Fish community assessment of the Bonyic and Teribe Rivers within the Naso-Teribe territory Bocas Del Toro, Panama: Possible implications of Bonyic Dam.

Shaylyn Austin

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Fish community assessment of the Bonyic and Teribe Rivers within the Naso-Teribe territory Bocas Del Toro, Panama: Possible implications of Bonyic Dam.

Shaylyn Austin
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School for International Training: Panama, Spring 2017
I. Abstract

In the Changuinola/Teribe watershed of Bocas Del Toro, Panama, changes to the fluvial system due to the recently constructed Bonyic Dam have implications connected to the biodiversity of a UNESCO Biosphere Reserve and the livelihoods of thousands of people of the Naso-Teribe indigenous group. This study investigated the composition of fish communities in 6 study sites in 3 different areas in relation to the Bonyic Dam. A total of 318 individual fish were captured, representing 5 families and 10 species, using the cast net sampling method. The biodiversity was analyzed using Simpson’s Diversity Index, Evenness Index, species richness, and species abundance counts. Analysis revealed that the abundance of most of the recorded species differed significantly from the expected distribution across study sites and areas (P<0.05). All five families were found in stretches below the dam, while only two were found above the dam. No diadromous species were found upstream from the Bonyic Dam, suggesting the inability for these fish to travel passed the dam closure. The results of this study suggest that the Bonyic Dam affects fish community composition, potentially due to its effects on habitat composition and fish migration patterns.
II. Acknowledgements

It is not an overstatement to say that this research could not have been conducted without numerous individuals facilitating the project at every step. My first thank you goes to Edwin Sanchez, his wife Carina, and their three children for their hospitality and kindness during my stay with them in Sieykin, as well as for allowing for and ensuring my safe access to each study site and helping with every sampling effort. Gratitude is also extended to the residents of Sieykin and Siejic for welcoming me into their communities and aiding this project. Thank you also to my fellow Bonyic investigator, Harris Wagner, for his enduring support and friendship throughout this process.

Thank you to my research advisor, Dr. Edgardo Diaz, for his patience and direction, and sharing his passion for fish with me. To Yari and Abdiel for providing for our well being and coordinating the materials for this work. To my classmate and friend Benjamin Shipley for fielding all of my statistics questions. And last but not least, thank you to Dr. Aly Dagang for her collected guidance and unwavering encouragement.
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III. Introduction

Location

With a seeming abundance of rivers running through the isthmus of Mesoamerica, many countries have initiated plans for massive hydroelectric dam development to meet electricity demands at lower costs (McLarney and Mafla 2006). Although hydroelectric dams are often referred to as “alternative” and “green” sources of energy, numerous studies have revealed that dams can significantly alter the geomorphology of the riverine habitat and catapult a series of changes to the biological composition of the ecosystem (Ahearn and Dahlgren 2005). The Changuinola/Teribe watershed in the province of Bocas del Toro in Panama is under particular pressure from the threats of hydroelectric projects (McLarney et al. 2010).

Bocas del Toro is located in northwest Panama, bordered by Costa Rica to the west, the Caribbean Sea to the north, and Chiriquí province to the south. Chiriquí and Bocas del Toro are divided along the Talamanca Mountain Range, resulting in clearly distinguishable Atlantic slope and Pacific slope watersheds between the two provinces. These watersheds serve as drainages to Parque Internacional La Amistad (PILA), a national protected area, World Heritage Site, and UNESCO Biosphere, encompassing areas in both slopes. The Changuinola/Teribe watershed is one of three watersheds that drain PILA on the Atlantic slope. Moreover, San San/Pond Sak Wetland of International Importance and the Gandoca/Manzanillo Wildlife Refuge safeguard the lower stretches and estuaries of the Changuinola River (McLarney et al. 2010).

Of the 3,445 square kilometers that make up the Changuinola/Teribe watershed, approximately 2,069 square kilometers are located within PILA. The Changuinola River is the largest river within the watershed. The Teribe River, the primary tributary to the Changuinola River, accounts for 28% of the total watershed, and the Bonyic River is a tributary to the Teribe River (McLarney and Mafla 2007). Moreover, both the Bonyic and the Teribe run through the Naso-Teribe indigenous territory, which is home to approximately 3,500 Naso people. This stretch of Naso-Teribe territory is largely contained within Palo Seco Forest Reserve, a rainforest preserve created with the intent to act as a corridor linking Fortuna Forest Reserve and PILA.

Effects of dams on river flow connectivity and fish community composition

The River Continuum Concept (Vannote et al. 1980) asserts that the entire river system, from the headwaters to the mouth, is a continuous series of physical gradients that affect shifts in fluvial biological communities. Therefore, any changes in physical or biological composition upstream influence the downstream composition. This concept comes into play when considering the implications of a dam disrupting the natural flow of a river. A dam closure of a river not only divides the river into two isolated ecosystems, but it also creates a third, entirely artificial habitat – a reservoir lake. The creation of a reservoir above a dam is especially damaging in tropical environments, where lakes are not common phenomena. Therefore, a majority of tropical fauna is not pre-adapted to lentic (or unmoving) aquatic habitats (McLarney et al. 2010). This three-fold division of the fluvial system, domino effects of division rippling both upstream and downstream and the intrusion of a motionless habitat in a traditionally moving current, is especially pertinent to the life histories of migratory fish species.

