Shrimp Aquaculture in Aguadulce: Impacts on mangrove forest health and shrimp larvae populations in two sites on the Salado coastline

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Shrimp Aquaculture in Aguadulce: Impacts on mangrove forest health and shrimp larvae populations in two sites on the Salado coastline

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SIT Panamá Fall 2017
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Abstract

Shrimp aquaculture is an important industry in Republic of Panama, providing jobs and infrastructure, while supplying the country with seafood and export income. Aquaculture is accompanied by many negative impacts on mangrove ecosystems, and subsequently offshore marine stocks. The abundance and diversity of gastropods and shrimp were sampled in the Salado coastline of Aguadulce, Panama to evaluate the impacts of aquaculture disturbance on mangrove forests. Gastropods were sampled at 3 sites on 9, 100m transects in a “pristine” and disturbed forest. Shrimp were sampled using a push net in 24 sites in tide pools and abandoned shrimp ponds of the two areas. The “pristine” location recorded a higher biodiversity, and a significantly higher abundance of gastropods than the disturbed site. Gastropods of the Potamidae family dominated the disturbed site, while the “pristine” site harbored significant populations of the Littorinidae, Potamidae and Neritina families. Significantly more shrimp were found in the “pristine” site, and only a few individuals were documented in the disturbed site. The disturbance caused by shrimp aquaculture affects the composition and habitat complexity of mangrove ecosystems. The findings of this study illustrate the drastic impacts of aquaculture on mangrove ecosystems and marine faunal populations.
1. Introduction

On the southwestern edge of Coclé province, the struggle between nature and economics is starkly visible. A kilometer inland of the coast of Salado, Aguadulce, the land is bare of forest or field, all replaced by salt and aquaculture production. The community of Aguadulce is deeply connected to nature and all it provides. Salt and sugar production, agriculture, cattle ranching, fishing and aquaculture all play an important role in the history of the area. The beach, reef and mangrove ecosystems have also long provided locals with a protein and income source. However, the balance between human and nature has become greatly skewed. Locals undervalue nature’s services and replace forest with aquaculture or infrastructure. Overfishing stresses fishing stocks, plastic and chemical production harms marine life and the destruction of mangroves for food production impacts offshore recruitment. Shrimp aquaculture has been seen as a sustainable development tactic globally, as it provides food security, economic growth and employment in low income areas (Jennings, 2016). However, the destruction of nursery habitat and larvae harvesting for pond stocking negatively affects wild populations, and is unsustainable. A balance between human and nature is desperately needed to ensure the environmental and economic stability of Aguadulce.

2. Literature Review

Aquaculture

Increases in world population and global development have led to an unprecedented consumption of fish and seafood worldwide. Fish and seafood consumption has increased by 65% in the last 20 years (FAO, 2013). Seafood is a healthy and economic protein source, especially for global coastal communities. Industrialized fishing practices, employed to keep pace with increasing seafood demands, have put immense pressure on global fish stocks (Bolanos, 2012). Overfishing impacts marine ecosystems by reducing top-down control of macro-algae, and reducing productivity, as fewer fish and crustaceans of reproductive age are present in populations (Hughes et al. 2007). Decreasing fish stocks have led to a global expansion of aquaculture, and as of 2015 according to NOAA, over 50% of global fish consumption is produced through aquaculture (Dewalt et al. 1996, NOAA, 2015). Shrimp aquaculture has mirrored the larger trend, with large increases in production in Southeast Asia and Central America, for the last 40 years.

Benefits of Aquaculture

Aquaculture has numerous environmental and economic benefits (Bolanos, 2012). Aquaculture prevents the exploitation of wild fish stocks, and provides people with healthy, efficiently grown seafood (Porchas et al. 2012). Aquaculture is the fastest growing animal-food industry; from 1970 to 2008 global aquaculture production increased at a rate of 8.3% per year (Porchas et al, 2012). Aquaculture is often associated with sustainable development, as it can be employed at various scales, and is accompanied by poverty alleviation, job growth, and economic development (Porchas et al. 2012, Bolanos, 2012). Aquaculture grants food security to local communities. According to Jennings et al., food security is defined as being sufficient, safe, sustainable, shockproof and sound. When aquaculture is practiced using sustainable methods it provides income, and a healthy protein source with minimal impact to the environment. Aquaculture has been used as a crucial stepping stone from artisanal fishing to business globally.
Aquaculture supplies 50% of the world’s seafood, and employs 23 million workers, approximately 16 million directly and about 6.5 million indirectly (FAO, 2016).

Environmental Issues

Despite its extensive benefits, aquaculture is accompanied by detrimental effects on marine coastal ecosystems and subsequently offshore marine populations. Aquaculture requires large areas of coastal lands for the creation of ponds and infrastructure. Mangrove aquaculture is the most employed method. The majority of ponds are created by removing hectares of mangrove trees from the middle of forests, leaving a mangrove border for protection from wave action. Ponds are dredged, and surrounding mangroves are drained from the construction of inflow and outflow canals (Kungvankij et al., 1986). As aquaculture has increased, so has the deforestation of mangrove forests. The creation of aquaculture has been the largest factor of a 20% to 40% decrease of mangrove forests globally since 1980 (Cienfuegos et al., 2015, TEEB, 2009). Mangrove removal leads to increased sedimentation, coastal erosion, nursery habitat destruction, and the release of carbon stores. Aquaculture practices are detrimental to mangrove ecosystems long after farming has stopped. Mangrove restoration case studies have found that restoration is expensive, labor intensive, and often unsuccessful. It can take decades for mangrove forests to return to their pre-cleared status (Brown et al., 2014, Machin, 2015).

