part of the sampling frame. Respondents were asked if they owned, or previously owned, a marine aquarium. If they had never owned a marine aquarium, they were disqualified from the survey. The survey was also set up with to use a "cookie" that would prevent a respondent's computer from accessing the survey more than once.

Methods for the consumer survey

We constructed a rough draft of the stated preference survey that looked at willingness to pay for aquarium fishes. This type of survey ought to include background information on the problem, a description of the "good" that the survey is analyzing, questions to measure willingness to pay, and demographic questions (Kolstad, 2011). Our survey followed this outline. The survey started with a description of the survey's purpose, which gave a general statement about the marine ornamental trade in the U.S. and informed the respondent that fish in the trade are either wild-caught or captive-raised, rare or common in the wild, and expensive or inexpensive. We then indicated that the survey's purpose was to analyze consumer preferences for marine ornamental fish.

The introduction gave a brief background of the subject of our study, the marine ornamental trade, as well as the specific good in question, marine ornamental fishes. After the introduction, the survey asked about certain demand drivers, such as what characteristics consumers look for in a fish or why they choose one retailer over another. The survey then asked several questions about willingness to pay for captive-raised versus wild-caught fish and fish with a warranty versus without a warranty. We asked demographic questions at the end of the survey.

We worded questions carefully to avoid bias within each question. Methods to minimize bias include avoiding issues such as ambiguous questions, multiple questions in one, leading questions, abbreviations, slang, jargon, and negatively phrased questions (Goodwin, 2008). In addition, questions should be balanced instead of favoring one side or another (Goodwin, 2008). We incorporated these guidelines into the design of our questions. Finally, to eliminate the potential bias associated with the order of multiple-choice options, we randomized answers for multiple choice questions and captive-raised versus wild-caught willingness to pay questions.

Surveys should also be designed in a way that attracts the respondents' interest and is respectful of their personal information. Goodwin (2008) suggested beginning the survey with interesting questions and putting demographic questions at the end of the survey since they are more sensitive. We followed this advice, placing demographic information questions on the final page of the survey and starting the survey with questions about consumer knowledge and preferences. We followed further suggestions to minimize respondent discomfort and encourage answers with non-sensitive queries such as asking for date of birth instead of age and putting income choices in ranges instead of asking respondents to reveal their specific income (Goodwin, 2008). These questions can be found in the copy of the survey provided in Appendix A. By implementing these measures we maximized the potential for respondents to commit to taking the entire survey.

Development of willingness to pay questions required deciding between several different query types such as contingent valuation, conjoint analysis, and choice approach. Contingent valuation would estimate the demand for a product at various prices. A contingent valuation question would ask survey respondents whether or not they would be willing to purchase a product at a given price. This method generally would be used for looking only at price and would not consider other factors that may influence demand, such as comparison with substitute products. Conjoint analysis, on the other hand, could take multiple factors into consideration to estimate how these factors affect demand. Conjoint analysis questions would give survey respondents a few different options, each with different attributes, and ask respondents to rank each option by how likely they would be to purchase it. Choice analysis is similar to conjoint analysis in that it would provide respondents with at least two options to choose from, and each choice has multiple attributes. However, in choice analysis, respondents would be asked to choose among the different options instead of ranking each one.

A similar, previous study that examined willingness to pay for tank-bred and Marine Aquarium Council (MAC) certified fish used the choice analysis approach (Alencastro, 2005). Another study comparing willingness to pay for farmed versus wild bear bile also utilized this approach (Dutton et al., 2011). Since our study was looking at similar demand factors, we chose to use the choice approach for the questions concerning willingness to pay for captive-raised versus wild-caught fish. These questions included two different attributes: fish origin (captive-raised or wild-caught) and price. Respondents were asked to pretend that they wanted to purchase a new fish, and they were given three options: a captive-raised fish, a wild-caught fish, or neither fish. The survey varied prices for each fish from person to person. A respondent was randomly assigned a wild-caught fish with one of four different prices, and then was assigned a captive-raised fish with a randomly chosen price between the wild-caught price and 150% of the wild-caught price. We also gave the respondent the option to not choose either fish in order to eliminate bias in the question that would force respondents to choose an answer they did not want.

For the questions about willingness to pay for a warranty, we decided to use the contingent valuation method. This method gave respondents the typical price of the fish species that they had chosen in from a menu of fishes, and then asked respondents whether they would be willing to purchase that fish with a warranty at a specified higher price. Each respondent was shown a specific warranty length and price combination. The price was chosen at random from between the typical price for the fish and 150% of the typical price. The warranty length was randomly given as either 7, 14, or 30 days. Because the respondent was only asked to give a "yes" or "no" answer to a single option, the contingent valuation approach was the most straightforward.

After completing the first draft of the survey, we had the survey reviewed by an expert economist, Dr. Chris Costello, for feedback. We then included suggested improvements such as decreasing the number of willingness to pay questions presented to respondents, since we would be able to reach the same conclusion with fewer questions. After revision, the survey presented just one question on captive-raised versus wild-caught fish and one question on warranties per respondent.

We then sent out the survey to a small group of graduate students and faculty members at the University of California, Santa Barbara's Donald Bren School of Environmental Science & Management for a test run. A total of 58 people completed the survey. We used this step to determine if we needed to make any changes to questions in order to improve the quality of data we would collect. We also provided a space for comments at the end of the survey to gather feedback and suggestions for improvement. Based on the test run results and respondents' feedback, we incorporated the following changes into the survey:

- We created a disqualification for people who currently do not own, and previously did not own, a saltwater aquarium.
- We changed the wording in the instructions after question 1 to "Answer the following questions based on your past experiences with owning an aquarium."
- We changed question 12 from "What percentage of fish purchases in the past year were to replace a fish that has died?" to "How many fish did you buy in the past year in order to replace a fish that had died?"
- We changed questions 16 through 20, which asked about survival rates, to ask about numbers of surviving fish instead of percentages.
- For question 25, where the respondent chooses among a selection of fishes, we added an option to not choose any of the fishes.

Finally, we submitted the survey for approval to the University of California, Santa Barbara's Human Subjects Committee. In order to meet approval for public distribution, the survey needed to consider the following requirements:

- The survey had to avoid coercion, meaning that it could not make anyone feel forced to take the survey.
- Minors could only take the survey with consent from both the minor and their legal guardian.

- The survey had to take measures to minimize potential distress to the respondent.
- The survey had to respect respondent privacy and confidentiality.
- The survey had to protect respondents' rights to autonomy, beneficence, and justice.

To satisfy Human Subjects protocols, we first included a short paragraph at the start of the survey explaining who we are, what research we are doing, and how to contact us. We also noted that respondents could stop taking the survey at any time if they felt uncomfortable. In addition, we were careful to ensure that we only received responses from adults 18 years or older. For question 28, which asked what year the respondent was born, we added the choice "1994 or later." This option would let us know if a respondent was under the age of 18, in which case we would discard the respondent's data. In order to maintain confidentiality, we did not collect any personal information in the survey. When collecting e-mail addresses for the gift card drawing, the respondent was electronically transferred to a different survey so that their email could not be matched with their survey responses.

Distributing the survey
There are a variety of methods that can be used to distribute a survey, none of which guarantees a perfect sample. Using in-person distribution, mail distribution, and telephone surveys are all methods that were decided against, due to financial, geographic and time limitations. For this research project, we decided to use an internet-based survey for various reasons:

An internet-based survey allowed us to reach a large geographic area with minimal time input and financial commitment. Using the Internet also has the added benefit of avoiding manual data entry.

To encourage participation in the survey, we offered participants the opportunity to enter a raffle for a $100 gift card to liveaquaria.com. Including an incentive may have introduced some bias into the survey, as non-aquarium owners may have taken the survey to enter into the raffle. We tried to mitigate this bias by making the gift card appealing only to aquarium owners.

Additionally, using the Internet as the method of distribution for the survey prevented fish owners without Internet access from participating. According to the American Pet Products of America (APPA) market survey, 76% of saltwater fish owners have Internet access (APPA, 2010). Therefore, we expect that our sample did not include 24% of saltwater fish owners.

The survey targeted only saltwater fish owners (or those who had previously owned a saltwater tank). According to the APPA survey, only 700,000 households in the U.S. owned saltwater tanks in 2010 (APPA, 2010). The U.S. population in 2010 was

308,745,538 according to the U.S. Census, so the survey had to target a very specific 0.23% of the U.S. population, which again may have introduced bias into our sample (U.S. Census Bureau, 2010). In order to gather a large enough sample from such a specific subset of the population, we decided to intentionally target aquarium owners rather than distribute a survey to the general population.

In order to reach a broad enough audience, we paid for an advertisement on Facebook (www.facebook.com), which allows advertisers to target their audiences based on interests listed on user profiles. We made six similar advertisements and distributed them to both a general and a targeted audience. For the general audience, the ads targeted adults who live in the U.S. For the more targeted audience, the ads targeted Facebook users who have referenced one of the following topics in their profiles: Environment, Home & Garden, Outdoor Fitness Activities, Pets (All), Science/Technology or Traveling, My Aquarium, Tropical fish, Tropical Fish Hobbyist, Live tropical fish, Pet fish, Saltwater aquariums, Saltwater fish tanks, Aquarium, Aquarium Fish International, Fish, Seahorse, Fish tanks, Coral, and Coral reef. Overall, the ad was viewed by 298,338 Facebook users, and clicked on by 294 Facebook users. The advertisements can be viewed in Appendix B.

We also decided to post the survey on online forums for aquarium hobbyists. Our survey was posted on three forums: MASNA (Marine Aquarium Society of North America), Reefcentral.com and Fishtankforums.com. It should be noted that the survey was on the reefcentral.com forum for 10 hours before it was removed by the administration, the MASNA posting got 80 views total, and the survey at fishtankforums.com only received one view, so the forums had a much smaller impact than the Facebook advertisement. Additionally, the survey was posted briefly on Craigslist (www.craigslist.org), but only received 7 views through Craigslist. The survey was administered between November 23, 2011 and January 11, 2012.

Determining an appropriate sample size for the survey

Using the sample of 97 survey responses we had collected by November 29, 2011, we calculated the sample standard deviation ($\hat{\sigma}$). To ensure our sample information encompassed the whole population, we used the question that had the largest standard deviation. This question was: "How much did you spend in the past year to purchase fish for your saltwater aquarium? (just on fish, not on equipment, food, etc.)." By choosing the question with the largest standard deviation, we ensured we were considering the question with the greatest variability among respondents so that we could scale our sample population to generate answers with a reasonable level of precision.

The sample standard deviation for this question was: $\hat{\sigma} = 764.27$. The mean ($\bar{x}$) = $407.52.We used a 95% confidence interval, which (assuming a normal distribution) meant our range of values could be 1.96 standard deviations from the mean. We set the margin of error at $100. This meant that when we had reached our appropriate sample size, we would be 95% confident that our estimate of the amount of money that the total population of fish owners spent last year on fish was accurate within ± $100.

$$n = \left(\frac{1.96 \times \hat{\sigma}}{Margin\ of\ error}\right)^2$$

$$n = \left(\frac{1.96 \times 724.27}{100}\right)^2 = 224.39$$

We continued collecting data until we gathered at least 225 survey responses. Our final number of survey responses was 232. The survey can be found in Appendix C.

Results for consumer survey

Our consumer survey analyzed U.S. consumer preferences and willingness to pay for captive-raised or wild-caught marine ornamental fish. We used the results from our survey to explore the potential for a mandatory warranty, which would be a novel economic strategy that might reform the supply chain.

Warranty analysis

Cyanide fishing has been widely documented as a common fishing practice in the Coral Triangle, and it has been estimated that at least 70% of fishes sold for marine aquariums were caught using cyanide (Mak et al 2005). Fish exposed to cyanide suffered from chronic toxicity due to exposure (Mak et al 2005). Many of the effects of cyanide were irreversible, so even if a fish was given the best possible care after it was caught, cyanide-induced mortality might be unavoidable (Mak et al 2005). Additionally, fish faced other stressors from the supply chain that increased mortality, including variable temperatures, salinity, oxygen, and pH levels, being jostled during transport, and being shipped in overcrowded packing materials.

Based on the information gathered from our survey, approximately 80% of mortality that occurred after fish had been purchased could be attributed to problems in the supply chain. Reducing these sources of mortality could reduce the number of fish needed to meet consumer demand, therefore reducing the number of fish harvested from the reef. Additionally, according to our survey, 28% of all fish sold were replacements for fish that had died within a year. In the marine aquarium trade, a significant amount of sales have been made because customers were unknowingly buying a damaged product.

As the market currently stands, stores (and suppliers) have no incentive to change their practices, because each level of the supply chain is profiting from customers buying fish to replace a significant number of fish that die in home aquaria. Stores suffer fish losses before the fish are sold, but the profits made from customers buying replacement fish are high enough that stores do not have incentive to purchase healthy fish to avoid fishes dying in stores. One option for a simple, top down legislative solution to reform the marine aquarium trade would be to implement a mandatory warranty for all vendors in the United States.

A warranty would address two problems:

1. A warranty would provide consumer protection against buying (and then paying again to replace) an inferior product.
2. A warranty would provide a simple, top down solution to motivate stores to only purchase from suppliers that do not use harmful collection or handling practices throughout the supply chain.

A warranty would only be an effective tool if stores lost money with a warranty in place. When facing an expected loss in profits, stores would have an incentive to look for alternative ways to make money. Stores could regain some of their losses if they reduced the number of fish dying in customers' homes by purchasing sustainably sourced fish. If a mandatory warranty provided a financial incentive for stores to reform their supply chain, a warranty could be a simple, effective tool to promote change.

Methods for warranty analysis

To run a warranty analysis, we first had to consider the current state of the market and how the revenue and costs would change if a mandatory warranty were implemented. For this analysis, we only included costs and revenues directly related to fish sales. We did not include fixed costs of maintaining and running a store, which we assumed were constant and not directly related to fish sales. After analyzing how a store's costs and revenues would change with the implementation of a mandatory warranty under current practices, the final step was to calculate how the costs and revenues would change under a mandatory warranty if all fish supplied to stores were sustainably sourced.

In order to run this analysis, we used the following equation to represent the revenues and costs of fish-related sales for U.S. stores:

Total Profits Related to Fish Sales =
Customer purchase price – Store's initial investment in fish +
Expected future replacement sales – Costs of in-store mortality

With a warranty, we could use the same equation except stores could charge a price premium for a warranty, and stores would have to pay the costs of replacing fish under a warranty. The equation of total fish-related profits under a warranty would be:

Total Profits Related to Fish Sales =
Customer purchase price – Store's initial investment in fish + Expected future replacement sales – Costs of in-store mortality + Warranty premium – Costs of replacing fish covered under warranty.

To organize this analysis, we inputted our calculations into the following table that compared profits related to fish sales under our three different market scenarios: the current market, the current market under a warranty, and a reformed supply chain under a warranty (Tbl. 1). Our end goal was to compare the relative changes in profits under each market scenario. If a warranty could be an effective tool, we should see profits decrease under a mandatory warranty with current practices, and then stores should be able to recoup some of their losses under a mandatory warranty when the supply chain is reformed.

Table 1. Process for comparing the profits related to fish sales in different market scenarios: the current market, in the current market with a warranty, and with a reformed supply chain and a mandatory warranty. All prices are in USD.

	Current Market	Current Market with Warranty	Reformed Supply Chain with Warranty
Customer purchase price			
Store's investment in fish			
Expected future replacement sales			
Costs of in-store fish mortality			
Warranty premium price			
Costs of replacing fish covered under warranty			
Total profits related to fish sales			
Relative change in profits from current market			

Under a warranty, we would expect the customer purchase price and the store's initial investment in fish to stay the same as in the current market. We expected a decrease in future replacement sales, because then some of those fish that customers were paying to replace would be covered under a warranty. We expected the costs of in-store mortality to remain the same. We expected customers to be willing to pay a price premium for a warranty, and we expect the store to face costs to replace fish that are covered under a warranty. Overall, we needed to know how the store's fish-sales related profits will change if a mandatory warranty were implemented.

Our third scenario looked at a warranty when the supply chain has been reformed. We needed to know how the store's fish-sales related profits will change if a mandatory warranty were implemented and the store reformed the supply chain and eliminated all mortality due to problems in the supply chain. Under a warranty with a reformed supply chain, we expected the customer purchase price and the store's initial investment in fish to stay the same. We expected a decrease in future replacement sales, because then some of those fish that customers were paying to replace would be covered under a warranty and overall mortality would have decreased. We expected all costs of in-store fish mortality to be removed when the supply chain was reformed. We expected customers to be willing to pay a price premium for a warranty. We expected the store to face lower costs to replace fish that are covered under a warranty because now fewer fish are dying overall. Finally, we investigated whether stores could recoup some of their losses under a warranty by reforming the supply chain.

Current market breakdown

Total Profits Related to Fish Sales =
Customer purchase price – Store's initial investment in fish +
Expected future replacement sales – Costs of in-store mortality

For ease in this analysis, we set the customer purchase price at $1.00. Therefore, all numbers discussed in this analysis are calculated relative to a baseline number of ***$1.00***.

Our supply chain analysis (discussed later in this paper) showed stores include a markup of 265% on average. Therefore, for every dollar of fish sold, the store paid an average of $0.3774 for that fish. Therefore, the store's initial investment in fish is ***$0.3774***.

To calculate the expected future replacement sales, we used information from our survey. Our survey showed that 28.19% of all fish purchased each year were to replace fish that had died. This means that for each $1.00 of fish purchased today, stores expect to make roughly $0.2819 in additional sales. In fact, in the long run stores can expect to replace 28.19% of those additional sales as well, and then 28.19% of those sales, and so on. Considering the amount that the stores initially paid for the additional sales ($0.3774 for every dollar of fish sold), stores expect to make a profit of $0.6226 for every additional sale. Therefore, the future profit stream from replacement sales is as follows:

$$\$0.6226 \times (0.2819 + 0.2819^2 + \ldots + 0.2819^n) = \textit{\$0.2444}$$

Finally, we had to determine costs of in-store mortality. Stores, like customers, can have fish die because of poor practices in collection and in the supply chain. However, stores face varying amounts of mortality resulting from supply chain practices because some fish are sold sooner than others. Fish that are sold more quickly are less likely to die in the store, and therefore are less likely to be a loss to the store. The amount of money that stores could expect to lose due to in-store mortality from supply chain mortality varies depending on how quickly stores sell their fish (and therefore, how quickly stores transferred the risk of a fish dying onto their customers). For this analysis, we assume that a reasonable estimate for stores is an average turnover rate of two weeks for each fish.

In order to determine the losses that stores face due to problems in the supply chain, we first considered that there are two different sources of fish mortality. Customer error mortality occurs when customers make an error when caring for their fishes, which results in fish death. Customer error can be expected to decrease for each individual over time as hobbyists learn to better care for their fishes.

The second source of mortality is due to problems in the supply chain, including fishing with cyanide and improper handling and care during transport. Mortality due to problems in the supply chain should be constant across all customers, regardless of experience.

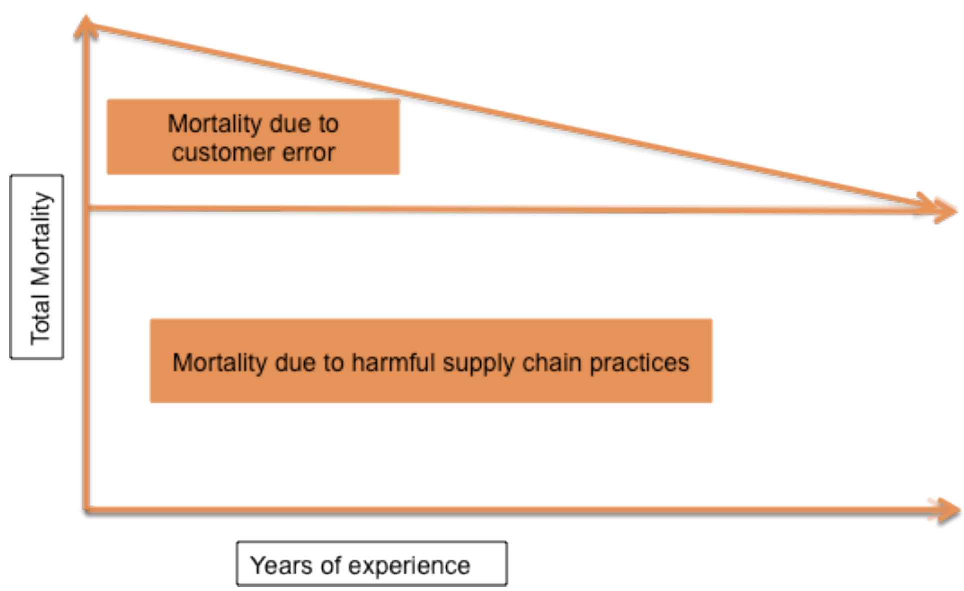


Figure 3. Factors affecting fish mortality in aquarists' homes based upon the aquarists' years of experience owning an aquarium.

There is the possibility that people with more experience are more likely to purchase captive-raised fish over wild-caught fish, which would lower the probability of death for experts due to supply chain error. To ensure that supply chain error truly was constant across all experience levels, we asked consumers:

- Where do your saltwater fish come from?
- How sure are you of your answer to the previous question?"

We then compared the mean years of experience for people who answered that they were "Completely sure" or "Very sure" that their fish are "Wild-caught, not sure of method" with the mean years of experience for people who answered that they were "Completely sure" or "Very sure" that their fish are "Bred in captivity."

Our hypothesis was that there was a difference between the mean years of experience and the sources of fish chosen (in other words, people with more experience and knowledge were more likely to purchase captive-raised fish than inexperienced people who may not know as much about the marine aquarium trade). After performing a t-test, we found that people who bought tank bred versus wild-caught fish did not differ significantly in their years of experience ($P = 0.105$ – see Appendix E for the full statistical table). Therefore, to the best of our knowledge, death due to problems in the supply chain can be treated as constant across all experience levels.

We are interested in determining the in-store losses due to supply chain mortality only. Therefore, using the information we gathered from our survey, we must isolate supply chain mortality in order to determine store losses.

Distinguishing customer error from supply chain error
To determine total mortality over time, we included the following questions in the survey:

- How many years have you had your saltwater aquarium?
- How many fish did you buy in the past year for your saltwater aquarium?
- Of all the fish that you purchased in the past year, how many survived at least 3 days in your care?
- Of all the fish that you purchased in the past year, how many survived at least 7 days in your care?
- Of all the fish that you purchased in the past year, how many survived at least 14 days in your care?
- Of all the fish that you purchased in the past year, how many survived at least 30 days in your care?
- Of all the fish that you purchased in the past year, how many survived at least 6 months in your care?

In order to distinguish fish mortality due to customer error from mortality due to problems in the supply chain, we compared mortality rates with years of experience. To estimate the proportion of mortality that can be attributed to customer error, we separated years of experience into three categories or "bins": 0-1 years of experience = novice, 2-5 years of experience = beginner, 5 or more years of experience = expert. Based on our survey, we were able to get information on mortality levels at six months of ownership for each respondent. To estimate the six-month mortality for each bin, we subtracted the fraction of fish that survived [i.e. number of fish that survived at least six months (S_6) divided by the number of fish each person bought last year (B)] from 1. We averaged these mortality estimates across all individuals (n) within each experience class.

$$\textbf{Average six month mortality} = M_6 = \sum(1 - (B/S_6))/n$$

Based on our analysis above, we decided that the amount of mortality due to supply chain error (which is constant across all experience levels) is best represented by the amount of mortality experienced by experts. It should be noted that these numbers represented our best estimates. We realized that there would still be some customer error even at the expert level, but the point of this analysis was to determine the ratio of supply chain error to customer error.

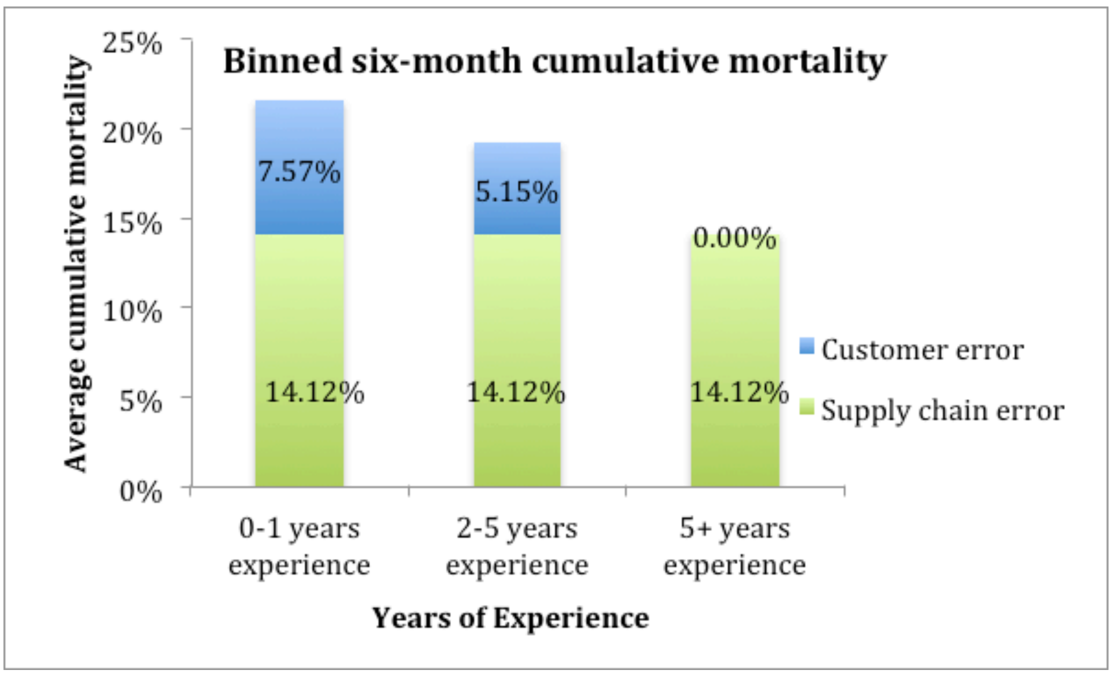


Figure 4. Average cumulative six-month mortality for "Novice," "Beginner," and "Expert" aquarium owners. Customers were separated into three categories or "bins": 0-1 years of experience = Novice, 2-5 years of experience = Beginner, 5 or more years of experience = Expert. The relative mortalities were compared with years of experience and separated by customer error mortality and supply chain error mortality.

We were interested in determining how many fish are expected to die after two weeks (the amount of time we assumed fish stay in stores before they are sold) from problems in the supply chain. In order to determine the mortality due to supply chain error, we ran an analysis using only responses from "experts," (survey respondents with five or more years of experience) to find the cumulative mortality over time due to problems in the supply chain. To find the mortality rates per day, we used the following equation for each separate time interval (0-3 days, 4-7 days, 8-14 days, 15-30 days, 31-180 days):

$$\boldsymbol{D_t = 1 - \sqrt[t]{1 - M_t}}$$

$\mathbf{M_t}$ = mortality rate at day t
$\mathbf{D_t}$ = mortality rate per day at day t

We then used the per-day mortality rates to find the cumulative mortality through 14 days using the following equation:

$$\boldsymbol{\sum_{t=1,14}^{n} D_t * (1 - D_{t-1})}$$

We found that 11.3% of fish are expected to die within 14 days due to problems in the supply chain. Stores make an initial investment of \$0.3774 for each dollar's worth of expected fish sales, so the overall losses to stores are 11.3% × \$0.3774 = ***\$0.0427***. We realize that in-store mortality may vary greatly from store to store, and for this analysis we chose to assume that fish remain in stores for two weeks on average before they are sold. See Appendix F for a chart of possible losses to stores under varying turnover rate scenarios, including a range from a 1-day turnover to a 2-month turnover. We now had a complete picture of all revenues and costs related to profits from fish sales under the current market.

Table 2. Scenarios comparing the fish sales related profits in the current market, in the current market with a warranty, and with a reformed supply chain and a mandatory warranty.

	Current Market	Current Market with Warranty	Reformed Supply Chain with Warranty
Customer purchase price	$1.00		
Store's investment in fish	-$0.3774		
Expected future replacement sales	$0.2444		
Costs of in-store fish mortality	-$.0427		
Warranty premium price	N/A		
Costs of replacing fish covered under warranty	N/A		
Total profits related to fish sales	$0.8256		
Relative change in profits from current market	N/A		

Next, we need to see how profits related to fish sales would change with the implementation of a mandatory warranty.

Scenario: Current market with mandatory warranty

Under this scenario, we expect to see a variety of changes in comparison with the current market. We expect to see an increase in revenue, as stores can now charge a price premium for a warranty, but we also expect to see an increase in costs, as stores pay to replace fish under warranty. We also expect stores to lose revenue as the warranty covers fish that customers would have paid to replace without a warranty.

Current market under mandatory warranty

With the implementation of a mandatory warranty, we used the same equation as when determining the current state of the market, but we included a price premium for the warranty and the costs of covering mortality under the warranty.

Total Profits Related to Fish Sales =
Customer purchase price – Store's initial investment in fish + Expected future replacement sales – Costs of in-store mortality + Warranty premium – Costs of replacing fish covered under warranty

For this scenario, the customer purchase price is again ***$1.00*** and the initial investment by stores is ***$0.3774***. The costs of in-store mortality also should not change, and is ***$.0427***.

Determining warranty length and price premium
In order to conduct this analysis, we first had to discover the willingness to pay for a price premium for a warranty for 7, 14 or 30 days of coverage. We ran this analysis with the warranty premium that would bring the highest increase in revenue to stores. In order to determine the warranty premium that brings the highest increase in revenue, we asked customers whether they would be willing to pay a specific price premium for a warranty of either 7, 14 or 30 days.

We assumed that if a person indicated that they were willing to pay a higher price premium for a warranty, they would also be willing to pay a lower price premium for a warranty. For example, if a consumer indicated that they would pay a 15% price premium, we also assumed they would be willing to pay a 10% price premium. Likewise, we assumed that if a person indicated they were not willing to pay a lower price premium for a warranty, they would not be willing to pay a higher price premium either. For example, if a consumer indicated they would not pay a 30% price premium, we assumed they would also not be willing to pay a 35% price premium. Using this logic, we were able to calculate cumulative positive and negative responses for each price premium. To determine the probability that a consumer will buy a warranty at price increase of n%, we used the following equation:

$$\mathbf{P_n = (Cumulative\ Y_n)/(Cumulative\ Y_n + Cumulative\ N_n)}$$

$\mathbf{P_n}$= probability that a consumer will buy a warranty at price increase n%
$\mathbf{Y_n}$= positive response: a consumer would buy a warranty under price increase of n%
$\mathbf{N_n}$= negative response: a consumer would not buy a warranty under price increase n%

In order to make a recommendation, we needed to know how the price of a warranty would influence a store's net revenue. Each negative answer to the survey ultimately represented a fish that would not be sold. Therefore, a vendor could lose significant revenue if a large enough number of consumers were not willing to pay the price premium. For each increment, we calculated the total expected increase in revenue by using the following equation:

$$\mathbf{X = P_n \times (1 + n)}$$

X = total change in overall revenue
$\mathbf{P_n}$ = probability that a consumer will choose fish at price increase n
n = percent price increase

Our analysis showed people were willing to pay the most for the 30-day warranty relative to a 7 or 14-day warranty. The maximum total change in revenue for a 7-day warranty was a 4.85% increase, and the maximum total change in revenue for a 14-day warranty was a 7.58% increase (Tbl. 3). The maximum total change in revenue for a 30-day warranty was a 25% increase, with a price premium of ***$0.25***. The probability tables for 7- and 14-day warranties can be found in Appendix D.

Table 3. Willingness to pay a price premium for a 30-day warranty. The percentage of customers who would be willing to pay a price premium for a 30-day warranty and the maximum total percent increase in revenue that can be expected at each price premium.

30-day Warranty Willingness to Pay											
n= Price premium for tank bred fish	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
Y=Positive responses	3	7	5	6	7	3	3	3	7	1	1
N=Negative responses	0	0	0	0	0	3	1	2	2	2	1
Cumulative positive responses	46	43	36	31	25	18	15	12	9	2	1
Cumulative negative responses	0	0	0	0	0	3	4	6	8	10	11
P=Percentage of customers who would buy warranty	100.0%	100.0%	100.0%	100.0%	100.0%	85.7%	78.9%	66.7%	52.9%	16.7%	8.3%
X=Total change in revenue	105.0%	110.0%	115.0%	120.0%	125.0%	111.4%	106.6%	93.3%	76.8%	25.0%	12.9%

The price premium that brings the greatest change in revenue is ***$0.25***.

Next, we need to determine the amount of mortality that is covered under a 30-day warranty. To do this, we used the same analysis as above, but we looked at mortality after 30 days (not 14), and we included all customer experience levels in this analysis. To find the mortality rates per day, we used the following equation for each separate time interval (0-3 days, 4-7 days, 8-14 days, 15-30 days, 31-180 days):

$$\boldsymbol{D_t = 1 - \sqrt[t]{1 - M_t}}$$

$\mathbf{D_t}$ = mortality rate per day at day t
$\mathbf{M_t}$ = mortality rate at day t

We then used the per-day mortality rates to find the cumulative mortality through 30 days using the following equation:

$$\boldsymbol{\sum_{t=1,30}^{n} D_t \times (1 - D_{t-1})}$$

After running the analysis, we determined the expected mortality rate after 30 days was 17.39%. Here again, we can assume that 17.39% of the replacements will be replaced again under warranty, and so on for 12 months. Therefore, the total expected future costs of a warranty are:

$$\mathbf{\$0.1739 + 0.1739^2 + \ldots + 0.1739^{12} = \$0.2105}$$

Therefore, for every dollar of fish bought today, there is a 21.05% chance that it will be replaced under warranty in the future. This translates to an expected future cost of a warranty equal to ***$0.2105***.