Fish employ several different forms of migration. These include diadromy (transit between fresh and salt waters) and potamodromy (migration within freshwater only). These primary fresh water fishes have been slow to disperse because of their inability to survive in saline environments, offering a competitive advantage to euryhaline (able to tolerate a wide range of salinity) fishes (Bussing 1988). Therefore, Mesoamerican rivers contain a relatively
high proportion of “secondary” freshwater fishes. A study in Costa Rica revealed that 70-94% of individual fish in small upland streams are diadromous species (McLarney and Mafla 2007).

While studies on the impacts of newly operating dams in Mesoamerica are just starting to emerge, Puerto Rico, a country whose major rivers were dammed by the United States, provides insight into the possible ecological effects of dams on Mesoamerican rivers. In Puerto Rico, the majority of freshwater shrimps and fish have disappeared from the river stretches above dams (Greathouse et al. 2006).

**Reported fish species of the Changuinola/Teribe watershed**

The Costa Rican non-profit conservation and sustainable development organization Asociación ANAI (Asociación Nacional de Alcaldías e Intendencias), led by William O. McLarney, synthesized multiple surveys of the Changuinola/Teribe watershed in a paramount 2010 paper detailing threats of dam construction in the watershed (McLarney et al. 2010). ANAI counted 42 species of freshwater fish in the Changuinola/Teribe watershed, of which 13 are diadromous. Of the 42 species, 19 have been confirmed within PILA, including 9 diadromous species (McLarney et al. 2010). Because a sizeable portion of diadromous fish species occupies the Changuinola/Teribe watershed, it should be expected for dams on rivers within this region to have a significant effect on fish migration patterns, and therefore fish community composition throughout the river system (Larinier 2001).

The main families reported for the Changuinola/Teribe watershed include Gobiidae, Mugilidae, Eleotridae, Characidae, Poeciliidae, and Cichlidae (McLarney and Mafla 2007). Of these, Gobiidae and Mugilidae are two of the most prominent known diadromous species. *Sicydium spp.* of Gobiidae is the most abundant fish in the Changuinola/Teribe watershed. Nearly all of the freshwater fish eaten by the Naso-Teribe are included in larger-bodied diadromous fish species, such as *Agonostomus monticola* and *Joturus pichardi* (McLarney et al. 2010). Furthermore, potadromous behavior has been reported for *Astyanax aeneus* in Guanacaste (McLarney et al. 2010). Therefore, it is possible that river flow disconnectivity caused by the dams impacts the life histories of all characins.

Overall, the most common families of fishes reported in PILA are nearly identical to those reported in the Changuinola/Teribe watershed, including Gobiidae, Mugilidae, Characidae, Rivulidae, Pimelodidae, and Poeciliidae (McLarney et al. 2010).

**Secondary effects of diversity loss above dams**

The loss of abundance and diversity of fish above dams after closure can result in significant secondary-effects both in PILA and downstream, including changes to sediment dynamics, detrital processing, algal biomass and diversity, and structure of macroinvertebrate assemblage (Freeman et al. 2003; McLarney et al. 2010). For instance, the loss of diadromous fauna upstream from dams would essentially eliminate all bioturbators. Additionally, sedimentation processes occur at higher rates in the reservoir created by the dam (Ligon et al. 1995). Both of these elements would cause greater retention of accumulated sediments at high elevations, resulting in effects on sedimentation patterns, channel dynamics, and biotic interactions both within and downstream of the World Heritage Site (McLarney et al. 2010).

Additional effects may result from the loss of important seed disperser species (i.e. *Brycon guatemalensis* and *Brycon hilarii*) and disruptions in the predator-prey relationships (McLarney et al. 2010; Banack et al. 2002; Rey et al. 2009). For instance, the food-chain length (the number of feeding links from basal species to the top predator) of impounded reaches has
been shown to be significantly lower than free-flowing reaches and to have fewer top-predator taxa (Kautza and Sullivan 2015). Even more severe effects seem to result from the loss of omnivores, herbivores, and detritivores (such as *A. monticola*, *J. pichardi*, and *Sicydium spp.*) This is due to the fact that in tropical ecosystems, fish and shrimp are the main consumers of both leaf and fruit drop and algae, unlike temperate ecosystems in which insects serve this role. (McLarney et al 2010).

**Dam effects on stream flow**

Habitat composition and stability, both properties that are a function of flow regime, can greatly influence fish community composition. For example, drastic changes to stream flow can reduce community complexity by excluding species in need of consistent, shallow coastline areas and only providing a functional living environment for habitat generalists (Bain et al.1988).

In Costa Rica, a study on the Doña Julia hydropower project revealed a significant correlation between downstream distance from the dam and fish species richness, suggesting the inhabitable environment of dewatered stretches of stream for some fish species (Anderson et al. 2006).

A study of the impacts of 21 dams in the United States showed that two-year discharge decreased up to 60% on average following impoundment (Magilligan et al. 2003). Flow modification of this magnitude has been connected to riparian disconnectivity, limiting the transport of sediment, nutrients, and water onto higher floodplain surfaces. Depending on the way that fish use stream habitat, unpredictable flow regimes can highly impact certain fish species, since fish community structure is greatly dependent on habitat composition and stream regime stability (Bain et al. 1988).