Larvae Harvesting

Many methods of aquaculture impact fishery replenishment through the harvest of larvae for pond stocking (Bolanos, 2012, Dewalt et al., 1996). Traditional aquaculture practices were reliant on populations of wild shrimp fry. Larvae were captured using nets in surrounding mangrove forests, or through filling ponds at the high tide. Tidal water could also be pumped from canals into ponds; however, these methods led to cultivation of many unwanted species (Kungvankij et al., 1986). Larval capture has impacts on the wild populations and the offshore shrimping industry. Larvae harvesting reduces shrimp recruitment in to offshore stocks, and reduces the number of adults of reproducing age in wild populations. The widespread destruction of mangrove forests, a high demand for larvae, and the outbreak of many diseases in the late 20th century led to the use of laboratory-grown fry by many farmers (Bolanos, 2012). Laboratory fry are selectively bred for resistance against disease, fast-growth and a high tolerance for changes in environmental conditions. Laboratory fry have a higher survival rate, and stocking density than natural fry and are both environmentally and economically beneficial (Fernández, 2012).

Panama Seafood Production

Fish and seafood production dominates the Pacific coast of Panama. Summer trade-winds cause upwelling in the Panamanian gulf, which is accompanied by immense fish harvesting. In order to supplement fish harvesting, vast stretches of Panamanian coastal ecosystems have been replaced with aquaculture ponds. Shrimp aquaculture is a key industry on the Pacific coast of Panama. In 2012, there were over 5000 hectares of shrimp ponds in Panama (Bolanos, 2012). Shrimp aquaculture in Panama boomed in the 1980s and was largely subsidized by the Panamanian government as it was seen as a catalyst of economic growth, especially along the Azuero Peninsula (Bolanos, 2012). Panamanian aquaculture has decreased dramatically in the 21st century due to a combination of widespread criticism of aquaculture techniques and mass mortality caused by the white spot syndrome virus. Shrimp production has remained low in
Panama, however the industry has been slowly recovering in recent years, with continued aid from the Panamanian government (Bolanos, 2012).

**Aguadulce City**

Aguadulce City, located 200km southwest of Panama City, is home to a flourishing shrimp aquaculture industry. Aguadulce borders the gulf of Parita, which harbors vast areas of coastal mangrove forests, many of which have been converted to salt flats or aquaculture ponds (Bolanos, 2012). Aguadulce was the site of Panama’s first shrimp processing plant, built in 1974, and has remained one of Panama’s largest shrimp producers until today. In the late 1990s, at the peak of shrimp production, five major shrimp producing companies as well as many small shrimp farmers were present in Aguadulce. Today, Aguadulce harbors two major producers, many small farmers, a larvae production center, and the Autoridad de los Recursos Aquáticos de Panamá (ARAP), which facilitates education of sustainable aquaculture practices. Conservation of marine ecosystems is not a focus to locals in Aguadulce. Mangrove ecosystems are viewed only as an eyesore, mosquito breeding grounds, and a source for wood. The economic consequences of the white spot outbreak left hectares of abandoned ponds throughout Aguadulce. These areas are barren and unused, neither producing income or being restored to mangrove ecosystems.

**White Spot Virus**

The white spot virus was the cause for the devastation of shrimp aquaculture in Latin America in the early 2000s. The white spot virus affects the epidermal cells of the shrimp, and causes rapid death. The white spot virus emerged in Taiwan in 1992, the USA in 1995, and Panama in 1998 (Sánchez-Paz, 2010). The virus is very contagious and spread quickly through farms on the Pacific coast of Panama. In 1998, Panama contained 9000 hectares of shrimp production, exported 10,000 tons of shrimp yearly, and the industry provided 8000 jobs. After the outbreak, the industry suffered a 60% loss in employment, and export dropped to 870 tons in 2000. (Endo, 2004, Fernández, 2012). Today production has been slowly increasing as farmers gradually increase production after virus free seasons. The use of selective breeding, and disease resistant species has allowed increased production, however the industry is far from returning to pre-white spot levels (Fernández, 2012).

**Shrimp Species**

Aquaculture producers in Aguadulce generally have produced two species of shrimp: *Litopenaeus vannamei*, and *Litopenaeus setiferus*. These species are easy to produce at many different scales, as they have a large range of living conditions, and have a high food conversion rate which allows for high economic suitability.

*Litopenaeus Vannamei* (Boone, 1931), Pacific White Shrimp

*Litopenaeus Vannamei* is one of the most widely produced species of shrimp globally. It is native to the eastern Pacific Ocean; however, it is produced in 27 countries worldwide. *Litopenaeus Vannamei* is fast growing, and can be produced at very high densities, up to 70 individuals per m² (Briggs et al, 2004). *Litopenaeus Vannamei* is also tolerant of a wide range of pH, salinity, and temperature. *Litopenaeus Vannamei* has a high survival rate among larvae (Fofonoff et al., 2017). *Litopenaeus Vannamei* production was devastated by the white spot virus in the 1990s and early 2000s, however through controlled selective breeding, *Litopenaeus*
Vannamei has developed resistance to the virus, and the species continues to be the most produced in Panama (Briggs et al., 2004).

