Artisanal Fishing in Limoncocha, Ecuador:
An Ichthyofaunal Census

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ABSTRACT

Limoncocha Lagoon, Ecuador is frequently fished by the local community for subsistence. There is little research on the effect of artisanal fishing on the development and dynamics of the ichthyofauna in the Ecuadorian Amazon. This study aims to analyze biodiversity and species richness of Limoncocha Lagoon as well as of six zones that make up the lagoon. Data were collected via the catches of the local fishermen as they exited the lagoon. Length, weight, and identification was recorded for each individual fish. Location of extraction was reported by the fisherman. A total of 756 individuals and 23 fish species were found. The flood pulse (Junk, Bayley, & Sparks, 1989) greatly influences the population dynamics and trophic levels in Limoncocha Lagoon by increasing the connectivity with the Napo River and therefore allowing migratory species to enter Limoncocha and reproduce. The flooding events take place multiple times each year. Larger individuals can be found in the lagoon during these events, and smaller individuals from recent reproduction can be found just after the floods. The comparison of the six zones demonstrated that there was little difference in species composition of each zone. However, when compared to a census from 2002 from the Reserve, Limoncocha Lagoon showed lower levels of biodiversity, suggesting that the ichthyofauna has been affected by the fishing activities of the Limoncocha community. Future research could focus on the seasonality of fish population biodiversity and species richness in response to drought and flood events.

RESUMEN

La comunidad de Limoncocha pesca frecuentemente la laguna Limoncocha, Ecuador para la alimentación. Hay pocas investigaciones del efecto de la pesca de la alimentación sobre el desarrollo y los dinámicos de la ictiofauna en la amazonia ecuatoriana. Este estudio analiza la biodiversidad y la riqueza especifica de la laguna Limoncocha además de seis zonas de la laguna. Se colectó los datos por las pescas de los pescadores locales cuando salieron la laguna. Se grabaron la longitud, el peso y la identificación para cada pescado. Se reportaron a los pescadores el lugar de la extracción de la laguna. En total, se encontraron 756 individuos y 23 especies del pescado. El pulso de las inundaciones (Junk et al., 1989) se influyen los dinámicos de las poblaciones y los niveles tróficos en la laguna Limoncocha por el aumento de la conexión con el Río Napo, y por eso, se permiten unas especies migratorias a llegar a la laguna para reproducir. Los eventos de las inundaciones ocurren muchas veces cada año. Se puede encontrar los individuos más grandes en la laguna durante las inundaciones, y se puede encontrar los individuos más pequeños de la reproducción un poco después de las inundaciones. La comparación de las seis zonas demostró que había pocas diferencias entre composición de las especies en cada zona. Sin embargo, por la comparación de un censo de 2002 de la Reserva Biológica Limoncocha, la laguna Limoncocha mostró un nivel más bajo de la biodiversidad. Esto sugiere que se haya afectada la ictiofauna por la pesca de la comunidad Limoncocha. Investigaciones futuras pueda enfocar en la estacionalidad de la biodiversidad y la riqueza especifica en respuesta a los eventos de la sequía y la inundación.

Keywords: Conservation, Ichthyofauna, Floodplain, Artisanal fishing

INTRODUCTION

Background

Limoncocha, Ecuador is a small indigenous Kichwa community bordering the Limoncocha Biological Reserve. Situated on the Napo River, the reserve covers 4613 hectares, and was established in 1985. It is located 210 kilometers almost directly east of Quito, Ecuador in the Shushufundi Canton of the Sucumbios Province. The bodies of water that are protected by the Reserve (including Limoncocha Lagoon and the Napo River) are made up of black waters, which are low in sediment and get their dark color from the tannins released from decomposing plant material on the edges of the forest and the floodplain. The local people of Limoncocha have been using Limoncocha Lagoon as a main source of food for hundreds of years (Vargas, 2017). The location of the town lends itself to easy fishing access, and the skill is passed from generation to generation to support families with a consistent source of protein. Currently, there are approximately 50 families living in Limoncocha, 70% of which fish in Limoncocha lagoon in one form or another. Approximately 80% of the fishing is done with large gill nets, while the other 20% is done with a simple fishing pole (Vargas, 2017). The local people of the town of Limoncocha are the only people with fishing access in Limoncocha Biological Reserve. This right is preserved under the category of “artisanal fishing” by the “Código de Conducta de Pesca Sustenable en La Reserva Biológica Limoncocha”, a guide to the regulations of fishing in the reserve. “Artisanal fishing” is defined here as the removal of fish from the lagoon in quantities appropriate for sustaining members of the Limoncocha community, as well as occasional fish sales at weekend markets. Such weekend markets take place in Pompeya, a small town on the Napo river about a 30-minute drive from Limoncocha.