**Bonyic Hydroelectric Project**

ANAI identified the Changuinola/Teribe watershed as one of the most critically threatened watersheds in Mesoamerica by dam construction in 2007 (McLarney and Mafla 2007). Since 2011, two dams have been constructed within the watershed, including the Bonyic Hydroelectric Project. The Bonyic Dam is a 37-meter tall gravity dam located on the Bonyic River, approximately 7 km upstream from the mouth of the river (See map in Figure 1). Of the 144 square kilometers of upstream reach affected by the dam, 76 are located within PILA (McLarney et al. 2010).

The Bonyic Dam, which was completed in 2014, was constructed amidst controversy, when the dam developers, Empresas Públicas de Medellín, did not follow international standards for free, prior, and informed consent from the Naso people (Finley-Brook 2011). Given the designation of the region encompassing the Teribe territory as Palo Seco Protected Forest, the Panamanian national government has greater control over the use of the natural resource (Paiement 2007). During construction of the Bonyic Dam, the Panamanian government ignored nearly all questions from the Naso people and other stakeholders (McLarney et al. 2010). This is especially egregious because Naso people’s main source of wild-protein collection is freshwater fish, placing more importance on the abundance of this resource and, the habitat in which it resides (Rohrbach 2012). Given the importance of the Teribe River, both for subsistence and cultural value, any obstructions to the riverine environment have the potential to severely threaten daily lives in Naso communities.
Implications of this study

Although the Bonyic Dam is technically located outside of PILA, negative effects will likely cascade upstream within the boundaries of the World Heritage Site is to be expected (Pringle 2001). The potential for the continuing operation of the Bonyic Dam to greatly reduce the biodiversity of the fish communities of PILA, limit the freshwater resources needed by the Naso people, and drastically alter the geomorphology and biological composition of the fluvial system asserts the need to assess the effects of the Bonyic Dam before more dams are approved for construction. This study focused on determining the differences in fish community composition among reaches of the Bonyic above the dam, below the dam, and on the Teribe River. It took a site-specific approach, attempting to capture a snapshot of the possible effects of the dam on these communities. However, the connection of this narrow area to the rest of the watershed, especially the headwaters within PILA and the lengths of stretches fueling the livelihoods of thousands of Naso people, cannot be emphasized enough.

IV. Research Question
What is the fish species composition at both sides of the Bonyic dam and a mid-point of the Teribe River?

V. Methods
Study area

This work was conducted at six different sites within the Changuinola/Teribe watershed: two above the Bonyic Dam, two below the Bonyic Dam, and two on the Teribe River. Sites were chosen first based on relationship to the Bonyic Dam and distance from other sites, and second by convenience of access. The six sampling sites are illustrated in a map of the area in Figure 1.

The six sampling sites are illustrated in a map of the area in Figure 1. The first sampling effort in the upstream Bonyic reach was taken 0.86 km away from the dam in normal flowing stream (N 9° 18' 54.6" and W 82° 39' 15.9"). The second upstream sample was taken within the dam reservoir, 0.84 km away from the dam (N 9° 19' 7.7" and W 82° 38' 59.5"). The first sample downstream from the dam was taken 0.47 km away from the dam (N 9° 19' 21.9" and W 82° 38' 42.7") and the second was taken at the mouth of the Bonyic, 7.49 km away from the dam (N 9° 21' 35.7" and W 82° 35' 36.4"). The two samples on the Teribe were taken upstream from the Bonyic convergence, 1.02 km apart (N 9° 23' 4.0" and W 82° 39' 23.7") (N 9° 22' 42.2" and W 82° 38' 58.5").

Sampling took place from 20 Apr 2017 to 24 Apr 2017, and only one repetition was completed, resulting in a total of six sampling efforts, each with a distinct site.
Figure 1. Map of Panama showing general study area and satellite image of sample sites. T1 is next to the port of Sieykin, a Naso Teribe community of approximately 500 people. T2 is downstream from Site 1. Bd1 is downstream of the Bonyic Dam. Bd2 is at the mouth of the Bonyic River, within 100 meters of the Teribe River. Bu1 is upstream from the Bonyic Dam in naturally flowing river, within site of the reservoir lake. Bu2 is within the reservoir lake.

Physical parameters
For each sampling effort the latitude and longitude coordinates and elevation were recorded using a Garmin GPSMAP® 64s handheld GPS. Additionally, conductivity (S/m), TDS (mg/L), salinity (ppm), and water temperature (°C) were recorded using an Extech EC400: ExStick®. Barometric pressure (hPa), air temperature (°C), relative humidity (%) and wind speed (mph) were recorded using a Kestrel 3500 Weather Meter. Water depth was recorded by inserting a D-net upside down vertically into the stream until it hit the bottom. The surface of the water on the D-net pole was marked and the distance from the end of the pole to the surface of
the water was measured on the shore using a tape measurer. Surface flow rate was calculated by timing the float of an inflated plastic bag attached to a 3-m long cord. The time it took for the securely held cord to fully unravel as the plastic bag floated with the stream was recorded three separate times, and the average was calculated. The average time was then divided by the distance (3m) to calculate the stream velocity (m/s) (adapted from Bain et al. 1988).