*Litopenaeus setiferus* (Linnaeus, 1767), Northern White Shrimp

*Litopenaeus setiferus* has a range from the Gulf of Mexico to the Northeastern coast of the USA. *Litopenaeus setiferus* was an important species for cultivation in the USA in the mid 20th century, however it has been largely replaced by *Litopenaeus Vannamei*. Today, *Litopenaeus setiferus* is cultivated in Florida and in areas of Central and South America. *Litopenaeus setiferus* has a high tolerance of cold temperatures, and thrives in low salinity waters (Hill, 2002). *Litopenaeus setiferus* is more resistant to disease than *Litopenaeus Vannamei* and was minimally affected by the white spot outbreak (Alpuche et al., 2005).

![Common shrimp species. A. Litopenaeus Vannamei, B. Litopenaeus setiferus](image)

**Figure 1.** Common shrimp species. A. *Litopenaeus Vannamei*, B. *Litopenaeus setiferus*

*Mangroves as a Nursery Ecosystem*

Mangrove forests play a crucial role in the health and productivity of marine ecosystems. Mangroves act as nurseries for juvenile fish and many invertebrates. Mangrove trees and root systems provide protection from predators and nutrients for larvae to grow before replenishing offshore populations (Kathiresan et al., 2001). The presence of coastal mangrove ecosystems has been correlated to higher biomass and higher biodiversity of coral reefs (Manson et al., 2005, Nagelkerken et al., 2007). In multiple studies, the fishery services provided by mangroves were valued between 1,700$ and 10,000$ per hectare (Barbier et al. 1997, Cienfuegos, et al., TEEB, 2009). Mangroves also prevent coastal erosion and eutrophication, and produce wood, tannins, and dyes (Kathiresan et al., 2001).

From a shrimp aquaculture standpoint, intact mangrove forests are essential for the success of the industry. Mangrove aquaculture is the most globally used method, as mangroves provide nutrients for larval growth and protect ponds from wave action (TEEB, 2009). Mangrove forests provide a cleaning mechanism for shrimp ponds as they absorb excessive nutrients from shrimp waste (Minh Thu et al., 2007). Most aquaculture methods include harvesting shrimp larvae from mangroves to stock shrimp ponds. A lack of intact forests puts economic pressure on companies to stock ponds using other methods, often through laboratory grown larvae (Bolanos, 2012).

*Panamanian Mangrove Forests*
On the Pacific coast of Panama, tidal inundation levels are uncommonly high. Tides are more than a meter higher than on the Caribbean coast of Panama and can flood more than a kilometer inland. Such tide levels provide large habitat for mangrove forests. Mangroves between the Gulf of Parita and the Bay of San Miguel are known as the Gulf of Panama mangroves and are part of the larger ecoregion of the Panama Bight mangroves (Milchovich, 2011). Panama Bight mangroves are some of the most biologically diverse ecosystems in the world. Stands can reach 30m in height and harbor an incredible diversity of terrestrial and marine life, including many threatened and endangered species (Milchovich, 2011). Panamanian Bight mangroves are threatened by many anthropogenic factors. The creation of aquaculture ponds has destroyed thousands of hectares of mangroves in the last half century. Although restoration projects have been employed, mangrove recovery is slow (Milchovich, 2011). Climate change threatens Panamanian mangrove ecosystems. Both sedimentation caused by rising sea levels and increased storm strength, are damaging the composition and biodiversity of mangrove forests. Strong El Niño years have destroyed vast areas of mangrove forest in Panama, Colombia, and Ecuador (Ward, 2017).

**Mangrove Monitoring:**

Biological monitoring is used in mangrove forests to evaluate ecosystem health and impacts of anthropogenic factors such as deforestation and pollution. Biomonitoring consists of collecting selected groups of animals, identifying them, and using comparative biodiversity to determine ecosystem health (Ryan, 2013). Gastropods have been determined as ideal organisms for use as mangrove biological indicators, as they are easy to sample and form an important link in mangrove food webs (Kathiresan et al., 2001). Gastropods are generally abundant in many compositions of mangrove environments. (Nazim et al. 2015, Shanmugam et al., Duarte, 2016). Gastropods also are sensitive to pollution and disturbance; thus biological monitoring can be used to measure the effect of deforestation on mangrove ecosystems, as well as the impacts of mangrove restoration (Amortegui-Torres et al. 2013, Dewanti, et al. 2012).

**Common Gastropod Families**

**Potamidae**

The Potamidae family of gastropods is one of the most prominent families that dwell in estuaries and mudflats. Members of the Potamidae family, commonly known as horn snails, are highly tolerant of large variations in salinity, temperature and pH (Ricketts, 1985). Members of the Potamidae family are very resistant to desiccation, and live for days either submerged or lacking water. The Potamidae family as used as a biological indicator of mangrove disturbance (Kabir, 2014, Macintosh, 2002). Mangrove ecosystems lacking Potamidae individuals are uncommon, and thus may be severely disturbed or unhealthy. *Cerithidea californica, Cerithidea cingulata, Cerithidea valida,* and *Cerithidea montagnei* are common species in the Potamidae family, and have been used as bioindicators (Macintosh, 2002, Nazim et al., 2015, Contreras et al., 2008).