The warranty covers mortality within 30 days of the purchase, but some fish will die outside of warranty and will be paid for when replaced by consumers. This value is our expected future sales. To find expected future sales, we needed to find the cumulative mortality at 1 year and then subtract the mortality covered by warranty. Based on current practices, we assume customers will pay for the fish that die outside of warranty.

In order to determine the number of fish that die outside of warranty (expected future sales), we found cumulative mortality rates through 180 days (which is the maximum length of time reported by our survey) for all experience levels by using the following equations for each separate time interval (0-3 days, 4-7 days, 8-14 days, 15-30 days, 31-180 days):

$$\boldsymbol{D_t = 1 - \sqrt[t]{1 - M_t}}$$

$\mathbf{D_t}$ = mortality rate per day at day t
$\mathbf{M_t}$ = mortality rate at day t

We then used the per-day mortality rates to find the cumulative mortality through 180 days using the following equation:

$$\boldsymbol{\sum_{t=1,180}^{n} D_t \times (1 - D_{t-1})}$$

In order to run a full analysis of how a warranty would affect the market each year, we extrapolated from our cumulative mortality rates what the cumulative mortality would be on day 365. We used a logarithmic regression to fit a line to our cumulative mortality at each day. This line was used to estimate future mortality rates. The regression had an R^2 value of 0.9705, so the projected regression was a good fit for our data.

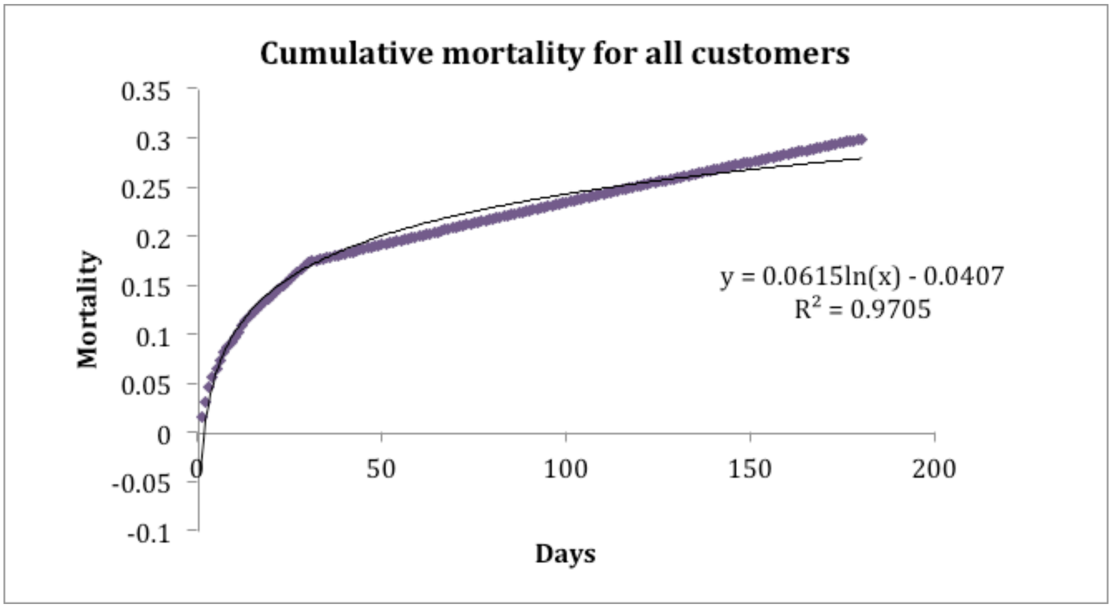


Figure 5. Projected cumulative fish mortality per day for all customers. Cumulative mortality was plotted against days in the home. The data points were then fit with a logarithmic line.

To find the projected mortality rate at day 365, we substituted x = 365 into the logarithmic equation.

$$\mathbf{y = 0.0615 \ln (365) - 0.0407 = 0.3221}$$

Therefore, we estimated that the average cumulative mortality for all customers after one year is 32.21%.

We know that consumers originally had a demand for 100% of the fish they bought, and were willing to pay 128.19% of their original investment per year to fill the demand for 100% of their fish. Therefore, we can expect that customers would be willing to pay to replace the number of fish that have died (x) (32.21%) minus the number of fish that would be covered under warranty (w) (17.39%), buying at most 28.19% (the number of fish that customers are currently paying to replace) of the original quantity of fish purchased.

$$\mathbf{x - w = r} \text{ (subject to } r \leq 28.19\%)$$

x = % fish that have died within one year
w = % fish that would be covered under warranty
r = % fish purchased to replace those that died outside of warranty

$$\mathbf{32.21\% - 17.39\% = 14.82\%}$$

For the percent of replacement fish bought under warranty, we determined the future profits from replacement fish. To do this, we used the following equation, assuming that of the 14.82% of fish that were purchased to replace those that died outside of warranty, 14.82% of those fish would also be purchased as replacements outside of warranty, and so on:

$$\$0.6226\ (0.1482 + 0.1482^2 + \ldots + 0.1482^n) = \$0.1084$$

Finally, we are able to see how a warranty would change profits related to fish sales if stores use current sourcing practices (Tbl. 4). Based on this analysis, a mandatory warranty would cause stores to lose 11.7% of their profits if the stores continued with current practices.

Table 4. Profits related to fish sales in different market scenarios: Scenarios comparing the fish sales related profits in the current market, in the current market with a warranty, and with a reformed supply chain and a mandatory warranty.

	Current Market	Current Market with Warranty	Reformed Supply Chain with Warranty
Customer purchase price	$1.00	$1.00	
Store's investment in fish	-$0.3774	-$0.3774	
Expected future replacement sales	$0.2444	$0.1084	
Costs of in-store fish mortality	-$.0427	-$.0427	
Warranty premium price	N/A	$0.25	
Costs of replacing fish covered under warranty	N/A	-$0.2105	
Total profits related to fish sales	$0.8256	$0.7290	
Relative change in profits from current market	N/A	-11.7%	

Market with mandatory warranty and reformed supply chain

For a warranty to be an effective tool to motivate reform, stores must be able to recoup some of the losses that they face with the implementation of a mandatory warranty if they purchase sustainably sourced fish.

In order to determine how the market would change if the supply chain were reformed to eliminate supply chain mortality, we repeated the above analysis of the current market under a mandatory warranty. This time, we assumed that mortality rates due to supply chain error are now nonexistent, and the only sources of fish death are due to customer error. We use the same equation as before:

Total Profits Related to Fish Sales =
Customer purchase price – Store's initial investment in fish + Expected future replacement sales – Costs of in-store mortality + Warranty premium – Costs of replacing fish covered under warranty

For this scenario, the customer purchase price is again ***$1.00*** and the initial investment by stores is ***$0.3774***. The warranty premium that brings the greatest change in revenue is ***$0.25***. Because we expect to have eliminated all in-store mortality when we eliminate mortality due to supply chain error, the costs of in-store fish mortality is now ***$0.00***.

To find the new costs of replacing fish covered under warranty, we must determine the number of fish that are expected to die from customer error within 30 days. To determine the expected mortality due to customer error, we subtracted the "expert" mortality (aka, the supply chain mortality, from the weighted cumulative mortality from each separate bin), using the following equation:

Cumulative 30-day mortality attributed to customer error =
(Weighted 30-day cumulative mortality for novices + weighted 30-day cumulative mortality for beginners + weighted 30-day cumulative mortality for experts) – (30-day cumulative mortality for experts)

To find the cumulative mortality for each bin after 30 days, we used the following equations for each separate time interval (0-3 days, 4-7 days, 8-14 days, 15-30 days, 31-180 days) for each bin of consumers:

$$\boldsymbol{D_t = 1 - \sqrt[t]{1 - M_t}}$$

$\mathbf{M_t}$ = mortality rate at day t
$\mathbf{D_t}$ = mortality rate per day at day t

We then used the per-day mortality rates to find the cumulative mortality through 30 days for each bin of consumers using the following equation:

$$\boldsymbol{\sum_{t=1,30}^{n} D_t \times (1 - D_{t-1})}$$

We found the weighted cumulative 30-day fish mortality for each bin of consumers' experience level (Tbl. 5).

Table 5. Cumulative fish mortality per category of experience for respondents for 30 days.

Weighted Averages- 30 days	Cumulative mortality, day 30	% population with experience level	Weighted mortality
Novice	0.1852	24.19%	0.0448
Beginner	0.1811	31.18%	0.0565
Expert	0.1532	44.62%	0.0683

We then substituted these values into our equation to determine the amount of fish mortality after 30 days that can be attributed to customer error.

Cumulative 30-day mortality attributed to customer error = (Weighted 30-day cumulative mortality for novices + weighted 30-day cumulative mortality for beginners + weighted 30-day cumulative mortality for experts) − 30-day cumulative mortality for experts

We discovered that 1.64% of fish are expected to die from customer error within the first 30 days. Here again, we assumed 1.64% of the replacements would be replaced again under warranty, and so on for 12 months. We calculated the total expected future costs of a warranty to be:

$$\mathbf{0.0164 + 0.0164^{2} + \ldots + 0.0164^{12} = 0.0167}$$

Therefore, the expected cost of replacing fish under warranty when the supply chain has been reformed would be ***$0.0167***.

Finally, we need to calculate the expected future replacement sales when all mortality due to problems in the supply chain has been removed. To do this, we need to determine the total expected mortality after one year due to customer error, and we need to subtract the number of fish that die and are covered under warranty. In order to determine the number of fish that die outside of warranty, we found cumulative mortality rates through 180 days for each experience level by using the following equations for each time interval (0-3 days, 4-7 days, 8-14 days, 15-30 days, 31-180 days) for each separate bin:

$$\boldsymbol{D_t = 1 - \sqrt[t]{1 - M_t}}$$

$\mathbf{M_t}$ = mortality rate at day t
$\mathbf{D_t}$ = mortality rate per day at day t

We then used the per-day mortality rates to find the cumulative mortality through 180 days using the following equation:

$$\boldsymbol{\sum_{t=1,180}^{n} D_t \times (1 - D_{t-1})}$$

We repeated this equation for each category of expertise: novices, beginners and experts. To predict the mortality rate for each bin on day 365, we again used a logarithmic regression to fit our data points (Fig. 6).

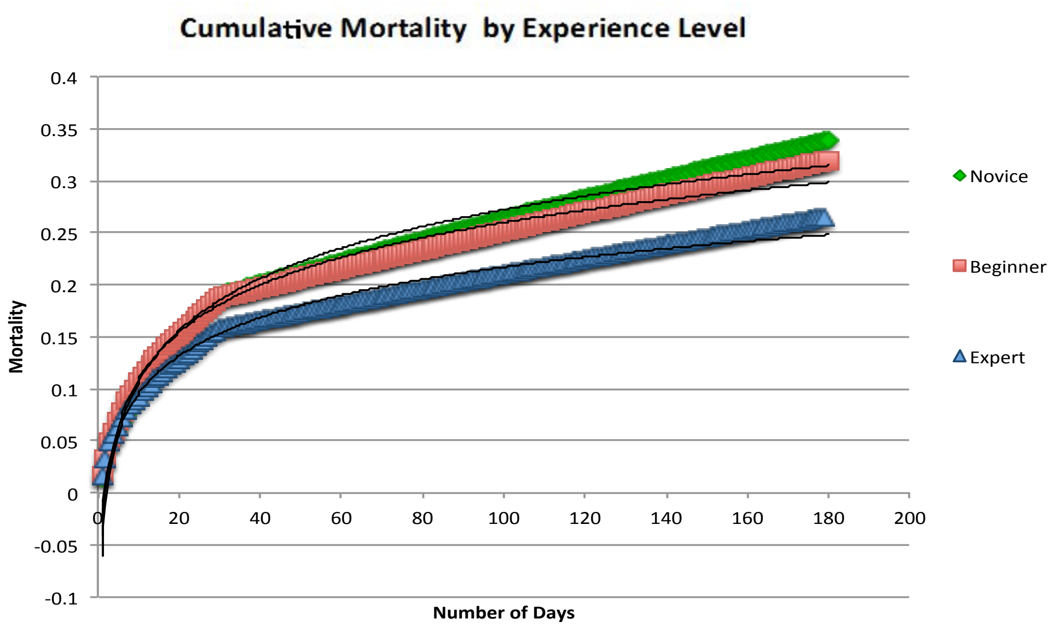


Figure 6. Fish mortality over time for each level of experience. The mortality for each category of experience level for respondents was plotted against days in the home. The data points were then fit with a logarithmic line.

Novice:	**$y = 0.0722 \ln(x) - 0.0604$**	**$R^2 = 0.968$**
Beginner:	**$y = 0.0655 \ln(x) - 0.0417$**	**$R^2 = 0.973$**
Expert:	**$y = 0.053 \ln(x) - 0.0271$**	**$R^2 = 0.973$**

Our regressions had high R^2 values, and can be considered a good fit for our data. We calculated the expected cumulative mortality at 365 days for each bin based on the equations for the fitted lines.

To determine the mortality rates that could be attributed to customer error at 365 days, we took a weighted average of the expected cumulative mortality rates for novices, beginners, and experts, and then subtracted the expert mortality rate (which represented the amount of mortality attributed to supply chain error) from the weighted average. To do this, we used the same equation as before, but we used the mortality after 365 days.

Cumulative 365-day mortality attributed to customer error = (Weighted 365-day cumulative mortality for novices + weighted 365-day cumulative mortality for beginners + weighted 365-day cumulative mortality for experts) – (365-day cumulative mortality for experts)

Based on this analysis, we determined that 3.78% of fish are expected to die after 365 days due to customer error (Tbl. 6).

Table 6. Cumulative fish mortality for each category of experience for respondents for 365 days.

Weighted Averages-365 days	Cumulative mortality, day 365	% population with experience level	Weighted mortality
Novice	0.3656	24.19%	0.0884
Beginner	0.3447	31.18%	0.1075
Expert	0.2856	44.62%	0.1274

To determine the number of replacement sales, we found the amount of annual mortality due to customer error that would not be covered by warranty. This was the number of fish that have died in a year due to customer error (x) minus the number of fish covered by warranty (w).

$$\mathbf{x - w = r}, \text{ (subject to } r \leq 28.19\%)$$

$$\mathbf{3.78\% - 1.64\% = 2.14\%}$$

To determine the expected profits of future replacement sales, we calculated the following, assuming that 2.14% of future replacement sales will also be replaced into the future:

$$\mathbf{\$0.6226 \times (0.0214 + 0.0214^2 + \ldots + 0.0214^n) = \textit{\$0.0136}}$$

Finally, we inputted all of our revenue and cost values from the scenario with a mandatory warranty and supply chain reform into our table.

Table 7. Scenarios comparing the fish sales related profits in the current market, in the current market with a warranty, and with a reformed supply chain and a mandatory warranty.

	Current Market	Current Market with Warranty	Reformed Supply Chain with Warranty
Customer purchase price	$1.00	$1.00	$1.00
Store's investment in fish	-$0.3774	-$0.3774	-$0.3774
Expected future replacement sales	$0.2444	$0.1084	$0.0136
Costs of in-store mortality	-$0.0427	-$0.0427	$0.00
Warranty premium price	N/A	$0.25	$0.25
Costs of replacing fish covered under warranty	N/A	-$0.2105	-$0.0167
Total profits related to fish sales	$0.8256	$0.7290	$0.8695
Relative change in profits from current market	N/A	-11.7%	5.33%

Warranty analysis results

Our analysis showed that under the current supply chain conditions, a warranty implemented today would cause retailers to lose 11.7% of their current profits (Tbl. 4). However, if the supply chain were reformed to eliminate mortality attributed to harmful practices, stores could earn up to 5.33% more than what they are earning today (Tbl. 7). The goal of our warranty analysis was to analyze if a mandatory warranty would provide the impetus for stores to improve collection and handling practices throughout the supply chain. In order for a mandatory warranty to be an effective tool to encourage sustainability throughout the supply chain, reforming the supply chain must be feasible and more profitable than the state of the current market under warranty. Our analysis showed that there is in fact a strong financial incentive for stores to look into supply chain reforms under a mandatory warranty.

One factor that was not considered in this analysis was the potential cost to stores of supply chain reform. While stores have the opportunity to make 5.33% more profits, it is reasonable to think that this profit margin might not cover the cost of changing supply sourcing. The second half of our analysis examines sustainable production methods for fish that allow stores to easily access alternative sources for ornamental fishes.

Based on our analysis, there is a clear financial incentive for stores to look for reliable, clean, sustainable sourcing suppliers under a mandatory warranty. A warranty would be an effective method for protecting consumers from buying and paying again to replace poisoned or damaged fish. A warranty would also provide a simple, top down solution that would motivate stores to reform the supply downstream through market-driven pressure. Moreover, this analysis showed that in the long run, there is a significant financial incentive for stores to renovate their supply chain if a mandatory warranty were implemented.

Supply Chain Analysis & Potential for Mariculture

The marine ornamental trade supply chain between the Coral Triangle and the U.S. is made up of many steps, including collectors, middlemen, exporters, importers, wholesalers, and retailers. Each player takes a cut of profits along the way, and these profits vary throughout the supply chain. In addition to these varying profits, a large proportion of the markup in the supply chain can be attributed to fixed shipping costs. Mariculture operations in the Coral Triangle have to compete with collectors of wild fish, and may not be able to successfully compete in the market given the low prices paid for fish at the producer level. However, a direct market contract with a business farther along the supply chain could give a mariculture business a competitive advantage. Figure 7 below shows the most basic steps of the supply chain and the potential insertion points of a mariculture business into the supply chain. We wanted to find out how fish prices changed throughout the supply chain and how this affected the potential for mariculture to be successful under various market scenarios. We had the following questions:

- To what degree would shortening the supply chain, such as through utilization of a direct market contract, improve the ability of mariculture operations in the Coral Triangle to compete successfully in the market?
- Are consumers willing to pay more for a captive-raised fish, and if so, how does this willingness to pay affect the price at which a mariculture operation in the Coral Triangle is able to sell its fish?

Methods for supply chain analysis

We first explored how price changed as a fish moves through the supply chain. This analysis included finding the average price at each step of the supply chain, calculating the percent price markup (and thereby the profit) between each step of the supply chain, and determining the overall markup at various steps from the initial producers in the Coral Triangle. In order to calculate profit accurately, we took into account fixed costs such as shipping and adjusted the price markups accordingly. We then used this information to calculate the price that a mariculture operation could sell its fish with or without a market contract.

We then calculated how much more consumers in the U.S. were willing to pay for a captive-raised fish than a wild-caught fish. Assuming that retailers would place a price premium on captive-raised fish that would maximize their profit, and assuming that this entire price markup would be passed up the supply chain, we calculated the highest cost at which a mariculture operation could produce its fish and remain competitive in the market.

The best case market scenario would be a price premium on captive-raised fish with a direct market contract that afforded a mariculture operation the highest price for their fish. We combined the two analyses to determine the "best case" price to sell captive-raised fish from the Coral Triangle.

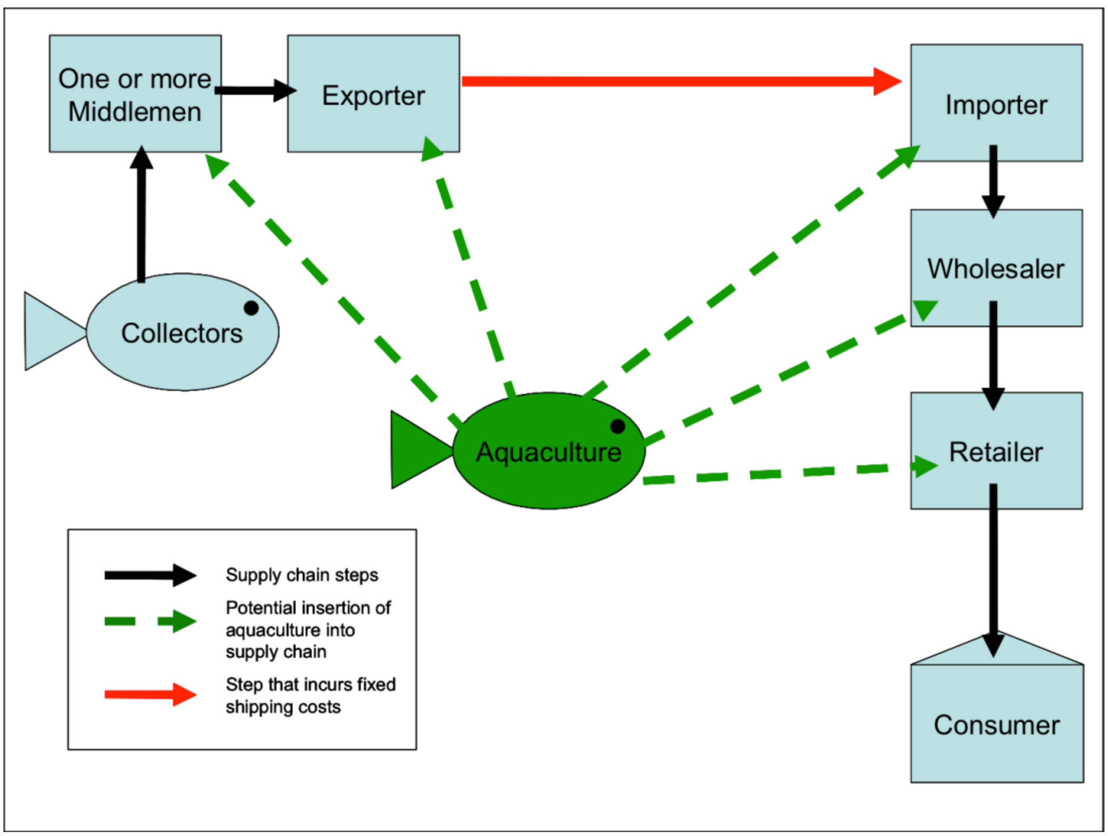


Figure 7. Path of fish through the supply chain for the marine ornamental trade. Importers pay a substantial, fixed shipping cost in addition to the price of the fish. Collectors generally only sell to middlemen, but a mariculture business could potentially contract with one of several different players along the supply chain.

Supply Chain Breakdown

Prices at each step. The first part of our supply chain analysis determined the average price of a fish at each step along the supply chain. We gathered price data from sources at various points along the supply chain and then used these data to determine the average fish price at each step. Our analysis focused on 85 species, which can be found in Appendix G. We found price information for the following steps of the supply chain: prices paid to collectors, prices paid by importers, wholesale sales prices, and retail sales prices. For prices paid to collectors and prices paid by exporters, we used data from three literature sources (EC-PREP, 2005; MAMTI, 2006; Shuman, Hodgson, & Ambrose, 2004). These sources used case studies in Indonesia and the Philippines and gave us information on prices paid to collectors per fish caught, for a variety of fish species. These prices were reported from 2004-2006, and we assumed that prices paid to collectors have not changed significantly since then. There are two main types of collectors in the Coral Triangle: local and roving. Local collectors collect fish from the reefs near their communities, while roving collectors will travel up to several days by boat to collect fish from less disturbed reefs. Roving collectors make up about 80% of collectors in the Coral Triangle and are paid much less per fish than local collectors (MAMTI, 2006). In the case of roving collectors, the middleman bears the burden of maintaining the boat over longer trips, so he pays his fishermen less per fish. Since we had data from both types of collectors, we used a weighted average to determine the average price paid to collectors, which we calculated as:

> **(0.8 × Price to roving collectors) + (0.2 × Price to local collectors)**
> **= average price to collectors**
>
> (Prices paid to collectors, the weighted average of roving and local collectors, and prices paid by exporters can be found in Appendix H)

Prices paid by importers came from random samples of invoices for 16 species that were imported into the United States in 2005 (Rhyne, 2012) (App. J). Wholesale prices came from Sea Dwelling Creatures, a wholesaler located in the United States (Cohen, E. (2011, September 27), Interview by S Horii [Personal Interview]) (App. K). We used average sales prices based on sales data from this company from 2009 and 2010. Sea Dwelling Creatures is a wholesaler that also acts as an importer, dealing directly with exporters in the Coral Triangle. Therefore, we made the assumption that our import prices are typical prices at which an importer/wholesaler such as Sea Dwelling Creatures might purchase its fish.

Retail prices came from four websites: That Fish Place (http://www.thatpetplace.com), Fresh Marine (http://www.freshmarine.com), Doctors Foster and Smith LiveAquaria.com (http://www.liveaquaria.com), Blue Zoo Aquatics (http://www.bluezooaquatics.com), and Petco (http://www.petco.com). We recorded prices from each website for the 85 fish species between Jan. 27, 2012 and Jan. 29, 2012. Prices for a particular species sometimes varied based on factors such as size, sex, or unique visual characteristics. Therefore, we calculated average prices for each species on each website, and then for each species we calculated an overall average price among retailers. This estimated price for each species was then assumed to be the current average retail price. In calculating this price we assumed that physical retail stores sell their fish for comparable prices as online retailers, and that the overall average fish price from all retailers is represented by the average of popular online retailers. Retail price data and calculations of average price per species can be found in Appendix L.

In addition to these steps, we also estimated the fixed costs of shipping fish between exporters in the Coral Triangle and importers in the U.S. Shipping costs were broken down into two components: packaging and freight. Packaging costs depended on the cost of boxes and the number of fish that fit in a box. Boxes cost between $10 and $20 each (A. Rhyne, personal communication, January 13, 2012). We assumed an average price of $15 per box. The cost of packaging for each fish species then depended on the number of fish packed into each box. Freight costs were based on weight and were estimated at $4.50/ kg - $5.50/ kg (A. Rhyne, personal communication, January 13, 2012). For the purposes of our study, we assumed an average freight cost of $5.00/ kg. Full boxes weigh 20 kg - 25 kg (A. Rhyne, personal communication, January 13, 2012). We assumed an average box weight of 22.5 kg. Using these numbers, we estimated the cost of freight to be $112.5/ box. The cost of freight for different fish species then depended on the number of fish that fit into a box. We used existing data from a case study in Indonesia to estimate the number of fish per box for various species (EC-PREP, 2005). For each species, the cost of shipping was then ($15/ box) / (number of fish/ box) + ($112.50/ box) / (number of fish/ box). These estimates can be found in Appendix I.

The average price paid to collectors for a wild-caught fish was found to be $0.54 USD, and the price increased with each step up to $57.49 at the retail level (Tbl. 8). Estimated average shipping costs were $10.38 per fish, with a range of costs between $1.28 and $31.88 per fish. Shipping costs had a wide range because some fish were much larger than others – only a few large fish can fit in a shipping box, which meant that shipping was much greater for each large fish than it would be for a very small fish that packed 100 per box. The range of prices was quite large throughout the supply chain, and this range was especially apparent at the retail level, where the cheapest fish sold for $4.15, and the most expensive sold for over $200. Because the wide range of prices made it difficult to analyze price changes in the supply chain, we assumed the data were normally distributed and used the average prices for our analysis.

Table 8. Average prices at each step of the supply chain, range of prices at each step, and sample size of each data set used.

	Average price	Range	Sample size
Paid to collector	$0.54	$0.02 - $5.39	60
Paid by exporters	$0.62	$0.06 - $3.09	32
Paid to exporter	$3.29	$0.27 - $23.38	28
Shipping costs	$10.38	$1.28 - $31.88	56
Paid to wholesaler	$15.75	$1.25 - $84.97	84
Paid to retailer	$57.49	$4.15 - $219.87	80

As expected, prices trended upward as a fish moved along the supply chain. This meant that each player in the supply chain, from the collectors to the retailers, were receiving some kind of profit, although some made a much larger profit than others (Fig. 8). The largest jump in price happened at the retail level.

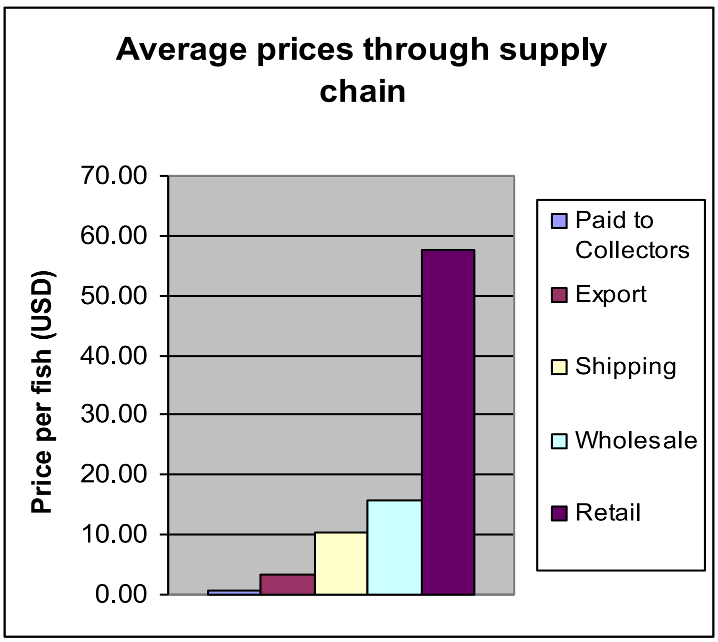


Figure 8. Increase in price as a fish moved along the supply chain.

Markups in price between steps. The next step in our analysis was to determine the size of the markup between each step. This would tell us which steps profited the most and least in the trade. We also determined the percentage of markups that fixed shipping costs make up, and how significantly these costs factored into the supply chain.

Using the averages calculated at each step of the supply chain, we found the average price markups between adjacent steps. In addition, we used a t-test with a 95% confidence level to determine whether each pair of adjacent steps had a significant difference in mean price (Tbl. 9). The smallest significant markup was between exporter and wholesaler prices, and the largest was between export and collector prices. The greatest absolute gain in price was at the retail level.

Table 9. Comparison of prices between consecutive steps in supply chain. All steps showed a significant increase in price except for the first step – price paid by exporters versus price paid to collector.

	t-statistic comparing means	Price difference	Percent price markup
Paid to collector vs. paid by exporters	0.60	$0.08	15%
Paid by exporters vs. paid to exporters	1.26×10^{-2}	$2.67	431%
Paid to collector vs. paid to exporters	4.18×10^{-4}	$2.75	509%
Paid to exporter vs. paid to wholesaler	9.44×10^{-4}	$12.46	379%
Paid to expoter vs. paid to wholesaler, considering markup	4.70×10^{-5}	$2.08	63%
Paid to wholesaler vs. paid to retailer	5.96×10^{-13}	$41.74	265%

We used a t-statistic rather than a z-score to compare our data means because one of our data sets, the price paid to wholesalers, had a sample size less than 30. Since the t-statistic converges toward the z-score for $n>30$, using a t-statistic for the other data sets would not significantly alter our statistical analysis.

The t-tests compared the average price differences between price paid to collector and price paid by importers, price paid by exporters and price paid by importers, price paid by importers and price paid to wholesalers, and price paid to wholesaler and price paid to retailers. They showed a statistically significant difference at the 95% confidence level between average prices for almost every pair of steps along the supply chain. However, the difference between mean price paid to collectors and mean price paid by exporters was not significant ($p = 0.6$). Therefore, the rest of the supply chain analysis did not look at any relationship between these two steps, but focused instead on the relationship between prices paid to collectors and prices paid by importers, which had significantly different means at the 95% confidence level ($p= 4.18 \times 10^{-4}$). The difference between mean price paid by exporters and mean price paid by importers was also significant ($p = 0.01$). When shipping prices were considered in the equation, the difference between importer and wholesaler prices remained significant ($p = 4.70 \times 10^{-5}$).

The highest markup in the supply chain was 509%, between the price paid to collectors and the price paid by importers to exporters. This markup meant that if a collector was paid $1 for a fish, an exporter would sell that same fish for $6.09. Two explanations for the large markup at this part of the supply chain would be: 1) exporters could be adding a large markup to the fish they sell to importers and making a large profit, or 2) the analysis we conducted was based on a simplified model, when in reality, there were several additional supply chain points between the collector and the importer, including the exporter and one or more middlemen. The markup therefore represented the aggregate markup of several steps that make up the initial part of the supply chain; logic would suggest that the actual markup between any two steps of the initial supply chain would likely be much smaller.

The markup between what was paid by the exporter and what was paid by the importer was calculated with only four data points, which we decided may not be enough data to draw a meaningful conclusion. Therefore, we took a conservative approach omitted this step from further analysis, instead focusing only on the markup between collectors and importers.

The markup between the price paid by importers and the price paid by wholesalers was 379%. However, this markup was not nearly as high when shipping costs were taken into account. Importers had to pay for shipping costs in addition to paying for the fish itself, and this cost needed to be considered. The shipping cost, which included the cost of packaging and freight, was calculated to be an average of $10.38 per fish. When the cost of shipping was subtracted from the price at which importers sold their fish, the price markup between importers and wholesalers dropped to 63%. By omitting the cost of shipping, we revealed the true markup price. When we considered the substantial fixed cost, shipping costs actually made up a dominant fraction of the cost for a fish at the importer level. Importers actually received the smallest significant profit margin out of all the steps in supply chain.