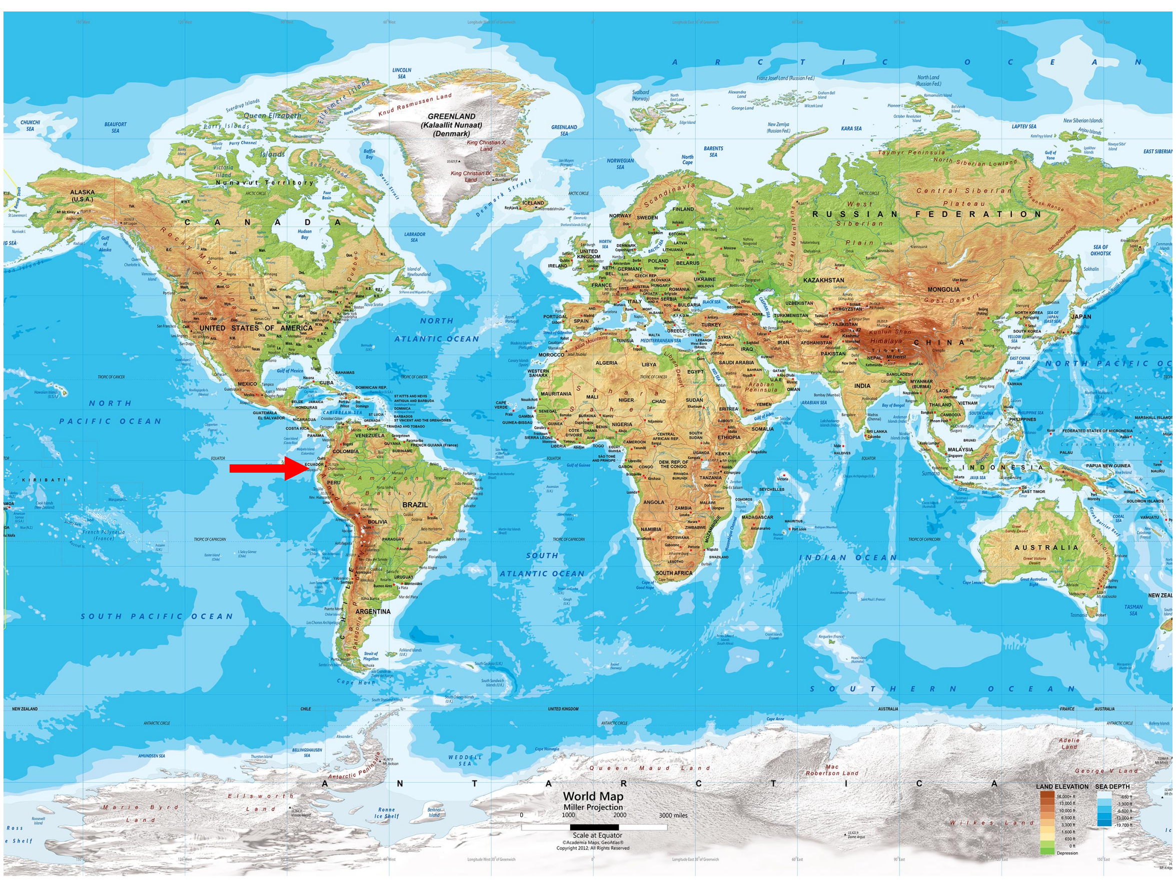

Figure 1 (page 4) World map with Ecuador denoted by a red arrow; map of Limoncocha Biological Reserve with map of Ecuador noting location of Limoncocha in red rectangle.

The rivers, floodplains, and lakes of the Amazon Basin support some of the highest ichthyofaunal biodiversity on the planet. Its isolation from other water systems lends itself to having higher vertebrate biodiversity (Albert et al., 2011; Barros et al., 2013; Portocarrero-Aya & Cowx, 2016). Isolation of individual habitats has further increased the species richness (i.e. number of species present), as individual habitats are able to support different species, despite being connected by smaller waterways (Albert et al., 2011). Located East of the Ecuadorian Andes, the Napo River Basin is a region with remarkably high biodiversity. The connected lagoons, floodplains, and rivers provide plenty of area for migratory fish that will spawn in the rivers and migrate to the lakes for adult life (Albert et al., 2011; Granado-Lorencio, Cerviá, & Lima, 2007; Osorio et al., 2011; Portocarrero-Aya & Cowx, 2016; Stewart, Ibarra, & Barriga-Salazar, 2002). It is for this reason that Limoncocha residents prefer to fish after rains, when the water level has risen to connect the Napo River with Limoncocha Lagoon (Residents, 2017). The Limoncocha Biological Reserve is also considered a Ramsar site; it is recognized by the Convention on Wetlands (called the Ramsar Convention) in order to raise awareness and protection for the conservation of wetlands and their resources. The reason for this label is due to the high biodiversity of vertebrates that reside in the multiple types of environment provided by the reserve. High biodiversity is important to prevent the spread of disease and to increase the genetic diversity and therefore species' resilience in the environment.