**Littorinidae**

The Littorinidae family is very prominent in mangrove ecosystems. Also known as periwinkles, members of the Littorinidae family are climbers and dwell on the roots and
pneumatophores of mangrove trees. Periwinkles graze algae from the roots of mangrove trees, and move up and down the trees in response to tidal inundation. Littorinidae individuals are present in many mangrove ecosystems but are more prominent in dense complex forest habitats. Periwinkles have been used for biological indicators of pollution, and have been considered as viable organisms for bioindicators of mangrove health, however they are not widely used in scientific studies (Miranda, Ubrihien, 2012). Periwinkles were introduced to the Americas and thus have not ideal bioindicators in Panamanian ecosystems.

**Neritidae**

Members of the Neritidae family have small rounded shells often with ornate coloration. The Neritidae family is tolerant of high salinity and changes in ecosystem change. The Neritidae family is very wide spread in central America, as individuals are able to live in fresh, brackish, and saltwater. Species of Neritidae have been used as bioindicators of mangrove disturbance and the edge effect in mangrove ecosystems (Amortegui-Torres, 2013). Individuals are able to withstand minor environmental changes; however, they tend to migrate when large scale change occurs. The Neritidae family is more prominent in high quality forests. The most prominent terrestrial Neritidae species in Panama is *Neritina Virginea* (Amortegui-Torres, 2013).

**Thais kiosquiformis** (Muricidae)

*Thais kiosquiformis* of the Muricidae family is a carnivorous, spiral shelled gastropod that is common in Panama and central America. *T. kiosquiformis* lives on roots logs or in tidal pools and feed on micro-fauna in the crevices of the substrate. *T. kiosquiformis* generally dwells solely in the low tidal inundation level (Blanco, 1999). *T. kiosquiformis* is essential to a healthy mangrove ecosystem as the species plays an important role by cleaning mangrove roots of pests and parasites. *T. kiosquiformis* is not a largely used bio-indicator however the species is often present in healthy ecosystems (Kathiresan, 2001).
Figure 2. Political map of Panama. Aguadulce is located on the Gulf of Parita, 200 km southwest of Panama City.

**Study Site:**

The Salado coast of Aguadulce is located 10km east of Aguadulce and is dominated by seafood production. Salado is approximately 15 km in distance and holds 300 hectares of shrimp farms. Salado also holds a shrimp larvae production center, and a shrimp processing center. The Salado coast is home to a small fishing community, as well as small shrimp farmers. Mangrove forests which once were 2 - 5 km wide have been cleared for shrimp and salt production (Salado, 1969). Humans have produced salt on the Salado coast since before the arrival of the Spanish in the 16th century. In the 20th century production greatly increased which led to increased mangrove deforestation.

Sampling was conducted in two sites, one minimally impacted by shrimp farms and one in-close proximity to shrimp farming activities.

**“Pristine” Site**

The unaffected site was a 150m wide strip of mangrove forest directly on the coast. The forest was varied with distinct zonation; sparse forest in the high-tide zone, transitioning into dense mangrove forest further away from the coast. High-tide inundated between 50%-80% of the study area. The forest is young, made up of mainly red and white mangrove trees of approximately 10-15m in height. The forest held a large variation in substrate, including, calcareous rock, peat moss, sand, mud and dirt. The site was approximately 250m from shrimp farming activities, and separated by a road and houses.

**Disturbed Site**

The disturbed site was a group of mangrove forest corridors surrounding a small 43-hectare shrimp farm. Sampling was conducted on the edge of abandoned shrimp ponds and in narrow strips of mangrove forest. Most of the forest was old, and approximately 30m tall,
however the abandoned pond areas contained very young forest no more than 3m in height. Red, Black, and White mangrove forest was present. The substrate was dense organic mud.

Figure 3. The study site in Aguadulce, at 8°11'09.8"N, 80°28'55.7"W. The area shaded red is the disturbed site, the area in green is the “pristine” site.

3. Research Question

Does the abundance and species diversity of gastropods, and non-farmed shrimp in mangrove forests change across two sites of varying aquaculture disturbance along the Salado coast in Aguadulce, Panama?

4. Research Objectives

- To analyze the impact of shrimp farms on the biodiversity and abundance non-farmed shrimp populations in mangrove forests in Aguadulce, Panama.
- To evaluate the impacts of shrimp aquaculture disturbance on the health of mangrove forests in Aguadulce, Panama using gastropods as bioindicators.

5. Methods

Data Collection

Data was collected between November 14, and November 25, in two sites of mangrove forest on the Salado coast of Aguadulce. One site was in mangrove forest surrounding a 43-hectare shrimp farm. The second site was a “pristine” mangrove forest on the Salado coast.
Sampling occurred only at low tide. Sampling methods varied based on the accessibility of the sampling sites.

**Gastropod Sampling**

Sampling was conducted at every 50 meters at three sites on 100m transects. Three, one m$^2$ quadrats were randomly placed at each sampling site. 60 sites were sampled in total, 27 in the “pristine” site and 33 in the “disturbed” site. All mollusks in the quadrats were sampled by removing them from the substrate and taking a picture of each species for later identification (Nazim et al., 2015). Sampling occurred on ground level substrate, such as mud, as well as on roots, up to breast height. (Shanmugam, 2009). The substrate and site description was recorded. Gastropods were identified using, Contreras et al. 2008, and the Smithsonian Tropical Research Institute website (Hill, 2002).