Of all the points along the supply chain, retailers appeared to enjoy the greatest benefits from price markups. At a 265% markup, the percent markup at the retail level was not the highest in the supply chain. However, because the actual price of the fish was so high at that point, the same percent increase led to a much higher increase in absolute value of the fish. Retailers gained much more from a 286% markup when the fish was already worth $15.75, as compared to a 509% increase at the importer level when the fish from collectors was is only worth $0.54.

Market contract potential

Cumulative markups from producer level. In order to understand how price markups would affect the possibility of a market contract that cuts out one or more steps of the supply chain, we looked at the total aggregate markup at each point along the supply chain from the collector level. By subtracting out the shipping cost from the supply chain markups, we estimated the percent of the markup that could be transferred to the producer by creating a direct market contract with either wholesalers or retailers. This new markup allowed us to estimate the increased cost at which suppliers could sell fish under a market contract and remain competitive in the market.

Table 10. Total percent price markups from initial step (price paid to collectors) throughout supply chain, and total percent markups taking shipping into consideration.

Supply chain step	Price	Percent markup from initial	Percent markup from initial, considering shipping
Paid to collector	$0.54	0%	0%
Paid by importer	$3.29	509%	509%
Paid by retailer	$15.75	2817%	894%
Paid by consumer	$57.49	10546%	8624%

To determine how prices at each level of the supply chain relate to the initial prices paid to collectors, we calculated markups as the total percent increase in price from the collector level (Tbl. 10). The price markup between the price paid to collectors and the price paid by importers was 509%, which meant that if a collector were paid $1.00 for a fish, he could sell that same fish to an importer for $6.09. Likewise, if the collector sold the fish directly to a retailer, he would earn $9.94 (894% markup). If he sold directly to a consumer, he would earn $87.24 (8,624% markup). These numbers considered the reduced markup due to the fixed cost of shipping. A comparison of these numbers is illustrated in Figure 9.

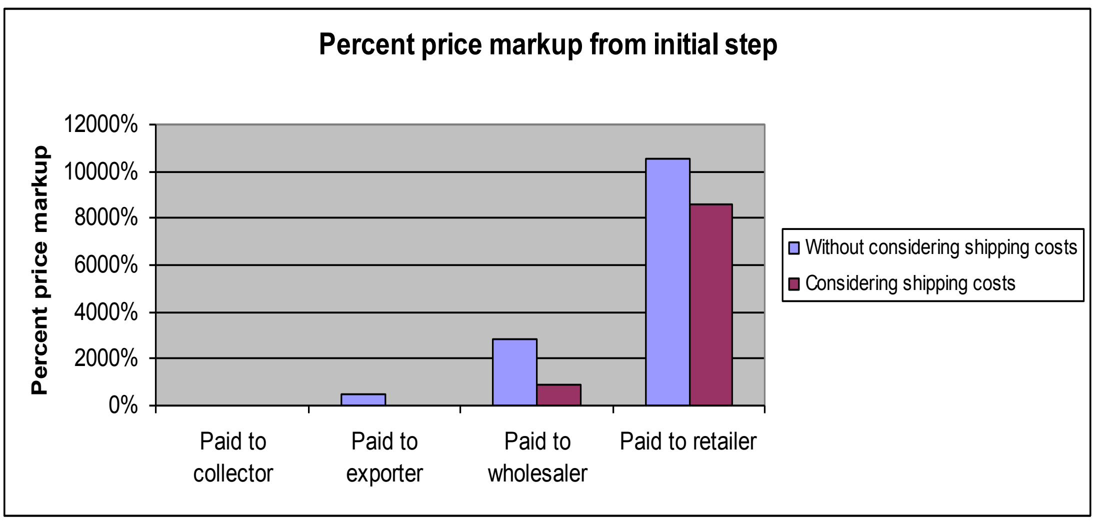


Figure 9. Percent price markup from the initial step, price paid to collectors. The graph includes price markups for wholesaler and retailer when shipping costs were removed from the equation, which was the true markup that a producer could earn from a direct market contract.

The markup from collectors ranged between 509% to import costs and 8,624% to retail prices. This meant that if producers also acted as exporters and sold directly to an importer, they would be able to apply a 522% average markup on their fish (or produce fish at 522% of the cost of wild fish collection) and still remain competitive with exporters. If producers had a direct market contract with a retailer, skipping the export, import, and wholesaler steps, they would be able to mark up their fish prices by 894% and still remain competitive with wholesalers. If producers were able to sell their fish directly to consumers in the U.S., acting as a retailer, they would be able to have a markup of 8,624% and still remain competitive with other retailers. However, it was unlikely that a fishing community in the Coral Triangle could successfully sell fish directly to consumers in the U.S. Therefore, we chose to focus only on the direct market contracts with importers and with retailers.

A direct market contract between a producer and an importer would allow a mariculture business to produce its fish at over six times the cost of collecting a wild-caught specimen and still remain competitive in the market. Since the average payment for collecting a wild specimen is $0.54, a competitive price for a mariculture-produced fish under a market contract would be anything less than $0.54 + 509%, or $3.29 per fish. Under a direct market contract with a retailer, a mariculture facility could successfully compete in the market if it produced its fish at an average price of $0.54 + 894%, or $5.37 per fish. These numbers are shown below in Table 11.

Table 11. Maximum price at which a fish could be produced under a direct market contract with an importer or retailer, compared with current price paid to collectors for wild-caught fish.

	Maximum producer price per fish
Current conditions	$0.54
Market contract with importer	$3.29
Market contract with retailer	$5.37

One possible issue with direct market contracts was that they might not be limited only to sustainable mariculture businesses. Theoretically, any roving collector operation or community that heavily exploited local reefs for aquarium fish could directly contract with an exporter, importer, or wholesaler. If a large enough fraction of wild fish collectors used this method, the market could shift to fewer supply chain steps, decreasing the overall value of fish and eliminating any competitive advantage for mariculture operations. However, most collectors likely did not have the resources and knowledge to set up a direct market contract – this step will likely be facilitated by a third party such as a nonprofit organization interested in promoting sustainably produced aquarium fish. This barrier to creating a direct market contract would help to keep this option exclusively available to mariculture businesses. In addition, wholesalers or retailers are unlikely to seek out producers and secure direct market contracts because the research and development of such a program would be too expensive and time consuming, considering the complexity of the supply chain in producer countries. Because of these associated costs, these businesses might see a direct market contract as too risky of a venture to undertake by themselves. Mariculture facilities also would have an advantage when dealing with higher levels in the supply chain, because captive-raised fish have been shown to be healthier, more robust, and an overall better product. In addition, as compared with a supply of wild-caught fish, a mariculture operation could produce a more stable and reliable supply of fish, as it would know what species would be available months beforehand, while the fish were still being grown out. A direct market contract would be more likely to succeed when it could consistently supply a superior product.

Comparing different supply chain scenarios

Supply chain with 30% price premium

Our survey data showed that consumers are willing to pay more for captive-raised fish and that retailers made the largest profit from selling these fish at a 30% premium. We investigated how this price premium would lead to higher prices throughout the supply chain as well as how it would ultimately affect the price at which a mariculture operation would be able to sell its fish.

We assumed that this markup would be passed on through the supply chain all the way to the producer level. By making this assumption, we could calculate the greatest price at which a producer ideally could sell its fish, and therefore the greatest cost at which it could produce fish and remain competitive in the market. Realistically, the producers will only receive a fraction of the retail price markup, so the actual benefit to producers will lie somewhere between the current situation and that under an ideal price premium.

To calculate the new average retail price for a captive-raised fish, we added a 30% markup to the current average price:

$$\textbf{(Average retail price)} \times \textbf{1.3} = \textbf{New retail price}$$

As shown in Table 13 below, a 30% premium resulted in a new retail price of \$74.74. Likewise, the new wholesale price was 30% more than the original wholesale price, or \$20.48.

However, in calculating the new price paid by importers to exporters, we once again had to consider shipping prices. Wholesalers received 30% more for the fish they sell to retailers, so they should also be willing to pay 30% more for that fish from an importer. Therefore, importers should be willing to pay 30% more than they currently do. However, importers paid both for the fish itself and for the cost of shipping, so the new price they would pay is 30% greater than both of those costs combined:

1.3 × (Original price paid by importer) = 1.3 × (Price paid for fish + Cost of shipping)

= [1.3 × (Price paid for fish) + 0.3 × (Cost of shipping)] + (Cost of shipping)

The cost of shipping remained constant, and when it was separated from the equation, we could find the new price of a fish sold to importers:

New price = 1.3 × (Price paid for fish) + 0.3 × (Cost of shipping)
= 1.3 × ($3.29) + 0.3 × ($10.38)
= $7.39

Therefore, under a 30% price premium at the retail level, importers were willing to purchase fish from exporters at an average price of $7.39 instead of $3.29, or a 125% increase in price. This new markup was then transferred to the producer level:

New producer price = 2.25 × (Original producer price)

Under a 30% price premium at the retail level, the new price at which a producer of captive-raised fish could sell was $1.21 per fish. These numbers are all shown in Table 12 below.

Table 12. New average prices throughout supply chain, as well as new market contract prices, resulting from a 30% price premium for captive-raised fish at the retail level. All prices are in USD.

	Average price	Average price with 30% premium	Market contract price
Paid to collector	$0.54	$1.21	N/A
Paid to exporter (contract with importer)	$3.29	$7.39	$7.39
Paid to wholesaler (contract with retailer)	$15.75	$20.48	$10.10
Paid to retailer	$57.49	$74.74	N/A

Therefore, even without a direct market contract, and just considering the potential price increase available from existing demand, a mariculture operation could sell its fish at over twice the price of wild-caught fish. However, if a mariculture business were to insert its fish into the supply chain at the level of the middleman, the business will only be able to sell its fish at this price if the fish remains clearly marked as captive-raised throughout its entire journey along the supply chain. If at any point these fish get mixed in with wild-caught fish, their added value will be lost.

Combining 30% with market contract

Finally, we reached our final market scenario, which was to combine market contracts with a 30 % price premium at the retail level. For a direct market contract with a retailer, we subtracted the shipping costs from the new average price with the premium:

Market contract price = (New average price) – (Shipping costs)
= ($20.48) – ($10.38)
= $10.10 per fish

If a mariculture operation entered into a direct market contract with a retailer, it could sell fish for $10.38 each and remain competitive with wholesalers.

For a direct contract with an importer, a mariculture operation would act as an exporter and so would not pay shipping costs. Therefore, it would sell the fish at the same price that other exporters would under a 30% retail premium, or at $7.39 per fish. Table 13 below shows these prices, as well as other possible producer-level prices under each market scenario investigated.

Table 13. Maximum price that producers could sell fish for under various market scenarios. All prices are in USD.

	Maximum producer price per fish
Current market	$0.54
With 30% price premium at retail level only	$1.21
Market contract with importer	$3.29
Market contract with retailer	$5.37
Market contract with importer, plus 30% retail premium	$7.39
Market contract with retailer, plus 30% retail premium	$10.10

Supply chain analysis results and conclusions

Direct market contracts and increased willingness to pay for tank-bred fish would only help mariculture businesses to be competitive if they were able to produce fish at or below the prices afforded by these options. The average cost of producing a fish through post larval capture and culture (PCC) has been estimated to be quite low. According to one study, the price of production ranged from $0.33 per fish in the family Panuliridae up to $2.75 per fish, on average, for the family Scorpaenidae (Hair, Doherty, Bell, & Lam, 2000). The overall average price of producing a fish with this method using light traps or crest nest was estimated to be $0.54 per fish (Hair, Doherty, Bell, & Lam, 2000). Surprisingly, this estimate was exactly the same as our estimate of the average price paid to a collector for a wild-caught fish in the Coral Triangle. This meant that even without added-revenue from a direct market contract or increased willingness to pay for captive-raised fish, mariculture businesses could possibly be competitive in the market. In addition, Hair et al. based their price estimate on a land-based facility (2000). This type of facility would likely be more expensive to run than water-based method such as a Micropod™, which meant that a business that practiced water-based mariculture would likely be able to produce fish at a lower average price. By taking advantage of these options, mariculture businesses could increase their profit, produce a greater number of higher-value fish, and actually become a more lucrative option for producers than catching wild fish.

Mariculture feasibility in producer communities in the Coral Triangle

Introduction to marine ornamental trade producer communities

Both communities in the Coral Triangle and conservation organizations have recognized the potential role that aquaculture could play in reducing harvesting pressure on wild stocks and promoting species conservation (Tlusty, 2002; Koldewey & Martin-Smith 2010). Aquaculture could also provide a more stable income and other economic benefits for developing coastal communities (Tlusty, 2002). Ideally, the transition to more sustainable collection and culture methods would pre-empt any potential regulatory mandates and the decimation of ornamental fish populations.

The goal of this guidance document was to provide a feasible scenario for producer communities to start a mariculture operation in the Coral Triangle that was economically and environmentally viable in the long-term. The recommended system involved a combination of post-larval capture and culture (PCC) techniques with a unique grow-out operation using an ocean-cage called the Micropod™. In the following section of this report, we examined technical feasibility, current legal and political statuses, business considerations, and the community dynamics of the Coral Triangle, all of which would ultimately affect the viability of any mariculture operation proposed in the area.

Technical considerations for ornamental mariculture

Mariculture of ornamental fish is a promising method for alleviating pressure on wild stocks in coral reef habitats and providing producer communities with a more stable income. There are a variety of mariculture techniques that may be considered, and the most appropriate systems will likely be appropriate only on a case-by-case basis. Table 14 lists appropriate and inappropriate cases for mariculture production of ornamental species (Tlusty, 2002). While some communities and their nearby reef habitats may benefit from the introduction of a mariculture operation, other communities are better suited to alternative solutions. It is important to gauge the appropriateness of mariculture considering both community dynamics and ecological factors, because once a mariculture operation begins in a small community, livelihoods rest on the success of the operation.

Table 14. Appropriate and inappropriate cases of aquaculture production of ornamental species. From Tlusty, 2002.

Appropriate	Example
Demand cannot be met by wild harvest	dwarf cichlids (*Apistogramma* spp.)
Rare in wild	Golden dragon fish (*Scleropagus formosas*)
Rare in trade (abundant in wild)	cichlid (*Hoplarchus psittacus)*
Destructive harvest methods	hard corals
Benefit collectors and wild populations	Conchs (*Trochus* spp.), hard corals
"domesticated" strains	guppies (*Poecilia reticulata*), goldfish (Carassiu auratus), bettas (*Betta splendens*), angelfish (*Pterophyllum scalare*)
Inappropriate	**Example**
Wild harvest maintains habitat	Cardinal tetra (*Paracheirodon axelrodi*)
Maintains cultural traditions	Cardinal tetra (*Par. axelrodi*)
Removal of economic benefit from depressed/developing area	Sri Lanka and Brazilian ornamental fishery
Propagation hastens decline of wild population	seahorses (*Hippocampus* spp.)

The development of ornamental mariculture is still in its infancy, partially because there is substantially less funding and interest in the ornamental trade than in aquaculture for food production. Many aspects of a full-cycle mariculture process (which includes breeding fish and raising them to adulthood all in captivity) for marine ornamental fish, such as broodstock management, larval rearing, and knowledge of gamete physiology and larval morphology, are not feasible or replicable on a large scale (Moorhead and Zeng, 2010). Furthermore, the basic stages of full-cycle fish mariculture often require substantial on-land infrastructure, high start-up capital, management skills, and advanced technology requirements (Pomeroy, 2006).

These requirements often make full-cycle mariculture infeasible for rural or underdeveloped island locations without access to basic necessities such as a consistent electricity source. Another drawback to land-based mariculture is the potential for transfer of production away from developing countries. Once a breeder discovers a method to complete a species' full life cycle in captivity, that fish can technically be raised anywhere in the world in a closed re-circulating mariculture system. In fact, many species of tropical aquarium fish that have been successfully reared in captivity are cultured in locations far from the species' native habitat (MASNA, n.d.).

If a producer community in a developing country takes an interest in starting a mariculture operation, the mariculture system must be feasible within the technological, social, and economic constraints of the area. Low maintenance technologies with low levels of investment capital and management requirements would likely be most appropriate for rural coastal communities (Pomeroy, 2006).

Post-larval capture and culture (PCC)

Introduction to PCC
Post-larval capture and culture (PCC) is one potential method for low-technology mariculture. PCC still involves the harvest of wild stock, but eliminates the need to care for larval fish in captivity or maintain a broodstock. Rather than attempting to mimic the entire fish life cycle through full-cycle culture, the PCC method involves harvesting post-larval fish before they settle onto reefs. In the bipartite fish lifecycle, adult fish release their larvae into the water column for dispersion (Bell et al., 2009). The larvae then metamorphose into postlarvae and have a limited amount of time to settle onto reefs (see Figure 10, which depicts the bipartite life cycle of coral reef fish).

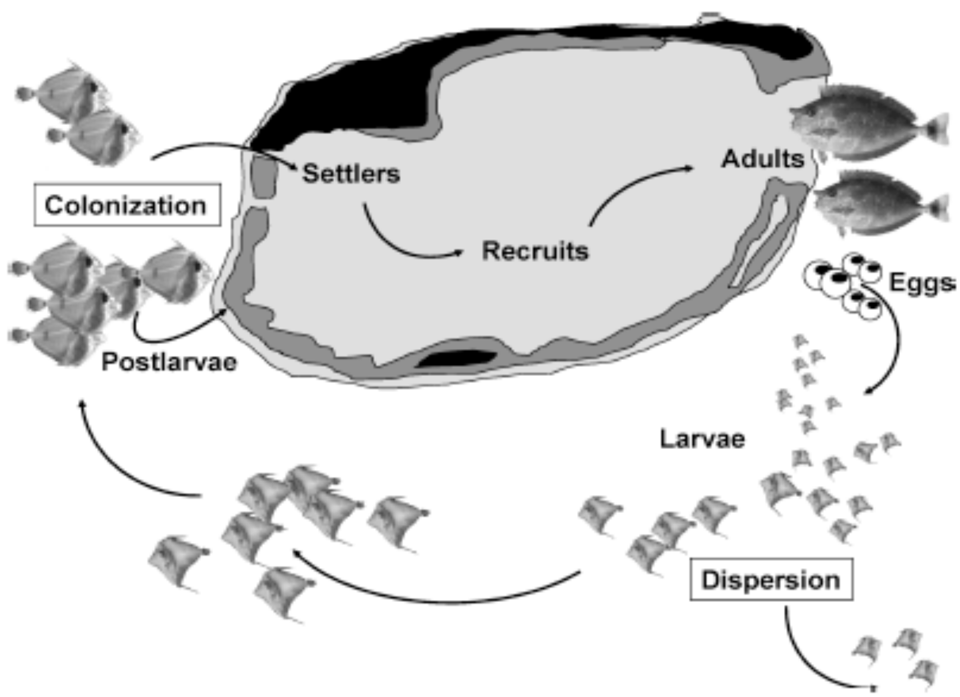


Figure 10. The bipartite cycle of coral reef fish and invertebrates, where the adults are associated with coral reef habitats and the pelagic eggs and larvae develop in the ocean. From Bell et al., 2009.

While there may be millions of postlarvae in the water column, this life stage has extremely high mortality as the postlarvae attempt to settle out (Bell et al., 2009, Forrester, 1995; Hair et al., 2000). Only one to ten percent actually settle on suitable substrate and survive to adulthood. PCC targets the vulnerable settlement stage by capturing a portion of the postlarvae and providing them with habitat and resources so that they might have a higher survival rate in captivity (Bell et al., 2009).

Due to the naturally high mortality at the post-larval life stage, capturing a fraction of post-larval fish from the water column would theoretically little or no decline of the adult population (Lecchini et al., 2006) and would have minimal impact on the overall population. However, while over-fishing of postlarvae is unlikely to occur, researchers caution using PCC techniques on small, isolated islands, where reef species populations are characterized by high self-replenishment (Bell et al., 2009).

Benefits of PCC

In addition to transitioning fish postlarvae with high mortality rates into successfully captive-raised fish, PCC has several other advantages over full-cycle mariculture. In the current wild harvest scenario, the high market value for juvenile and adult ornamental fish has created a short-term economic incentive for producer communities to over-harvest fish from coral reefs. As a result, many communities are already experiencing the rapid depletion of fish populations on nearby coral reefs. PCC, in contrast, creates an incentive to maintain a healthy reef in the long term (A. Rhyne, personal communication, January 11, 2012). If adult populations are maintained at healthy numbers, there will be more larvae in the water column from larger spawning events and provide a larger overall supply of desirable fish for the ornamental trade.

Unlike the food fish industry, the marine aquarium trade prizes diversity. PCC allows for the capture of hundreds of different species from the reef simultaneously, including species that cannot currently be captive-bred. In full-cycle culture operation, only one species is typically grown at a time because each species require specific environmental conditions. Currently, only about 25 marine ornamental fish species have been successfully cultured through full-cycle mariculture (Pomeroy, 2006).

Technical aspects of PCC

In PCC, fish are primarily collected with light traps, hoa nets, or crest nets. Figure 11 shows the different types of capture methods used in PCC. The most appropriate technology will depend on the physical properties of the supplying reef, and the species desired for collection. Light traps, crest nets, and hoa nets all have fairly low technology requirements, and accessible literature provides step-by-step directions for constructing or obtaining these devices (Hair et al., 2007; Lecchini et al., 2006; Ellis, 2010).

Figure 11. Examples of post-larval capture devices (a,b) Light traps, (c) hoa net, and (d) crest net. Adapted from Bell et al. (2009).

Light traps attract photopositive species that possess directional swimming ability, which limits collection to certain taxa and sizes (Fig. 11a,b). Additionally, it may be possible to target certain families of fish species by adjusting light intensity and wavelength (Heenan, 2010). Light traps are best for sampling the outer reefs, since they can be submerged in the water column to catch photopositive larvae (Bell et al. 2009; Lecaillon, 2004). Light traps are best placed in the water column where it is deep enough (15-20 m) to avoid illuminating the sea bed (Lecaillon, 2010). Some light trap designs are highly effective, but very expensive (Watson et al., 2002; Lecaillon, 2004).

One device, C.A.R.E. ("Collected by Artificial Reef Eco-friendly"), was developed by the NGO EcOcean, and has been tested at multiple locations. C.A.R.E. traps were tested in Indonesia and collected a wide array of species after three nights of sampling. While its design has benefits that decrease bio-fouling and physical damage to the animals, it costs $1000 USD (Lecaillon, 2004).

Some other light trap designs have been modified to use cheaper materials with comparable results (Watson et al., 2002). In one study, a light trap costing $3000

USD caught twice the amount of fish as simplified version, but the simpler trap cost $300 USD (Watson et al., 2002). Another light trap has been even further modified to cost only $75 USD (A. Rhyne, personal communication, January 13, 2012).

Crest nets are an alternative larval capture method to light traps (Fig. 11d). Unlike light traps, crest nets are passive filtering devices that collect an unbiased collection of species. They require unidirectional flow of water and are best positioned right behind the surf zone of reef crests (Hair et al., 2000). Crest nets can harvest a larger number and diversity of species, but without proper collection chambers they risk crushing animals (Bell et al., 2009).

Nets that take advantage of the channels leading into lagoons are called "hoa nets" (Bell et al., 2009). These are similar to crest nets, but there are large mesh walls that direct larvae into the net (Fig. 11c). Like crest nets, hoa nets work best in unidirectional flow.

Post-larval collection should ideally be at locations with the largest and most consistent supply of postlarvae (Bell et al., 2009). However, the spatial distribution of settling larvae is highly complex and difficult to predict. Factors such as varying currents and weather patterns, changing reef habitat quality, and well-evolved sensory systems and behaviors exhibited by postlarvae can severely inhibit long-term predictions on distribution and abundance (Bell et al., 2009). In general, however, postlarvae are often concentrated on the outer reef slopes as they either move over reef crests or into channels entering the safety of lagoons.

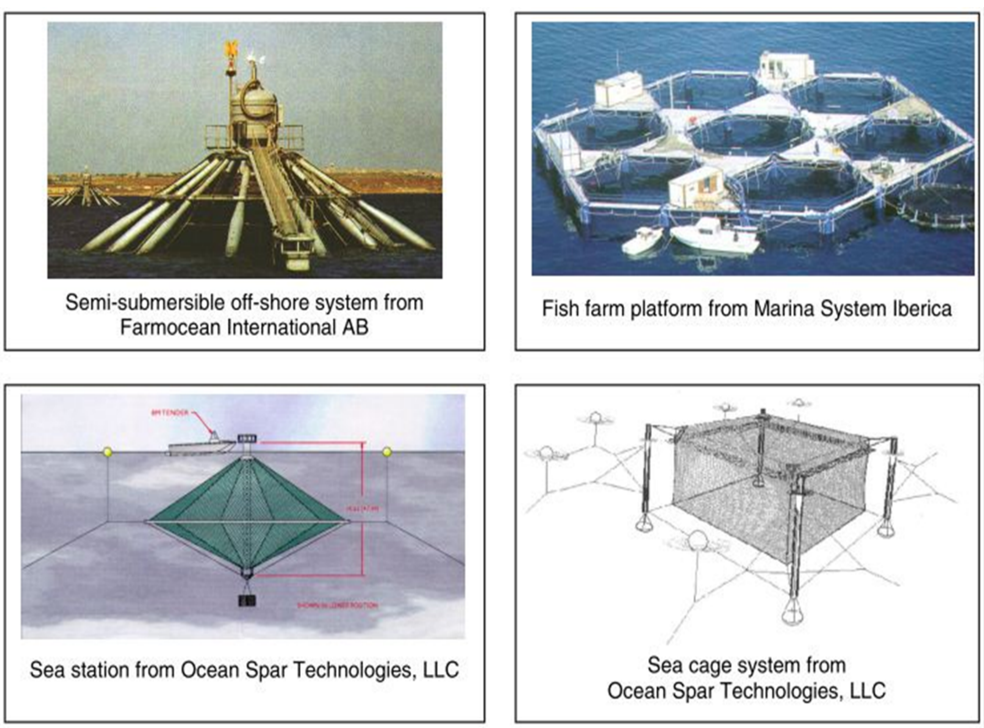
Culturing: Grow-out methods
After fish are collected at the post-larval stage through PCC, they must be transferred to a grow-out facility to reach a size suitable for the marine ornamental market. Many PCC operations use on-land tank systems for this portion, which require capital and on-land infrastructure. Another drawback to land-based mariculture is the potential for the transfer of production away from developing countries. Once a breeder discovers a method to complete a species' full life cycle in captivity, that fish can technically be raised anywhere in the world in a closed re-circulating mariculture system. In fact, many species of tropical aquarium fish that have been successfully reared in captivity are cultured in locations far from the species' native habitat (MASNA, n.d.).

While the knowledge gained from breeders' efforts has expanded breeding methods for marine ornamental mariculture, concerns have been raised over socio-economic impacts to the original collector communities (Tlusty, 2002). Even if collectors do discover the means to breed and raise native species, they might not have the technological capacity available in developed countries to build complex facilities. Open-ocean containment systems offer a low-technology way for species to be raised in captivity in the same habitat they originated from, thus keeping the economic and social benefits in the original collector community.

Open-ocean containment systems

Coastal mariculture operations can have an effect on water quality and conflict with other nearshore activities such as shipping lanes (Tlusty 2002; OFT, n.d.). Recently, the finfish aquaculture industry has begun exploring the viability of open-ocean cages, which would significantly decrease coastal influences (Scott & Muir, 2000; Upton and Buck, 2010). Mariculture in the deep open ocean will have cleaner water and better current flow (Upton and Buck, 2010). However, these cages need to be extremely robust to withstand strong currents and storm events. Other maintenance issues such as cleaning, feeding, and harvesting also should be as efficient as possible, and environmental impacts should be assessed for any new project site.

There are four structural types of open-ocean mariculture cages: 1) floating flexible, 2) floating rigid, 3) semi-submersible flexible/rigid, and 4) submersible rigid (Scott & Muir, 2000; Fig. 12). There are multiple variations of these cage types with varying degrees of durability, ease of operation, and costs (Scott & Muir, 2000).



Semi-submersible off-shore system from Farmocean International AB

Fish farm platform from Marina System Iberica

Sea station from Ocean Spar Technologies, LLC

Sea cage system from Ocean Spar Technologies, LLC

Figure 12. Different structural types of off-shore mariculture cage systems. Adapted from Scott and Muir (2000).

Aquapod™ technology

Because the food fish industry has more developed research, methodologies, and technology, ornamental culture techniques are often adapted from the food fish aquaculture industry. Our client, Olazul, works with coastal communities to implement mariculture as an option to create sustainable livelihoods. Olazul is currently researching the viability of a fully-submersible open-ocean cage called the Aquapod™ for shrimp mariculture. Additionally, Olazul is interested in applying Aquapod™ technology to ornamental species on a smaller scale. We explored the possibility of a combined PCC and Aquapod™ grow-out model to help alleviate environmental and technical issues facing marine ornamental harvest and culture.

The Aquapod™ is a spherical, submersible, rigid open-ocean containment system developed by Ocean Farm Technologies (OFT, n.d.; Fig. 13). Figure 13 shows a schematic for the mooring of an Aquapod™. It is 11,000 m^3 and constructed of individual triangular panels fastened into a sphere shape for maximum geometric stability and efficiency (OFT, n.d.). Aquapods™ experience high levels of drag due to its large size, but more drag leads to better flow and fresh saltwater delivery, and the spherical shape can have less drag compared to other cage-shapes (OFT, n.d.). The Aquapod™ is a geodesic sphere, meaning it is made of triangular panels with an approximate 2.5 cm mesh size that adds to the structural stability. The older version of these panels was made of galvanized steel, which added strength and decreased the need for anti-fouling agents. However, newer versions are made of reinforced polyethylene (100% recycled content), which can reduce negative buoyancy and likely decrease maintenance costs, while still retaining many of the advantages of the original design (F. Hurd, personal communication, January 24, 2012). Large floats on the outside of the cage can be used to easily adjust the buoyancy, which allows for the Aquapod™ to be brought to the surface for easier maintenance or sunk down in case of strong storm events (F. Hurd, personal communication, January 24, 2012).

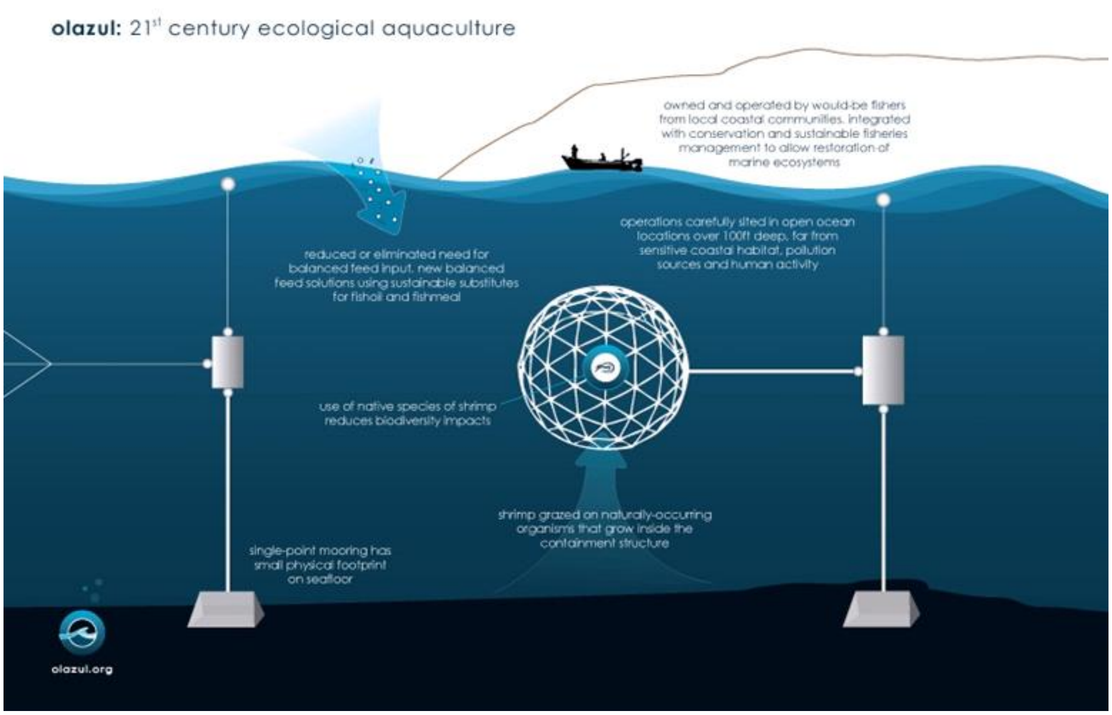


Figure 13. Schematic for single-point mooring system for the Aquapod™. Image provided by F. Hurd, personal communication, January 24, 2012.

The Aquapod™ has been designed to be more conducive for stock growth and have a lower environmental impact than many other conventional open-ocean cages (OFT, n.d.). The rigid panels prevent outside predation, which is a problem that flexible cages often have (Page, 2005). A nursery net is placed on the inside of the pod, adding to stock health and security. The Aquapod™ also has a 1-point concrete block mooring design that has a pyramid shape and a 1x1 meter base (OFT, n.d.; F. Hurd, personal communication, January 24, 2012). This mooring design has a much lower impact on the benthic habitat than alternative multi-point mooring designs (OFT, n.d.; Page, 2005).