There has been an overall lack of research in terms of assessing the state of fish populations in lakes and lagoons in the Western and Ecuadorian Amazon. These types of studies have the potential to provide essential information about how artisanal fishing and local activity affects the biodiversity and species richness of an area. Local fishing in the Amazon Basin often takes place in indigenous communities without means of monitoring and recording data; these communities are not easily accessible or monitored. Anthropogenic activity can have a very large effect on aquatic flora and fauna (Chu, Minns, Lester, Mandrak, & Rosenfeld, 2015). The Limoncocha Biological Reserve possesses population data from a past fish census of Limoncocha Lagoon, thus providing an opportunity to track the fish populations' developments over time in comparison to fishermen's activities. Overall, the quantity of fish in Limoncocha Lagoon is sufficient to provide a steady food supply to local fishermen. The possibility of overfishing the lake to complete extinction is unlikely due to its connection to the Napo River. Migratory fish have the unique opportunity of filling the niches of suffering local fish populations as they periodically migrate to spend time in the lake when the water level rises (Albert et al., 2011; Granado-Lorencio et al., 2007; Osorio et al., 2011; Portocarrero-Aya & Cowx, 2016; Stewart et al., 2002). However, it is the composition of the catches of the fishermen that is subject to major change.

Barriga (1994) states the movement and location of where the fish spend most of their time in the Amazon basin is determined partly by the rainfall, and therefore also the different seasons of the year. This phenomena, known as the flood pulse (Junk et al., 1989), greatly influences the populations and geographic distribution of fish that inhabit water systems such as floodplains, rivers, and lakes (Costa & Freitas, 2015; Junk & Wantzen, 2002; Osorio et al., 2011; Sousa & Freitas, 2008). Junk et al. (1989) suggested that the productivity of a water system as well as the survival and success of the organisms depends mainly on the flood pulse. Fish activity and residence in floodplains such as Limoncocha lagoon also exhibit drastic seasonality, i.e. the biodiversity and species richness varies greatly between the dry, slack, and wet seasons (Yamamoto, Soares, & Freitas, 2004).

In addition to the flood pulse and rainfall affecting fish communities within the lake, this water movement is also responsible for a recent invasion of water lettuce in Limoncocha. The floodplain protected by the Limoncocha Biological Reserve undergoes one large flood per year in addition to many small inundations (Vargas, 2017). The large flood that occurred in January of 2017 allowed many individuals of *Pistia stratiotes* L., a plant commonly known as water lettuce, to enter the lagoon and invade the area. Due to the invasive nature and rapid reproduction of *P. stratiotes* L., Limoncocha has been plagued with millions of individuals monopolizing the surface of the lake (Webb, 2017). The dense mats formed by *P. stratiotes* L. have altered the physical geography of the lake by blocking off the northeastern stream access. Multiple studies have also proposed that macrophytes such as *P. stratiotes* L. can increase production and diversity of fish populations (Osorio et al., 2011; Schiesari et al., 2003). There has been little research done on *P. stratiotes* L. specifically on its effects in Limoncocha lagoon, and therefore it cannot be said for sure that the community of fish living in Limoncocha lagoon have been negatively or positively affected.

It is possible that the artisanal fishing has progressed at a slow enough rate that the fish have yet to be over exploited. There is a lack of studies on Limoncocha Lagoon, preventing any previous conclusions from being made about the impact of artisanal fishing in the past. According to personal communications (2017) with the local fishermen of Limoncocha, there are still plenty of fish in the lake to provide for the families of the indigenous community.

This study compared the fish populations caught via artisanal fishing in Limoncocha lagoon in April and May of 2017 to that of 2002. Using this information, the impact of artisanal fishing was analyzed and monitored for the first time in the Ecuadorian Amazon. This study also considered the anthropological implications, incorporating the fishing regulations set by the Limoncocha Biological Reserve.

METHODS

Study site

Limoncocha Biological Reserve is located in the Sucumbíos province in Ecuador and sits at an elevation of 213 meters above sea level. This study was performed at the Ministerio del Ambiente in the town of Limoncocha (see *Figure 1*). Data was taken at the entrance and office of the reserve and Limoncocha lagoon. Local artisanal fishermen from the town of Limoncocha enter and exit through this area, allowing for consistent data collection. When there was little traffic into and out of the lake, the park guard on duty scanned the lake from the dock of the lake to spot if there were more fishermen still collecting their nets and catches.

Materials

A 0.5-meter-long ruler was used to measure in centimeters the lengths of the fish collected. The weight of each fish was taken from one of two spring scales, depending on the size of the fish. Smaller fish were weighed using a scale with a maximum weight of 1000 grams and increased via increments of 5 grams (Pesola Medioline 1000g). This scale was used by closing a clip at the end of the fish's mouth; the fish was then suspended by the clip in order to read the weight of the individual on the cylinder of the scale. The second scale was used for larger fish and had a maximum weight of 5000 grams (Pesola Macroline 5kg). It increased via increments of 10 grams. This scale was used by hooking a large hook into the gill slit of the fish; the fish was then suspended by the hook in order to read the weight of the individual on the cylinder of the scale. Coca-Cola and bread rolls were provided to the fishermen in appreciation for participating in the present study.