**Figure 4.** Gastropod sample transect locations. All transects are 100m in length, and three samples were taken every 50m. A. Disturbed site. B. “Pristine” site

**Shrimp Larvae Sampling**

Shrimp larvae were collected using a push net with a width of 0.6m and height of 0.8m. Each sampling site was composed of a quad of approximately 10m$^2$. In the quad the push net was swiped through the tide pool sixty times (Ferdousy et al. 2017). The number of captured shrimp were counted every 12 swipes, and 5 values were recorded at each site. Shrimp larvae were identified in the field and classified as *Litopenaeus setiferus*, *Litopenaeus Vannamei* or other individuals. Larvae were released outside of the study area to prevent double counting. In the “pristine” site, sampling was conducted in groups of 3 sites in a radial quad of 15m in radius, in tide pools. Sampling was conducted in the three largest pools in each quad, as small shallow pools were difficult to sample. In the disturbed site, sampling was conducted at 4 sites, every 25m along 75m transects. A total of 48 sites were sampled, 24 in both the “pristine” and disturbed site. Surface temperature and water depth were measured at each site.
Figure 5. Shrimp sample site locations. A. Disturbed site. Transects were 75m in length, 4 samples were taken on each transect, every 25m. B. “Pristine” site. Three sites were sampled in each of 8 groups.

Figure 6. Push net for shrimp larvae capture. The net has an area of 0.24m². The netting is mosquito net with 0.6mm holes.
Data Analysis

The gastropod data was analyzed using Shannon’s and Simpson’s biodiversity index. Sorenson’s index was also calculated comparing the sites. T-tests were calculated to test significance of abundance findings.

\[
\text{Shannon's index} - H' = - \sum p \ln(p) \\
\text{Simpson's index} - D' = \frac{1}{\sum p^2} \\
\text{Evenness} - E_H = H/\ln(S) \\
\text{Evenness} - E_D = D \times \frac{1}{S} \\
\text{Sorenson's index} = \frac{2(\text{Shared Species})}{\text{Site 1} + \text{Site 2}}
\]

6. Ethics

Research was conducted with the goal of minimizing impact on organisms and ecosystems. Mangroves were not cleared during sampling, and damage to mangrove roots was minimized by refraining from standing on roots when possible. During gastropod sampling individuals were only removed from the substrate when a photo was needed for identification. The use of the push net for shrimp sampling led to the capture of unwanted species, however all bycatch was released before counting shrimp. Evaluating shrimp abundance was conducted as efficiently as possible to minimize the time shrimp were in the net. No organisms were removed from the study sites and no organic matter was sampled from mangrove trees.

7. Results

Gastropods

The abundance and diversity of gastropods were significantly different between the “pristine” site and the disturbed site. A total of 1194 gastropods were sampled at the pristine site, and 345 gastropods were sampled at the disturbed site. The pristine site contained more individuals of all species, other than Cerithidea valida, Thais kiosqiformis, and Ellobium stagnalis. Gastropod data included 11 different species in 5 different families. A significant difference in abundance was calculated with a p-value of 0.0001 indicating extreme significance. Shannon’s and Simpson’s biodiversity indices indicated a higher diversity in the pristine site. Biodiversity value for Shannon’s index for the pristine and disturbed site were 0.793, and 0.592, respectively. Values using Simpson’s index were 1.849 and 1.301 for the pristine and disturbed sites respectively. The evenness of the pristine sample was higher than that of the disturbed sample using both indices. The special composition of the samples was skewed toward the Potamidae and Littorinidae families. In the pristine site, Cerithidea montagnei and Littoraria varia individuals represented 96% of the total sample. In the disturbed site, Cerithidea valida represented 87% of the sample.

Shrimp

The abundance of documented shrimp varied greatly between sites. A total of 2,416 shrimp were sampled in the “pristine” site, while only 32 individuals were documented in the
disturbed site. The samples were both dominated by the *Litopenaeus setiferus*, as more than 98% of the sampled shrimp were of that species. Using a two-tailed t-test an extremely significant difference in shrimp abundance was established between the two sites. Of the 24 sample sites in the disturbed location, 12 documented zero shrimp. In the “pristine” location, all sites documented shrimp. Analysis of the depth and temperature of the sample sites found minimal correlation between the number of shrimp caught and the depth or the temperature.

8. Discussion

**Gastropods**

As gastropods are key organisms in food web of mangrove ecosystems the composition, abundance and biodiversity of gastropods reflects on the health of the larger forest. The gastropod data illustrates the environmental destruction of aquaculture. The creation of aquaculture ponds in Salado coast, greatly altered the mangrove ecosystems. The abundance, diversity and composition of gastropods indicates that the “pristine” site is a much healthier and biologically complex ecosystem than the aquaculture disturbed site.

**Gastropod Special Composition**

The gastropod special composition of the two sites depicts a stark difference in health of the ecosystems. The disturbed site was dominated by a disturbance tolerant species, *Cerithidea valida*, of the Potamidae family. *Cerithidea valida* thrives in mudflats with high temperature and salinity, and tolerates areas of little mangrove cover. The homogenous, mud substrate present in the disturbed site explains the higher abundance of *Cerithidea valida* individuals (Ricketts, 1985). The disturbed site contained individuals of the Pseudomelatomidae, Muricidae, and Ellobiidae families, all which are highly tolerant of salinity and temperature. The most abundant species in the “pristine” site was also of the Potamidae family, however the Littorinidae family, root and tree dwelling group was also highly present. The Sorensen's coefficient of 0.706 indicates a high overlap in species between the sites, which can be explained by the close proximity of the sites.