The size of the pod can be customized to be as large as 28 meters in diameter (approximately 11,000 cubic meters) (OFT, n.d.; F. Hurd, personal communication, January 24, 2012). For ornamental species, however, it would be more appropriate to use the smaller Micropod™ (approximately 8 meters in diameter and 115 cubic meters in volume) (OFT, n.d.). While a steady supply of clean water is necessary, most coral reef fish are not adapted to strong currents (F. Hurd, personal communication, January 24, 2012). The Micropod™ system can accommodate this need, as water flow decreases dramatically to one tenth of the outside ambient flow as it moves through the outside cage and inner nursery net.

Other technical requirements for the Micropod™ system ensure its ability to withstand strong storm events and deliver cleaner water flow. The benthic swatch for the Aquapod™ system is estimated by 2 diameters of the pod on either side of the mooring (F. Hurd, personal communication, January 24, 2012). The top of the pod should be at least 6 meters from the surface and the overall water column should be at least 15.5 meters to 36.5 meter tall (the pod can move up and down along the mooring line). The benthic substrate is less important for the function of an Aquapod™ than the benthic slope, which should be no higher than a 10% grade (F. Hurd, personal communication, January 24, 2012).

Because the Aquapod™ system has high stability, easy maintenance, and low habitat impact, it is the most suitable for marine ornamental mariculture compared to other open-ocean cage systems.

Combining Micropods™ and PCC

Potential Benefits

The combination of PCC and a creative grow-out solution, such as the Micropod™, could help solve several issues in the marine ornamental trade, including food acclimatization, fluctuating market supply, destructive harvesting, and reef restoration. With this system, post-larval ornamental fish are collected from a reef and subsequently put into a Micropod™ for an extensive multi-species grow-out phase.

Problems with food acclimatization make up the greatest cause of fish mortality in aquaria (Lecchini et al., 2006). Food acclimatization is a difficult task to achieve with many specialized eaters like corallivores. Juvenile fish tend to acclimate to artificial feed better than adult species (A. Rhyne, personal communication, January 13, 2012), and therefore postlarvae fish meant for the aquarium trade should be grown to their juvenile stage. Since postlarvae grown in the Micropod™ would be exposed to their natural food items such as zooplankton from the ambient waters. This could dramatically reduce food for some taxa and cleaning costs. Even if there was an insufficient supply of plankton, there are various low-cost alternatives that can supplemental feed. Herbivores might be able to feed off of the algae that will grow o any hard substrates, and simple collection techniques such as conical plankton nets or demersal traps can provide additional feed (Alldredge & King, 1777; Evans & Sell, 1985; F. Hurd, personal communication, January 24, 2012).

Micropods™ could provide not only an environment for the grow-out phase, but also a place to store fish until they are most valuable on the market. Often, when a fish species is first successfully bred in captivity or a new source of a desirable wild fish is discovered, the demand for that species rises dramatically (A. Rhyne, personal communication, January 12, 2012). The industry naturally tries to supply enough of that species to meet high demand, and the market rapidly becomes inundated. This once high-value species no longer has perceived rarity by consumers, which drives down both demand and price. In order to avoid this problem, producers should carefully decide how much to export. If too many of one species are grown out together in a Micropod™, managers could simply keep some of the fish in the Micropods™ and sell them on the market in limited quantities over time to retain their value. In addition, importers may want to deal with fewer suppliers and would prefer an operation that consistently supplied a wide diversity of species.

Replacing destructive harvesting methods in favor of methods like PCC is a necessary step, but reefs that have already been decimated are also in dire need of restoration. Restocking the reef with some of the grown-out larvae from Micropods™ could help restore wild populations. Indeed, some species are too aggressive or inappropriate for the ornamental trade. Once these undesirable species are identified, they can easily be released onto the reef. Studies have shown successful survival rates after re-releasing captive-raised fish into a reef habitat (Bala, 2008). Conservation organizations may be interested in funding this type of mariculture operation if restocking proves a viable and lasting method for restoring fish populations.

As previously discussed, roving collection makes it difficult to enforce against cyanide use and overharvesting. If a community is invested in running a mariculture operation that involved PCC and open-ocean structures such as Micropods™, they could effectively police the supplying reef area and grow-out structure, thus providing protection against roving collectors.

Potential barriers

Although PCC combined with an open-ocean grow-out phase shows potential for success, this combination of techniques has not been attempted for marine ornamental species on a commercial scale. There are many unknown variables to consider before implementing a mariculture system of this complexity.

Environment management. Environmental impact assessments have not been performed on Aquapod™ grow-outs with ornamental fish, and there are logistical considerations for transfer of post-larval fish from the reef to the Aquapods™. In the near future, this type of operation should use an adaptive management approach during an experimental ornamental fish grow-out in an Aquapod™ or conduct modeling and small-scale laboratory experiments. These issues must be addressed before recommending this method to producer communities who will ultimately depend on the operation to support their livelihood.

Market contracts for mariculture

Well-managed contract farming is considered an effective way to resolve many of the supply chain and market access problems that small farmers face (Root Capital, 2012). Paralleling the plight of many small farmers and agricultural producers around the world, producers in the marine ornamental trade could implement the practice of contract mariculture to leverage their product in the market. An additional factor to consider is the potential for providing a direct marketing guarantee of harvesting practices that would be in compliance with warranties for fish health. If stores were mandated to use warranties then they may be more likely to purchase fish that they know are sustainable as could be guaranteed by a direct market contract. The economic implications of the warranties for retailers has been determined by the market analysis section of our research.

The PCC and Micropod™ technology has great potential, but other factors such as a coastal community's social and political capacity need to be conducive as well. In the following section of this report, we examine technical feasibility, current legal and political status, business considerations, and community dynamics of the Coral Triangle, all of which will ultimately affect the viability of any mariculture operation proposed in the area.

Legal considerations and framework

The Coral Triangle is formed by Indonesia, The Philippines, Papua New Guinea, The Solomon Islands, Timor-Leste, and Malaysia. Their laws are by no means uniform, but have several key aspects in common that could be advantageous to communities engaging in alternative methods of marine ornamental production, especially mariculture. The Coral Triangle Initiative (CTI) is multilateral partnership formed in 2009 between the six countries to address the threats facing their coastal and marine resources. Each country adopted its own version of a CTI Plan of Action in 2009-2010, but the following themes are common in either the CTI Plan of Action or their own domestic laws and policy publications:

- More effective management and more sustainable trade in live-reef fish and reef-based ornamentals.
- Implementation of community-based adaptive management plans for profitable, sustainable harvest of marine resources.
- Cooperation with international and national organizations to facilitate communities gaining technical knowledge and business skills (CTI-CFF, 2009).

Overall, governments have recognized alternative methods of producing marine resources as a beneficial future trajectory, and have made a concerted effort to streamline regulations to encourage community-level producers. While the Food and Agriculture Organization of the United Nations (FAO) provides a more in-depth look at national fisheries policies, relevant laws are highlighted below. Additionally, while many laws and legal frameworks are available from either FAO or the country's government websites, it is possible the published laws are not strictly enforced, or that other laws and regulations may be in place and be completely unpublished, especially in the less developed nations such as Timor-Leste and Papua New Guinea.

Political stability

We included political stability in our evaluation because our analysis strongly indicates that international partners will be crucial to a successful aquaculture venture; additionally, political stability is an important consideration for logistical and security reasons regarding foreign NGOs working in these countries, as well as to any potential partners or investors. We chose to use Polity Fragility Scores as our metric, because they assign a quantitative value to governing institutions' effectiveness and legitimacy in four distinct areas: security, political, economic, and social effectiveness and legitimacy. While the entire political realm of a country cannot be captured in one score, it is a useful tool when assessing the risk of an international investment and polity scores are widely regarded as a robust metric (Hadenius & Teorell, 2005; Rydland et al., 2008).

Countries are scored on a scale of 1-25 points measuring legitimacy and effectiveness of governing institutions with the following interpretation:

> A country's fragility is closely associated with its state capacity to manage conflict; make and implement public policy; and deliver essential services and its systemic resilience in maintaining system coherence, cohesion, and quality of life; responding effectively to challenges and crises, and continuing progressive development. (Marshall & Cole, 2010: 7)

Extreme Fragility: 20-25 points
High Fragility: 16-19 points
Serious Fragility: 12-15 points
Moderate Fragility: 8-11 points
Low Fragility: 4-7 points
Little or No Fragility: 0-3 points

Within the Coral Triangle, Malaysia is assigned a "low" fragility rating; Indonesia, the Philippines, the Solomon Islands, and Papua New Guinea are in the "moderate" category; and Timor-Leste is considered "serious" (Marshall & Jaggers, 2010). Using these metrics, along with political information from the CIA WorldFactbook and current events, we made recommendations about the suitability of each country for a startup mariculture operation, summarized below in Table 15. A more complete analysis of each country's Polity Fragility Score is included in the national stability section below.

Table 15. Political stability summary for the Coral Triangle nations. Recommendations are based upon the Polity Fragility score metrics and political information from the CIA WorldFactbook and current events.

Country	Polity Fragility Score	Suitable or Unsuitable
Indonesia	10	Suitable
Malaysia	5	Suitable
Philippines	11	Suitable
Papua New Guinea	10	Not Suitable
Solomon Islands	9	Possibly Suitable
Timor-Lest	13	Not Suitable

Legal profiles for each country within the Coral Triangle

Indonesia

Current Status of Fisheries and Aquaculture. Indonesia has 5.8 million km^2 of marine areas and 81,000 km of coastline. Ornamental export in fish, corals, and shells in 2004 was valued at USD $17,220,361, or about 1% of total fisheries exports. Aquaculture production accounted for approximately 26% of total fisheries, with mariculture (not distinguished between food and ornamental production) forming approximately 28% of aquaculture production. Current mariculture operations are dominated by seaweed, grouper, lobster, and abalone (Suastika, 2008).

The Directorate General of Aquaculture has identified approximately 121,390 km^2 of area as "available" for mariculture, with about 12,000 km^2 or 10% of the area identified as "optimal" for mariculture, mostly in the eastern part of the Indonesia Archipelago because of its lower annual precipitation and higher solar radiation (Suastika, 2008).

Indonesia has tremendous potential to expand its mariculture industry. The Indonesian government has identified mariculture as a method to reduce the widespread poverty in the country and has developed Technical Implementation Units (TIUs) across the country with the mission of propagating aquaculture technology and providing training and education for all types and levels of aquaculture (Suastika, 2008).

Legal Framework. Along with the multilateral CTI, Indonesia's own National Plan of Action includes a goal to "develop community based capture fisheries and aquaculture enterprises in the border and remote areas."(CTI-CFF Indonesia, 2009: 34). The main fisheries authority in Indonesia is the Ministry of Marine Affairs and Fisheries. On matters related to aquaculture, the Ministry operates through the Directorate-General of Aquaculture Development. The national Fisheries Law No.

31/2004 regulates fisheries and aquaculture at the national level and underscores the importance of sustainable use of aquatic resources in the development of fisheries; however, Law No. 22/1999 on Regional Administration notes that provincial governments are held responsible for the management, use and conservation of marine resources in their own territory. This regional difference in legal policy and enforcement has created barriers to environmental protection initiatives in the past, and is one of the reasons for favoring small-scale production instead of large-scale reform. In Indonesia, small-scale fisherman and fish breeders are exempt from the Government Regulation No. 54 of 2002 on Fisheries Business, which requires a permit with an extensive application process to be procured before engaging in any fishery. The law also stipulates that, "the government shall consider small fishermen and small fish breeders as a protected category and provide them with loans, local or foreign funds, education, and training" (FAO Indonesia, 2012). An Environmental Impact Analysis (EIA) is required for any activity likely to have a major impact on the environment.

National Stability
Polity Fragility Score for Indonesia: 10 (Moderate)
Indonesia's democratic regime has been in place since 1999 and is considered to have high legitimacy, but its effectiveness is hampered by persistent security concerns as it transitions to a more democratic government (Marshall & Jaggers, 2010a). The government faces the dual challenge of expanding infrastructure and broad economic reform to allow Indonesia to expand and grow, but with 13.3% of the population living in poverty, such projects have yet to garner widespread public support (CIA World Factbook, 2012a). However, despite security concerns, conclude that Indonesia is an excellent candidate for additional mariculture operations and would be receptive to outside partnerships, especially those that focus on poverty alleviation in coastal communities.

Malaysia
Current Status of Fisheries and Aquaculture. Malaysia has a coastline of 4,800 km, much of which is lined with mangrove forests. Malaysia's tropical climate and abundant natural resources give it excellent potential for mariculture and aquaculture development. Coastal Malaysian fisheries face problems of overexploitation and as yet there is little investment or equipment to support deep-sea fishing. As a result, the government is relying on expansion of aquaculture to meet the demand for marine products in the future, but is committed to ensuring that it is done in an environmentally friendly, sustainable manner to avoid the short-sighted mistakes that have been made in capture fishery management.

To that end, various government agencies and institutions have been getting involved in research and development, education of stakeholders, and commercialization of the industry. They are actively encouraging partnerships with international or foreign organizations in order to bring capital and technical expertise (CTI-CFF Malaysia, 2009).

Marine fisheries in Malaysia are valued at approximately $1.61 billion USD per year. Aquaculture accounts for roughly 10% of annual fishery production or approximately $50 million USD per year. The top cultured species are cockles (44%), shrimp (22%), and seaweed (21%). Finfish and mussels are also cultivated, accounting for approximately 6% each of total production (Othman, 2008).

Since most fishing or culturing activities are either subsistence level or for domestic consumption, the Malaysian government is primarily interested in food fish. The government has ambitions to utilize the expansion of aquaculture to bolster food security, increase national revenue from exports, and contribute to poverty alleviation by increasing incomes of producers (CTI-CFF Malaysia, 2009) Ornamental production alone can fulfill two of the three goals, but would be a more attractive proposition if coupled with food fish production.

Legal Framework. Along with the multilateral CTI, Malaysia's own National Plan of Action includes the following goals:

- Rehabilitate abandoned shrimp farms to their natural state or for other sustainable aquaculture uses.
- Develop a program for the coastal community and fishers to report illegal activities.
- Achieve a more effective management and more sustainable trade in live-reef fish and reef-based ornamentals (CTI-CFF Malaysia, 2009).

The Director-General of Fisheries, head of the Fisheries Department, in consultation with the State Authority, is responsible for the development of marine and inland farming, including promoting inland aquaculture through the creation of experimental aquaculture stations for demonstrative purposes, fish-breeding facilities and training centers. Marine fisheries and aquaculture is considered a federal concern and is governed under Fisheries Act No. 317 (1985) and Fisheries (Marine Culture Systems) Regulations (1990). Additionally, any water use is governed by Waters Act No.418 (1920, as amended) and generally requires a license. In the event that an aquaculture project will require clearing of a mangrove swamp and covers 50 hectares or more, the project may be subject to an Environmental Impact Assessment Procedure (FAO Malaysia, 2012).

National Stability

Polity Fragility Score for Malaysia: 5 (Low Fragility)

Malaysia has had constitutional monarchy since 1957 and its government is classified as both legitimate and effective. There have been no serious violent outbreaks since 1969 and while the government has been accused of repressive tendencies, elections and power transitions have been peaceful (Marshall & Jaggers, 2010b). The government has historically favored pro-business policies as a tool to shift Malaysia's economy away from raw materials export and towards manufacturing, services, and tourism, although exports remain an important component of the economy. Under the current administration, Malaysia is attempting to reach "high income status" by 2020 (CIA WorldFactbook, 2012b). We conclude that Malaysia would be an excellent candidate for a mariculture operation, and highly receptive to outside organizations.

The Philippines

Current Status of Fisheries and Aquaculture. Aquaculture is a crucial component of the government's food security and poverty alleviation goals. In 2003, aquaculture production amounted to approximately $600 million USD, and accounts for about 45% of total fishery production (commercial and municipal fisheries contribute about 30% each). Brackish water fish pens and cages are used to culture milkfish, prawns and tilapia. Oysters and mussels are farmed in coastal waters. Marine production also provides employment to approximately 1.6 million people, although in 2004 less than 20,000 were employed in the aquaculture sector (Rosario, 2008).

The Philippine government has expressed concerns about being forced to choose between food security and environmental protection. One promising initiative of the Philippine government is the creation of mariculture parks: developing a grid-type cluster of marine sea-cages with a mooring facility at the village level (at least $1km^2$) (Rosario, 2008).

This initiative is intended to alleviate poverty through alternative sources of livelihoods for skilled fishers to expand the mariculture industry. It would also motivate communities to provide their own security to protect their resources. The most up to date information from 2008 indicates there are currently ten such parks open and currently operating, with four additional proposed sites (Rosario, 2008).

Legal Framework. Along with the multilateral CTI agreement, the Philippines' National Plan of Action includes the following goals (CTI-CFF Philippines, 2009):

- Develop and implement sustainable live reef fish trade (LRFT) management plans
- Develop full-cycle mariculture projects for live reef fish species, especially high value species
- Improve capacity for cyanide detection test laboratories
- Conduct assessment and develop management schemes for reef-based ornamentals

Fisheries, aquatic resources, and the development, management, conservation, and utilization thereof are regulated by the Philippine Fisheries Code (2008) in The Philippines. Chapter II, Article III (Sections 45-57) of the Code deals specifically with aquaculture. Additionally, anyone wishing to enter the aquaculture industry must reference Fisheries Administrative Order No.214 (2001): The Code of Practice for Aquaculture, which details specific practices and guidelines for sustainable development within the aquaculture industry. Like other nations in the Coral Triangle, local laws may differ from federal ones, and in the Philippines coastal waters fall under the responsibility of the municipal or city governments (FAO Philippines, 2012).

National Stability
Polity Fragility Score for The Philippines: 11 (Moderate Fragility)
As a democracy, the Philippines scores well on regime legitimacy, although its effectiveness score suffers because of security concerns stemming from insurgencies from dissenting ethnic and political groups (Marshall & Jaggers, 2010c). Despite stable economic growth throughout a global recession, poverty has increased to a 33% level because of high population growth and unequal access to resources (CIA WorldFactbook, 2012c). Despite security concerns (which tend to be concentrated regionally, we find the Philippines to be a good candidate for a start up mariculture operation, especially ones that focus on coupling environmental protection and local employment.

Papua New Guinea
Legal Framework. Along with the multilateral CTI agreement, Papua New Guinea's own CTI National Plan of Action establishes several very specific goals with the aim of encouraging sustainable aquaculture and/or mariculture, including, but not limited to:

- Channel funding to National Development Bank targeted towards promoting micro- and small-scale fisheries through the National Fisheries Authority
- Build a mariculture Research Station in Kavieng.
- Develop a national management plan for the ornamental fishery.
- Educate and train fishermen to understand LRFF trade and ornamental fish (CTI-CFF, 2009).

The National Fisheries Authority Corporate Plan for 2008-2011 notes that:

> The concept of "fishermen communities" has limited applicability to Papua New Guinea. Nearly all households in coastal villages are involved in fishing activities. It could therefore be stated that all coastal villages in PNG are "fishing communities". (NFA, 2008: 12)

However, the plan has listed the promotion and development of sustainable aquaculture and fisheries as a priority action, specifically noting that consultation with international and national stakeholders in the areas of research, education, and development opportunities will be a crucial part of such ventures.

According to the Papua New Guinea National Fisheries Authority, the government is favorably inclined to support sustainable mariculture efforts, including those involving outside stakeholders. Commercial mariculture in the form of giant clam harvesting for pearls has only been established in one known location but the fisheries authority is optimistic about its potential to increase export revenue, although it sees mariculture as a complement to, rather an a replacement of, capture fisheries (NFA, 2010).

National Stability
Polity Fragility Score for Papua New Guinea: 10 (Moderate Fragility)
While Papua New Guinea is a democracy, its economic policies have been questioned both in terms of legitimacy and effectiveness. They are unable to address either the high levels of unemployment or the gang violence and insurgency it has contributed to. Unemployment is approximately 70% and high levels of poverty, crime, and gang violence threaten to undermine the stability of the country (Marshall & Jaggers, 2010d).

Numerous active volcanoes, frequent earthquakes, mudslides, and tsunamis have exacerbated this instability. Papua New Guinea is home to one of the most heterogeneous indigenous populations in the world. There are thousands of small but distinct communities, many of which have been at war with their neighbors on and off throughout history, and the hostilities show no signs of ceasing (CIA WorldFactbook, 2012d). As recently as January 2012, a small group of military rebels mounted an unsuccessful coup that lasted less than a week but managed to take over several buildings in the capital city of Port Moresby (*The Economist*, 2012). In the same week, a major mudslide estimated to be a kilometer long and several hundred meters wide buried two villages and killed almost 60 people and stranded 4,500 in a remote, mountainous region of the island (Kerr, 2012). Due to the political and geographic instability of the nation, we cannot recommend Papua New Guinea as a suitable site for startup mariculture operations.

The Solomon Islands
Legal Framework. While the Solomon Islands is a signatory to the multilateral Coral Triangle Initiative, its own National Plan of Action does not explicitly address aquaculture or mariculture, although priorities goals do include communication and education to encourage community-based integrated fishery management for both profit and food security. The most relevant piece of legislation is the Fisheries Act of 1998. It is currently under review and expected to be significantly adapted to reflect the commitment to profitable and sustainable use of marine and coastal resources (CTI-CFF SI, 2010: 45).

However, while explicitly defined fishery and aquaculture laws are not readily available, in 2009 the Ministry of Fisheries and Marine Resources (MFMR) published an Aquaculture Development Guide (SI MFMR, 2009) with the aim of using aquaculture to meet the food and income requirements of a growing population, especially by encouraging partner agencies. The document provides a list of challenges the nascent industry will face, provided below, including (but not limited to):

- A historically unstable government
- Lack of clear policies to either govern or encourage aquaculture
- Lack of technical expertise and business skills
- Lack of infrastructure to support an export-based business

While the report notes that farmed corals have an increasing value in the market and recommends that coral farming should be encouraged, the MFMR has legitimate reservations about the viability of larger scale aquaculture without intensive support and guidance from an outside organization. Such organizations are already present and facilitate the farming of giant clams, crustaceans, and some fish species, including those raised by more sophisticated PCC methods. [See Appendix M: Case Study: Coral Farming in SI, p 160] However, the MFMR believes the ornamental industry's capacity is limited by current export logistics, noting:

> There are only two exporters of aquarium fish/corals in Honiara [the capital city, located on the island of Guadalcanal]. Both supply the same wholesaler in the U.S. and only a fixed amount of farmed corals can be shipped in the limited weekly air-cargo freight space, although this is changing with more airlines flying to and from Honiara. (SI MFMR, 2009: 30)

Additionally, the MFMR performed an analysis on different types of domestic aquaculture to determine potential positive national impact and economic feasibility and determined that while it has potential to make a positive impact, it has a low potential for successful developing into a profitable commodity. Historically, aquaculture operations have had mixed results due to ongoing ethnic conflicts and government instability, which resulted in the destruction of the Coastal Aquaculture Center (operated by the WorldFish Center, an international NGO) in 2000. The Solomon Islands are committed to encouraging aquaculture, but while they remain amenable to international partners' efforts in the aquarium trade, they are choosing to prioritize the production of food fish over ornamentals (SI MFMR, 2009).

National Stability
Polity Fragility Score for The Solomon Islands: 9
Despite the Solomon Island's critical self-assessment, Polity rates their parliamentary democracy as highly legitimate and moderately effective in the last 10 years, although ethnic groups continue to clash over island government and land ownership policies (Marshall & Jaggers, 2010e). The Regional Assistance Mission to the Solomon

Islands (RAMSI), a task force of police and military primarily from Australia who entered the country at the Prime Minister's invitation in 2003 maintain a very small contingent on the islands, although it has been scaled back in recent years (CIA WorldFactbook, 2012). However, given that the Solomon Islands already hosts at least one successful mariculture operation (App. M), we conclude that the Solomon Islands may be suitable for additional mariculture operations, although security concerns may have to be addressed.

Timor-Leste

Legal Framework. Along with the multilateral CTI agreement, Timor-Leste's own CTI National Plan of Action prioritizes the following goals:

- Support sustainable alternative livelihoods and Food Security programs for communities in Coastal Communities.
- Start implementing community-based fisheries management scheme in selected priority areas.
- Develop an Aquaculture Development plan that will become a part of Timor-Leste's coming National Development/Strategic Plan (CTI-CFF TI, 2009).

The legislation relevant to aquaculture in Timor-Leste is Decree-Law No. 6/2004 Of 21 April 2004: General Bases of the Legal Regime for the Management and Regulation of Fisheries and Aquaculture. This law provides rules on aquaculture activities and establishes the state as the ultimate owner of the country's fishery resources, giving it the right to determine how they can and should be utilized.

Overall, the law takes a favorable view of aquaculture, even going so far as to create a Marine and Aquacultural Development Fund (drawn from tariffs and fishing permits) to research how best to exploit marine and aquaculture resources. Similar to other Coral Triangle countries, Timor-Leste demands a permit for aquaculture activities, but exempts small operations or those that take place on private property. The law acknowledges the lack of resources within the country and encourages cooperation with international partners to increase scientific knowledge (FAO TL, 2010).

National Stability

Polity Fragility Score for Timor-Leste: 13 (Serious Fragility)

The publishers of Polity question both the effectiveness and legitimacy of Timor-Leste's regime, especially in the area of economics, as over a quarter of the population was displaced and over 70% of the country's infrastructure was destroyed in 1999 during a large-scale civil conflict. Timor-Leste has made great strides in rebuilding, but poverty and political divisions persist (Marshall & Jaggers, 2010f). One such political division led to a UN Peacekeeping Mission in 2006 and a failed coup in 2008. Currently, Timor-Leste is in its longest-ever stretch of peace since gaining independence from Indonesia in 1999. The government has increased spending on basic infrastructure, with a focus on providing access to electricity and roads (CIA WorldFactbook, 2012f). Despite this optimistic outlook, we cannot currently recommend Timor-Leste as a suitable site for a mariculture operation. In the future, its suitability may change, but its political instability make security concerns too high.

Local enforcement of laws

Several well-researched reports, along with overwhelming anecdotal evidence, indicate that many of the national or regional laws regulating fishing or marine harvesting activities are poorly enforced, subject to bribery and corruption, and ignored altogether in some cases (Bellamy & Winsby, 2008, EC-Prep, 2005:15 Wood, 2001:30,). Many well-documented cases show the prevalence of illegal and destructive harvesting techniques that communities ignore in exchange for a share of the harvest price or a flat bribe (Bellamy & Winsby, 2008). A far more effective model would be for the community to have an economic stake in the health of their reefs, for two reasons. First, local enforcement is far more effective than national policy (Rubec et al., 2001:124), and second, the community can retain the full economic benefit of harvesting or culturing marine ornamentals in a sustainable manner without sharing profits with outside harvesters or roving collectors.

NGO support

Our analysis indicates that support from an outside organization will be crucial to the success of any aquaculture or mariculture initiative, as local communities generally lack the technical knowledge and business expertise required for such a venture. Currently, a variety of international NGOs have bases in critical areas of the Coral Triangle. While not all of them are explicitly interested in the ornamental trade or aquaculture in general, they can act as a valuable resource of knowledge and funding for any project that involves sustainable livelihoods. The map below (Fig. 14) indicates the locations of several major NGOs including Conservation International (CI), World Wildlife Fund (WWF), The Nature Conservancy (TNC), and the World Conservation Society (WCS). We strongly recommend contacting any nearby NGOs as part of the planning process to take advantage of their expertise and resources. Additionally, NGOs can act as liaisons to community members who might be reluctant to enter into agreements or negotiations with strangers.

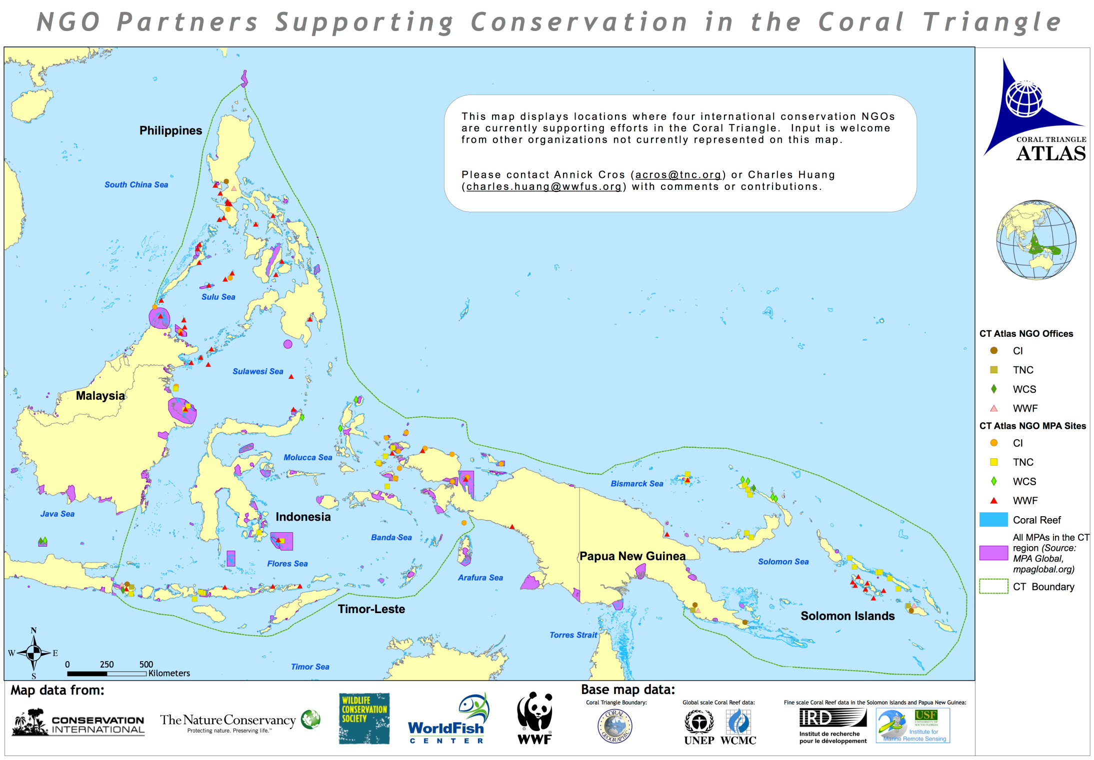


Figure 14. Map of NGO partners supporting conservation in the Coral Triangle. Map Source: Reefbase, 2009.

Demand-side market feasibility

Demand in the marine ornamental trade is highly variable but subject to certain rules and trends. Rarity is prized in the community, as experts compete to obtain elusive species. These species will command very high prices, but only as long as the number available remains small. Once the supply increases (as it can, once producers recognize and respond to the high price commanded by a given species) the demand and price will decrease, and continue to do so until it levels off at a point where "average" hobbyists will purchase them. It is important to note that the value of an ornamental species is tied to whether or not they are *perceived* as rare, not whether they actually are rare in the wild or particularly difficult to culture (A. Rhyne, personal communication, January 11, 2012). As a result, one possible business strategy that has worked in some communities is to act as a monopoly and culture a species that is endemic to the area, then control the supply by only releasing a few fish at a time, artificially keeping the demand and thereby, price high (A. Rhyne, personal communication, January 11, 2012).

Business considerations for marine ornamental production

The nature of the coral reef ornamental trade with its long supply chain, high mortality rates, and inconsistent supply and demand limits the number of production models that are well suited to marine ornamental production. Major business considerations for the feasibility of mariculture for the marine ornamental trade include: **funding**, **market share security, and identification of a willing entrepreneur.** Initially, mariculture may seem unrealistic as an alternative practice for individual producers in the marine ornamental trade due to both the potentially large startup cost and the perceived volatility of the market. However, businesses can overcome the aforementioned barriers by implementing creative couplings of business models and market strategies. Based on consultation with industry experts and our analysis of pertinent literature and the state and behavior of the marine ornamental market, potential business strategies to move the producer-side of the trade towards sustainability are outlined below, considering both the benefits and barriers of each option. The ultimate goal for a mariculture development project is to develop a sound business model with significant community ownership that provides sustainable jobs for marine ornamental producers. Thus, the goal is also to increase environmental stewardship by making the long-term health of coral reef ecosystems worth more to producers than the small short-term profits made by using destructive harvesting practices.

Funding

From production materials to distribution needs and ongoing maintenance, beginning a mariculture business could involve a large initial capital investment as well as a significant risk. While the extensive production method that this study considered could be significantly less expensive than an intensive production method, the following expenses would remain for an extensive production method:

- Open-ocean cage
- Gear
- Boat
- Labor
- Fuel
- Maintenance
- Shipping

These costs have been estimated and are included in our cost analysis that will be discussed further in this document. Generally our extensive model could save on expensive costs such as feed, packaging, and on-land tank facilities. We did predict potential returns within ten years depending upon factors such as market contracts. However, additional funding would expedite financial returns and investments.

Considering the above costs, Pomeroy et al. (2006) emphasized the point that "…[g]overnment subsidies, small business loans, and private donor investment may need to be available to small-scale [producers] for start-up and operational costs" (p. 126). While governments of some countries in the Coral Triangle support new mariculture and aquaculture ventures [see section: Legal Framework and Political Considerations], a significant portion of funding for the development of alternative collection or culture practices will most likely have to come from the private sector. These funders may include individuals, corporations, and NGOs that can provide a range of funding options for a mariculture startup.