**Fish fauna sampling**

Each sample consisted of a 30-minute fishing effort using a 3.14 m² cast net. The net consisted of nylon net mesh with 13 mm holes, and therefore anything larger than 13 mm was caught in the net. The net was weighted with a continuous lead line around the circumference of the net. Fishing took place continuously for 30 minutes. The net was thrown randomly into the study site area and retrieved within seconds of the sinkers hitting the water by being pulled back in by the fisher. Any fish caught within the pockets of the net were released into either a bucket or water-permeable sack filled with fresh water (adapted from Emmanuel et al 2008). When the bucket was used, the water was exchanged with new water every five minutes. When the sack was used, water was also added to the sack continuously and it was laid to rest in the stream to allow water to flow in from the bottom as well. Five of the sampling efforts were carried out by a 37-year old local Naso man, and one was conducted by a 27-year old local Naso man. With more than ten years of fishing experience each, it can confidently be stated that both fishermen possess highly skilled fishing abilities.

At the end of the 30-minute sampling effort, the total length of each fish was measured using a ruler (cm) and photographed with an iPhone 6 on high definition. Each fish was also identified to the common name by a Naso fisherman, but not to scientific identification. Each fish was handled with proper technique. The gill area was avoided, and the fish were not held by the caudal peduncle (Ashbrook 2004). Fish that were unable to be identified to the species level in the field were identified at a later time by comparing their photographs to various taxonomical keys and reference guides.

**Fin clipping**

One fin clipping of each suspected species was taken throughout the data collection period to be used in future DNA analysis. Scissors were used to cut a thumbnail size portion of the dorsal fin off, and the clipping was placed in a small vial filled with 95% ethanol. Each vial was labeled with species name, site, and date (NRDPFC 2017).

**Data Analysis**

Species richness (number of species in a defined area), abundance (number of individuals per species), and evenness (or relative abundance) were calculated for each site (1-6) as well as study area (Teribe, Bonyic Up, and Bonyic Down). Evenness ranges from 0 to 1, with 0 signifying no evenness, and 1 signifying complete evenness. Greater evenness indicates that the abundances of each species in the population are closer in number. Evenness for each site and area was calculated with the following equation:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

$$H' = \frac{\sum_{i=1}^{s} p_i \ln p_i}{\ln(r)}$$
where \( r \) = species richness for the community, and \( p = n/N \), were \( n \) = number of individuals within a species, and \( N \) = total number of individuals in the community.

Simpson’s Diversity Index was used to calculate diversity for each site and study area. Simpson’s Diversity Index takes into account both species richness and the abundance of each species in the community. The following equation was used:

\[
1 - D, \quad D = \sum_{i=1}^{S} \frac{p_i^2}{N}, \quad \text{and} \quad p = n/N,
\]

where \( n \) = number of individuals within a species, and \( N \) = total number of individuals in the area.

The result \((1-D)\) is the probability, without units, that two individuals selected randomly from this sample will be different species (Kwak and Peterson 2007). The diversity value ranges from 0 to 1, and the greater the value, the greater the sample diversity is.

Sorenson’s coefficient (community similarity) was calculated between all of the sites and the three areas using the following equation:

\[
\frac{2a}{2a + b + c}
\]

Where \( a \) = number of common species between the communities, \( b \) = number of species present in community 1, but absent in community 2, and \( c \) = number of species present community 2, but absent in community 1. Sorensen’s index value can vary between 0 and 1, where 1 indicates maximum similarity and zero indicates no similarity. (Dubey et al. 2013).

A Chi Squared Goodness of Fit test was used to determine whether the values for species richness within species and families for both sites and areas were significantly different from an expected distribution. The same test was run for overall abundance across sites and areas as well as abundance within each species across sites and areas (Bhatt et al. 2012).

Lastly, the mean length of individuals of each species with more than 5 recorded individuals was calculated by site and area.

**VI. Results**

Due to political reasons, data collection was cut short. However, it can confidently be stated that the data is reflective of the sampling sites.

Sampling sites will be referred to using nomenclature that depicts area (T for Teribe, Bd for downstream from the Bonyic Dam or Bonyic Down, and Bu for upstream from the Bonyic Dam or Bonyic Up) and site 1 or 2 within each respective area.

A total of 318 individual fish were captured across the six study sites, representing 10 species and 5 families. The five families found in this study were Gobiidae, Characidae, Mugilidae, Poeciliidae, and Cichlidae. All individuals were identified to the species level except for *Sicydium spp.* and *Astyanax spp.*, due to inability to distinguish *Sicydium adelum* and
Sicydium altum, and Astyanax aeneus and Astyanax orthodus. Of the 10 species, 3 are known to be diadromous, Sicydium spp., A. monticola, and J. pichardi (McLarney et al. 2010).

Due to the loss of 10 study subjects prior to either photographing or measuring them, 8 individual lengths were not measured and 2 characins could not be identified to the genus level. Individual counts of each species are listed in Figure 9, and images of all recorded fish species are featured in Figure 12. The results were analyzed in relation to both study site and area.

**Richness, diversity, and evenness**

Figure 2 lists richness, evenness, and diversity values by site and area. All 5 families were found in the Teribe, 3 were found in the Bonyic downstream stretch, and 2 were found in the Bonyic upstream stretch. The area with the greatest species richness was Teribe with 9 species. The area with the greatest Simpson Diversity value was Bonyic Down (0.65) followed by Teribe and Bonyic Up with equivalent values (0.62). Bonyic Down also had the greatest Evenness (0.97). The Chi Squared Goodness of Fit test for species richness did not show that the data was significantly different from an expected distribution. The Simpson Diversity values by area were very similar to each other and not biologically significant.