**Gastropod Biodiversity**

Biodiversity indices of the two sites revealed low biodiversity and low evenness in both sites using both Simpson’s and Shannon’s index. The low values are likely attributed to the above-ground sampling method. As many gastropods dwell within the soil in or niches in the substrate, sampling may not have documented all of the gastropods present, thus resulting in low biodiversity values. When comparing the sites, Simpson’s and Shannon’s index indicated similar conclusions. Both indices found higher biodiversity and evenness in the pristine site. This conclusion can be explained by the discrepancy in abundance between the sites and the dominance of *Cerithidea valida* in the disturbed site. In the pristine site, although *Cerithidea montagnei* was the most populous gastropod, *Littorina varia* was also very prevalent thus increasing the evenness value. As gastropod sampling was conducted in close proximity to the Aquaculture ponds, the edge effect altered the biodiversity of the mangroves. According to Amortegui-Torres et al., the edge-effect exposes organisms to higher temperatures, alterations in substrate, and less habitat complexity, leading to lower biodiversity (Amortegui-Torres et al. 2013, 2013). The “pristine” mangrove forest contained many niche microhabitats, allowing for a
higher diversity of gastropods. In the disturbed site, the homogenous substrate didn’t allow for niche partitioning (Robertson, 1992).

**Gastropod Abundance**

The most significant finding of the gastropod data was regarding gastropod abundance. The “pristine” site harbored an extremely significantly higher abundance of gastropods than the disturbed site. The drastic difference of abundance between sites, is due many factors. The disturbed site had a lower mangrove cover than the “pristine,” resulting in less protection from predation. Studies have shown that pneumatophores provide protection to gastropods, and smaller populations are correlated to areas of few pneumatophores (Amortegui-Torres et al. 2013). Low gastropod abundance in the disturbed site could be due to gastropod migration. In response to environmental stressors, a lack of food, or habitat, some gastropod species migrate to areas more beneficial areas (Kayo, 2009). Also, the habitat simplicity of the ecosystem in the disturbed site, prevents nutrient cycling, and the creation of niches within the forest.

The disparity between sites is again shown by the species-abundance graph. The graph depicts a higher abundance of gastropods in the pristine site for all species other than *Cerithidea valida* and *Thais kiosquiformis*. Abundance of a species is often reliant on the amount of resources. As the “pristine” site likely contained a high amount of nutrients, large populations were able to be sustained without interspecies competition (Robertson, 1992).

**Mangrove Health Based on Gastropod Bioindicators**

Gastropod sampling indicates that the “pristine” site is healthier than the disturbed site. The “pristine” site held a significantly higher abundance, and biodiversity than the disturbed site. The composition of each sample also supports this result. The gastropods population in the disturbed site was dominated by *Cerithidea valida* a mud living species which is tolerant of disturbance, high temperature, salinity and homogenous habitats. The “pristine” site however, contained a wide variety of gastropods with difference tolerances of disturbance. As gastropods are an important link in the mangrove food web and are responsive to ecosystem disturbance, it is safe to assume, the gastropods data is representative of the larger ecosystem (Amortegui-Torres et al. 2013, Dewanti, et al. 2012).

**Shrimp**

Shrimp sampling data indicates the difference in health between the two sites. Shrimp abundance and biodiversity is directed impacted by site disturbance, as seen by the sampling data.

**Shrimp Abundance**

The most striking result of the shrimp sampling is the vast difference in abundance between the “pristine” and disturbed site. This difference could be explained many ways. The site location relative to the coast, the site makeup, and the disturbance level all could affect shrimp populations. All natural areas that would have supported shrimp had been removed through the construction of shrimp ponds. Instead, the only habitat for shrimp was abandoned shrimp ponds, which were filled with algae and little animal life. The pristine sample sites were tidal pools that were inundated daily, which allowed for the input of clean water and nutrients.

**Composition**
The Northern White shrimp (*Litopenaeus setiferus*), was the most sampled species in both locations. In the disturbed site all but four individuals were Northern White shrimp. Other species were, the Pacific White shrimp (*Litopenaeus Vannamei*) and the mangrove snapping shrimp (*Alpheus antepenaenultimus*). In the Pristine site, the Northern white shrimp was most prominent. This result was unexpected, as *Litopenaeus Vannamei* is the most farmed shrimp species in Panamá. This could be explained as while the Pacific white shrimp is the most farmed shrimp species, the Northern White shrimp may be more prominent in the wild. Although, the size of sampled shrimp larva was not recorded, through generally observation, shrimp sampled in the disturbed site were larger, all more than 1cm in length. In the pristine site, there were far more small larvae than large.

**Depth and Temperature**

The depth and temperature data demonstrated little correlation between the number of individuals captured and the depth and temperature of the study site. In the pristine site there was a slight upwards correlation between temperature and the number of shrimp captured, however there was no correlation between between depth and shrimp. In the disturbed site there was a slight negative correlation between both depth and temperature and shrimp. Both *Litopenaeus setiferus* and *Litopenaeus Vannamei* tolerate water over 20 °C, as all sample sites were warmer than 20 °C a correlation is not expected. However, in both sites, most shrimp were caught at a temperature between 28 and 29 °C. In sites of higher and lower water temperature fewer shrimp were documented, however this trend is not significant. Although temperature was not a significant factor when examining shrimp catch in each site, the surface water temperature of the sites in the disturbed area was significantly warmer than the water temperature in the “pristine” area. Water temperature could be a factor in the difference of shrimp abundance between sites. This result parallels that of Tropea, et al. 2015, which found that penaeid shrimp were most productive when grown at 28 °C, and shrimp suffered reproduction issues when grown at 32 °C (Tropea, et al. 2015). It is not surprising that there is little correlation between between depth and shrimp abundance as the swipe sampling method minimizes the factor of area in a site.