For identification of individuals, the guide book *Guía de peces de Limoncocha* was provided by the Limoncocha Biological Reserve. This book also came with a field pamphlet companion for ease of identification (see Appendix A for identification plates). Pictures of the fish were taken with an iPhone 6 for later identification of unable to be identified in the field.

Data collection

Fishermen were awaited and approached every morning from April 17, 2017 through May 8, 2017 from 5:30am to 8:30am in front of the main reserve station/office on the fishermen's way out of the reserve. This time period was selected because it is the most common time for fishermen to collect their nets from the lagoon. However, a few fishermen set their nets in the morning and collect them at different times in the afternoon (Vargas, 2017). These times were not monitored or studied. The study required a park guard on duty waiting with me as well; people with a connection to the local/indigenous population of Limoncocha could approach the fishermen in an appropriate and inoffensive way, while also persuading them that the study was only measuring and weighing the fish. It was emphasized that the study's purpose was not to confiscate or harm any of the fish extracted from the lake. In general, the relationship between the residents of Limoncocha and the park guards and authority figures of

Limoncocha Biological Reserve was friendly but distant (Vargas, 2017). The local people acknowledge the reserve is there to protect the area, but there also is some resistance because the reserve has placed restrictions on daily fishing activities intended to provide for the families of the fishermen. For this reason, there is some tension between the reserve and the members of the community.

Figure 2 Materials and setup for taking data outside of Limoncocha Biological Reserve office.

After a fisherman agreed to participate in the study by bringing his catch of fish to the table in front of the reserve entrance (see *Figure 2*), the fish were laid out on a standard-sized wooden table and sorted carefully by species and size (length and width). A steel ruler was used to obtain a measurement of the length of the individual from the tip of the caudal fin to the tip of the mouth (or front of the head if the mouth was in an inferior position) as well as from the tip of the mouth or head to the exact place on the fish in which the muscle stops and caudal fin begins. If the catch exceeded 20 fish, individuals of the same species and same size (determined by length and width) were all given the same measurements and weights, then multiplied to their appropriate quantity later in an Excel spreadsheet. After recording weight and length of the fish, they were sexed (when possible) and scanned for visible physical damage or parasites. A photograph was then taken of the fish with an iPhone 6 on the table if permitted by the fishermen (see *Figures 3-6*); some of the residents of Limoncocha had an aversion to photographs being used in research.

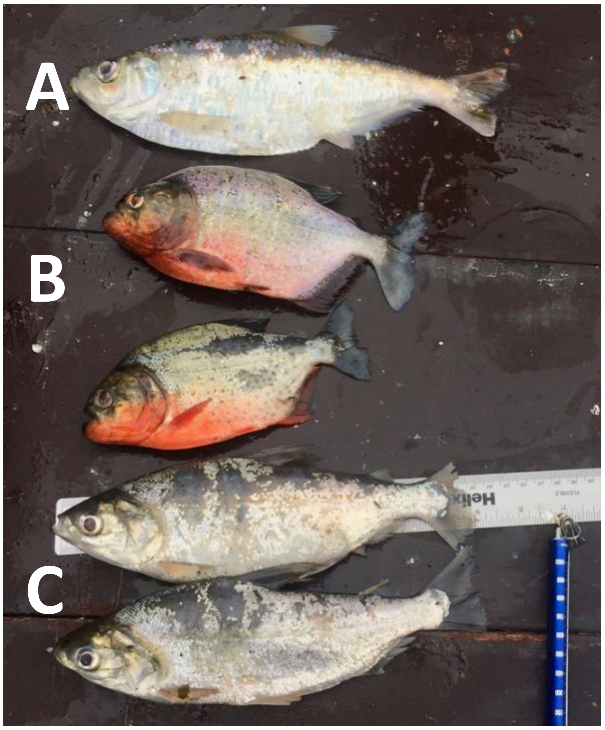

Figure 3 Examples of fish: **(A)** *Prochilodus nigricans* ("Bocachico"); (**B**) *Pygocentrus nattereri* ("Piraña roja"); (**C**) *Steinachnerina bimaculata* ("Boquiche").