In terms of site, T2 had the highest species richness with 9 species, while Bd2 had the lowest species richness with 2 species. T2 also had the greatest Simpson Diversity Value (0.85), and Bu1 had the lowest (0.04).

<table>
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<tr>
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<td>T2</td>
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<td>Bd2</td>
<td>Bu1</td>
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</tr>
</tbody>
</table>

**Figure 2.** Species richness, Simpson diversity value, and Evenness by site and area.

**Abundance**

Abundance counts for all species across sites and areas are listed in Figure 8. Of the 316 individual fish identified to the species level, 87 were caught in Teribe, 55 in Bonyic Down, and 178 in Bonyic Up. Across all study sites, B. scleroparius was the most abundant fish recorded, making up 32.59% of individuals caught. Sicydium spp. was the second most abundant fish recorded, at 22.15% of individuals. A Chi Square Goodness of Fit test revealed a significant difference between observed values of overall abundance and expected values, across both sites and areas (P<0.05). Additionally, abundance for each individual species with more than 5 recorded individuals was significantly different from the expected values across both site and area (P<0.05).

Figure 3 illustrates the relative abundance of fish families by sample area. In both Teribe and Bonyic Down, the most abundant family caught was Gobiidae, at 58.33% and 42.86%, respectively. The most abundant family in Bonyic Up was Characidae, making up 50.85% of species caught. Figure 4 illustrates the relative abundance of each species for each area. There were evident differences in species composition among study areas. All of the recorded Sicydium spp., A. monticola, and J. pichardi, were found in Teribe and Bonyic Down. In particular,
Sicydium spp. accounted for 59.04% of individuals caught in Teribe, and B. scleroparius made up 47.75% of individuals caught in Bonyic Up.

**Figure 3.** Family composition (%) by area. Five families were caught in total among all sampling areas. All 5 families were found in the Teribe, 3 were found in the Bonyic downstream stretch, and only 2 were found in the Bonyic upstream stretch.

**Figure 4.** Species composition by area. Ten species were captured in total among all sampling areas. Nine species were recorded in the Teribe River area, 3 were recorded in the reach below the Bonyic Dam, and 5 were recorded in the reach above the Bonyic dam.

Figures 5 and 6 illustrate the relative abundance of families and species by site, respectively. Only one family, Characidae, was found in the upstream site in natural flowing river (Bu1), and two were found in the reservoir lake (Bu2). However, Poeciliidae made up
96.67% of the sample in Bu2. The overwhelming majority of individuals at Bu1 were B. scleroparius (97.70%). P. gillii made up 69.23% of individuals recorded at Bu2. Sicydium spp. made up 74.19% of individuals caught in T1 and 55.56% of individuals caught in Bd2.

The most abundant family caught near the mouth of the Bonyic (Bd2) was Gobiidae at 55.56%, while the most abundant family closer to the dam (Bd1) was Characidae, at 65.52%. The main difference between Teribe sites 1 and 2 was the presence of Poeciliidae in the Teribe 2 sample.

**Figure 5.** Family composition (%) by site.

**Figure 6.** Species composition (%) by site.
Community comparisons

None of the three known diadromous species observed in this study, Sicydium spp., A. monticola, and J. pichardi, were found above the Bonyic Dam. However, both Sicydium spp. and A. monticola were found up to the site closest to the dam in the Bonyic River, Bd1. The four species found upstream of the Bonyic Dam were Bryconamericus scleroparius, Astyanax spp., Poecilia gillii, and Hyphessobrycon panamensis.

Sorensen’s coefficient, or community similarity, among all sites and between the three areas is listed in Figure 9. The greatest similarity among sites was between T1 and Bd2, with a Sorensen’s coefficient of 0.67. There was no similarity between the sites of Bd2 and Bu1, Bd1 and Bu2, and Bd2 and Bu2. The two study areas with the greatest similarity were Teribe and Bonyic Up, followed by Teribe and Bonyic Down.

Fish sizes

Fish length distribution for all species with more than 5 individuals is depicted in Figure 11, by both site and area. Two-sided t-tests revealed statistically significant differences in sizes between areas for Sicydium spp., B. scleroparius, and A. cultratus (P<0.05). Sizes of Sicydium spp. were larger on average in Bonyic Down than in Teribe (P=0.0041). Sizes of B. scleroparius were greater on average in Bonyic Up than in Bonyic Down (P=7.54e-6), and A. cultratus sizes were greater on average in Bonyic Upstream than in Teribe (P=1.4e-4). Size distribution of all three species is positively correlated with elevation.