Pomeroy and Balboa (2004) highlight the business considerations of a mariculture operation and summarize its potential in the following quote:

> [S]ubstantial work must be done to make ornamental fish aquaculture feasible and sustainable for fishing communities in developing countries. With financial subsidies for culture operations, appropriate technology transfer, a constant demand for cultured ornamental fish, and a research agenda which works to make current technologies more simple and seeks to apply current technologies to other, high-demand species, aquaculture of marine ornamental fish has the potential to be a financially sustainable solution to relieve fishing pressures on this coral reef fishery. (Pomeroy and Balboa, 2004:374-5)

The potential benefits of a privately funded and operated business.
A large-scale private mariculture operation, started by an individual or established corporation, could lead to jobs in producer nations. In addition, such an operation could possibly supply more income per person than a roving collection operation, while utilizing the area's natural resources in a more sustainable manner.

One option for funding is through social investment. Social investments are investment funds that are established with the objective of contributing to the development and social capital of developing countries. The term social capital encompasses idea that "involvement and participation in groups can have positive consequences for the individual and the community" (Portes, 1998, p. 2). Thus, social capital refers to the role of cooperation and confidence to get collective or economic results, as well as the value of the social networks within a community (Portes, 1998). Projects funded through social investments range from international poverty alleviation programs to microloans for small business owners (Morley et al., 1998). The advantages of social fund investments include: the ability to support developing countries, the potential to reduce corruption by increasing transparency, and the opportunity to introduce and finance innovations. Social funding has supported a highly community-integrated type of development, known as community-driven development (CDD). CDD projects are entirely based in local communities, in which community-based organizations make decisions about how to administrate and invest funds. The goal of this approach is to build confidence, ensure that the specific needs of a community are met in a culturally appropriate manner, and increase the transparency and accountability of the use of funds (Morley et al., 1998). Pairing social investment funding and a structured CDD project provides a viable option for developing and funding an ornamental mariculture operation for the marine ornamental trade in producer countries. However, it must be noted that social funds have been criticized for displacing existing (local) institutions and for lacking exit strategies to phase out temporary projects.

NGOs are financially capable of covering (or procuring through investments) startup costs for a producer business and then transferring the rights and responsibilities of the business to the local communities. This option, however, does not ensure the equal distribution of benefits. Equal distribution of benefits is a function of number of jobs created, wages, and gender equity for both factors. Additionally, a community may feel less commitment and incentive to maintain the business, because the local community or individuals did not invest in the operation from the beginning and were prescribed a project as a solution. Available literature and the history of NGO involvement in the marine ornamental trade show that this sort of misdiagnosis or doling out of resources seems to be a fatal trend of many best management practices campaigns (A. Rhyne and M. Tlusty, personal communication, January 13, 2012). Beyond NGO support, small-scale operations may also seek funding independently through fiscal sponsorship, microfinance, and microcredit options.

See following case studies in Appendix M for examples:

- Privately owned operation: *Marshall Islands Mariculture Farm*
- NGO-initiated operation: *North Bali Les Village Ornamental Shrimp Aquaculture*

In planning to finance a potential mariculture operation it is crucial to evaluate what size operation (i.e. how many Micropods™ and how densely stocked with fishes) is most appropriate for a given community, based on the market share size for the particular region. The extensive mariculture model that we recommend allows for the flexibility in customizing an operation to a specific community by varying some of the production variables.

Securing a market share

Potential exists for producer communities to secure a portion of the marine ornamental market through market contracts with distributors. Currently, inconsistencies on both the supply and demand side create risk for producers, distributors, and retailers. Market contracts would provide security to all parties throughout the supply chain: the producers have a guaranteed market to sell their good, and distributors and retailers have a fixed supply of products, which ideally are sustainably raised and harvested.

Clauses of a typical market contract, adapted to mariculture as a production option

1. General reciprocal obligations: the overall responsibilities of the contracting partners.
2. Specification of the mariculture product to be produced / sold under the contractual obligation.
3. Production technology to be used.
4. Conditions for purchase, payment obligations, timing and modality of delivery.
5. The system to determine the final prices to be paid to producers, frequently considering effects of variations in product quality and any applicable loan repayments associated with the provision of inputs or services.
6. Choice of a jurisdiction to govern the contract, from the legal standpoint. If the two parties are located in states or municipalities that are not in the same legal jurisdiction, then only one should be chosen to be applied.
7. Reference to a dispute settlement mechanism or to an arbitrator to resolve disagreements, which is always preferable to legal action.

Barriers to contract mariculture

The unwillingness of both distributors and retailers to enter a contract with a small-scale producer could be substantial barrier to the success of market contracts for the marine ornamental trade. However, this assumes that an increase in demand for sustainably raised species would translate into a commitment from retailers to sell sustainably raised species. In terms of mariculture as a specific production method, production may not be able to supply for the current demand. Hobbyists value diversity, and producers may not be able to ensure a level of species variety that stores, and ultimately the consumers, demand. Currently, full-cycle mariculture technology is not able to produce the wide array of species in demand.

Case Study: A Root Capital success

An example of a successful market contract and microfinance program is Root Capital. Root Capital a social investment fund that is focused on grassroots businesses in rural areas of developing countries. Root Capital was ranked 36th on the "Top 100 Best NGOs" list by Global Magazine for 2012. With a 99% repayment rate from borrowers and a 100% repayment rate to investors, Root Capital has dispersed 895 loans since the company began in 1999. In addition to providing capital, the fund also works with such businesses to provide them with financial training and to help them develop market connections that they would otherwise not be able to access due to their size and lack of resources. A market failure exists as many remote grassroots businesses are too small, thus risky, for investment by mainstream business and too large for microfinance lending. In order to address this market failure, Root Capital created a lending model to serve such businesses with a new class of capital between microcredit and commercial lending. Considering the variable size and business structure of potential mariculture operations, Root Capital may be a viable financing scheme.

Social Media and Smartphones for Sustainability: Creative direct marketing in the Marine Ornamental Trade

Quality Marine, a wholesaler based in the U.S., links producers and consumers through the supply chain with a creative use of the Smartphone realm and Quick Response (QR) code technology. QR codes are small square matrix barcodes that can store large amounts of information that can be obtained by scanning the code. Quality Marine educates and engages consumers through QR codes on tank tags for individual species. In addition to providing important information about caring for the tagged species, Quality Marine has chosen to go further and educate consumers about where the fish comes from *and* how long it was in transport from the wholesaler. This use of technology is a step in the right direction for direct marketing on the platform of sustainable supply chains and educated consumers.

Excerpt taken from Quality Marine's website:

"On each label is a 'QR code', a techy, matrix looking box. All you have to do is scan it with your Smartphone and it takes you to our mobile site where you can learn key facts about that animal. People will be able to identify an animal, see if that animal is suitable for their aquarium, what foods it needs, what country it came from, and when it arrived at and departed from Quality Marine, even if every employee in the store is busy." (Quality Marine, 2012)

Another creative marketing strategy that has taken off in the past couple of years is the use of Facebook Group Pages. Retailers commonly have pages for Facebook users to "Like" and subsequently follow the "status updates" of the chosen retailer. This mechanism allows users to stay informed about sales or specials that the retailer may have. An online distributor of aquarium fishes has taken this one step further: Wow Voyage Discus Farms from Kuala Lumpur, Malaysia, links their Facebook page to an online bidding system for fishes. By posting pictures and tracking the interest by consumers through the bidding process, Wow Voyage Discus Farms provides an innovative example of direct marketing by a single, small-scale producer. The bidding process happens before the fish are shipped, and fishes that are not bid for are not shipped, which results in a large shipping savings (Wow Voyage Discus Farms, 2012). This bidding system could also help to eliminate the waste that is a result of oversupply at the supplier end because the demand for the fish can be gauged from the bidding process. If there is a large demand for the certain fish then the producer can go out and collect more, instead of having to infer the demand when collecting initially.

Identifying a willing entrepreneur

The aforementioned constraints and options highlight the numerous and potentially complex business considerations of mariculture Therefore, successful implementation of a business depends on the identification and involvement of an interested entrepreneur (A. Rhyne, personal communication, January 13, 2012). Ideally, this entrepreneur would have had previous successful business ventures and be based in the potential location of operation. Whether or not this individual (or group of individuals) is a member of the local community or a non-local could be either a barrier or a benefit. Both the potential apprehension and mistrust of non-locals in some communities must be considered if the entrepreneur is a non-local, as well as the potential history of conflict or social structure in the community, if the entrepreneur is a local.

An entrepreneur will fulfill the following essential roles:

- The startup/establishment of the business
- The maintenance of the business (in terms of finances, marketing, etc.)
- The establishment and maintenance of market contracts with retailers in major importing countries
- Taking advantage of opportunities that arise from market variability through ongoing communication with retailers in major importing countries

While NGOs could facilitate entrepreneur involvement, the optimal situation would ivolve both an entrepreneur and an NGO. This combination could also preempt the danger of NGO pullout, which communities involved in development projects often worry about.

[See following case studies in Appendix M: “Solomon Islands Coral Farms” and “North Bali Les Village Ornamental Shrimp Aquaculture”.]

Business Recommendations

In conclusion, many factors must be considered when beginning a mariculture operation in a producer nation in the Coral Triangle. A willing entrepreneur must be identified and incorporated into the business plan for the business-side of a mariculture operation to be viable. A private venture is recommended because it will be quicker to implement on average than a publicly funded venture. Market contracts should be arranged between producers and retailers because they would increase the percentage of profits that producers receive. Additionally, market contracts could be coupled with guarantees of sustainable production practices and, consequently, fish health if retailers were to implement a warranty program. Finally, the financial feasibility of a business may depend on market contracts to command a price premium for sustainably grown species through ornamental mariculture.

A study arranged by the Secretariat of the Pacific (SPC) compiled recommendations from stakeholders to the SPC on how mariculture operations can be supported at the federal level. Suggested solutions recommended providing development assistance in the following areas (Lindsay, Ledua, & Stanley, 2004, PAGE 7):

- Human resource skill development
- Infrastructure development
- Marketing and business skills development

These are important considerations for NGOs when assessing the general suitability of an area is for a mariculture operation. If development is lacking in the above-described areas then the establishment of a mariculture business may not be suitable. It is suggested that an NGO seeks to partner with a federal agency, such as the SPC, in order to provide the necessary development assistance prior to starting a business venture.

Social Considerations

Consideration of the social dynamics in producer communities is essential to the success of a mariculture business. Major social considerations for the feasibility of mariculture for the marine ornamental trade include: **a co-operative production model**, **community dynamics, and gender roles and considerations.** The failure to address these considerations could fatally hinder the success of a mariculture business, even if the business were financially viable and technically feasible. While these are the major and most evident concerns, other site-specific considerations may exist. As a result, there is no substitute for on-the-ground knowledge and experience.

Co-operative mariculture

A co-operative model is a production-side solution that could ensure accountability and transparency and thus make certain that profits are returned to and invested in the producer communities (A. Rhyne and M. Tlusty, personal communication, January 13, 2012). The International Co-operative Alliance defines a co-operative as "…an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly owned and democratically controlled enterprise". The function of the co-operative is to provide greater benefits to the members by increasing individual incomes or enhancing a given member's livelihood by providing important needed services (Rapp & Ely, 1996). In theory, a co-operative is not designed with the primary intention of maximizing profits. However, profits are necessary in our scenarios to run the business without continual external funding and NGO support. We recommend that a mariculture co-operative should be designed as a for-profit co-operative, as opposed to a non-for-profit co-operative. As a for-profit co-operative, members would redistribute surplus profits (dividends) amongst themselves. The British Columbia Institute for Co-operative Studies (BCICS) recommends that these dividends are proportional to each member's business transactions with the co-operative during the given fiscal year.

Co-operatives differ from other businesses because they are user-owned, user-controlled, and user-benefited (Rapp & Ely, 1996). Given the startup cost and the level of community coordination that would be involved in planning for a mariculture operation using a combination of PPC and grow-out in Micropods™, we recommend a co-operative structure for a business.

Types of co-operatives

A co-operative model can be implemented at a variety of stages within the production process, as well as along the supply chain. As a result, there are many potential types of co-operatives. It is important to understand the different types of co-operative possible, because the needs and the capacity for developing a mariculture co-operative will vary amongst producer communities. Some communities may be able and wish to fully cooperate, while others may not. Different types of co-operatives and examples for co-operative mariculture are outlined below.

A **marketing co-operative** includes all activities needed to move a product from production to consumption, including: planning production, raising and harvesting, packing, transport, storage, processing, distribution and sale.

Example: A marketing co-operative could be done in an ornamental mariculture marketing co-operative through the promotion of a certain species within the aquarium trade.

A **supply co-operative** functions to aggregate purchases, storage, and distribution of inputs for co-operative members. Supplies needed to run a given production operation are bought in bulk for member cost savings.

Example: A supply co-operative for mariculture producers could include bulk purchases of diving gear, boat parts, nets, etc.

In a **production co-operative**, production resources, such as land or equipment, are pooled and owned jointly by all members.

Example: A production co-operative for mariculture production could share Micropods™, boats, and vehicles.

A **service co-operative** finds its advantages in processing, shipping, and/or packing orders of multiple producers en masse for cost savings; also, a service co-operative can fill large orders with smaller contributions from multiple producers.

Example: A service co-operative could send organisms harvested by separate producers in bulk to save on the costly airfare. Additionally, a service co-operative could be formed amongst producers that use sustainable practices to harvest or cultivate species. If the co-operative could guarantee such practices, and thus better health of the fish, then species may be sold at a price premium.

[For a case study, see *Soloman Island Coral Farm* in Appendix M]

The benefits of a co-operative model

Co-operative ornamental mariculture has the potential to work in a variety of socio-economic and ecological conditions in producer nations. Founded on and guided by the seven co-operative principles as defined by the Rochdale Principles (outlined below), co-operatives are designed to be conscious of their impact and largely invested in the betterment and education of local communities:

> [V]oluntary and open membership; democratic member control; member economic participation; autonomy and independence; education, training and information; cooperation among co-operatives; and concern for community. (International Co-operative Alliance, 2011)

Co-operatives have also been shown to be resilient in the face of economic recessions. A study by the International Labour Organization as part of the Sustainable Enterprise Programme provides historical evidence that co-operatives in all sectors survive better than their competitors in times of economic recession

(Birchall & Ketilson, 2009). Additionally, the study proclaims that when compared to conventional businesses, co-operatives have a higher survival rate as new start-ups. The same study also showed longevity (both success and permanence) of co-operatives to be "impressive". The ability of co-operatives to pool and use member capital instead of borrowing from banks allows them to provide goods and/or services to a market of risk-averse consumers and middlemen (Birchall & Ketilson, 2009).

We see co-operative a more viable way of running a mariculture business in the Coral Triangle for two main reasons:

1. Cooperatives differ from other businesses because they are member-owned versus investor-owned; thus, they operate for the benefit of members, rather than earn profits for investors. We believe that this can help to increase the transparency and community acceptance of the business. This assumes that there is more trust amongst community members than there would be between community members and foreign investors.
2. Since co-operatives are democratically run, all members have equal say as to the running of the business, regardless of the number of shares that they own or the amount of business that they bring in. We believe that this help can help to insure a more widespread involvement and commitment from producers to both the business and the stewardship of the environment.

Barriers to co-operative mariculture

Barriers to creating co-operative mariculture include the lack of stakeholder (mainly individual producers) and/or community interest. Any preexisting distrust amongst producers participating in the trade, as well as a climate of distrust within the community, could hinder the creation and success of a co-operative of any type.

Another barrier is legislation that regulates the establishment of co-operatives in producer communities in the Coral Triangle. Table 16 outlines the two major restrictions for establishing a co-operative in three out of the six Coral Triangle nations (FAO, n.d.).

Table 16. Relevant restrictions on co-operatives in select Coral Triangle nations.

Nation	Minimum number of members	Maximum length for registration
Indonesia	No restriction	6 months
The Philippines	15 members	30 days
Malaysia	100 members*	No restriction

* Reduced to 50 members if qualify as an agriculture cooperative with the Farmers' Organization Authority.

Additionally, Timor Leste has support for the development of co-operatives written into the national constitution (Article 138) (Hanjam, 2008). As with all of our legal and political recommendations, we suggest that any laws and community customs be confirmed through communication with relevant government agencies and in interviews of community members.

Relevant case studies

EcoAquariums in Papua New Guinea [See Appendix M] provides an example of a business that considers the volatility of demand in order to avoid reckless overfishing of endemic species.

The **Solomon Island Coral Farm** [See Appendix M] is a for-profit operation where a for-profit business based in the U.S. utilized stakeholder involvement (in the form of community leader support) to develop a coral farming business. By approaching a producer community mariculture in such a way, NGOs and private business ventures can garner more confidence and support from a community.

While not an explicit business operation, **Apo Marine Sanctuary** in the Philippines [See Appendix M] employed the same type of community involvement when creating a marine protected region, which has led to the rehabilitation of the fishery. In reality, this may be a necessary and precursory step for producer countries that are already experiencing fishery collapse.

Community dynamics: Gender roles and considerations

> [F]or research and development in mariculture to support poor people's livelihoods, people and communities must be placed at the centre of development planning, where an understanding of their livelihoods will require a comprehensive and broad-based approach that goes beyond a focus on assessments of locally available resources and technologies…[A]n acknowledgement and understanding of the complex nature of livelihoods in poor coastal communities is essential (Gonzalez et al., PAGE 83).

In order for a co-operative to be a viable solution for an extensive mariculture operation they will need to account for how to appropriately incorporate the current community and livelihood structure. Additionally, a successful co-operative will need to understand the gender roles in producer communities and address what their impact will be on these roles. Such impacts would ideally include: monetary compensation for work and access to additional education and stewardship; the latter could be achieved through partnership with a locally based NGO.

The role that women play in the marine ornamental trade in producer communities may not be blatantly apparent, but women play a key role in many collection operations in producer communities (EC Prep, 2003). Thus, the most effective change will come from understanding the gender dynamics of a given producer community, given the cultural nuances, as well major differences in gender roles between communities—even within a single country.

A comprehensive study funded by EC Prep (2003) looked at the different gender structures in two distinct communities in Indonesia as they relate to the dual goals of improving livelihoods while promoting sustainability. The Banggai Archipelago and Banyuwangi were chosen as case studies for Indonesia, as they flanked the range of different involvement and affiliation that coastal communities have with the marine ornamental trade (EC Prep Project EP/RO3/R14, 2003, PAGE xv). The study defines the gender issue for women in the trade in Indonesia in the following way:

> *"Women often have little say in how money is used when they do not earn it. Without education, women find it hard to make a living, even more so than men who can do quite well-paid unskilled work. Marriage as a way to securing a livelihood is not necessarily a safe option"* (EP/RO3/R14, 2003, PAGE xxxii).

While most women are not commonly on or in the water with the men harvesting fishes, they play a crucial role in "preparation and post-harvest activities" (EP/RO3/R14, 2003, p. xiii). Women were identified to work as screeners and aquarium cleaners alongside men. Screeners work at the exporter level and are "skilled and experienced" individuals that are charged with the task of evaluating fishes for quality and acceptability; only those fish that pass this evaluation will be paid for (EP/RO3/R14, 2003, p. xviii). Additionally the EC Prep study noted that the staff of screeners are also sometimes in charge of "finding of fish that are ordered by buyers but not in stock" (p. xviii). Another example is in The Soloman Islands, where one of the few economic opportunities for women is coral culture, which also happens to be largely managed by women (Tlusty, 2002).

The study also found that most families in the Banggai ethnic group have farming as a "main or important secondary occupation" (EC Prep Project EP/RO3/R14, 2003, p. xxviii). This highlights the complexity of developing solutions for producer communities because marine ornamental harvest and culture are often not the sole livelihoods of producers. It is important that an NGO understands that producer participation in the marine ornamental trade is often as part of additional or supplemental livelihood. This understanding may be crucial when gauging producers' interest in starting a mariculture co-operative.

The FAO Fisheries Proceeding of 2008 features a study by Gonzales et al. on the livelihood opportunities associated with the development of mariculture, which found similar patterns to the EC Prep Project study (2003). Many of these stakeholders throughout the Asia-Pacific region that were identified as participating in the marine ornamental trade were women who are heavily involved in the processing of aquatic products throughout Asia. One example is in Vietnam, where women account for 90 percent of the labor force for processing aquatic products (Gonzales et al., 2008, p. 91).

Using local input and knowledge from on-the-ground observations, mariculture businesses and NGOs alike should consider and try to optimize the equal employment of men and women, in an attempt to further the goals of gender and livelihood equity. The study by Gonzales et al. (2008) stresses the importance of identifying appropriate "entry points", when trying to positively affect livelihoods. These entry points would be defined by the time, location, and social climate deemed appropriate for carrying out a development project. These entry points are important considerations when establishing a co-operative. It is suggested that, by using a livelihoods-based approach, appropriate low-risk entry-points are identified where "coastal communities (including women) can become involved in mariculture activities and where they can receive maximum benefits" (Gonzales et al., 2008, p, 84). Additionally, these areas or communities would need to be identified as technically and culturally appropriate for "mariculture interventions" (Gonzales et al., 2008, p. 84). On a larger scale, the study calls for the continued recognition by regional government of the need for "pro-poor mariculture policies" (Gonzales et al., 2008, p. 82).

Social conclusions & recommendations

We suggest a co-operative production model as a way of ensuring equitable distribution of income across the community while increasing the accountability and transparency of a mariculture operation in a given producer community in the Coral Triangle. On-the-ground knowledge and experience is necessary to inform an NGO on how to appropriately incorporate the current community and livelihood structure into the business structure of a mariculture venture. This would be an important step in determining community interest and thus the availability and number of workers. We also suggest that the parent organization assesses preexisting gender roles within a given community and determine the potential impact of a mariculture venture on these roles.

The NGO must consider how and if a mariculture project and/or venture would be accepted by local communities. The best-case scenario would be to have community buy-in in the form of a co-operatively owned business. If the community or the participating producers are initially unable to provide funds to establish the business in a co-operative manner, then the NGO can fund the establishment of the business and hand over the business to the community in the future. However, a plan for doing so much should be drafted and approved by the community prior to the start of the venture.

Cost-Feasibility Assessment

Benefits of the cost-function analysis

We compiled our analyses to investigate the feasibility for a coastal community to operate a combined PCC and open-ocean mariculture system in the Coral Triangle. Based upon our case study literature review and economic analyses, we developed a cost-function model that would help predict the potential economic effects under various market scenarios. We believe this will be most useful for business entrepreneurs and conservation NGOs who wish to support a coastal community's transition towards sustainable practices. They will be able to estimate the costs and benefits of a PCC and mariculture grow-out system, predict revenue and profit, and calculate when they should expect to see desirable returns.

Review of our justification for choosing PCC and Micropods™
We chose to create a cost-function model that utilized PCC and Micropods™, because to our knowledge, no one has ever combined the two techniques for ornamental mariculture. In the past, many researchers have supported the potential for PCC as it could supply the market with fish that are not easily tank-bred and raised, but they note that PCC can be expensive if the postlarvae are cultured in on-land facilities. These come with high costs such as filtration, pumping, and feeding. Micropods™ incur a significant initial cost, but have the potential for alleviating annual costs by using the natural environment to provide fresh water and food found in fishes' natural diet.

Impact on the environment. One concern that could not be addressed within the scope of our project is the environmental impact of combined PCC and Aquapods™. Since this a completely novel combination of technologies and methods, it is difficult to predict impacts with certainty. However, the existing knowledge indicates that the effects will be minimal. PCC, which takes advantage of high natural mortality rates of post-larval fish, is not anticipated to have a significant effect on adult populations (Lecchini et al., 2006). Our model includes limiting the number of post-larval species harvested to less than 30,000 per year, as recommended by Lecaillon (2010) in a comparable pre-feasibility study.

Micropod™ technology has not yet undergone any formalized environmental impact studies. Offshore cage aquaculture is considered to have a lower environmental impact, as well as increase the overall health of cultured species as compared to nearshore cage aquaculture (Kirchoff et al., 2011), although there are no known studies of ornamental species.

An ongoing study (Sims et al., 2012) under a NOAA research permit in Hawai'i to assess the feasibility of raising kampachi (*Seriola rivoliana*) in drifting Aquapods™ has had three relevant preliminary results. First, the pods and associated maintenance activities had no noticeable impact on water quality or nearby wild species. Second, no significant marine mammal interactions were observed. Third, the pods appeared to increase stock density in their immediate vicinity, increasing catch of wild fish (Sims et al., 2012). While these results are optimistic, the study is still underway, and involves food fish, rather than ornamentals. We stress the need for a site specific impact assessment with the appropriate diversity of species, but believe our method can offer a more sustainable alternative to both traditional harvesting and near shore aquaculture pens.

Cost feasibility analysis formulae and criteria

For a business venture to make a profit, the capital earned from selling ornamental fish must be higher than the costs for producing the fish. These costs include the initial start-up costs and the annual costs. The general formula for a business' profit is:

Profit = Revenue – Costs
Costs = Initial Costs + Annual Costs
Revenue = Price × Quantity

Cost analysis parameters and assumptions

An ornamental mariculture system that utilizes PCC and Micropods™ is unprecedented; therefore neither a value for cost of operations nor fish production capacity exists. However, we compiled relevant information that can provide a decent estimate. We chose a scenario in which a coastal community had the following resources: four light traps, one Micropod™, one boat, SCUBA gear for three divers, one vehicle, and major maintenance gear such as a pressure washer (Tbl. 17). These would be the fixed, initial start-up costs. Annual costs would include: labor (divers, packagers/ sorters, and a project manager), fuel costs, and regular maintenance costs such as water, buckets, tank re-fills, etc. (Tbl. 18).

Table 17. Major initial costs for a PCC and Micropod™ operation. Personal communication(s) that influenced estimated values: A. Rhyne, personal communication, January 13, 2012 and F. Hurd, personal communication, February 13, 2012.

Initial Costs	Totals per year (USD)	Source
Light Trap	$300	A. Rhyne
Micropod™ with installation	$55,000	F. Hurd
SCUBA Dive Gear	$4000	F. Hurd
Boat	$2,000	Lecaillon, 2010
Pressure Washer	$2,500	F. Hurd
Car/Truck	$2,440	www.adpost.com
Total	**$64,879**	

Table 18. Major annual costs for a PCC and Micropod™ operation. Personal communication(s) that influenced estimated values: F. Hurd, personal communication, February 13, 2012.

Annual Costs	Totals per year (USD)	Source
Fuel (liters)	$7200	F. Hurd
Labor-divers (3)	$40,140	F. Hurd
Labor-project manager	$26,796	F. Hurd
Labor- harvest help	$896	www.asiafloorwage.org
Maintenance	$6,000	F. Hurd
Total	**$81,032**	

Our estimates were guided through consultations with experts in the aquaculture field, peer-reviewed and gray literature, and appropriate retailer prices from the internet. We decided upon four light traps assuming they were modified versions that would drive down the per capita cost from $300 to $75 (A. Brooks, personal communication, January 23, 2012). Depending on the stocking capacity of the Micropod™, more or fewer light traps can be used. We also decided to use only light traps rather than in conjunction with crest nets because light traps can target desirable aquarium trade species by emitting certain wavelengths of light. This may reduce the number or territorial or aggressive species stocked into the Micropods™. We decided one Micropod™ would be best for the beginning of operations, as there will undoubtedly be adaptations to management with this new technology. We believe, however, as the PCC and Micropod™ business grows to more profitable, additional Micropods™ would provide other options such as growing ornamental fish to larger sizes in which they might be either suitable for food or for re-stocking the reef.

For recurring annual costs, we incorporated salaries, fuel, maintenance, and shipping costs (Tbl. 18). We did not include costs for feed because the Micropod™ grow-out system will use plankton from ambient waters. This ensures that fish will be getting the adequate nutrients from their natural diet. If water flow does not deliver sufficient quantities of plankton, then using low-cost plankton towing nets or emersion traps can easily provide additional food. We also did not incorporate boxes and bags for shipping fish to the exporter or importer, as we assumed these would be the financial responsibility of either the exporter or importer (E. Cohen, personal communication, September 1, 2011).

Another recurring annual cost is labor wages. One of our main objectives was to investigate the potential for current collectors to reap greater benefits from the trade. We assumed our scenario should be viable only if collectors were earning more than their current wage. While roving collectors receive only $4,500 per year, we incorporated a much higher wage of $13,380 based on wages for divers on current Aquapod operations. Since Micropods™ are relatively small, three divers should be more than adequate for larvae stocking and pod maintenance. This estimate was guided by management of the larger version of the Micropod™, the Aquapod™, which requires three divers for maintenance (F. Hurd, personal communication, February 13, 2012). According to our analyses, as long as collectors are making more than $4,500, they are doing better than they were as roving collectors.

In addition to the divers, we incorporated wages for a project manager, and 16 days of additional help during harvest and packaging times. The project manager would be responsible for oversight of the operation and maintaining connections with importers and retailers in the U.S. We also strongly recommend the project manager train another individual(s) who is from the coastal community. This is in direct alignment with our objective to promote the self-capacity of coastal communities to govern their own sustainable livelihoods.

To estimate feasible levels of stocking densities of ornamentals in an open-ocean cage, we researched recommended stocking densities for ornamental fish is saltwater aquariums. Based on available data, our choice was to either compare stocking densities for ornamentals in saltwater aquarium tanks, or stocking densities for food fish in open-ocean cages. A sustainable food fish stocking density is 25-35 kg per cubic meter, while an average recommendation for the stocking density of fish in a saltwater aquarium is 1 kg per cubic meter (Microcosm Aquarium Explorer, 2008). Used the lower density for fish in an aquarium, and made it even more conservative, limiting our stocking density to 0.521 kg per cubic meter. Aquarium fish weigh an average of 8 g, which yields an ultimate stocking density of 7500 fish per grow out cycle.

Hair et al. (2007) estimated that it would take two to three months to grow ornamental fish to marketable size, so we chose four grow-out cycles per year as a conservative estimate for production. Therefore, the Micropod™ could potentially provide 30,000 fish per year. We incorporated a $150,000 loan into our cost analysis to cover the initial and first year's annual costs of the operation. The loan has a 5% interest rate with a 10-year payback period.

Cost analysis results

Figure 15 shows the profits per year for our proposed mariculture operation under different market scenarios. The pattern in the line is due to the loan we incorporated into the cost analysis. The first year sees a higher profit because the loan pays off the initial and first years annual costs. In years two through ten monthly loan payments increase the annual costs, but after the loan is paid off in year ten profits again increase.

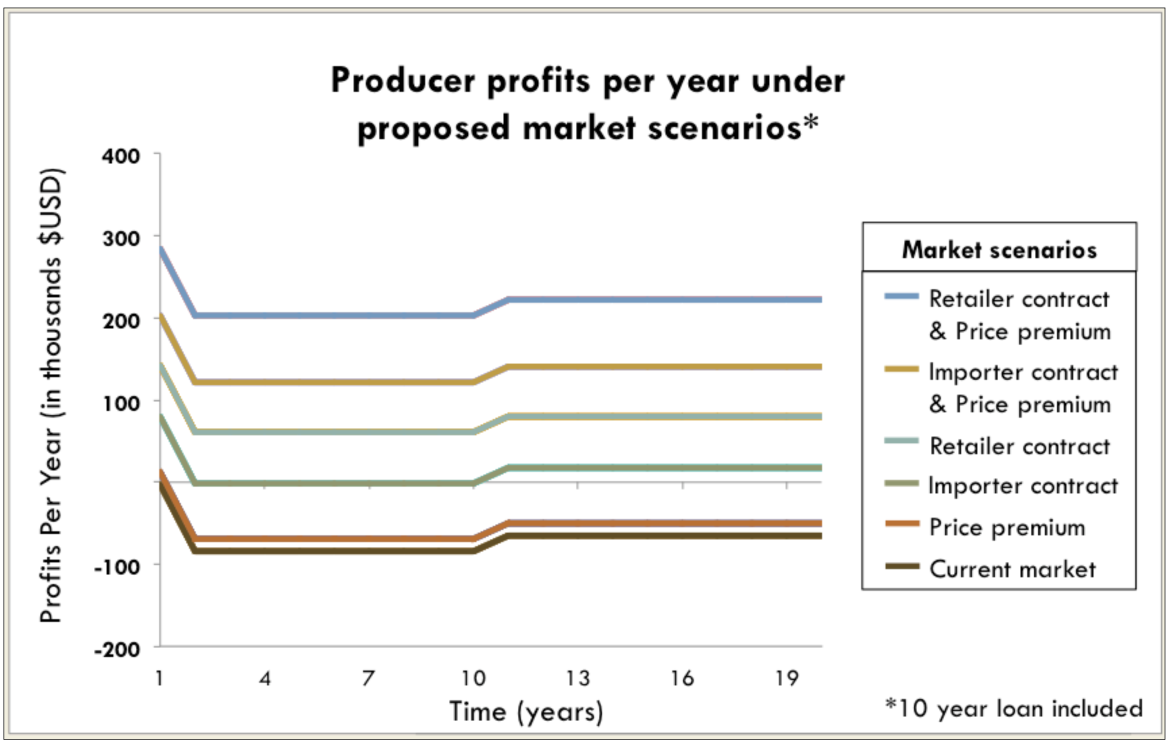


Figure 15. Producer profits per year under different market scenarios: current market, price premiums, retailer direct contract, importer direct contract, and both direct contracts in combination with price premiums.