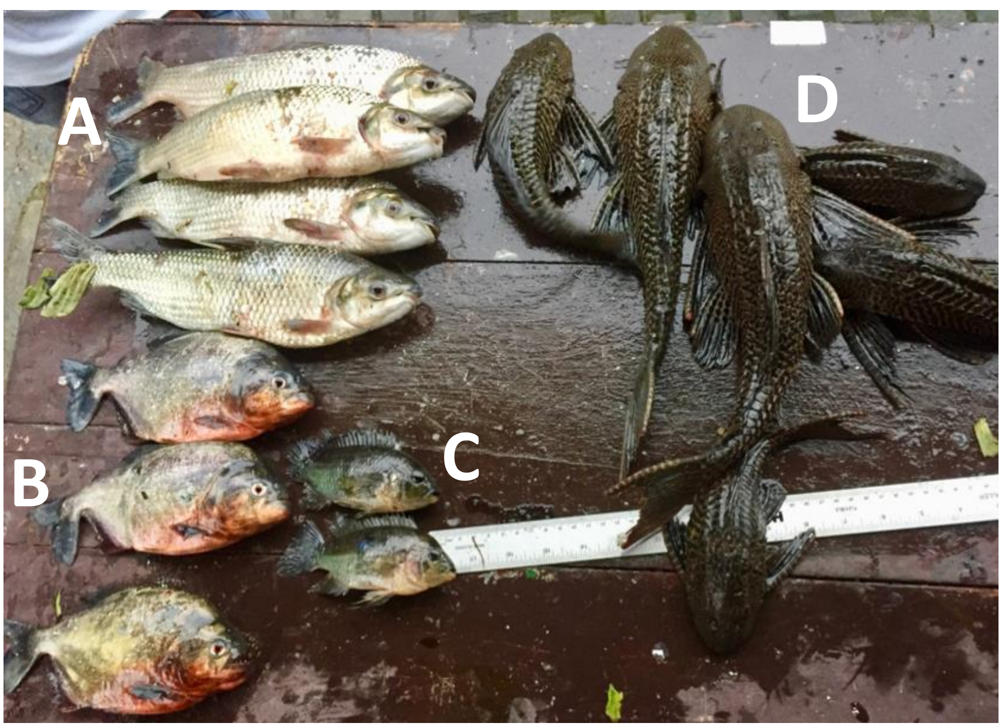

Figure 4 Examples of fish: **(A)** *Prochilodus nigricans* ("Bocachico"); (**B**) *Pygocentrus nattereri* ("Piraña roja"); (**C**) *Aequidens tetramerus* ("Vieja"); (**D**) *Pterygoplichthys weberi* ("Campeche").

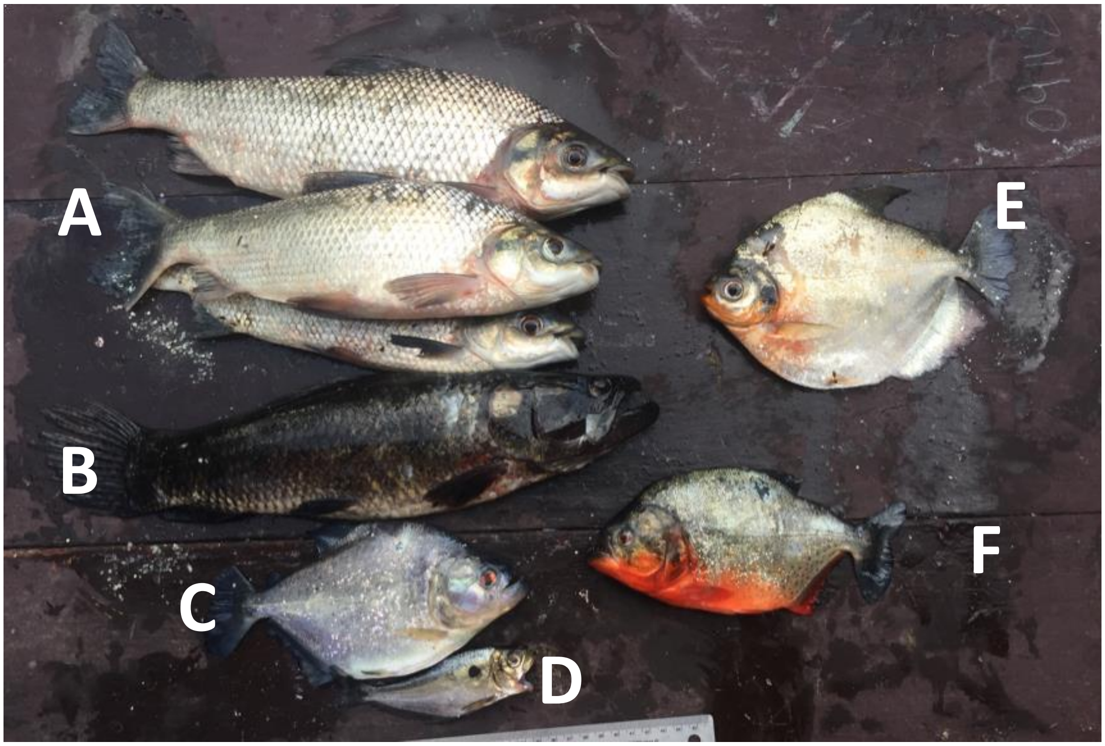

Figure 5 Examples of fish: **(A)** *Prochilodus nigricans* ("Bocachico"); (**B**) *Hoplias malabaricus* ("Guanchiche"); (**C**) *Serrasalmus rhombeus* ("Piraña blanca"); (**D**) *Roeboides myersii* ("Dientón"); (**E**) *Mylossoma duriventre* ("Palometa"); (**F**) *Pygocentrus nattereri* ("Piraña roja").