Physical parameters

All physical and chemical parameters recorded at each site are listed in Figure 6. The average conductivity levels by area were 98.96 S/m (Teribe), 134.8 S/m (Bonyic Down), and 120.65 S/m (Bonyic Up). The average water temperatures were 24.95 °C (Teribe), 23.9°C (Bonyic Down), and 24.25 °C (Bonyic Up). The average stream flow rates were 0.79 m/s (Teribe), 0.91 m/s (Bonyic Down), and 0.42 m/s (Bonyic Up). The reservoir lake site (Bu2) had the lowest stream flow rate (0 m/s) among sites. The site with the greatest conductivity level and highest temperature was also the reservoir lake site (141.3 S/m, 26.3 °). Bottom composition for each study area was primarily distinguished by mud and sand in Bonyic Up and mixed-sized pebbles in Bonyic Down and Teribe.
VII. Discussion

Abundance

The most striking result of this study was the stark distinction between fish community composition in sites below the Bonyic Dam and the Teribe River, and sites in the watershed above the Bonyic Dam, supported by significant differences in abundance counts and noteworthy changes in numbers of families and species. The largest difference in community composition is evident in the Chi-Squared values for abundance within each species. Every species with more than 5 recorded individuals demonstrated that abundance distributions across sites and areas significantly different from the expected values.

A likely explanation of the community differences observed in this study is the stream disconnectivity caused by the Bonyic Hydroelectric Project. Interestingly, the results of this study do not align with community composition gradients recorded in past surveys of nearby watersheds. A study of the Sixaola River basin, another watershed that drains PILA on the Atlantic side, found that contribution of diadromous fishes to richness and abundance increased significantly with elevation (Lorion et al. 2011). On the contrary, in this study, no diadromous fishes were found in the sites of highest elevation. The primary distinction between the two studies is that the Sixaola survey was conducted on a natural flowing river, whereas, a dam separated the site of highest elevation from the other sites.

Diversity index

According to the calculated values, Bonyic Down had a greater Simpson Diversity Value than Bonyic Up (0.65, 0.62). These results align with past studies of dammed rivers that have observed less diversity in the impounded reaches of the river due to the loss of diadromous species (Sá Oliveira 2015). However, Teribe unexpectedly had an equivalent diversity value to Bonyic Up. This result may be due to the impact that evenness has on the diversity value. Though it had the highest species richness, Teribe was the area with the lowest evenness, effectively decreasing its diversity value. Given multiple sampling repetitions at each site and a larger sample size, the Simpson Diversity Values may change. Therefore, in this study, species richness may have been a better gauge for community composition than Simpson’s Index. More sampling of these sites is necessary to more accurately calculate relative abundance. The observed species richness for each area aligns with past studies, which have found less species richness in sites above dams (Anderson et al. 2006).

Diadromy

*A. monticola, J. pichardi, and Sicydium spp.*, all known diadromous species, were not recorded in the stretch above the Bonyic Dam. A study of the Bonyic River prior to the construction of the Bonyic Dam revealed that 95% of the fish in the reach that would be impounded by the dam were diadromous (McLarney and Mafla 2007). Therefore, the absence of diadromous fish in the sample sites of this reach in this study is especially notable. However, the absence of these species above the dam is not surprising, given that they require longitudinal movements within a stream to carry out their life spans. Additionally, these results align with expectations based on previous studies of habitat occupation of these species following dam closure in other watersheds. When rivers populated with diadromous fish are dammed, follow-up studies generally show a higher density of diadromous fish below the dam than above the dam, suggesting that these fish are unable to return upstream to spawn (Katano et al. 2006; Holmquist et al. 1998; Gehrke et al. 2002).
In Turrialba, Costa Rica, *A. monticola* and *J. pichardi* were recorded up to the Angostura Dam on the Reventazon River, as well as up to the Tuis Dam on the Tuis River, but were not found above either dam (Vormiere 2007). McLarney (unpublished observations) found *J. pichardi* prevalent in these same stretches prior to the dam closure (McLarney et al. 2010).

Standing at 36-meters high, the Angostura Dam and the Bonyic Dam differ by only one meter in length. Therefore, it is reasonable to draw parallels between the effects of the two dams on tropical stream composition.

**Diadromy: Sicydium spp.**

*Sicydium spp.* are able to climb vertically over natural barriers like waterfalls, and in fact was the only species found above natural barriers in PILA in a 2009 sample carried out by ANAI (McLarney et al. 2010). Therefore, it may be possible for *Sicydium spp.* to climb over the dam during its migration upstream under proper conditions. However, it is most likely that the reservoir lake is an insurmountable obstacle for both adults and post larvae ascending and free embryos descending to reach their estuarine nursery areas (McLarney et al. 2010). In a study surrounding length and velocity of rivers in Mexico and Central America, *Sicydium spp.* were rare or absent in slow moving rivers over wide plains (Lyons 2005). Additionally, survival rate of drifting embryos has been inversely related to time of transit (Iguchi and Mizuno 1998). It is reasonable to conclude that the Bonyic Dam has resulted in extirpation of *Sicydium spp.* within areas of the stream above the dam

Interestingly, *Sicydium spp.* is also one of the few species that had significant differences in size distribution among sites. In this study, average size of *Sicydium spp.* was positively correlated with altitude. Adult and post-larvae *Sicydium* continue to grow as they migrate upstream from their estuarine nursery areas. Therefore, it is normal to encounter the largest individuals at the highest altitudes (McLarney et al. 2010). However, the natural presence of large numbers of *Sicydium* at high elevations makes their absence in the highest elevations of this study (244 m and 250m) more alarming. In ANAI’s 2009 study, *Sicydium spp.* was most abundant upstream and was a considerable contribution to the freshwater aquatic fauna in PILA (McLarney et al. 2010). Of most concern are the secondary effects that could result from extirpation of *Sicydium spp.* The extirpation of *Sicydium spp.* in these areas may have more profound ecological effects due to their sheer abundance in the unaltered river and its role within the ecosystem (McLarney et al. 2010). *Sicydium* have been shown to greatly influence macroinvertebrate abundance and algal standing crops in Costa Rican streams (2001). Therefore, taking the River Continuum Concept into consideration, extirpation of this species upstream of the Bonyic Dam could greatly disrupt the algae biomass equilibrium of the entire fluvial system (Vannote et al. 1980).