The current market price for fish does not allow our proposed operation to be profitable. Only securing a price premium for captive-raised fish also does not allow the operation to make a profit. However, if a producer is able to secure a direct market contract with either an importer or retailer, this operation can be profitable in the long term. Combining a direct market contract with a price premium allows for even more profits. Our analysis shows that eliminating large mark-ups for middlemen in the supply chain is vital to starting a profitable mariculture operation in the Coral Triangle.

Recommendations

Recommendations for the implementation of a mariculture operation in producer communities in the Coral Triangle

Economic feasibility recommendations
A direct contract with the retailer and a price premium would provide the highest annual returns, however considering the large volume of retailers compared to the number of wholesalers, this might not be a realistic option. In contrast, a direct contract with a wholesaler would likely be easier and still satisfy the break-even point within 10 years. The price premium would not be as crucial as the direct contract. The recommend the best and realistic option would be a direct contract with a wholesaler along with a price premium.

Technical feasibility recommendations
Any potential site for mariculture must have the biodiversity and species density to allow multiple ornamental species to be harvested through PCC. Coastal communities in which the aquarium trade is or once was a lucrative business would be easiest to identify and good places to consider. Community surveys in the scientific literature would be able to identify additional sites. However, if these areas suggested are found to be in pristine condition, then we would advise a different location to avoid any environmental damage risk. Furthermore, operators must locate a suitable harvest site to ensure maximum harvest. They must be able to access the site and the Micropods™ regularly using both boat and either hookah or SCUBA gear. Light traps offer a high potential for capturing postlarvae species that often settle on the fore-reef. This is an area that is often deeper and exposed to stronger wave action. Since they would be captured in a light trap and then transferred over to a Micropod™, divers would not have to put themselves at risk of harvesting wild fish on the fore-reef.

Coastal communities may not have the technical resources necessary for a PCC & Micropod™ operation. The form of mariculture that we recommend can be carried out without being hooked into a formal electricity grid; however, gasoline generators at the minimum will be needed to run air compressors, charge batteries, etc. We recommend choosing a site within suitable transportation. This would mean the community must be within a radius where supplies can be delivered relatively easily either by ship or airplane. The more important consideration would then be shipping costs.

Legal recommendations
We recommend that organizations interested in starting a mariculture operations consider both national laws and regional or local customs, and be aware that these may differ widely. While all six of the Coral Triangle countries have a multilateral agreement and national laws that encourage sustainable mariculture and outsider investment, it will be crucial to thoroughly investigate local laws, customs, and traditions of any site selected for a mariculture operation. Laws that may be particularly relevant are fishing and/or culturing permits, as well as any exemptions that may be granted to local-scale producers.

Political recommendations
We recommend that potential investors seek out areas with the highest degree of political stability possible within the geographic confinements coral reef aquarium species harvesting. Within the Coral Triangle, the political stability of Indonesia, the Philippines, and Malaysia make them best suited to attract outside investments in mariculture. The Solomon Islands may also be a viable option, but is less stable than the other three countries. Due to the political and social unrest in Papua New Guinea and Timor-Leste, we are unable to recommend them to outside organizations.

Business recommendations
We recommend that Olazul identifies a willing entrepreneur and incorporate him/her into the business plan for the successful management of a mariculture operation. A private venture is recommended because it will be quicker to implement on average than a publicly funded venture. Producers and retailers should arrange market contracts, because they would increase the percentage of profits that producers receive. Additionally, if retailers were to also implement a warranty program, market contracts could be coupled with guarantees of sustainable production practices and, consequently, fish health. However, a private enterprise might need to seek additional funding, depending on whether a direct contract can be made with a wholesaler and/or a price premium can be implemented.

Social recommendations
We suggest that Olazul uses cooperative production model as a way of ensuring equitable distribution of income across the community while increasing the accountability and transparency of a mariculture operation in a given producer community in the Coral Triangle. On-the-ground knowledge and experience is necessary to inform Olazul on how to appropriately incorporate the current community and livelihood structure into the business structure of a mariculture venture. This would be an important step in determining community interest and thus the availability and number of workers. We also suggest that Olazul assesses preexisting gender roles within a given community and determine the potential impact of a mariculture venture on these roles.

Olazul must consider how and if a mariculture project and/or venture would be accepted by local communities. The best-case scenario would be to have community buy-in in the form of a cooperatively-owned business. If the community or the participating producers are initially unable to provide funds to establish the business in a cooperative manner, then Olazul can fund the establishment of the business and hand over the business to the community in the future. However, a plan for doing so much be drafted and approved by the community prior to the start of the venture.

Recommended next steps for Olazul

We recommend the following next steps for Olazul:

- Choose nations with the greatest capacity for supporting a community-operated mariculture system based upon our per country legal and political analyses.
- Use Global Information System (GIS) technology to identify communities that are within an appropriate distance from international transportation.
- Identify locations in which there is a high probability for a large diversity fish species.
- Identify locations that would be suitable for Micropods™.
- Identify and contact conservation or humanitarian NGOs that have worked in the vicinity to gain further background intelligence and estimate the potential for joint, collaborative investments.
- Identify and meet leaders (both official and non-official) in communities with the greatest potential to gauge interest and receive feedback.
- Customize our cost-function model to the unique resources available in that community.
- Conduct at least preliminary environmental impact assessments on the effects of Micropods™ on coral reef ecosystems.
- Draft a market contract that defines expectations, objectives, roles and responsibilities, and a timeline for expected operations management with detailed protocols for adapting operations as the business matures.

Conclusions

The marine aquarium trade has benefits for consumers to enjoy and learn more about the marine ecosystem, and provides producing coastal communities with a source of supplemental income. However, the current state of the trade is causing serious damage to coral reef ecosystems. Destructive fishing methods and inefficiencies throughout the supply chain predict the industry's downfall, which can be avoided with relatively simple reforms.

For this project, which looked at the marine ornamental fish trade based out of the Coral Triangle, we had two main goals. Our first goal was to consider market-based solutions from within the U.S. that would provide motivation to producers and stakeholders throughout the supply chain to seek out sustainable production methods as a source for fishes. Secondly, we sought to understand the economic and technical feasibility for producer communities in the Coral Triangle to start a mariculture operation as a sustainable method of production that is economically, socially and environmentally viable in the long-term. Additionally, we considered the legal, political, business, and social requirements for our recommended mariculture operation. Based on our research, we think a mandatory in-store warranty combined with mariculture operations in producer communities, using market contracts and price premiums is a viable solution to help reform the marine ornamental trade while preserving livelihoods of collectors in developing countries. Independently, each of these solutions will not work as effectively as they would if a warranty was combined with a sustainable mariculture production method using market contracts.

Our project has outlined the considerations and reforms that would be necessary on both the retailer and producer sides to make mariculture with PCC and Micropods™ a viable solution. Our deliverables include an analysis of the expected economic impacts of a mandatory in-store warranty, predicted price-premiums that customers will be willing to pay for fish raised in mariculture, and an analysis of the viability of direct-market contracts. We also researched a producer-side feasibility study of the potential for mariculture operations in Coral Triangle nations. Our initial assessment of the feasibility of a producer level mariculture operation in the Coral Triangle countries can help guide Olazul in choosing appropriate technology, locations and communities in which a mariculture operation should be established. Our feasibility analysis also indicates that establishing an ornamental mariculture operation may be financially viable in the long run, when used in combination with the direct market contracts and price premiums this project investigated and quantified.

As it stands, the marine ornamental trade is environmentally and economically unsustainable for producer communities. Collection practices are harmful for coral reef ecosystems and are not providing long-term sources of income for producer communities. Harmful collection practices and poor care throughout the supply chain leads to high mortality within the supply chain and ultimately, in consumer homes. From our customer research survey, we found that approximately 80% of fish mortality in home aquaria can be attributed to "supply chain error." Additionally, our study found that 28% of all fish sold are replacements for fish that have died. The trade is unsustainable at the producer level, but at higher levels of the supply chain, stakeholders are profiting from harmful collection practices when customers purchase replacement fish and therefore currently have no incentive to reform the trade. There have been proposals for enforcing a ban on U.S. imports of cyanide-caught fish because of the harm it causes to reef environments. Tighter import regulations at either the U.S. or UN level could result in producer communities being unable to sell their product, which would impact their source of income and jeopardizing their livelihoods. Our warranty analysis provides a simple option for legislation that not only protects consumers from buying damaged fishes, but also provides a top-down, market-based solution to reform the marine aquarium trade without prohibiting ornamental imports and thus avoiding injuring producer communities. After performing our warranty analysis, we conclude that legislation requiring a mandatory warranty would provide a strong financial incentive for stores to purchase aquarium fishes from sustainable sources.

In addition to showing that a warranty would increase demand for sustainably sourced aquarium fishes, this project recommended methods for producing fish while considering both environmental and social welfare. We recommend an extensive approach to mariculture that uses PCC with grow-out in Micropods™, which appears to be technically feasible. Using PCC in combination with Micropods minimizes impacts on existing populations of reef fishes, provides a potential source of fishes with which a reef may be restocked, and facilitates community reef protection and monitoring. Our proposed business combination of PCC and open-ocean Micropod™ cages is unprecedented, and therefore does carry risk and uncertainties. However, based upon our literature reviews, economic analyses, and current technological knowledge, we have compiled the key parameters under which this mariculture system might be feasible. Further research will provide greater insight to this mariculture system's potential and will decrease risk.

When considering our recommendations to Olazul as to where and when a mariculture facility is appropriate, we considered the legal frameworks and political stability in each country within the Coral Triangle. All countries in the Coral Triangle have national legislation encouraging the expansion of aquaculture and mariculture operations. However, we advise any startup operations to conduct a detailed analysis of the local laws and customs of the specific region they select, as the enforcement of national laws may vary widely across regions. Political stability is another key component of the success of a community-based startup venture. Without political stability, we cannot recommend starting a mariculture venture.

Based on Olazul's interest in creating sustainable, community-based ventures, we conclude that a cooperative model is the best business model to ensure that profits are returned to and invested in the producer communities. Development solutions that promote the recommended extensive mariculture will need to account for how to appropriately incorporate the current community and livelihood structure and gender roles in producer communities. Guidance from a non-profit organization with technical and business expertise, such as Olazul, will be crucial for a coastal community to develop its capacity and transition towards a productive and sustainable future.

While considering the viability of mariculture using PCC and Micropods, we needed to consider the costs associated with starting up and running a mariculture facility. To keep mariculture competitive with wild-caught fish, we examined the use of direct market contracts and/or price premiums for tank-bred fish, in order to shorten the supply chain and increase the price at which producers can charge for fish. Our cost model showed that using PCC and Micropods, in combination with direct market contracts and price premiums, is a financially viable venture that provides quality fishes to the market while ensuring long-term sources of income for producer communities.

Based on our research, we believe a mandatory warranty will provide a market-based solution that will lead producers to seek out sustainable sources of fish. To support industry reform, we recommend PCC and Micropod mariculture operations that utilize direct market contracts and price premiums for tank-bred fish. We think our novel approach to mariculture and market reform can result not only in the restoration and eventual protection of coastal resources, but also a stable livelihood for producer communities and a quality product for U.S. consumers for years to come.

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Appendices

Appendix A

Copy of our stated preference survey designed to examine consumer preferences and their willingness to pay for marine ornamental fish in the U.S.

This survey is part of a research project conducted by students at the University of California, Santa Barbara. The survey results will be used for academic purposes only. We are not affiliated with any business. If you feel uncomfortable you may stop taking this survey at any time. If you have questions regarding this survey, you can contact us at coralreefgp@gmail.com.

You are eligible to take this survey if you are a current or previous owner of a saltwater aquarium. In the United States, keeping a saltwater aquarium tank is a popular hobby. Marine fish used in aquariums are either caught in the wild or bred in captivity. Some fish are rare in the wild and others are more common. The prices for different aquarium fish species range from a few dollars to over a thousand. This survey looks at consumer preferences for marine aquarium fishes.

The survey has 30 questions and will take approximately 10 minutes to complete. Please answer the questions to the best of your knowledge. Upon completion of this survey, you will have a **chance to win a $100 gift certificate to liveaquaria.com.**

Thank you for your participation.

1. Do you currently own a saltwater aquarium?
   - Yes
   - No

1b. If you do not currently own a saltwater aquarium, did you own a saltwater aquarium in the past?
   - Yes
   - No

(Respondents were disqualified if they answer "No" to both 1 and 1b)

Answer the following questions based on your past experiences with owning an aquarium.

2. Do you currently own a freshwater aquarium?
   - Yes
   - No

All following questions in this survey apply only to **saltwater aquariums** or **saltwater aquarium fish**.

3. Why do you own a saltwater aquarium?
   - It is a hobby
   - I do aquaculture of marine aquarium fish
   - I do research on marine aquarium fish

Other:

4. How many years have you had your saltwater aquarium?

5. Where do your saltwater fish come from?
    Wild-caught, not sure of the method
    Wild-caught with nets
    Bred in captivity
    Not sure
    Other:

6. How sure are you of your answer to the previous question?
    Completely sure
    Very sure
    Somewhat sure
    Not very sure
    Not at all sure

7. What is the most (in dollars) you have ever spent on a saltwater fish?

8. What was the species?

9. What was the least amount you have ever spent on a saltwater fish?

10. What was the species?

11. How much did you spend in the past year to purchase fish for your saltwater aquarium? (just on fish, not on equipment, food, etc.)

12. How many fish did you buy in the past year for your saltwater aquarium?

13. How many fish did you purchase in the past year in order to replace a fish that had died?

14. How do you choose which species of saltwater fish to buy?

From the statements below, choose the 3 that you agree with most, drag them into the box on the right, and rank them in order of importance with 1 being the most important.

I buy fish I recognize (for example: Nemo)
I buy expensive fish
I buy rare fish
I buy attractive fish
I buy inexpensive fish
I buy fish to fill a role in my aquarium (for example: cleaner shrimp)
Other

If one of your answers to the above questions was “other,” pleas describe here:

15. Of all the fish that you purchased in the past year, how many survived at least 3 days in your care?

16. Of all the fish that you purchased in the past year, how many survived at least 7 days in your care?

17. Of all the fish that you purchased in the past year, how many survived at least 14 days in your care?

18. Of all the fish that you purchased in the past year, how many survived at least 30 days in your care?

19. Of all the fish that you purchased in the past year, how many survived at least 6 months in your care?

20. How do you choose where to buy your saltwater fish?

From the statements below, choose the 3 that you agree with most, drag them to the box on the right, and rank them in order of importance with 1 being the most important.

The fish purchased from by retailer tend to survive longer than from other retailers
The retailer sells captive bred fish
The retailer has competitive prices
The retailer has a wide selection
The retailer offers replacement fish or money back in case of fish death
The retailer provides me with detailed information about how to care for my fish
The retailer sells sustainably certified fish
The retailer is close to my house / is convenient to shop from
I had a good experience with my retailer (not listed above)
Other

If you chose "other" as one of your answers for the question above, please describe here:

21. When you go to purchase a fish, how often do you go with the intention to buy a specific fish?
Always intend to browse
Mostly intend to browse
About half and half
Mostly intend to buy a specific fish
Always intend to buy a specific fish

22. If you have the intention to buy a specific fish, how likely are you to also browse and then buy additional fish?
Not at all likely
Not very likely
Somewhat likely
Very likey
Extremely likely
I never have the intention to buy a specific fish

23. If you have the intention to buy a specific fish, how likely are you to end up buying a different fish instead of the fish you intended to buy?
Extremely likely
Very likely
Somewhat likely
Very unlikely
Not at all likely
I never have the intention to buy a specific fish

The fish pictured below represent a few of the fish that people purchase for their saltwater aquariums. The prices attached to these fish are typical for a wild-caught specimen. Pretend that you want to purchase a new fish for your aquarium and you can choose from the selection below.

24. Click on the fish that you would be most likely to purchase. Then click "Next."

Orange Clownfish – Average price: $33.00

Sapphire devil – Average price: $4.00

Pinnatus Batfish – Average price: $71.50

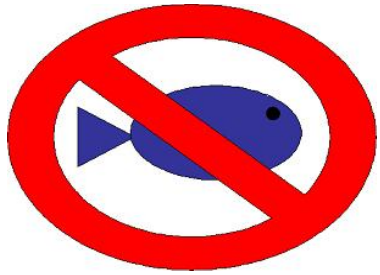
Emperor Angelfish – Average price: $167.00

Flame Angelfish – Average price: $48.50

Blue Tang – Average price: $54.50

Yellow Tang – Average price: $43.50

Banggai Cardinalfish – Average price: $20.50

Lined Seahorse – Average price: $140.00   I would not choose any of these fish

Why did you decide to not choose any of the pictured fish? (Asked only if respondent chose “I would not choose any of these fish”)

25.

You have chosen the Sapphire Devil. Average price: $4.00
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It is also possible to breed this species in captivity.
Imagine your retailer has two Sapphire Devil fish in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [random value between $3-$10, $4-$10, or $5-$10]
Wild-caught / [Either $3.00, $4.00, $5.00, or $6.00]
I would not purchase either fish

OR

25.

You have chosen the Emperor Angelfish. Average price: $167.00
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It also may soon be possible to breed this species in captivity.

Imagine your retailer has two Emperor Angelfish in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [random value between $150-$225, $167-$251, $184-$276, or $209-$213]

Wild-caught / [Either $150, $167, $184, or $209]

I would not purchase either fish

OR

25.

You have chosen the Banggai Cardinalfish. Average price: $20.50
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It is also possible to breed this species in captivity.
Imagine your retailer has two Banggai Cardinalfish in stock. Based on the descriptions below, which one would you purchase?

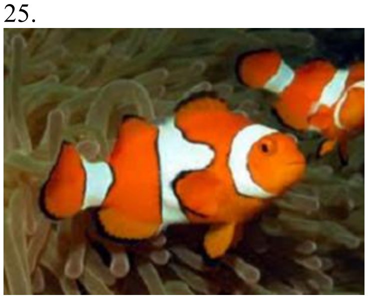
tank-bred / [Random value between $18-$28, $20-$31, $23-$34, or $26-$38]

Wild-caught / [Either $18, $20, $23, or $26]

I would not purchase either fish

OR

25.



You have chosen the Orange Clownfish. Average price: $33.00
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It is also possible to breed this species in captivity.
Imagine your retailer has two Orange Clownfish in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [$30-$45, $33-$50, $36-$54, or $41-$62]

Wild-caught / [Either $30, $33, $36, or $41]

I would not purchase either fish

OR

25.

You have chosen the Lined Seahorse. Average price: $140.00
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It is also possible to breed this species in captivity.
Imagine your retailer has two Lined Seahorses in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [$126-$189, $140-$210, $154-$231, or$175-$263]
Wild-caught / [Either $126, $140, $154, or $175]
I would not purchase either fish

OR

25.

You have chosen the Flame Angelfish. Average price: $48.50

This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It is also possible to breed this species in captivity.
Imagine your retailer has two Flame Angelfish in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [Random value between $44-$65, $48-$73, $53-$80, or $61-$91]
Wild-caught / [Either $44, $48, $53, or $61]
I would not purchase either fish

OR

25.

You have chosen the yellow tang. Average price: $43.50

This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It also may soon be possible to breed this species in captivity.
Imagine your retailer has two Yellow Tang in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [Random value between $39-$59, $43-$65, $48-$72, or $54-$82]
Wild-caught / [Either $39, $43, $48, or $54]
I would not purchase either fish

OR

25.

You have chosen the Blue Tang. Average price: $54.50

This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It also may soon be possible to breed this species in captivity.
Imagine your retailer has two Blue Tang in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [Random value between $49-$74, $54-$82, $60-$90, or $68-$102]
Wild-caught / [Either $49, $54, $60, or $68]
I would not purchase either fish

OR

25.

You have chosen the Pinnatus Batfish. Average price: $71.50
This fish is native to the Indo-Pacific waters of Indonesia and the Philippines. It also may soon be possible to breed this species in captivity.
Imagine your retailer has two Pinnatus Batfish in stock. Based on the descriptions below, which one would you purchase?

tank-bred / [Radom value between $64-$97, $71-$107, $79-$118, or $89-$134]
Wild-caught / [Either $64, $71, $79, or $89]
I would not purchase either fish

26. The Sapphire Devil sells for an average price of **$4.00**.
Would you pay **$ [Random value between $5-$10]** for a Sapphire Devil that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Emperor Angelfish sells for an average price of **$167.00**.
Would you pay **$ [Random value between $168-$251]** for an Emperor Angelfish that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Banggai Cardinalfish sells for an average price of **$20.50**.
Would you pay **$ [Random value between $22-$31]** for a Banggai Cardinalfish that comes with a **[7 / 14 / 30]-day warranty** to replace or refund the purchase in case of fish death?

Yes
No

OR

26. The Orange Clownfish sells for an average price of **$33.00**.
Would you pay **$ [Random value between $34-$50]** for an Orange Clownfish that comes with a **[7 / 14 / 30]-day warranty** to replace or refund the purchase in case of fish death?

Yes
No

OR

26. The Lined Seahorse sells for an average price of **$140.00**.

Would you pay **$ [Random value between $141-$210]** for a Lined Seahorse that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Flame Angelfish sells for an average price of **$48.50**.

Would you pay **$ [Random value between $50-$73]** for a Flame Angelfish that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Yellow Tang sells for an average price of **$43.50**.

Would you pay **$ [Random value between $45-$65]** for a Yellow Tang that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Blue Tang sells for an average price of **$54.50**.

Would you pay **$ [Random value between $56-$82]** for a Blue Tang that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

OR

26. The Pinnatus Batfish sells for an average price of **$71.50**.

Would you pay **$ [Random value between $73-$107]** for a Pinnatus Batfish that comes with a **[7 / 14 / 30]-day warranty** to replace or refund your purchase in case of fish death?

Yes
No

27. What is your gender?

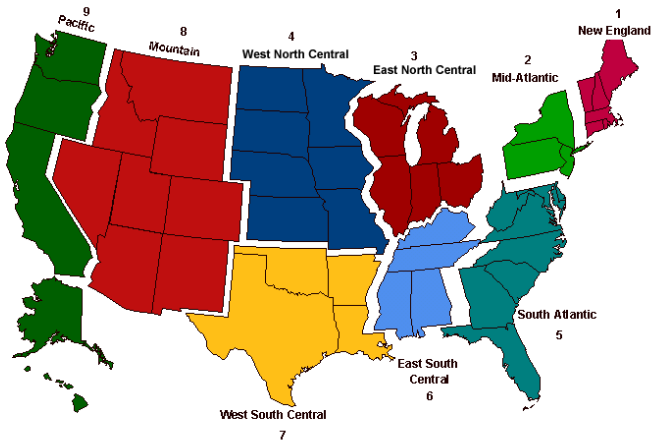
Male
Female

28. In what year were you born?

(dropdown menu)
1930 or earlier
1931
1932
…
1993
1994 or later

29. What is your yearly income?

$0 - $20,000
$20,001 - $40,000
$40,001 - $75,000
$75,001 - $100,000
$100,001 or more



30. Where do you live?

New England
Mid-Atlantic
South Atlantic
East North Central
East South Central
West North Central
West South Central
Mountain
Pacific

Optional: Please leave any other comments you would like to share.

One more step! You have the opportunity to enter to win a $100 gift certificate to liveaquaria.com. What would you like to do?

If you choose to enter the contest, you will be asked to provide your email address. Your email address will not be shared, and we will only use your email to contact you if you have won the prize. Your email address will be collected separately from your survey responses to maintain anonymity.

Yes! Enter me in the contest.
No, thank you. I would not like to enter the contest.

Thank you for taking our survey. Your response is very important to us.

Appendix B

Facebook advertisements for our online, stated preference consumer survey:

Fish Owner? Win $100
edu.surveygizmo.com

Do you own a saltwater aquarium? Take our 10 minute survey for a chance to win a $100 gift certificate!

Love Saltwater Fish? ×
edu.surveygizmo.com

Do you own, or have you previously owned a saltwater aquarium? Take our 10 minute survey for a chance to win a $100 gift certificate!

Saltwater Tank? Win $100!
edu.surveygizmo.com

Do you own a saltwater aquarium? Help our academic research! Take our 10 minute survey for a chance to win a $100 gift certificate!

Own Fish? Win $100!
edu.surveygizmo.com

Do you own a saltwater aquarium? Help our academic research! Take our 10 minute survey for a chance to win a $100 gift certificate!

Love Fish? Win $100!
edu.surveygizmo.com

Do you own, or have you previously owned, a saltwater aquarium? Take our 10 minute survey for a chance to win a $100 gift certificate!

Appendix C

Willingness to pay for tank-bred versus wild-caught fishes

Banggai Cardinalfish

Banggai Cardinalfish Willingness to Pay												
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%	55-60%
T=Number who chose tank bred	5.00	1.00	2.00	2.00	0.00	3.00	1.00	4.00	5.00	0.00	1.00	0.00
W=Number who chose wild caught	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	0.00	0.00	0.00	2.00
Cumulative number who chose tank bred	24.00	19.00	18.00	16.00	14.00	14.00	11.00	10.00	6.00	1.00	1.00	0.00
Cumulative number who chose wild caught	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.00	3.00	3.00	3.00	5.00
N=Number who chose neither tank nor wild	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	84.62%	76.92%	66.67%	25.00%	25.00%	0.00%
R=Total expected increase in revenue	5.00%	10.00%	15.00%	20.00%	25.00%	30.00%	29.62%	30.77%	30.00%	12.50%	13.75%	0.00%

Blue Tang

Blue Tang Willingness to Pay											
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%
T=Number who chose tank bred	3.00	1.00	5.00	1.00	4.00	3.00	3.00	3.00	2.00	0.00	2.00
W=Number who chose wild caught	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00
Cumulative number who chose tank bred	27.00	24.00	23.00	18.00	17.00	13.00	10.00	7.00	4.00	2.00	2.00
Cumulative number who chose wild caught	0.00	0.00	0.00	0.00	1.00	1.00	2.00	2.00	2.00	3.00	3.00
N=Number who chose neither tank nor wild	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	100.00%	100.00%	100.00%	100.00%	94.44%	92.86%	83.33%	77.78%	57.14%	40.00%	40.00%
R=Total expected increase in revenue	5.00%	10.00%	15.00%	20.00%	23.61%	27.86%	29.17%	31.11%	25.71%	20.00%	22.00%

Clownfish

Clownfish Willingness to Pay										
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%
T=Number who chose tank bred	3.00	3.00	1.00	0.00	2.00	2.00	3.00	0.00	0.00	1.00
W=Number who chose wild caught	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
Cumulative number who chose tank bred	15.00	12.00	9.00	8.00	8.00	6.00	4.00	1.00	1.00	1.00
Cumulative number who chose wild caught	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	3.00	4.00
N=Number who chose neither tank nor wild	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	1.00	1.00	1.00	1.00	1.00	1.00	0.67	0.33	0.25	0.20
R=Total expected increase in revenue	0.05	0.10	0.15	0.20	0.25	0.30	0.23	0.13	0.11	0.10

Emperor Angelfish

Emporer Angelfish Willingness to Pay										
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%
T=Number who chose tank bred	1.00	1.00	0.00	2.00	4.00	3.00	0.00	2.00	2.00	2.00
W=Number who chose wild caught	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	3.00	2.00
Cumulative number who chose tank bred	17.00	16.00	15.00	15.00	13.00	9.00	6.00	6.00	4.00	2.00
Cumulative number who chose wild caught	1.00	1.00	1.00	1.00	1.00	2.00	2.00	3.00	6.00	8.00
N=Number who chose neither tank nor wild	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	94.44%	94.12%	93.75%	93.75%	92.86%	75.00%	75.00%	66.67%	40.00%	20.00%
R=Total expected increase in revenue	4.72%	9.41%	14.06%	18.75%	23.21%	22.50%	26.25%	26.67%	18.00%	10.00%

Flame Angelfish

Flame Angelfish Willingness to Pay											
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%
T=Number who chose tank bred	3.00	3.00	1.00	2.00	3.00	6.00	3.00	4.00	4.00	1.00	0.00
W=Number who chose wild caught	0.00	0.00	0.00	0.00	2.00	1.00	1.00	0.00	2.00	1.00	1.00
Cumulative number who chose tank bred	30.00	27.00	24.00	23.00	21.00	18.00	12.00	9.00	5.00	1.00	0.00
Cumulative number who chose wild caught	0.00	0.00	0.00	0.00	2.00	3.00	4.00	4.00	6.00	7.00	8.00
N=Number who chose neither tank nor wild	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	96.77%	100.00%	100.00%	100.00%	91.30%	85.71%	75.00%	64.29%	45.45%	12.50%	0.00%
R=Total expected increase in revenue	4.84%	10.00%	15.00%	20.00%	22.83%	25.71%	26.25%	25.71%	20.45%	6.25%	0.00%

Lined Seahorse

Lined Seahorse Willingness to Pay										
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%
T=Number who chose tank bred	0.00	1.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	1.00
W=Number who chose wild caught	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Cumulative number who chose tank bred	5.00	5.00	4.00	3.00	3.00	3.00	3.00	2.00	2.00	1.00
Cumulative number who chose wild caught	0.00	0.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00
N=Number who chose neither tank nor wild	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	100.00%	100.00%	80.00%	75.00%	75.00%	60.00%	50.00%	50.00%	50.00%	33.33%
R=Total expected increase in revenue	5.00%	10.00%	12.00%	15.00%	18.75%	18.00%	17.50%	20.00%	22.50%	16.67%

Yellow Tang

Yellow Tang Willingness to Pay											
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%
T=Number who chose tank bred	3.00	1.00	0.00	1.00	1.00	2.00	2.00	2.00	3.00	2.00	1.00
W=Number who chose wild caught	0.00	0.00	0.00	1.00	2.00	0.00	2.00	0.00	2.00	1.00	0.00
Cumulative number who chose tank bred	18.00	15.00	14.00	14.00	13.00	12.00	10.00	8.00	6.00	3.00	1.00
Cumulative number who chose wild caught	0.00	0.00	0.00	1.00	3.00	3.00	5.00	5.00	7.00	8.00	8.00
N=Number who chose neither tank nor wild	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
P=Percentage of customers who would buy tank bred fish at the price premium	100.00%	93.75%	100.00%	93.33%	81.25%	80.00%	62.50%	61.54%	46.15%	27.27%	11.11%
R=Total expected increase in revenue	5.00%	9.38%	15.00%	18.67%	20.31%	24.00%	21.88%	24.62%	20.77%	13.64%	6.11%

Appendix D

Warranty analysis

7-day Analysis

7-day Warranty Willingness to Pay											
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%
Y=Positive responses	1	9	5	6	4	3	3	3	1	5	1
N=Negative responses	1	1	1	1	0	2	2	2	7	5	3
Cumulative positive responses	41	40	31	26	20	16	13	10	7	6	1
Cumulative negative responses	1	2	3	4	4	6	8	10	17	22	25
P=Percentage of customers who would buy warranty	97.62%	95.24%	91.18%	86.67%	83.33%	72.73%	61.90%	50.00%	29.17%	21.43%	3.85%
X=Total change in revenue	102.50%	104.76%	104.85%	104.00%	104.17%	94.55%	83.57%	70.00%	42.29%	32.14%	5.96%

14-day Analysis

14-day Warranty Willingness to Pay											
n= Price premium for tank bred fish	0-5%	5-10%	10-15%	15-20%	20-25%	25-30%	30-35%	35-40%	40-45%	45-50%	50-55%
Y=Positive responses	4	4	4	3	7	4	3	2	6	0	0
N=Negative responses	1	0	1	1	1	3	1	3	2	3	5
Cumulative positive responses	37	33	29	25	22	19	12	8	6	0	0
Cumulative negative responses	1	1	2	3	4	7	8	11	13	16	21
P=Percentage of customers who would buy warranty	10.81%	12.12%	13.79%	12.00%	31.82%	21.05%	25.00%	25.00%	100.00%	0.00%	0.00%
X=Total change in revenue	102.24%	106.76%	107.58%	107.14%	105.77%	95.00%	81.00%	58.95%	45.79%	0.00%	0.00%

Appendix E

T-test comparing mean years of aquarium experience by survey respondents

Mean years of experience for respondents answering "Completely sure" or "Very sure" that their fish are "Wild-caught, not sure of method" with the mean years of experience for people who answered that they were "Completely sure" or "Very sure that their fish are "Bred in captivity."