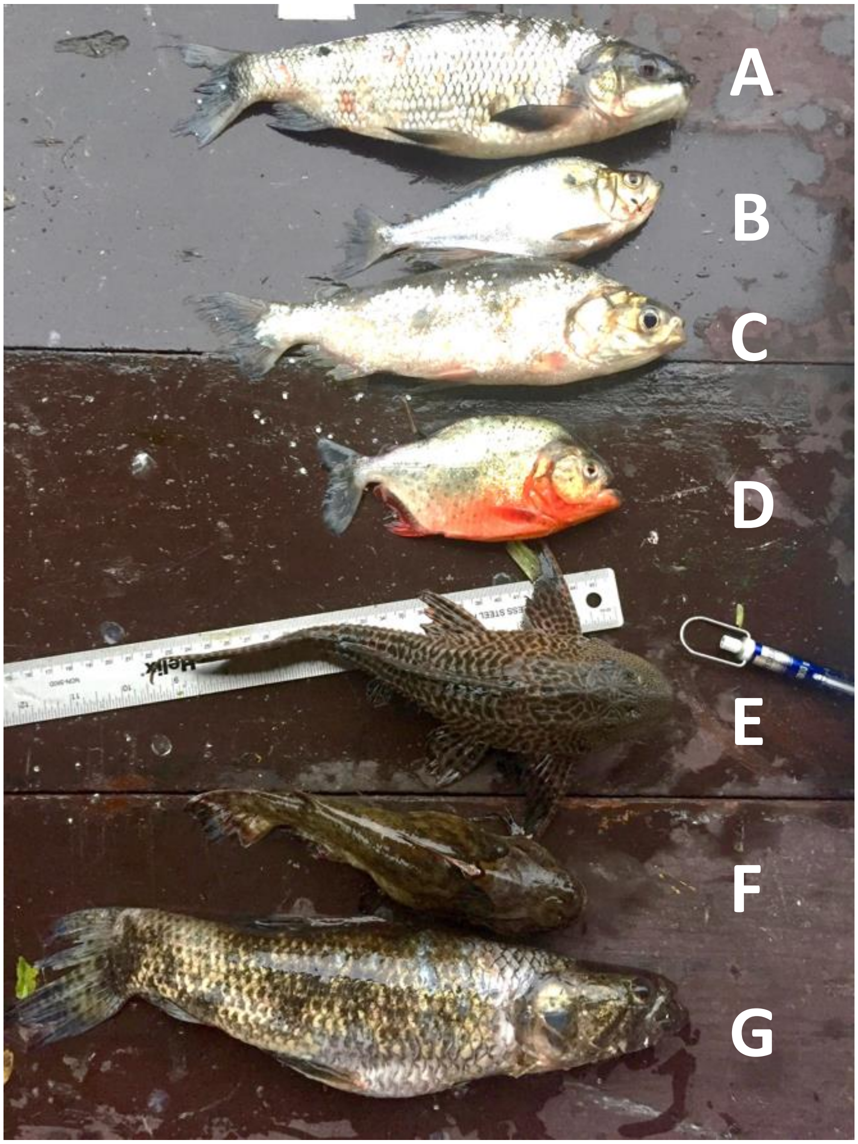

Figure 6 Examples of fish: (**A**) *Prochilodus nigricans* ("Bocachico"); (**B**) *Roeboides myersii* ("Dientón"); (**C**) *Steinachnerina bimaculata* ("Boquiche"); (**D**) *Pygocentrus nattereri* ("Piraña roja"); (**E**) *Pterygoplichthys weberi* ("Campeche"); (**F**) *Rhamdia quelen* ("Bagre"); (**G**) *Hoplias malabaricus* ("Guanchiche").

Finally, the fish were returned to the fishermen's bags, and the fishermen were asked two questions: 1) In which part of the lake were the nets placed, and 2) At what time were the nets set? Date and time of the exchange with the fishermen were also recorded. For maximum clarity when describing net location, the fishermen were asked to point to the location on a rough map of the lake, where the denoted location was then recorded. Fishermen were provided with a small glass of Coca Cola or a bread roll in return for participating in the study. All obtained data and information was recorded on a survey worksheet provided by the Limoncocha Biological Reserve for consistency in records (see Appendix B).

Data analysis

All measurements and gathered information were compiled into a spreadsheet in Excel. Limoncocha lagoon was split into 6 main zones: 1 on the eastern end, 1 on the western end (near the mouth of the stream), and 4 quarters in the middle section of the lake (see *Figure 7*).

Figure 7 Six zones of Limoncocha lagoon. Stream off of Zone 6 now blocked off at green line due to excessive *P. stratiotes* L. populations.