**The Effect of Aquaculture**

The destruction created by aquaculture creates the observed differences of shrimp abundance between the two study sites. The shrimp ponds in the disturbed site, have disrupted the tidal flow to mangrove forest surrounding the ponds. Areas of potential shrimp habitat have been drained and ponds have been constructed (Páez, 2001). According to Google Maps, the Salado area was cleared for aquaculture and salt production prior to 1969, however based on the location of forests today, mangrove once covered approximately 13,000 hectares on the Salado coastline, compared to the 3000 hectares of forest today (Salado, 1969). In Salado, the only areas of wild shrimp habitat are in abandoned ponds. These areas are not ideal for wild shrimp growth as they are deficient of oxygen, as high organic levels lead to eutrophication. Also, there is no replenishment of the water in the ponds, and thus there is little nutrient flow to facilitate shrimp growth. Finally, the lack of tidal flow prevents shrimp larva to reach these habitats. The sampled shrimp were likely individuals that escaped the shrimp ponds (Páez, 2001).

**Larvae Harvesting**

Larvae harvesting has the potential to devastate wild shrimp populations. Larvae harvesting was employed in the 1980s and 1990s in Panamá, however after the White Spot
outbreak most farmers, including those in Salado have been using laboratory grown shrimp larvae (Fernández, 2012). Larvae harvesting currently does not affect shrimp populations in the disturbed site.

**Impact on Offshore Populations**

The destruction of mangrove forests for aquaculture has widespread impacts on offshore populations. Mangrove forests provide areas of protection, low turbidity, and high nutrients all of which are ideal for shrimp larval growth. Studies have been conducted analyzing the connectivity of mangrove ecosystems and offshore shrimp populations, however no strong relationship has been observed (Browder, 1999, Zimmerman, 1989). However, the presence of coastal mangrove forests has been correlated to higher fish stocks, both in pelagic and reef communities (Mumby et al., 2004). As aquaculture stresses shrimp larvae, likely reducing recruitment, and shrimp fishing removes the adult reproducing shrimp from the population, shrimp stocks are being unsustainable impacted at all life cycles. This trend is only intensified in areas of larvae harvesting such as Ecuador (Zimmerman, 1989).

**Significance**

The significant results of this study allow the null hypothesis to be rejected and the alternate hypothesis to be accepted. The “pristine” site has a higher biodiversity and abundance of shrimp larvae, and mollusks than the disturbed site. The abundance of both gastropods and shrimp was significantly higher in the pristine site, with p-values of 0.0001 in both cases. The pristine site also harbored a higher diversity of gastropods, shown by both Simpson’s and Shannon’s Index. Thus study illustrates the effect of aquaculture disturbance on gastropod and shrimp populations.

**Research Issues and Sources of Error**

This study was conducted with the goal of minimizing bias and error in all aspects of research and analysis. However, the study sites and methods used during the study were not ideal. The two study sites were located at different distances relative to the coast. As distinct ecosystem zonation occurs throughout this area, the two sites were dissimilar in substrate and mangrove composition, thus creating an uncontrolled variable in the study. The differences in sites prevented the use of identical methods of shrimp sampling. The random distribution of tide pools in the “pristine” site, made transect sampling unrealistic, and group sampling was used instead. The study sites prevented total random sampling in certain occasions. Areas of mangrove forest were too dense to walk through, leading to a slight bias towards more cleared areas. Shrimp sampling was limited to the edge of abandoned shrimp farms in the disturbed site. The special composition of shrimp samples is the most likely source of error in the study. Shrimp larvae were transparent, often a few millimeters in length and difficult to see on the push net. Minimal phenotypic differences were observed between *Litopenaeus Vannamei*, and *Litopenaeus setiferus* individuals, and thus special data may not be accurate. Gastropod sampling favored the documentation of larger species as smaller gastropods may have camouflaged with the substrate of the site.

**9. Further Research**

In general, more studies of gastropods as bioindicators would be beneficial to the field of mangrove conservation. Researchers and conservationists need information on the impacts of
disturbance on gastropods, and the characteristics of mangrove forests that facilitate high biodiversity. More research on the effects of aquaculture pond construction on shrimp habitat would allow for a better understanding of the widespread effects of aquaculture. Although much research is present on the connectivity of mangroves and offshore fish stocks, little is known about the direct benefits of mangroves to wild shrimp stocks. Lastly, more studies evaluating the economic value of mangroves would allow for a more concrete understanding of the pros and cons of replacing mangroves with aquaculture.