Comparing Means [t-test assuming equal variances (homoscedastic)]			
Descriptive Statistics			
	Sample size	*Mean*	*Variance*
Wild Caught	16	10.	88.
Captive Bred	21	5.57143	47.05714
Summary			
Degrees Of Freedom	35	*Hypothesized Mean Difference*	0.E+0
Test Statistics	1.66036	*Pooled Variance*	64.60408
Two-tailed distribution			
p-level	0.10578	*t Critical Value (5%)*	2.03011
One-tailed distribution			
p-level	0.05289	*t Critical Value (5%)*	1.68957
G-criterion			
Test Statistics	#N/A	*p-level*	#N/A
Critical Value (5%)	#N/A		
Pagurova criterion			
Test Statistics	1.59173	*p-level*	0.87631
Ratio of variances parameter	0.71052	*Critical Value (5%)*	0.02531

Appendix F

Expected losses to stores due to supply chain mortality (dependent on number of days in store)

Days in Store	Per day mortality rate	Store Losses
1	0.0164	$0.0062
2	0.0324	$0.0122
3	0.0483	$0.0182
4	0.0564	$0.0213
5	0.0644	$0.0243
6	0.0723	$0.0273
7	0.0802	$0.0303
8	0.0845	$0.0319
9	0.0888	$0.0335
10	0.0930	$0.0351
11	0.0972	$0.0367
12	0.1014	$0.0383
13	0.1056	$0.0399
14	0.1098	$0.0414
15	0.1164	$0.0439
16	0.1198	$0.0452
17	0.1231	$0.0464
18	0.1261	$0.0476
19	0.1290	$0.0487
20	0.1317	$0.0497
21	0.1343	$0.0507
22	0.1367	$0.0516
23	0.1391	$0.0525
24	0.1413	$0.0533
25	0.1435	$0.0542
26	0.1456	$0.0549
27	0.1476	$0.0557
28	0.1495	$0.0564
29	0.1514	$0.0571
30	0.1532	$0.0578
31	0.1549	$0.0585
32	0.1566	$0.0591
33	0.1582	$0.0597

34	0.1598	$0.0603
35	0.1613	$0.0609
36	0.1628	$0.0615
37	0.1643	$0.0620
38	0.1657	$0.0625
39	0.1671	$0.0631
40	0.1684	$0.0636
41	0.1697	$0.0641
42	0.1710	$0.0645
43	0.1722	$0.0650
44	0.1735	$0.0655
45	0.1747	$0.0659
46	0.1758	$0.0664
47	0.1770	$0.0668
48	0.1781	$0.0672
49	0.1792	$0.0676
50	0.1802	$0.0680
51	0.1813	$0.0684
52	0.1823	$0.0688
53	0.1833	$0.0692
54	0.1843	$0.0696
55	0.1853	$0.0699
56	0.1862	$0.0703
57	0.1872	$0.0706
58	0.1881	$0.0710
59	0.1890	$0.0713
60	0.1899	$0.0717

Appendix G

Species used in supply chain analysis

Species	Common name(s)
Abudefduf vaigiensis	Common sergeant / Sergeant major damselfish
Acanthurus leucosternon	Powderblue surgeonfish / Powder blue tang
Acanthurus lineatus	Lined surgeonfish / Clown tang
Acanthurus maculiceps	Spot-face surgeon / Maculiceps tang
Acanthurus nigricans	Whitecheek surgeonfish / velvet surgeon / Powder brown tang
Acanthurus olivaceus	Orange-blotch surgeon / Orangeband surgeon / Orange shoulder tang
Acanthurus pyroferus	Mimic surgeonfish / Chocolate tang
Amphiprion clarkii	Yellow-tail clownfish / Clarks clown
Amphiprion ephippium	Red saddleback anemonefish / Saddle anemone
Amphiprion ocellaris	Clown anenomefish / Ocellaris clown
Amphiprion percula	Orange clownfish / Percula clownfish
Amphiprion polymnus	Saddleback clownfish / Black saddle clown
Amphiprion sandaracinos	Orange anemonefish / Orange skunk clown
Apolemichthys trimaculatus	Threespot angelfish / Flagfin angel
Bodianus diana	Diana's hogfish
Bodianus mesothorax	Mesothorax hogfish / Black belt hogfish / Eclipse hogfish
Centropyge bicolor	Bicolor angelfish
Centropege bispinosus	Coral beauty angelfish
Centropyge eibli	Eibl's angelfish
Centropyge loriculus	Flame angelfish
Centropyge nox	Midnight angelfish
Centropyge tibicen	Keyhole angelfish
Centropyge vroliki	Pearl scalleed angelfish / Half black angel
Cephalopholis cyanostigma	Bluespotted hind / Blue spotted grouper
Cetoscarus bicolor	Bicolor parrotfish
Chaetodon auriga	Threadfin butterflyfish
Chaetodon burgessi	Cirton butterflyfish / Burgess butterfly
Chaetodon kleini	Brown butterflyfish / Klein's butterfly
Chaetodon lunula	Raccoon butterflyfish
Chaetodon melanotus	Blackback butterflyfish
Chaetodon meyeri	Scrawled butterflyfish / Meyer's butterfly fish
Chaetodon rafflesi	Latticed butterflyfish / Rafflesi butterfly
Chaetodon reticulatus	Reticulated butterflyfish (s)
Chaetodon reticulatus	Reticulatid butterflyfish (m)
Chaetodon trifascialis	Chevroned butterflyfish
Chaetodontoplus melanosoma	Black velvet angelfish / Grey poma
Chelmon rostratus	Chelmon butterfly fish / Copperband butterfly
Chromis margaritifer	Half & half puller / Bicolor chromis
Chrysiptera cyanea	Sapphire devil / Blue damsel
Chrysiptera parasema	Goldtail demoiselle / Yellowtail blue damselfish

Chrysiptera talboti	Talbots damsel
Cirrhilabrus cyanopleura	Red-eyed wrasse / Blue sided fairy wrasse
Coris aygula	Clown coris
Coris gaimard	Yellowtail coris / Canary wrasse / Gaimard wrasse / Red coris wrasse
Dascyllus trimaculatus	Threespot dascyllus / Domino damsel
Doryrhamphus dactyliophorus	Ringed pipefish / Banded pipefish
Forcipiger longirostris	Longnose butterflyfish / Yellow longnose butterflyfish
Gomphosus varius	Bird nose wrasse / Bird wrasse / Brown bird wrasse
Gymnomuraena zebra	Zebra moray
Hemigymnus melapterus	Half & half wrasse
Hemitaurichthys polylepis	Pyramid butterfly-yellow
Hippocampus erectus	Lined seahorse
Labroides dimidiatus	Bicolor cleaner wrasse
Meiacanthus atrodorsalis	Forktail blenny
Naso elegans	Naso unicorn / Blonde naso tang
Naso lituratus	Orangespine / Orange-spine unicornfish / Naso tang
Naso unicornis	Shortnose Unicornfish / Unicorn tang
Nemateleotris magnifica	Fire goby / Firefish goby
Novaculichthys taeniourus	Dragon wrasse
Odonus niger	Redtoothead triggerfish / Niger trigger
Ostracion cubicus	Yellow boxfish / Yellow cubicus
Oxymonacanthus longirostris	Harlequin filefish / Orange spot file
Paracanthurus hepatus	Blue tang
Paraglyphidodon melas	Royal damsel (m) / Bluefin damsel
Parupeneus cyclostomus	Yellowsaddle goatfish / Yellow goatfish
Platax pinnatus	Pinnatus batfish
Plectorhinchus chaetodonoides	Spotted grunt sweetlips / Harlequin sweetlips / Spotted sweetlips
Plectorhinchus orientalis	Oriental sweetlips
Plectroglyphidodon lacrymatus	Jewel damsel
Pomacanthus imperator	Emperor angelfish / Imperator angel
Pomacanthus navarchus	Majestic angel
Pomacanthus semicirculatus	Semicircle angelfish / Koran angel
Pomacanthus xanthometopon	Blue-faced angelfish / Blueface angel
Premnas biaculeatus	Spinecheek anemonefish / Maroon anemonefish / Maroon clown
Pseudanthias pascalus	Purple queen / Purple queen anthias
Pterapogon kauderni	Banggai cardinalfish
Ptereleotris evides	Blackfin dartfish / Scissortail goby
Pterois antennata	Broadbarret firefish / Antennata lion
Pterois radiata	Radial firefish / Radiata lion
Pterois volitans	Lionfish / Red lionfish / Volitan lion
Pygoplites diacanthus	Regal angelfish
Rhinecanthus aculeatus	Blackbar triggerfish / Humu humu trigger
Zebrasoma desjardinii	Palette surgeonfish / Desjardinii sailfin tang
Zebrasoma flavescens	Yellow Tang
Zebrasoma veliferum	Sailfin tang

Appendix H

Average price paid to the various players along the supply chain

Average price paid to local or roving collectors. Estimated average price paid to a collector in the Coral Triangle. Prices paid by exporters for various species. All prices are in USD.

Source	**Species**	**Local collector price**	**Roving collector price**	**Price paid to collector-weighted average (80/20)**	**Paid by exporter**
EC-PREP, 2005	*Abudefduf vaigiensis*				0.06
MAMTI, 2006	*Acanthurus leucosternon*	4.50	2.25	2.70	
MAMTI, 2006	*Acanthurus lineatus*	1.12	0.56	0.67	
EC-PREP, 2005	*Acanthurus maculiceps*				0.12
EC-PREP, 2005; MAMTI, 2006	*Acanthurus nigricans*	1.12	0.31	0.47	0.93
EC-PREP, 2005; MAMTI, 2006	*Acanthurus olivaceus*	0.98	0.31	0.44	0.62
MAMTI, 2006	*Acanthurus pyroferus*	1.30	0.51	0.66	
MAMTI, 2006	*Amphiprion clarkii*	0.28	0.15	0.17	
MAMTI, 2006	*Amphiprion ephippium*	0.78	0.39	0.47	
MAMTI, 2006	*Amphiprion ocellaris*	0.76	0.37	0.45	
Shuman, Hodgson, & Ambrose, 2004	*Amphiprion percula*		0.06	0.06	
MAMTI, 2006	*Amphiprion polymnus*	0.17	0.08	0.10	
MAMTI, 2006	*Amphiprion sandaracinos*	0.17	0.07	0.09	
EC-PREP, 2005; MAMTI, 2006	*Apolemichthys trimaculatus*	2.24	1.12	1.34	1.85
MAMTI, 2006	*Bodianus diana*	0.34	0.11	0.16	

EC-PREP, 2005; MAMTI, 2006	*Bodianus mesothorax*	0.56	0.28	0.34	0.37
MAMTI, 2006	*Centropyge bicolor*	0.28	0.11	0.14	
EC-PREP, 2005	*Centropege bispinosus*				1.11
MAMTI, 2006	*Centropyge eibli*	0.78	0.39	0.47	
	Centropyge loriculus				
EC-PREP, 2005	*Centropyge nox*				0.25
EC-PREP, 2005	*Centropyge tibicen*				0.25
EC-PREP, 2005	*Centropyge vroliki*				0.19
MAMTI, 2006	*Cephalopholis cyanostigma*	0.56	0.28	0.34	
EC-PREP, 2005; MAMTI, 2006	*Cetoscarus bicolor*	0.90	0.34	0.45	0.37
EC-PREP, 2005; MAMTI, 2006	*Chaetodon auriga*	0.34	0.17	0.20	0.62
EC-PREP, 2005	*Chaetodon burgessi*				1.24
EC-PREP, 2005	*Chaetodon kleini*				0.22
MAMTI, 2006	*Chaetodon lunula*	0.90	0.34	0.45	1.24
MAMTI, 2006	*Chaetodon melanotus*	3.14	1.57	1.88	
EC-PREP, 2005; MAMTI, 2006	*Chaetodon meyeri*	0.90	0.34	0.45	1.24
EC-PREP, 2005	*Chaetodon rafflesi*				0.25
EC-PREP, 2005	*Chaetodon reticulatus*				0.17
EC-PREP, 2005	*Chaetodon reticulatus*				0.22
MAMTI, 2006	*Chaetodon trifascialis*	0.68	0.34	0.41	
EC-PREP, 2005	*Chaetodontoplus melanosoma*				1.85
Shuman, Hodgson, & Ambrose,	*Chelmon rostratus*		0.06	0.05	

2004					
EC-PREP, 2005	*Chromis margaritifer*				0.07
EC-PREP, 2005; MAMTI, 2006	*Chrysiptera cyanea*	0.04	0.02	0.02	0.07
MAMTI, 2006	*Chrysiptera parasema*	0.78	0.39	0.47	
EC-PREP, 2005	*Chrysiptera talboti*				0.07
EC-PREP, 2005; MAMTI, 2006	*Cirrhilabrus cyanopleura*	0.84	0.34	0.44	0.19
EC-PREP, 2005	*Coris aygula*				3.09
EC-PREP, 2005; MAMTI, 2006	*Coris gaimard*	0.59	0.23	0.30	0.93
MAMTI, 2006; Shuman, Hodgson, & Ambrose, 2004	*Dascyllus trimaculatus*	0.06	0.03	0.03	
MAMTI, 2006	*Doryrhamphus dactyliophorus*	0.17	0.07	0.09	
MAMTI, 2006	*Forcipiger longirostris*	0.73	0.31	0.39	
EC-PREP, 2005; MAMTI, 2006	*Gomphosus varius*	0.70	0.31	0.39	0.93
MAMTI, 2006	*Gymnomuraena zebra*	0.90	0.34	0.45	
EC-PREP, 2005	*Hemigymnus melapterus*				0.11
MAMTI, 2006	*Hemitaurichthys polylepis*	0.90	0.34	0.45	
	Hippocampus erectus				
MAMTI, 2006	*Labroides dimidiatus*	0.84	0.28	0.39	
MAMTI, 2006	*Meiacanthus atrodorsalis*	0.11	0.06	0.07	
MAMTI, 2006	*Naso elegans*	0.78	0.39	0.47	
EC-PREP, 2005;	*Naso lituratus*	1.12	0.17	0.36	0.74

MAMTI, 2006					
EC-PREP, 2005	*Naso unicornis*				0.28
MAMTI, 2006	*Nemateleotris magnifica*	0.90	0.29	0.41	
MAMTI, 2006	*Novaculichthys taeniourus*	0.34	0.17	0.20	
MAMTI, 2006	*Odonus niger*	0.17	0.06	0.08	
MAMTI, 2006	*Ostracion cubicus*	0.22	0.11	0.13	
MAMTI, 2006	*Oxymonacanthus longirostris*	0.34	0.11	0.16	
	Paracanthurus hepatus				
EC-PREP, 2005	*Paraglyphidodon melas*				0.07
MAMTI, 2006	*Parupeneus cyclostomus*	8.98	4.49	5.39	
	Platax pinnatus				
MAMTI, 2006; Shuman, Hodgson, & Ambrose, 2004	*Plectorhinchus chaetodonoides*	0.59	0.19	0.23	
MAMTI, 2006	*Plectorhinchus orientalis*	0.56	0.28	0.34	
EC-PREP, 2005	*Plectroglyphidodon lacrymatus*				0.07
MAMTI, 2006	*Pomacanthus imperator*	1.87	0.75	0.97	
MAMTI, 2006	*Pomacanthus navarchus*	6.74	2.81	3.60	
MAMTI, 2006	*Pomacanthus semicirculatus*	0.56	0.28	0.34	
MAMTI, 2006	*Pomacanthus xanthometopon*	0.28	0.14	0.17	
MAMTI, 2006	*Premnas biaculeatus*	0.85	0.43	0.51	
MAMTI, 2006	*Pseudanthias pascalus*	0.11	0.06	0.07	
	Pterapogon kauderni			.	
MAMTI, 2006	*Ptereleotris evides*	0.11	0.06	0.07	
MAMTI, 2006	*Pterois antennata*	0.17	0.06	0.08	
MAMTI, 2006	*Pterois radiata*	0.90	0.28	0.40	
MAMTI, 2006	*Pterois volitans*	0.73	0.31	0.39	

MAMTI, 2006	*Pygoplites diacanthus*	1.35	0.45	0.63	
MAMTI, 2006	*Rhinecanthus aculeatus*	0.56	0.17	0.25	
MAMTI, 2006	*Zebrasoma desjardinii*	0.56	0.28	0.34	
	Zebrasoma flavescens				
MAMTI, 2006	*Zebrasoma veliferum*	0.90	0.34	0.45	

Appendix I

Estimated shipping costs per fish for various species

Estimates of box and freight costs given by A. Rhyne. Number of fish per box from data from EC-PREP (2005). Prices in USD.

Species	# Fish per box	Box cost per fish (at $15/box)	Freight cost per box ($5/kg) × (22.5kg/box)	Freight per fish	Shipping per fish (box +freight)
Abudefduf vaigiensis	80	0.19	112.50	1.41	1.59
Acanthurus leucosternon	6	2.50	112.50	18.75	21.25
Acanthurus lineatus	12	1.25	112.50	9.38	10.63
Acanthurus maculiceps	12	1.25	112.50	9.38	10.63
Acanthurus nigricans	10	1.50	112.50	11.25	12.75
Acanthurus olivaceus	10	1.50	112.50	11.25	12.75
Acanthurus pyroferus	12	1.25	112.50	9.38	10.63
Amphiprion clarkii	80	0.19	112.50	1.41	1.59
Amphiprion ocellaris	100	0.15	112.50	1.13	1.28
Amphiprion polymnus	80	0.19	112.50	1.41	1.59
Apolemichthys trimaculatus	12	1.25	112.50	9.38	10.63
Bodianus diana	12	1.25	112.50	9.38	10.63
Bodianus mesothorax	12	1.25	112.50	9.38	10.63
Centropyge bicolor	16	0.94	112.50	7.03	7.97
Centropyge bispinosus	16	0.94	112.50	7.03	7.97
Centropyge eibli	16	0.94	112.50	7.03	7.97
Centropyge nox	16	0.94	112.50	7.03	7.97
Centropyge tibicen	16	0.94	112.50	7.03	7.97
Centropyge vroliki	16	0.94	112.50	7.03	7.97
Cetoscarus bicolor	16	0.94	112.50	7.03	7.97
Chaetodon auriga	12	1.25	112.50	9.38	10.63
Chaetodon burgessi	9	1.67	112.50	12.50	14.17
Chaetodon kleinii	6	2.50	112.50	18.75	21.25
Chaetodon lunula	11	1.36	112.50	10.23	11.59
Chaetodon melanotus	9	1.67	112.50	12.50	14.17
Chaetodon rafflesi	10	1.50	112.50	11.25	12.75
Chaetodon reticulatus	10	1.50	112.50	11.25	12.75
Chaetodon reticulatus	10	1.50	112.50	11.25	12.75
Chaetodontoplus melanosoma	12	1.25	112.50	9.38	10.63
Chrysiptera cyanea	80	0.19	112.50	1.41	1.59
Chrysiptera talboti	80	0.19	112.50	1.41	1.59
Coris aygula	12	1.25	112.50	9.38	10.63
Coris gaimard	20	0.75	112.50	5.63	6.38
Dascyllus trimaculatus	100	0.15	112.50	1.13	1.28
Doryrhamphus	12	1.25	112.50	9.38	10.63

dactyliophorus					
Gomphosus varius	60	0.25	112.50	1.88	2.13
Gymnomuraena zebra	6	2.50	112.50	18.75	21.25
Hemitaurichthys polylepis	12	1.25	112.50	9.38	10.63
Labroides dimidiatus	40	0.38	112.50	2.81	3.19
Nemateleotris magnifica	40	0.38	112.50	2.81	3.19
Novaculichthys taeniourus	20	0.75	112.50	5.63	6.38
Ostracion cubicus	12	1.25	112.50	9.38	10.63
Oxymonacanthus longirostris	12	1.25	112.50	9.38	10.63
Paracanthurus hepatus	12	1.25	112.50	9.38	10.63
Plectorhinchus orientalis	12	1.25	112.50	9.38	10.63
Pomacanthus imperator	8	1.88	112.50	14.06	15.94
Pomacanthus navarchus	5	3.00	112.50	22.50	25.50
Pomacanthus semicirculatus	5	3.00	112.50	22.50	25.50
Pomacanthus xanthometopon	4	3.75	112.50	28.13	31.88
Premnas biaculeatus	60	0.25	112.50	1.88	2.13
Ptereleotris evides	40	0.38	112.50	2.81	3.19
Pterois antennata	12	1.25	112.50	9.38	10.63
Pterois radiata	8	1.88	112.50	14.06	15.94
Pterois volitans	8	1.88	112.50	14.06	15.94
Pygoplites diacanthus	12	1.25	112.50	9.38	10.63
Zebrasoma veliferum	13	1.15	112.50	8.65	9.81

Appendix J

Prices paid for fishes by U.S. importers

Total price paid by importers was calculated by adding the estimated shipping cost per species to the price paid by importers for the fish itself (A. Rhyne, unpublished data). All prices are in USD.

Species	**Paid by importers (A. Rhyne, unpublished data)**	**Shipping Costs (Estimated)**	**Total paid by importers (fish price + shipping)**
Abudefduf vaigiensis	.	1.59	
Acanthurus leucosternon	.	21.25	
Acanthurus lineatus	.	10.63	
Acanthurus maculiceps	.	10.63	
Acanthurus nigricans	.	12.75	
Acanthurus olivaceus	.	12.75	
Acanthurus pyroferus	.	10.63	
Amphiprion clarkii	.	1.59	
Amphiprion ephippium	.	.	
Amphiprion ocellaris	.	1.28	
Amphiprion percula	.	.	
Amphiprion polymnus	.	1.59	
Amphiprion sandaracinos	.	.	
Apolemichthys trimaculatus	.	10.63	
Bodianus diana	.	10.63	
Bodianus mesothorax	.	10.63	
Centropyge bicolor	.	7.97	
Centropege bispinosus	.	7.97	
Centropyge eibli	.	7.97	
Centropyge loriculus	.	.	
Centropyge nox	.	7.97	
Centropyge tibicen	.	7.97	
Centropyge vroliki	.	7.97	
Cephalopholis cyanostigma	.	.	
Cetoscarus bicolor	.	7.97	
Chaetodon auriga	.	10.63	
Chaetodon burgessi	.	14.17	
Chaetodon kleini	.	21.25	
Chaetodon lunula	.	11.59	
Chaetodon melanotus	.	14.17	
Chaetodon meyeri	.	.	
Chaetodon rafflesi	.	12.75	
Chaetodon reticulatus	.	12.75	

Chaetodon reticulatus	.	12.75	
Chaetodon trifascialis	.	.	
Chaetodontoplus melanosoma	.	10.63	
Chelmon rostratus	.	.	
Chromis margaritifer	.	.	
Chrysiptera cyanea	.	1.59	
Chrysiptera parasema	.	.	
Chrysiptera talboti	.	1.59	
Cirrhilabrus cyanopleura	.	.	
Coris aygula	.	10.63	
Coris gaimard	.	6.38	
Dascyllus trimaculatus	.	1.28	
Doryrhamphus dactyliophorus	.	10.63	
Forcipiger longirostris	.	.	
Gomphosus varius	.	2.13	
Gymnomuraena zebra	.	21.25	
Hemigymnus melapterus	.	.	
Hemitaurichthys polylepis	.	10.63	
Hippocampus erectus	.	.	
Labroides dimidiatus	.	3.19	
Meiacanthus atrodorsalis	.	.	
Naso elegans	.	.	
Naso lituratus	1.26	.	
Naso unicornis	0.87	.	
Nemateleotris magnifica	0.82	3.19	4.01
Novaculichthys taeniourus	0.95	6.38	7.33
Odonus niger	1.20	.	
Ostracion cubicus	1.26	10.63	11.89
Oxymonacanthus longirostris	0.52	10.63	11.15
Paracanthurus hepatus	6.40	10.63	17.03
Paraglyphidodon melas	0.27	.	
Parupeneus cyclostomus	1.06	.	
Platax pinnatus	5.69	.	
Plectorhinchus chaetodonoides	1.57	.	
Plectorhinchus orientalis	1.85	10.63	12.48
Plectroglyphidodon lacrymatus	0.29	.	
Pomacanthus imperator	.	15.94	
Pomacanthus navarchus	21.98	25.50	47.48
Pomacanthus semicirculatus	5.12	25.50	30.62
Pomacanthus xanthometopon	23.38	31.88	55.26
Premnas biaculeatus	0.84	2.13	2.97
Pseudanthias pascalus	.	.	
Pterapogon kauderni	1.84	.	
Ptereleotris evides	0.71	3.19	3.90
Pterois antennata	1.14	10.63	11.77
Pterois radiata	2.75	15.94	18.69

Pterois volitans	2.25	15.94	18.19
Pygoplites diacanthus	3.75	10.63	14.38
Rhinecanthus aculeatus	1.14	.	
Zebrasoma desjardinii	0.39	.	
Zebrasoma flavescens	1.51	.	
Zebrasoma veliferum	1.43	9.81	11.24

Appendix K

Wholesale prices for various fish species.

Prices were calculated as average sales prices in 2009 and 2010 based on data from Sea Dwelling Creatures, LLC. All prices are in USD.

Species	**Wholesaler 2009 sales prices**	**Wholesaler 2010 sales prices**	**Average wholesale prices**
Abudefduf vaigiensis	1.24	1.25	1.25
Acanthurus leucosternon	19.00	18.96	18.98
Acanthurus lineatus	14.25	12.95	13.60
Acanthurus maculiceps	92.72	77.22	84.97
Acanthurus nigricans	13.40	13.90	13.65
Acanthurus olivaceus	14.72	13.63	14.18
Acanthurus pyroferus	19.26	17.80	18.53
Amphiprion clarkii	5.36	4.58	4.97
Amphiprion ephippium	15.13	14.55	14.84
Amphiprion ocellaris	4.96	5.19	5.08
Amphiprion percula	11.20	10.52	10.86
Amphiprion polymnus	9.14	9.80	9.47
Amphiprion sandaracinos	11.71	10.91	11.31
Apolemichthys trimaculatus	23.38	23.38	23.38
Bodianus diana	10.99	11.81	11.40
Bodianus mesothorax	13.93	12.95	13.44
Centropyge bicolor	8.31	8.39	8.35
Centropege bispinosus	9.04	7.82	8.43
Centropyge eibli	9.89	9.79	9.84
Centropyge loriculus	13.21	11.48	12.35
Centropyge nox	8.24	8.38	8.31
Centropyge tibicen	8.63	8.17	8.40
Centropyge vroliki	7.92	8.16	8.04
Cephalopholis cyanostigma	16.46	13.38	14.92
Cetoscarus bicolor	11.72	10.84	11.28
Chaetodon auriga	11.58	11.37	11.48
Chaetodon burgessi	52.03	46.79	49.41
Chaetodon kleini	9.57	9.43	9.50
Chaetodon lunula	12.76	12.52	12.64
Chaetodon melanotus	10.83	12.00	11.42
Chaetodon meyeri	15.00		15.00
Chaetodon rafflesi	12.33	11.00	11.67
Chaetodon reticulatus	11.00		11.00
Chaetodon reticulatus	18.00		18.00
Chaetodon trifascialis	13.86		13.86
Chaetodontoplus melanosoma	27.00	19.00	23.00

Chelmon rostratus	11.00	11.96	11.48
Chromis margaritifer	2.56	2.78	2.67
Chrysiptera cyanea	1.31	1.34	1.33
Chrysiptera parasema	1.30	1.33	1.32
Chrysiptera talboti	1.94	1.92	1.93
Cirrhilabrus cyanopleura	11.35	11.29	11.32
Coris aygula	37.80	32.70	35.25
Coris gaimard	11.30	13.12	12.21
Dascyllus trimaculatus	1.28	1.34	1.31
Doryrhamphus dactyliophorus	6.57	6.63	6.60
Forcipiger longirostris	11.86	11.38	11.62
Gomphosus varius	11.21	13.02	12.12
Gymnomuraena zebra	46.15	46.73	46.44
Hemigymnus melapterus	9.85	8.50	9.18
Hemitaurichthys polylepis	16.03	14.47	15.25
Hippocampus erectus	28.70		28.70
Labroides dimidiatus	7.71	7.64	7.68
Meiacanthus atrodorsalis	3.29	4.00	3.65
Naso elegans	34.84	29.81	32.33
Naso lituratus	15.54	14.15	14.85
Naso unicornis	30.93	15.34	23.14
Nemateleotris magnifica	2.25	1.88	2.07
Novaculichthys taeniourus	13.11	13.98	13.55
Odonus niger	9.05	7.13	8.09
Ostracion cubicus	8.63	9.03	8.83
Oxymonacanthus longirostris	6.52	7.00	6.76
Paracanthurus hepatus	22.86	27.56	25.21
Paraglyphidodon melas	1.78	1.68	1.73
Parupeneus cyclostomus	9.05	10.28	9.67
Platax pinnatus	39.00	22.04	30.52
Plectorhinchus chaetodonoides	9.26	9.27	9.27
Plectorhinchus orientalis	9.74	12.23	10.99
Plectroglyphidodon lacrymatus	1.95	2.00	1.98
Pomacanthus imperator	72.23	66.69	69.46
Pomacanthus navarchus	52.63	51.86	52.25
Pomacanthus semicirculatus	14.81	13.46	14.14
Pomacanthus xanthometopon	63.78	72.50	68.14
Premnas biaculeatus	8.00	9.29	8.65
Pseudanthias pascalus	7.29	7.42	7.36
Pterapogon kauderni			.
Ptereleotris evides	4.46	4.45	4.46
Pterois antennata	8.00		8.00
Pterois radiata	22.75	20.50	21.63
Pterois volitans	26.45	17.65	22.05
Pygoplites diacanthus	27.34	28.55	27.95
Rhinecanthus aculeatus	8.94	8.23	8.59

Zebrasoma desjardinii	19.20	20.44	19.82
Zebrasoma flavescens	15.11	12.15	13.63
Zebrasoma veliferum	11.93	10.95	11.44

Appendix L

Online retail price data for selected species

Price data from retailers were retrieved from the following websites (Dates obtained): http://www.thatpetplace.com (1/27/2012), http://www.freshmarine.com (1/272012), http://www.liveaquaria.com (1/28/2012), http://www.bluezooaquatics.com (1/29/2012), and http://www.petco.com (1/29/2012). All prices are in USD.

Species	That fish place	Fresh marine	Live aquaria	Blue Zoo Aquatics	Petco	Ave. price
Abudefduf vaigiensis						
Acanthurus leucosternon	86.24	81.73	52.49		62.79	70.81
Acanthurus lineatus	44.99	47.65	59.99	125.95	60.39	67.79
Acanthurus maculiceps	159.99	176.48		237.45		191.31
Acanthurus nigricans	69.99	44.31		74.95	60.39	62.41
Acanthurus olivaceus	59.99	56.98	123.81	87.45	53.99	76.44
Acanthurus pyroferus	79.99	34.98		54.95		56.64
Amphiprion clarkii	19.99 (tank)	16.65	23.99 (tank)	28.70	23.19	22.85
Amphiprion ephippium	24.99			34.45		29.72
Amphiprion ocellaris	29.99	30.32	15.32	18.75	27.07	24.29
Amphiprion percula	32.49	29.98	30.99	29.20		30.67
Amphiprion polymnus	24.99(tank)	20.50		28.62	22.39	23.84
Amphiprion sandaracinos	19.99	25.83		26.70		24.17
Apolemichthys trimaculatus	99.99	92.65		102.45		98.36
Bodianus diana	48.32	34.98	50.43	58.28	30.39	44.48
Bodianus mesothorax	37.49	26.65	36.99	32.45	30.19	32.75
Centropyge bicolor	29.99	29.98	24.99	27.06	27.19	27.84
Centropege bispinosus	27.49	26.98	24.99	36.48	21.44	27.48
Centropyge eibli	43.32	33.98	39.99	40.45	30.39	37.63
Centropyge loriculus	74.99	45.98	39.99	56.33	43.99	52.26
Centropyge nox	29.99	32.98	35.66	33.70	27.99	32.06
Centropyge tibicen	27.49	25.98	26.66	26.62	18.79	25.11
Centropyge vroliki	22.49	26.98	37.49	24.62	26.39	27.59
Cephalopholis cyanostigma	59.99					59.99
Cetoscarus bicolor	34.99	34.65		31.62	21.59	30.71
Chaetodon auriga	34.99	39.65	42.49	86.95	39.19	48.65
Chaetodon burgessi		113.31	119.99	146.20		126.50
Chaetodon kleini	24.99	26.98	27.49	23.54	28.79	26.36
Chaetodon lunula	43.32	53.48	54.99	57.45	26.39	47.13

Chaetodon melanotus	29.99	35.98		31.62	26.39	31.00
Chaetodon meyeri				79.95		79.95
Chaetodon rafflesi	34.99		33.49	41.70		36.73
Chaetodon reticulatus				49.95		49.95
Chaetodon reticulatus				59.95		59.95
Chaetodon trifascialis						
Chaetodontoplus melanosoma	84.99	71.65		112.45		89.70
Chelmon rostratus	41.66	40.31	93.32	96.95		68.06
Chromis margaritifer	9.99		18.99	19.96		16.31
Chrysiptera cyanea	4.99	4.98	3.99	4.95	12.23	6.23
Chrysiptera parasema	4.99	3.25	3.99	4.95	3.59	4.15
Chrysiptera talboti	6.99	7.50	7.99	11.95	6.39	8.16
Cirrhilabrus cyanopleura	26.66	54.98	34.99	36.62		38.31
Coris aygula	69.99		37.49	72.45		59.98
Coris gaimard	59.99	53.50	44.99	78.28	37.19	54.79
Dascyllus trimaculatus	4.99	2.98	4.99	4.95	12.23	6.03
Doryrhamphus dactyliophorus		13.98	19.99			16.99
Forcipiger longirostris						
Gomphosus varius	57.49	54.31	32.49	31.62	45.99	44.38
Gymnomuraena zebra	219.99	117.73	173.74	183.95		173.85
Hemigymnus melapterus				28.28		28.28
Hemitaurichthys polylepis	79.99	59.98		59.95	37.19	59.28
Hippocampus erectus		99.99	64.99 (tank)	62.45 (tank)		99.99
Labroides dimidiatus	19.99	8.50	27.49	10.91	18.39	17.06
Meiacanthus atrodorsalis	19.99	13.98		19.95		17.97
Naso elegans	106.66		200.76	168.17		158.53
Naso lituratus	79.99	97.23	94.99	132.83	99.99	101.01
Naso unicornis	79.99	85.98		175.66	72.79	103.61
Nemateleotris magnifica	12.99	11.98	8.99		10.39	11.09
Novaculichthys taeniourus	34.99	34.31	39.99	56.28	31.99	39.51
Odonus niger	27.49	34.25	51.70	43.70	29.59	37.35
Ostracion cubicus	39.99	32.31	27.99	36.95	26.39	32.73
Oxymonacanthus longirostris				44.95		44.95
Paracanthurus hepatus	72.49	68.02	48.75	70.95	47.59	61.56
Paraglyphidodon melas						
Parupeneus cyclostomus	42.49	42.17	49.99	33.70	27.79	39.23
Platax pinnatus		84.17	99.99(j)	123.28		103.73

Plectorhinchus chaetodonoides	34.99	33.65	26.66	25.95		30.31
Plectorhinchus orientalis				31.28	43.99	37.64
Plectroglyphidodon lacrymatus	5.99			9.95	11.19	9.04
Pomacanthus imperator	199.99	188.75	126.66	421.95	161.99	219.87
Pomacanthus navarchus	214.99	175.23	164.99	264.95	131.19	190.27
Pomacanthus semicirculatus	54.99	66.98		197.45		106.47
Pomacanthus xanthometopon	144.99	177.98	184.99	264.95	139.99	182.58
Premnas biaculeatus	37.49	29.50	32.99	52.95	31.19	36.82
Pseudanthias pascalus						
Pterapogon kauderni		21.98	19.99	24.95		22.31
Ptereleotris evides	16.99	17.98	12.49	15.42	14.79	15.53
Pterois antennata		32.98	49.99	38.95	22.79	36.18
Pterois radiata	79.99	43.98	76.66	96.62	45.59	68.57
Pterois volitans	57.49		72.49	124.24	59.19	78.35
Pygoplites diacanthus	79.99	87.49		149.95	74.79	98.06
Rhinecanthus aculeatus	43.74	38.31	34.66	55.12	30.39	40.44
Zebrasoma desjardinii	114.99		49.99	122.12	115.19	100.57
Zebrasoma flavescens	51.99		44.99	53.83	31.39	45.55
Zebrasoma veliferum	59.99	41.83	52.49	88.95	29.59	54.57

Appendix M

Case studies

The following is a list of case a list of case studies we found valuable in considering the various components of a successful mariculture operation, however it is by no means an exhaustive study of ornamental mariculture. Information was pulled from published papers and NGO websites, and may no longer be completely up to date.