This was done to allow for using similarity/dissimilarity indices to compare number of individuals and species collected from different parts of the lake. The SpadeR computer program (Chao et al. 2015) was used first to produce a Bray-Curtis index of dissimilarity between each individual zone to test the dissimilarity between different zones and micro-environments within the lake. I was interested in the dependence of fish populations on the different areas of the lake. SpadeR then was used to compare each zone to the entirety of the lake in order to test how well each zone represents the biodiversity of the lake as a whole. Finally, a sample-completeness curve was produced to determine if my data was complete, considering the sampling methods used. I used this curve to determine the validity and conclusiveness of the species list and data that was obtained from my data collection period.

Design weaknesses and strengths

The accuracy of this study is reliant on the willingness of the fishermen to cooperate and participate frequently in the study. Unfortunately, not all fishermen agreed to participate in this study. Some of the local people had an aversion to participating in research due to a lack of immediate benefit to the family or community. It is for this reason that it was not possible to record 100% of the fish removed from the lagoon. Similarly, there are three other locations along the side of the lagoon that are apparently used by some of the local fishermen to enter and exit the lagoon with their nets and catches. According the "Código de Conducta de Pesca Sustenable en La Reserva Biológica Limoncocha", a guide to the regulations of fishing in the reserve, this activity of exiting the lake outside the main entrance to the lagoon is discouraged, but it still occurs daily. Finally, due to the rushed nature of many of the encounters with the local fishermen, it was not always possible to measure each individual fish. Instead, the fish were sorted into size and species categories and were considered as all having the same length and weight.

The methods of this study were very close to those of the census taken in 2002 for the base line analysis of the Limoncocha Biological Reserve. The similarity between data collection methods allows for justified and fair comparison between the data and information obtained between the two censuses. Also, the fact that some of the employees and park guards at Limoncocha Biological Reserve belong to the community of Limoncocha allowed for more successful communication with the local fisherman. If the study had been completely carried out by someone without any connection to the local people, they may have difficulty with persuading the fishermen to participate in the study.

RESULTS

Data were collected for three hours each day on 19 mornings in Limoncocha Biological Reserve. Out of 54 fishermen who were approached over the course of these 19 days, eight (14.81%) refused to participate, while 46 fishermen (85.19%) agreed to participate. Those who refused listed multiple reasons, the most common being that they did not see any direct benefit to the community from the research at the Limoncocha Biological Reserve. Zone 4 returned the most individuals, followed by zone 3 and zone 2, respectively (see *Figure 8*). In total, 23 species and 756 individuals were measured, identified, and recorded from the fishermen's daily catches, with 95% of individuals belonging to just 10 out of the 23 total species (43.48%) (see *Figure 9*). The three most frequently-represented species were *Prochilodus nigricans* (Prochilodontidae family), *Potamorhina altamazonica* (Curimatidae family), and *Steindachnerina bimaculata* (Curimatidae family), respectively. Individuals were also counted in relation to their lake zone (see *Table 1*).