**Length distributions**

The other two fish species with significant differences in size distribution between areas were *A. cultratus*, an insectivore, and *B. scleroparius*, an omnivore, (Wootton and Oemke 1992).

The sizes of both species were largest on average in Bonyic Up. Although this study cannot draw direct conclusions relating the physical structure of the Bonyic Dam to habitat changes upstream, its possible effect on the upstream trophic levels, and thus the sizes of these fish, cannot be ruled out (de Mérona et al. 2001).
Potential effects of varied habitats

In a study prior to the construction of the Bonyic Dam, it was speculated that any reservoir created by the dam would most likely be a habitat for only a few tolerant fishes, such as *Astyanax aeneus* and *Poecilia gillii* (McLarney and Mafla 2007). This research corroborates that prediction, as the only species recorded in Bu2, the reservoir lake site, were the characin *Astyanax spp.*, and *Poecilia gillii* and *Alfaro cultratus* of the family Poeciliidae. Conclusions cannot be drawn connecting these parameters to the community compositions found. However, it is notable that this site had the highest temperatures and conductivity levels among all sites. Future studies on the impact of these parameters on the identified species are encouraged.

Surprisingly, the highest similarity among sample areas was between the Teribe and the stretch above the Bonyic Dam. However, the only common species between these two areas were *Astyanax spp.*, *P. gillii*, *A. cultratus*, and *H. panamensis*. In the Teribe area, three of these species were only found in T2. T2 was split between a faster moving river and a stagnant lagoon. Past studies have found high prevalence of *Poecilia gillii* in lagoons (Winmeiller and Mitchell 1992). Therefore, it is likely that most of these fishes were found in the lagoon area of T2. A key observation to note is that the Teribe is an undammed, naturally flowing river. There are no artificial physical structures on the Teribe with the potential to either block migration or alter river flows in a way that reduces habitable areas. The Teribe boasted the highest species richness among the three areas, potentially a product of the heterogeneity of habitats within the Teribe. On the other hand, only three different fish species were found in the downstream stretch of the Bonyic River. This low richness may be a result of the irregular stream flows caused by the Bonyic Dam that make this stretch of the river difficult for habitat specialists to occupy (Anderson et al. 2006, Bain et al. 1998).

Potential sources of error

A potential source of error may stem from the inability to repeat sampling at the six different sites. There is no reason to believe that the results of this study are not representative of the sampling sites. However, past sampling of the Changuinola/Teribe watershed and nearby watersheds have recorded up to 42 different species (McLarney and Mafla 2007; McLarney et al. 2010; Lorion 2011). While this study focused on a specific intersection of the watershed, and therefore a lower species richness could be attributed to elevation (Lorion 2011), it is unlikely that every single species present in the sampled stretches were caught in this limited study. Along the same lines, a larger sample size could result in different Chi Squared Goodness of Fit results as well as warrant the use of more statistical methods altogether to analyze the data. Sampling repetition of each site might have produced a more accurate sample due to a larger sample size. Additionally, repetition could have reduced error stemming from variability of the sampling method, cast netting.

While cast netting was an efficient method to capture fish in the primarily shallow sample sites on the Bonyic and Teribe Rivers, it poses problems with consistency, operator bias, and inherent biases of the method itself. For example, there was a high density of sunken wood and other vegetation in the reservoir lake site that the net was consistently caught in. The amount of time taken to release the net each time it was caught in the debris most likely led to fewer casting attempts within the 30-minute collection period. Even so, the most individuals of any site were captured during this sample effort, leading to the belief that this did not affect the sampling accuracy. Nonetheless, if this study were to be conducted again, casting repetitions would be recorded at each site to account for this variable. Additionally, a cast net is naturally biased
toward certain fish species and smaller sized fish. Therefore, varied sampling techniques (i.e. electrofishing) could deliver more accurate results of community composition.

Furthermore, a small hole was found in the net 7 minutes into the sampling effort at Bd2. At this time, the clock was stopped while the hole was sewed up using nylon wire, and restarted once the net was ready to be fished with again. However, it is impossible to know to what extent this hole resulted in lost individuals within the first 7 minutes. Also, fish would sometimes be lost during transition from the net to the holding basin. When this occurred, the fish was included in the study to the extent of which it could be identified before it was lost (family, genus or species). Unfortunately, some individuals could not be identified and therefore are not included in the study. Lastly, a different fisherman conducted the sampling effort at T1. While it can confidently be stated that both fishermen possesses relatively equivalent levels of fishing skill, the exact same level of skill was not executed across all sites.