Case Study Table of Contents

Financial viability of coral farming in the Solomon Islands

Financial viability tends to be the largest barrier to transitioning towards sustainable operations in the producer countries in the Coral Triangle, as it determines the viability of producer livelihoods. This comprehensive study compares the financial viability of a wild harvest-based coral fishery with a culture-based coral fishery in the Solomon Islands. The authors found wild harvest of coral and fish products at the two case study locations to be "financially viable but not highly profitable" (18). The largest cost was found to be transportation from collection site to the middleman, accounting for approximately half the gross revenue; this is even after factoring a subsidy of 30% of the gross value of coral products.

The study highlights key barriers to commercial feasibility, while making recommendations for overcoming those barriers. Commercial viability of a coral mariculture operation for the aquarium trade in the Solomon Islands is determined by the following factors:

- Local transportation and other costs
- Condition of local infrastructure
- Availability of air cargo space
- Regular air flights

Coral culture in the Solomon Islands can only be a financially viable option if the following conditions are met:

- A reasonable scale of operation is adopted
- Operators keep the number of marketing trips to at least one a month
- Transport costs are shared with other villagers
- The villagers are paid a higher price

Findings from this study support similar work done in Fiji by Lal and Cerelala (2005), who found coral culture to be financially viable even at a low scale of production. Lal and Cerelala (2005), however, found despite financial viability of coral culture operations, cultured corals without a price premium were not competitive against wild harvest .

Source:
Lal, P., & Knich, J. (2005). Financial Assessment of the Marine Trade of Coals in Solomon Islands. Retrieved on 12 Nov 2011 from <http://www.fspi.org.fj/>

Lal, P. & Cerala, A. (2005). Financial and Economic Analysis of Wild Harvest and Cultured Live Coral and Live Rock in Fiji. A Report prepared for the Foundation of the People of the South Pacific International, Suva, Fiji; and the South Pacific Regional Environment Programs, Apia, Samoa.

Successful "conservation mariculture" using sea cages off the Kanyakumari coast, India

Lobsters were identified as having financial potential for mariculture in India due to their high per capita value. This study tested the technical feasibility of sea cages off the coast of Kanyakumari, India, as well as the biological feasibility of raising spiny lobsters. A total of 2400 lobsters (juvenile lobsters that were caught using fish nets) were stocked in the 6 meter diameter cage at a depth of 4.5 meter, with the bottom of the cage lined with silpolin (a material that acts as a tarpaulin), which acts as a suitable substrate for the lobsters.

The operation was successful as "conservation mariculture," since full-cycle breeding was achieved after the initial stock of juvenile lobsters. An increase in ornamental fish and lobster populations around the outside of the cage was observed, signifying the potential ecosystem benefit of such sea cage "ecosystems". Due to lack of suitable technologies and production methods for the land-based farming of lobster, this study concluded that open-ocean cage farming of lobsters to be the "only best profitable alternative for lobster mariculture."

Source:
MFRI, Kochi. (2010). Successful harvest of sea cage farmed spiny lobsters and ornamental fishes at Kanyakumari and Mandapam. CMFRI Newsletter No.124 January- March 2010, 124:5-6.

Successful integrated ecosystem and community-based management in Seribu Islands, Indonesia

This is a success story about a group of fisherman and middlemen in Seribu Islands, Jakarta who, with the help of the Indonesian Coral Reef Foundation (TERANGI), effectively transitioned away from destructive cyanide-use practices to an ecosystem-based management approach for the local fishery. After a previous failure of MAC certification in the region in 2002 that only targeted certain fishermen and middlemen, TERANGI switched to a bottom-up approach. The organization helped to organize a community group of fishermen and middlemen and held a series of trainings of how to comply with MAC Collecting and Fishing and Handling Standards. Additionally, in 2006, upon consultation of local stakeholders, a collection area and associated management plan were created to rebuild the degraded coral reef ecosystem.

Much can be learned from the successes and difficulties of the community and TERANGI's efforts. Firstly, an integrated, ecosystem-based approach (or as the study describes, "holistic") is necessary to restore and recover the fishery, as well as manage it for future health. The initial ineffectiveness of the MAC certification standards was attributed to the following (quoted from study):

1. Limited group cohesion
2. Lack of program awareness in the community and wider government
3. Inadequate law enforcement
4. Lack of leadership in the community
5. No coordination between government and the community
6. Lack of stakeholder involvement

It was noted that cooperation between government and community is the key to making rule enforcement and integrated management possible. However, even with such support, monitoring and evaluation of the fishery was found to be difficult given the complexity of the trade documentation form; additionally, the MACTRAQ protocol does not include many of the most traded species in the area.

Source:
Syahrir, M., Timotius, S., Prastowo, M., Idris, Yusri, S. (May, 2009). Lesson Learned from Coral Reef Ornamental Fisheries Management in Seribu Islands, Indonesia: Beyond MAC Standards. Unpublished Paper Presented in the International Ocean Science, Technology and Policy Symposium at the World Ocean Conference, Manado, Indonesia.

North Bali Les Village Ornamental Shrimp Aquaculture

LINI is a local NGO in Indonesia. They worked with fishermen of Les village in North Bali to establish an ornamental shrimp farm. They have successfully constructed shrimp pods consisting of concrete structures placed on the sea floor at 15 meter depth. The collection methods are modified PCC; the fishermen collect broodstock and then transfer them to the pods. Currently three types of shrimp have been cultured this way: mostly camel shrimp (*Rhynchocinetes* spp.), but also White-banded Cleaner Shrimp (*Lysmata amboinensis*), and banded shrimp (*Stenopus hispidus*). White banded ornamental shrimp can fetch 7000 rupiah, or USD $0.80 per individual.

During the first 2 months, 4 species of shrimp were identified in the pods. To date, 500 ornamental shrimp (mostly camel shrimp) have been harvested from the pods (July 2010 to February 2011). Predation by various fish was a problem, so the pods are being modified and retested. The efforts have been promising so far, but the shrimp have not been distinguished from wild-caught and thus do not command a price premium (Gayatri, personal communication, January 16, 2012).

Source:
The Indonesian Nature Foundation. "Testing The Shrimp Pods For Ornamental Shrimp Farming In Les Village." Retrieved on 25 Jan 2011 from <http://www.lini.or.id/en/media-center/news/52-testing-the-shrimp-pods-for-ornamental-shrimp-farming-in-les-village>

Marshall Islands Mariculture Farm

In 2003, Oceans, Aquariums and Reefs (OAR) a private, for-profit company based in Florida Atlantic University's Harbor Branch Campus, opened a giant clam hatchery on the island of Majuro in the Marshall Islands. The company is a large producer of aquacultured saltwater fish, inverts, and live aquarium food fish for the aquarium hobby.

More recently, the Marshall Islands Mariculture Farm (MMF) and the Marshall Islands Conservation Society (MICS) started a joint project to empower local communities with sustainable practices without depleting natural resources. With additional support from the University of Hawaii's Sea Grant program, the MMF and MICS provided local communities with the tools and skills to culture clams locally and generate income.

Today, MMF operates in partnership with local farmers to harvest hard and soft corals along with several species of giant clams. MMF provides farmers with supplies to grow corals in cages. Local farmers place cages in lagoons in front of their houses and supply cultured corals to MMF. This has become an important export for many of the smaller islands. According to OAR: "Many Marshall Island, MMF, or Micronesia corals were grown by local farmers who have cages in lagoons in front of their homes," showing that mariculture can be feasible with minimal equipment.

Source:
Marshall Islands Conservation Society. (2011). Community Clam Farming. Project Summary. Retrieved on 25 Jan 2011 from <http://kobedia.org/projects/marine_program/community_clamfarming/community_clamfarming.html>

Oceans, Reefs, and Aquariums. (n.d.) Marshall Islands Mariculture Farm. Retrieved on 25 Jan 2011 from <http://www.orafarm.com/about/about_marshall.html>

Women's Collective Coral Farm in Marau, Solomon Islands

This mariculture operation is a coral farm sponsored by a coral aquaculture company called PacificEast Aquaculture, located in Maryland, United States. At the Solomon Island Coral Farm in Marau, an isolated area on the eastern side of the island Guadalcanal in the Solomon Islands, approximately 25 to 30 coral farmers practice onshore mariculture of coral species.

> 'The Marau area is remote and isolated with no roads or electricity, but our coral farming efforts provide the only source of income to the native Solomon Islanders and adds an increased respect for the local reefs that now become an even more important resource for the local farmers." –Statement from the PacificEast Aquaculture website

Spearheading the operation and idea, an expert from the PacificEast Aquaculture helped the farmers of Marau identify the parent colonies from which to propagate corals. After this, the operation was entirely turned over for ownership and operation by the farmers. The farmers are all women and collectively raise 15 species of coral. They then propagate coral without glues or epoxy, fastening coral fragments to cement discs using fishing line and then attaching these discs to wire racks with fishing line as well. These racks are then placed next to the respective parent species on the reef, in order to ensure exact conditions as well as mimic the structure and arrangement biodiversity of the reef. Each farmer "plants" coral in an area adjacent to her land based on traditions of customary use rights.

Small frags sell for approximately $4.00 USD and larger ones for $8.00 USD. The coral sales are organized through the sponsor company PacificEast Aquaculture, but are distributed through the wholesaler on the Solomon Islands, Aquarium Arts. Orders are shipped to retailers across the U.S. via Los Angeles. Providing the only source of income for the farmers in Marau and having cultivated local stewardship of the reefs, this operation is a success story of producer community onshore mariculture.

> "Our hobby is certainly a luxury, but the ability to use our purchasing power to have real, measurable impact on islanders half a world away is what makes me so passionate about supporting source country mariculture activities such as I observed in Marau Sound." –Ret Talbot, Coral Magazine. Retrieved on 11 Nov 2011 from <http://www.bluezooaquatics.com/resources.asp?show=424>.

Source:
Talbot, R. (n.d.). Field Report from Solomon Islands - Coral Farmers of Marau Sound. Retrieved on Nov 11, 2011 from <http://www.bluezooaquatics.com/resources.asp?show=424>.

PacificEast Aquaculture. (2010). *Our Solomon Island Coral Farm & The Inspiration Behind Our Pieces Of The Reef*. Retrieved on Nov 11, 2011 from <http://www.pacificeastaquaculture.com/solomon-islands-coral-farm.asp>

Collaborative Effort to Farm Corals in Micronesia

This was a collaborative research project on lagoon-based farming of corals conducted between the Center for Tropical and Subtropical Aquaculture (CTSA), MERIP, and the College of Micronesia. Over 18 months, eight commercially valuable species of hard and soft coral were cultured in Pohnpei, Federated States of Micronesia (FSM), although the authors note that much of the information is relevant throughout Southeast Asia. The methods are intended to be inexpensive and simple; and the report gives highly practical information for those with some prior knowledge of coral culture, including:

- Planting, cutting, and husbandry methods
- Dimensions and methods for constructing subsurface structures
- Shipping methods
- Price range derived from actual sales of the product in the United States
- Survival and growth data

The study also created a model of a fully-integrated farm entirely devoted to producing corals for the marine aquarium industry with one owner and three full-time employees. Capital costs came to approximately USD $60,000 and operating costs came to about U.S. $50,000 per year. Since the start-up costs create an extremely high barrier to entry, the model assumes a loan would be initially acquired and paid back at a reasonable rate. The results show that even with varying coral prices and production volumes, it is possible to make a profit by selling as few as 500 coral per month.

Source:
Ellis, S. & Ellis, E. (2002). Recent Advances in Lagoon-based Farming Practices for Eight Species of Commercially Valuable Hard and Soft Corals - A Technical Report. Center for Tropical and Subtropical Aquaculture Publication No. 147.

Technology and Knowledge Transfer in Aquaculture

The United Nations Food and Agriculture Organization (FAO) and the Network of Aquaculture Centers in Asia Pacific (NACA) have identified numerous courses and training activities within the Coral Triangle and in other surrounding countries. These programs are designed specifically to give local stakeholders information and training on all aspects of aquaculture – from one week courses on the basic fundamentals to year-long courses on hatchery management. These initiatives are co-funded by government and academic institutions, and many are paid. There are many opportunities for interested individuals to gain technical expertise, and we highly recommend anyone beginning an aquaculture program involving community members investigate the possibility of providing high quality, inexpensive training.

Source:
Wilkinson, S. (2006). Mechanisms for technology transfer. In A. Lovatelli, M.J. Phillips, J.R. Arthur and K. Yamamoto (eds). FAO/ NACA Regional Workshop on the Future of Mariculture: a Regional Approach for Responsible Development in the Asia-Pacific Region. Guangzhou, China, 7–11 March 2006. FAO Fisheries Proceedings. No. 11. Rome, FAO. 2008.

Post-larval Capture and Culture (PCC) grow-out in the Solomon Islands

Development project funded by the Australian Centre for International Agricultural Research (ACIAR) to study the feasibility of the capturing and culturing fish in the pre-settlement phase in the Solomon Islands. Using the relatively simple methods of light traps and crest nets, researchers captured and cultured ornamental species, which then showed rapid growth rates and were subsequently sold to aquarium fish exporters. The report concluded that harvesting and culturing pre-settlement ornamental species using low-technology methods is a viable option in off-shore reefs in the Solomon Islands, although it did not provide economic feasibility data.

Source:
Hair, C., Doherty, P., Bell, J., and Lam, M. (October 2000). Capture and culture of presettlement coral reef fishes in Solomon Islands. *Proceedings 9th International Coral Reef Symposium* (2):23-27

Modeling Multispecies Mariculture

For his doctoral dissertation, Hayden designed and modeled a small-scale multispecies mariculture system designed and constructed to have low start-up and operating costs. First, he constructed a simple mariculture system to be used from multiple species, including benthic egg laying species of fish, corals, and algae. The total capital costs were approximately $1974, much lower than previous estimates. Using multispecies tanks significantly lowered operating costs by having a built-in filtration system and converting waste into food products. Additionally, he used the lowest energy possible for a light source with the best photosynthesis of coral to minimize electricity costs while maximizing coral growth. The system was designed to be run by a single person in almost any location, so labor and land use costs were reduced as well, resulting in an estimated operating cost of $133 per month.

Source:
Hayden, J. (2010). A multispecies mariculture system: a holistic approach to ornamental aquaculture. (Unpublished doctoral dissertation). Cape Peninsula University of Technology, South Africa.

Sustainable Sea Cucumber Culture in Micronesia

These reports describe a project to develop a sustainable sea cucumber (*H. Scarbra)* hatchery in Micronesia with an emphasis on the transfer of technology and skills to the local community. The ultimate goal of the project was to revive the wild sea cucumber population that had apparently been decimated by overharvesting. The project successfully implemented a land-based tank system for long-term broodstock and trained local Micronesians to run the operation more or less independently within a year. In 2011, the Micronesian government is to provide grants for research and development of sea cucumber restocking efforts along with logistic support for sea cucumber hatchery development.

Source:
Ito, M. (2009). Sea Cucumber Hatchery Production Technology Transfer in Pohnpei, the Federated States of Micronesia, Years 1 and 2. Center for Tropical and Subtropical Aquaculture 2009 Annual Accomplishment Report*.* pp. 177-183

Ito, M. & Halverston, B. (2011). Pacific aquaculture development and extension support for the U.S. affiliated Pacific islands of the Federated States of Micronesia, FY2010. Center for Tropical and Subtropical Aquaculture 2011 Annual Accomplishment Report. pp. 161-167.

Environmentally Friendly Shrimp Aquaculture

Researchers from the Oceanic Institute are attempting to build knowledge and interest in profitable and environmentally-friendly shrimp aquaculture. This is a two year project that began in 2009 with approximately U.S. $70,000 funding. They conducted an aquaculture workshop that over 80 local stakeholders and government representatives attended and subsequently provided help and support to establish the first shrimp farm on the Tinian (CNMI island south of Saipan). Additionally, researchers visited other existing or potential aquaculture sites and gave site-specific demonstrations and training for the culture of shrimp with the aim of improving reproduction/culture efforts and educating local stakeholders. There have been no further updates published at the time of writing, but the Center for Tropical and Subtropical Aquaculture is expected to publish their annual accomplishment report shortly.

Source:
Moss, D., Moss, S., Otohsi, C., Lima, B., and Catalma, R. (2009). Shrimp production demonstration project and aquaculture training for industry stakeholders of the Commonwealth of the Northern Mariana Islands and Guam, Years 1 and 2. *Center for Tropical and Subtropical Aquaculture Annual Accomplishment Report.* 45-55.

Appendix N.

Guidance document

Gauging interest and assessing the feasibility of mariculture production in producer communities

BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

OLAZUL

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March 2012

This document was created as part of a group project submitted in partial satisfaction of the degree requirements for the Master of Environmental Science & Management. The objective of this document was to provide Olazul, or any other NGO, with the appropriate questions to ask members of producer communities in order to:

1. Gauge a given community's interest in mariculture production as a solution to the current unsustainable harvesting practices.
2. Gather information that is crucial to assessing the on-the-ground feasibility of a mariculture operation and/or business.

The intended respondent of the questions were participants or potentially interested participants in the marine ornamental trade in producer communities in the Coral Triangle or elsewhere.

Questionnaire table of contents

Ecological considerations

1.1. *What marine ornamental species are endemic to the area you are located?*

If the potential site has endemic species, fishes may command a higher price because of additional value that the "perceived rarity" holds from the perspective of consumers. However, this also means that operations need to be hyper-conscious of any impact they might have on the species' population. The FishBase Consortium is an online database of that can help determine the natural species assemblage at a potential mariculture site. This database can be accessed online at Fishbase.org.

1.2. *Is harvesting for the marine ornamental trade currently taking place in your community?*

If harvesting is not taking place, it is likely because: (1) the site is a poor habitat for marine fish or coral reef habitat; or (2) the site is part of a no-take zone in a marine protected area. If either of these are true, then this site would not be an ideal site for a mariculture operation.

1.3. *If yes, what harvesting practices have been used historically or are currently being used in your community and/or at the nearby reefs?*

The methods used can have significant information and value. Some implications are, but not limited to:

a. <u>Blast-fishing or cyanide:</u> This site would most likely have the greatest ecological damage if they have been using either of these methods. That may likely mean the community is not well educated in the environmental impacts of harvesting practice. Thus, this community also has the most to gain by transitioning to more sustainable methods.
b. <u>Quinaldine or clove oil</u>*:* These methods have been suggested as alternative anesthetic solutions because they have less of an ecological impact than the aforementioned blast-fishing and cyanide. However, there is still high risk associated with using any chemicals, and it would be best to pursue other alternatives.
c. <u>Nets</u>: Some nets can be detrimental to the coral reefs by damaging coral if the net snags, or by overharvesting species if the net is large and indiscriminate. Mesh size is important since it will select for a certain size class of fishes, which can lead to size class shifts in the population. Australia's marine aquarium fishery may serve as a good example of management. In Australia, the marine aquarium fishery limits their cast nets to less than 6 meters in diameter, less than 2 meters in any other dimension, and a mesh size smaller than 25 millimeters. Seine nets cannot be longer than 16 meters and mesh size must be less than 28 millimeters.

d. Mini-spears: These have likely been used to capture rare species that cannot be bred in captivity or are normally too deep to be easily captured. Look into whether these species have been found in post-larval traps. If so, then the spear method could be abandoned
e. Assisted breathing apparatus (SCUBA or Hookah): Harvesting with an assisting breathing apparatus allows for longer harvest periods and further risks overharvesting. Unsafe practices can also be detrimental to divers. It is important to investigate the type of diving method and safety protocols.
f. Mariculture/aquaculture: If pens are in the shallow lagoon, their operations are much more vulnerable to storms and the water quality may be low. If there are on-land facilities it implies there is electricity and adequate transportation options. This means the site has great potential, but there may be competing businesses present.
g. Marine Protected Areas (MPAs): Harvesting is likely allowed here, but under certain conditions such as, but not limited to: allowable harvest gear and methods, an open/closed fishing season, quotas, and/or a limited number of licensed fishers. Harvesting and developing an aquaculture operation may take more organizational work, but MPAs may serve as indicator of an ecologically productive site.

1.4. *Has your community been impacted by a decline in marine organisms available for harvest?*

This can be a good indication that the site may be ideal for operations because there used to be a great abundance and/or variety of species. However, this only holds true if the site is NOT the source of the recruits as well. If supply of larvae is the same site for where the larvae develop, it is a population self-replenishing site. This scenario would mean greater caution is needed if PCC harvesting were to be adopted.

2. Technical feasibility

2.1. *How close are you to a major airport or port?*

Convenient access to a major airport or seaport is essential to creating a business based on international export. Additionally, since the product that is being shipping are live organisms, the shorter time that the fishes are travelling, the better the condition that they will arrive in. Usually the fish are passed to the next step in the supply chain within 48 hours to decrease mortality and the need to change the fishes' water (E. Cohen, personal communication, September 1, 2011). Fish should ideally be transported from the collection site to the exporting airport within 36 hours (Kalinowski, 2007).

2.2. *Do you have ownership or other rights to coastal land? Does this include access to coastal waters?*

The answers to these questions are significant by coastal land ownership will determine technical aspects and thus the design of a mariculture facility. A coastal location would allow for a potential seawater flow-through system or off-shore grow out system. An inland location would limit mariculture to a recirculating on-land facility.

2.3. *Do you have a boat? If yes, how long of trips can you make in your boat?*

Boat ownership can provide an alternative to over-land transportation to major airports or seaports. If an adequate boat is already available, then it can be omitted as a variable from the cost model.

2.4. *Do you have access to any of the following harvesting materials: nets, snorkel gear, SCUBA gear?*

One or more set of this gear will be essential in various parts of establishing and maintaining a mariculture production operation. If these are already available, then these variables can be omitted from the cost model.

3. Business feasibility

3.1. *How do you participate in the marine ornamental trade? If you participate in the trade, what percentage of your income (ranges) does your participation in the marine ornamental trade represent?*

Possible answers to the first part of this question include: fisherman, distributor, wholesaler, or no current affiliation. It should be noted that producers may identify themselves by a variety job titles, including fishermen, harvesters, or collectors. It is important to interview a range of players in the trade within a given community and/or location in order to get a variety of perspectives and potential community involvement.

Understanding the percentage of income that individuals receive from participating in the trade will give insight into whether the participation in the trade is a supplemental or entire livelihood for respondents. Also, if multiple interviews are conducted, this information can be compiled to get an estimate of the number of people that this trade supports and the average percentage of livelihoods that the ornamental trade supports in a given community. Overall, this will help NGOs gauge the level of interest and commitment that a community may have for participating in an alternative production operation, such as mariculture. It is assumed that the larger the percentage of income that participation in the trade represents, the most interested producer communities may be in an alternative production method that helps to ensure the long-term sustainability of their livelihoods.

3.2. *Do you have capital to invest in a mariculture venture? If yes, how much? Do you have an external/additional source of funding? If yes, how much and from where?*

Answers to these questions could be factored into our mariculture cost model. The minimum amount of capital needed to start our proposed PCC-Micropod™ mariculture production operation is $145,911.

Building off of the previous question and answer, external sources of funding will likely need to be obtained given the large start-up cost. The more funding that the start-up operation receives, the faster they will turn a profit. This is valuable information to know earlier on in the development process because it is important to show to both investors and producers that the business will be viable within a desirable timescale. The time that it will take for an operation to make a profit is dependent on many variables and can be calculated through our cost model.

3.3. *Are you interested in mariculture as a business option? And if so, why are you interested?*

Gauging the community interest in a mariculture operation will be essential to understanding whether an operation will be viable on the ground. A mariculture operation should be considered unviable if there is not sufficient community buy-in. Community buy-in can be considered sufficient if there are enough willing participants to run the operation and their livelihoods (supplemental or entire) can be supported by the operation.

3.4. *Are you interested in a co-operative business structure? Do you know of other people that are interested in a co-operative as well? If yes, then how many other people do you currently have to start a co-operative?*

Community interest, and thus buy-in, is important to know prior to starting any business because it will ultimately determine how it is organized and who invests in it. There are documented national laws for three out of the six Coral Triangle nations regulating the registration and membership size of co-operatives. According to the FAO, some nations have legal minimums for the number of members needed to start a co-operative and well as the length of time by which a co-operative must register with the government. This information is in Table 16 in the See Final Paper: Business/Co-operative section, page 89.

Also, it is important to gauge the potential number of members of a co-operative in order to predetermine what the price per member share will be. The share price will be the minimum amount that individuals will need to invest in order to become members and share the services and responsibilities of the co-operative. According to the FAO (n.d.), all Coral Triangle nations have laws that restrict the maximum dividends earned from shares, in other words, the interest earned on capital invested. In founding a co-operative, the NGO must determine how to balance making the shares large enough to benefit the start up of the operation with making the dividends large enough to entice members, but small enough to remain within the law.

4. Legal and Political considerations

4.1. *Do non-governmental organizations operate in the area? If yes, do they deal with marine-related issues?*

Olazul should be prepared to provide technical knowledge and business expertise to communities in order to make this venture successful. However, there are already a variety of NGOs with bases established in the Coral Triangle. While not all of them are explicitly interested in the ornamental trade or aquaculture in general, they can act as a valuable resource of knowledge and funding for any project that involves sustainable livelihoods. Once a target community is identified, we recommend contacting any nearby NGOs as part of the planning process to take advantage of their expertise and resources. Additionally, NGOs can act as liaisons to community members who might be reluctant to enter into agreements or negotiations with strangers. The map below (Fig. 1) indicates the locations of several major NGOs in the Coral Triangle.

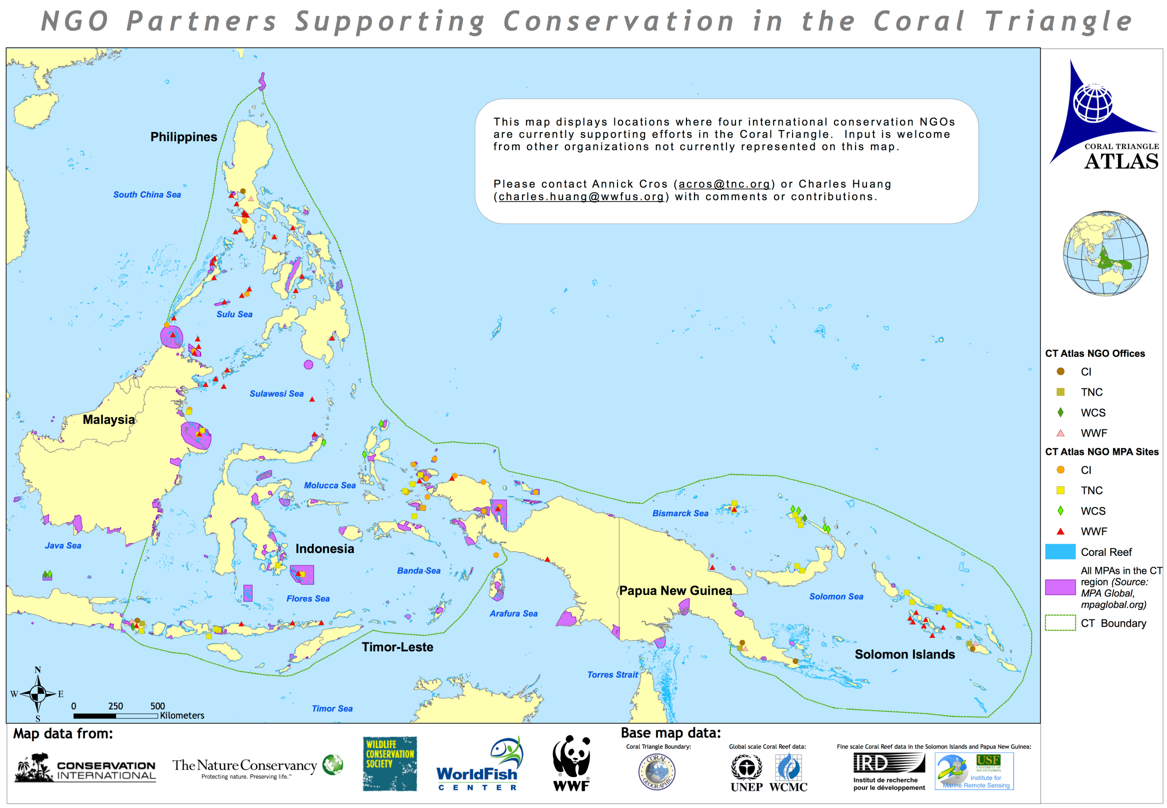

Figure 1. Conservation NGOs in the Coral Triangle. Map source: (Reefbase, 2009).

4.2. *Is the region that you are located in politically stable?*

Political stability is an important consideration for logistical and security reasons regarding foreign NGOs working in these countries, as well as to any potential partners or investors. We used a combination of quantitative metrics, governmental and independent assessments, and current geo-political events to determine the suitability of countries in the Coral Triangle. Table 1 below summarizes our results.

Table 1. Assessment of political stability.

Political Suitability Summary	
Country	**Suitable or Unsuitable**
Indonesia	Suitable
Malaysia	Suitable
Philippines	Suitable
Papua New Guinea	Not Suitable
Solomon Islands	Possibly Suitable
Timor-Leste	Not Suitable

4.3. *What is the legal status of fisheries and marine resources rights in your county? Are there any national laws that would prevent you from harvesting, culturing, and/or selling marine fishes?*

The countries of the Coral Triangle have recognized that many of their marine resources are overexploited and have taken steps to address this through multilateral agreements and national laws. Overall, governments have recognized alternative methods of producing marine resources as a beneficial future trajectory, and have made a concerted effort to streamline regulations to encourage community-level producers. This has included measures such as waiving permit requirements for small mariculture operations and stated commitments to collaboration with outside organizations. We recommend that Olazul closely examine the national laws, especially the recently enacted ones in their target areas, because there may be new initiatives to take advantage of.

4.4. *Are they any community laws or customs that would prevent you from harvesting, culturing, and/or selling marine fishes?*

In Coral Triangle nations, national laws may differ widely from regional laws, which may in turn differ widely from community laws, traditions, and customs. This is especially true of marine resource rights. In some areas, marine resources are collectively owned with strong community oversight. In others, they are treated as a commons and exploited by community and roving collectors alike. We recommend Olazul find out the local laws and customs governing the use of marine resources in any target community and determine whether they would be conducive to a cooperative model of mariculture as part of the planning process.

4.5. *Have there been any attempts or talk of regulating the marine ornamental trade in your country and/or in your community?*

All countries in the Coral Triangle have laws governing the harvest of marine resources, including ornamentals. They are designed to encourage responsible stewardship of coral reefs and their surrounding ecosystems while ensuring economic stability of the communities who utilize their resources. Many of them explicitly ban unsustainable techniques such as the use of cyanide. However, enforcement of the laws tends to be weak and subject to corruption.

Our analysis indicates that if a country or region begins to enforce their laws more stringently, communities who have already shifted away from bad practices will be at an advantage over other who will have lost a source of income. We recommend that Olazul keep stay informed about potential changes in legislation or enforcement that could make it more difficult for collectors who use destructive practices. This could create arguments in favor of shifting to alternative method of production that could sway reluctant community members.