10. Conclusion

This study set out to evaluate the impacts of aquaculture practices on the populations of gastropods and shrimp in mangrove ecosystems. Higher populations and biodiversity of gastropods were found in the pristine site than the disturbed site, and highly tolerant species were the most abundant in the disturbed site. These findings indicate the effectiveness of gastropods as indicators of mangrove disturbance. Also, an extremely significant difference in shrimp population was found between the sites. The environmental conditions of disturbed site were not viable for shrimp growth. These results can be explained as the creation of aquaculture ponds leads to drastic changes in mangrove habitat, reducing forest complexity, draining areas of animal habitat, and preventing water and nutrient flow through tidal inundation. Such changes reduce the habitat of shrimp and gastropods and break down the flora and faunal balance on mangrove ecosystems. Aquaculture is having drastic impacts on mangrove forests in Aguadulce. These impacts are not evident to the farmers and community members in Aguadulce. Community members do not value the mangrove forests and view them as eyesores and areas of mosquito breeding. Mangrove destruction has many adverse effects on offshore fish and crustacean stocks, and also leads to coastal erosion and the sedimentation of coral reefs. ARAP and other organizations in Aguadulce need to educate and train farmers of the importance of mangroves and the impacts of aquaculture on mangrove ecosystems. This study expands the field of mangrove conservation could be used to educate locals on the importance of mangrove ecosystems.
11. Bibliography


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11. Appendix

Table 1. Special composition of gastropod sampling by site. Potamidae and Littorinidae are the most populous families.

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Pristine</th>
<th>Disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerithidea montagnei</td>
<td>806</td>
<td>2</td>
</tr>
<tr>
<td>Littoraria varia</td>
<td>350</td>
<td>28</td>
</tr>
<tr>
<td>Cerithidea valida</td>
<td>0</td>
<td>301</td>
</tr>
<tr>
<td>Neritina virginea</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Thais kiosquiformis</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Zebra littorina</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Crassispira fusescens</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Littorina obtusata unicolor</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Littorina littorea</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Littorina angulifera</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ellobium stagnalis</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Data summary of gastropod abundance by site. A two-tailed t-test was conducted to compare gastropod abundance. The pristine site contained significantly more gastropods than the disturbed site.

<table>
<thead>
<tr>
<th></th>
<th>Pristine</th>
<th>Disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>133.00</td>
<td>31.36</td>
</tr>
<tr>
<td>SD</td>
<td>56.08</td>
<td>25.5</td>
</tr>
<tr>
<td>SEM</td>
<td>18.69</td>
<td>7.69</td>
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<tr>
<td>N</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two-tailed T-Test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0001</td>
</tr>
</tbody>
</table>

| T                    | 5.3912   |
| df                   | 18       |
Figure 7. A graph of the special abundance of gastropods for both sites. *Cerithidea montagnei*, *Littoraria varia* and *Cerithidea valida* were the most abundant species. Figure A. is on a scale of 0 to 900. Figure B. is on a scale of 0 to 14.

Table 3. Shannon’s and Simpson’s biodiversity values. The values are calculated from 33 sites at the disturbed area and 27 sites at the pristine area. Diversity and evenness is higher for in the pristine site for both indices. Sorenson’s value is calculated using species present at each site.

### Biodiversity and Evenness By Site

<table>
<thead>
<tr>
<th></th>
<th>Pristine Site</th>
<th>Disturbed Site</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shannon's</td>
<td>Simpson's</td>
</tr>
<tr>
<td>Diversity</td>
<td>0.793</td>
<td>1.849</td>
</tr>
<tr>
<td>Evenness</td>
<td>0.361</td>
<td>0.205</td>
</tr>
<tr>
<td>Sorenson's Index</td>
<td>0.70588</td>
<td></td>
</tr>
</tbody>
</table>
Sampled Gastropod Species

Table 4. A data summary of shrimp abundance. A two-tailed t-test was conducted comparing shrimp abundance between the two sites. Significantly more shrimp were documented in the pristine site than the disturbed site.

<table>
<thead>
<tr>
<th></th>
<th>Pristine</th>
<th>Disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>100.67</td>
<td>1.33</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>93.76</td>
<td>1.83</td>
</tr>
<tr>
<td><strong>SEM</strong></td>
<td>19.14</td>
<td>0.37</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two-tailed T-Test</th>
<th>P</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0001</td>
<td>5.1892</td>
</tr>
<tr>
<td>df</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. A comparison of surface water temperature at each sample site, between the “pristine” and disturbed site. A two-tailed t-test was conducted between the two sites. The temperature in the disturbed site was significantly higher than the “pristine” site.

<table>
<thead>
<tr>
<th></th>
<th>Pristine</th>
<th>Disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>28.179</td>
<td>29.761</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>1.363</td>
<td>1.370</td>
</tr>
<tr>
<td><strong>SEM</strong></td>
<td>0.278</td>
<td>0.286</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two-tailed T-Test</th>
<th>P</th>
<th>T</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0003</td>
<td>3.9681</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 9. A *Litopenaeus Vannamei* individual sampled in the “pristine” site.
Table 6. The table depicts the number of shrimp sampled in each site in pristine and disturbed area. The site data is sorted from most shrimp caught to least shrimp caught. A significantly higher abundance of shrimp was documented in the “pristine” site than the disturbed site.

<table>
<thead>
<tr>
<th>Site #</th>
<th>&quot;Pristine&quot;</th>
<th>Disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>394</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>334</td>
<td>5</td>
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<td>3</td>
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<td>4</td>
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<td>24</td>
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<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2416</td>
<td>32</td>
</tr>
</tbody>
</table>
Figure 10. The graphs depict the relationship between the number of shrimp sampled and the temperature or depth at each site. No strong relationships are present. A. Temperature and number of shrimp in the “pristine” site. B. Depth and number of shrimp in the “pristine” site. C. Temperature and number of shrimp in the disturbed site. D. Depth and number of shrimp in the disturbed site.