**Suggestions for future research**

Overall, more studies on the life histories of most of the fish present in this study sample are necessary to fully understand the impact of anthropogenic actions on fish community composition. However, it is evident from this study that the fish communities above the Bonyic Dam are highly divergent from those below the Bonyic Dam and the Teribe River, and inconsistent with past studies on fish community composition in similar environments of naturally flowing streams. Therefore, more in-depth research on the effect of these artificial fish community compositions along the Bonyic River on the entire fluvial system, both within the World Heritage Site and downstream leading into San San Pond Sak Wetlands is necessary, especially before construction of any more dams within the watershed. Future research is also needed in order to understand other effects, such as genetic diversity and connectivity. For instance, genetic-level identification of *Sicydium* spp. could clarify a difference between *Sicydium altum* and *Sicydium adelum*, thus increasing the diversity values in areas that *Sicydium* were recorded. Lastly, ichthyoplankton composition at both sides of the dam should be assessed in the near future to corroborate the possible impacts and implications of this physical structure on native biota.

**VIII. Conclusion**

The purpose of this study was to determine the species richness, abundance, and diversity of fish communities in three areas around the Bonyic Hydroelectric Project on the Bonyic and Teribe Rivers. While there were variances in species richness and diversity among study sites and areas, the only variable with significant differences across study sites and areas was abundance, both overall and for individual species. In particular, no diadromous fish were found above the Bonyic Dam, though these fish were reported in that area prior to construction of the dam. Additionally, species richness was higher on the Teribe River than on either reaches of the Bonyic River. Most notably, this survey shows divergent results from passed studies of this watershed and others like it. It is possible that effects from the closure of the Bonyic River by the Bonyic Dam, such as barring migration upstream from the dam site and fundamental changes to habitat composition, are responsible for these variances in community composition.

Though it is reasonable to assume that these results are representative of the sample sites, they may differ with a larger sample size and varied sampling techniques. This research serves as a baseline survey of the Bonyic and Teribe Rivers surrounding the Bonyic Dam, highlighting possible effects of the dam on fish community composition in this area. More studies on fish
community compositions surrounding the Bonyic Dam would help to corroborate these results. However, more pertinent lines of future research would be on the effects of these recorded changes to fish community composition on the chemical, physical, and biological aspects of the entire fluvial system. This study serves as a reference point for future surveys of this river stretch and opens doors for research focused on the biological interactions between the identified species in this paper and the trophic role of each of them in the community and the riverine system. Watersheds are interconnected networks vulnerable to artificial changes in any part of the system. For the sake of maintaining the biological and cultural importance of PILA and the livelihoods of the many people that rely on the rivers of the Changuinola/Teribe watershed, it is necessary to continue studies on the primary and secondary effects of the Bonyic Dam before the consideration of new dam construction within the watershed.
IX. Works Cited


Figure 8. Physical parameters for each site. Habitat composition was primarily characterized by rocky bottoms in the Teribe and sites downstream from the Bonyic Dam and muddy bottoms at sites above the Bonyic Dam.
### Figure 9

Abundance counts by site and area. Chi Squared Goodness of Fit tests revealed significant variances from the expected abundance distribution for all bolded species across both sites and areas. Thicker horizontal lines separate family groups.

<table>
<thead>
<tr>
<th>By Site</th>
<th>T1</th>
<th>T2</th>
<th>Bd1</th>
<th>Bd2</th>
<th>Bu1</th>
<th>Bu2</th>
<th>Teribe</th>
<th>Bonyic Down</th>
<th>Bonyic Up</th>
</tr>
</thead>
<tbody>
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<td>9</td>
<td>15</td>
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<td>49</td>
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<td>24</td>
<td>4</td>
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<td>0</td>
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<td>27</td>
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<td>91</td>
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<td>178</td>
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</table>

### Figure 10

Community similarity (Sorensen’s coefficient) among all sampling sites and among all three study areas.

<table>
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<tr>
<th>By Area</th>
<th>T1</th>
<th>T2</th>
<th>Bd1</th>
<th>Bd2</th>
<th>Bu1</th>
<th>Bu2</th>
<th>Teribe and Bonyic Down</th>
<th>Teribe and Bonyic Up</th>
<th>Bonyic Down and Bonyic Up</th>
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<td>Teribe and Bonyic Down</td>
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<td>0.57</td>
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**Figure 11.** Individual counts by species. B. scleroparius made up 32.59% of all individuals recorded in this study. Diadromous species, which are bolded, made up 37.97% of individuals captured.
**Sicydium spp.**  
Spanish common name: Chupapiedra, Tití  
Naso: Diogwo

**Astyanax spp.**

**Hyphessobrycon panamensis**  
Spanish common name: Sardinita  
English common name: Panama tetra  
Naso: Pimkwo

**Bryconamerics scleroparius**  
Spanish common name: Sardina  
English common name: Creek tetra  
Naso: Pezhwiling

**Agonostomus monticola**  
Spanish common name: Lisa, Tepemehín  
English common name: Mountain mullet  
Naso: Dremkwo

**Joturus pichardi**  
Spanish common name: Bocachica, Bobo  
English common name: Hogmullet  
Naso: Ma

**Archocentrus nigrofasciatus**  
Spanish common name: Burra, Carate  
English common name: Convict cichlid  
Naso: Shjirriyguengkwo

**Astatheros bussingi**  
Spanish common name: Mojarra  
Naso: Bumkwo
Figure 12. Photographs of each species recorded in this study. The scientific name of each fish is accompanied by the common names in Spanish, English, and Naso (when available) to facilitate understanding of this study by all stakeholders.