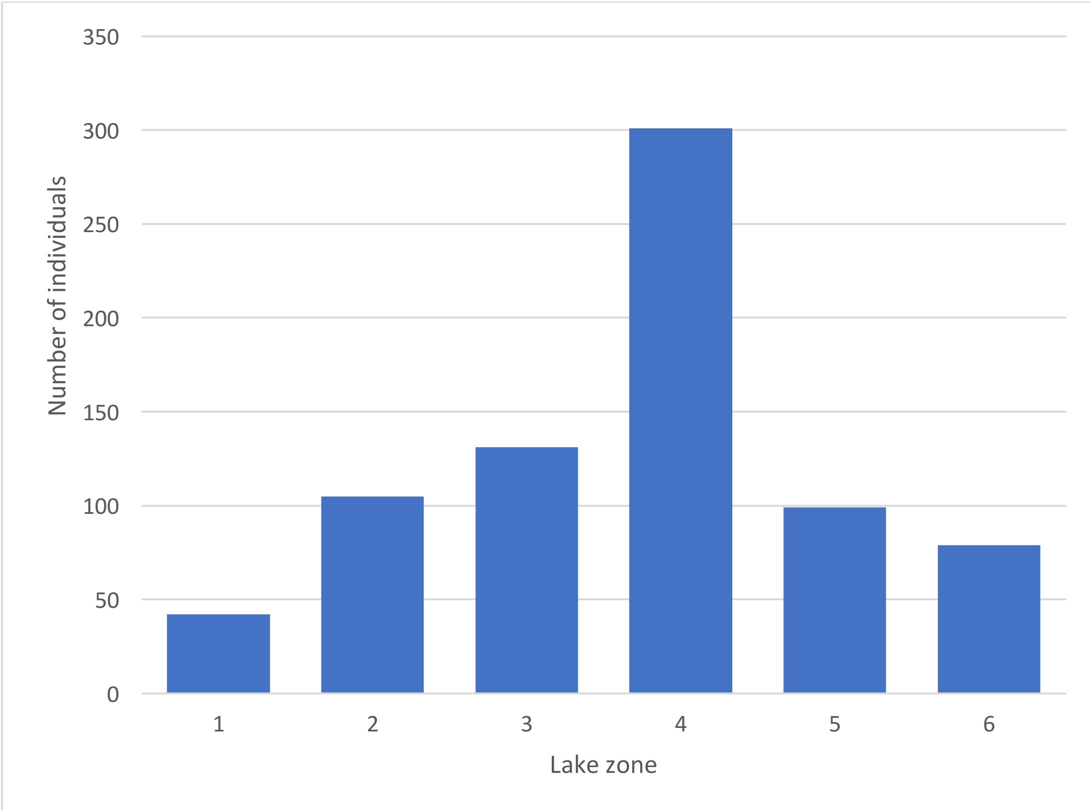

Figure 8 Total number of individuals collected from each zone (see *Figure 7* for map of zones).

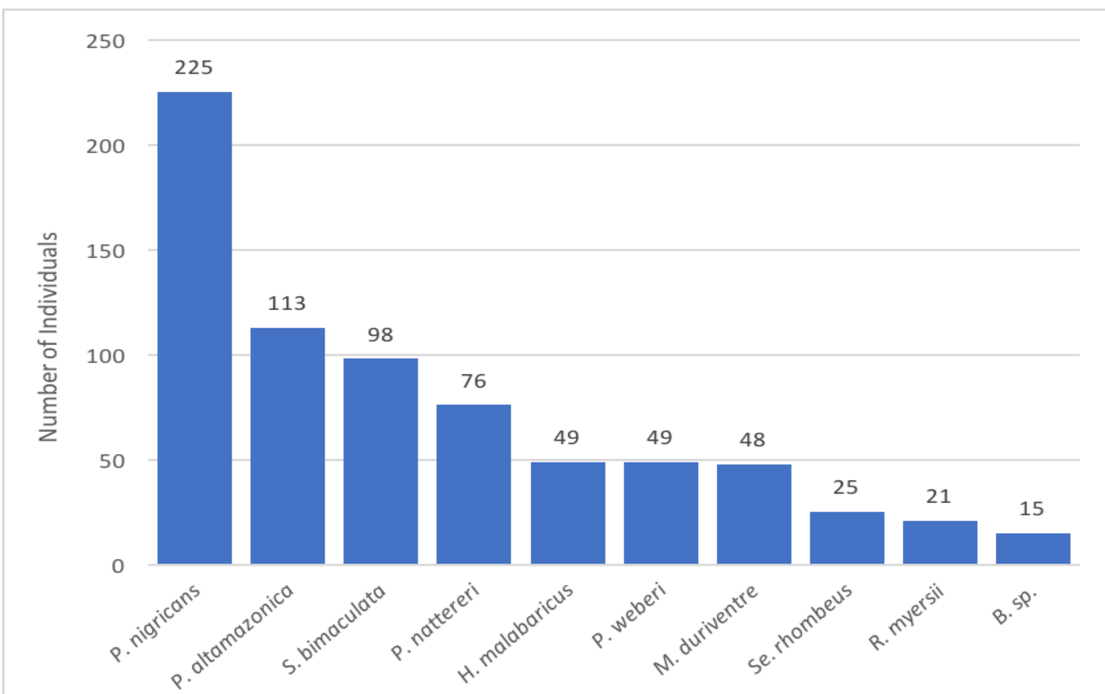

Figure 9 Frequency of 10 most frequently extracted species from Limoncocha lagoon. Frequency depicted as number of individuals per species (samples included from all 6 zones).

Table 1 Most abundant species found in each of the 6 zones followed by the frequency within each zone, displayed as percentage of total individuals in zone.

Zone	Most abundant species	Family	% of zone total
1	*Potamorhina altamazonica* ("Bocachico")	Curimatidae	19.05%
	Hoplias malabaricus ("Guanchiche")	Erythrinidae	19.05%
2	*Prochilodus nigricans* ("Boquiche")	Prochilodontidae	25.71%
3	*Prochilodus nigricans* ("Boquiche")	Prochilodontidae	19.08%
4	*Prochilodus nigricans* ("Boquiche")	Prochilodontidae	27.91%
5	*Prochilodus nigricans* ("Boquiche")	Prochilodontidae	47.47%
6	*Prochilodus nigricans* ("Boquiche")	Prochilodontidae	50.63%

All fish were also classified as juvenile or adult, adult signifying that the fish was fully grown. 39% of all individuals were considered "adult", while 61% were not fully grown and therefore considered "juvenile". The fishing Code of Conduct and the Base Line Analysis for the Limoncocha Biological Reserve both provide suggestions for minimum catch size, although roughly 40% of the fish that were measured would be considered under the minimum suggestion of fish size. "Juvenile" fish were not always smaller than the suggested minimum catch size. Average lengths and weights were also calculated for each of the six zones of Limoncocha lagoon (see *Figure 7*) for comparison of catches within each zone (see *Figures 10 and 11*).

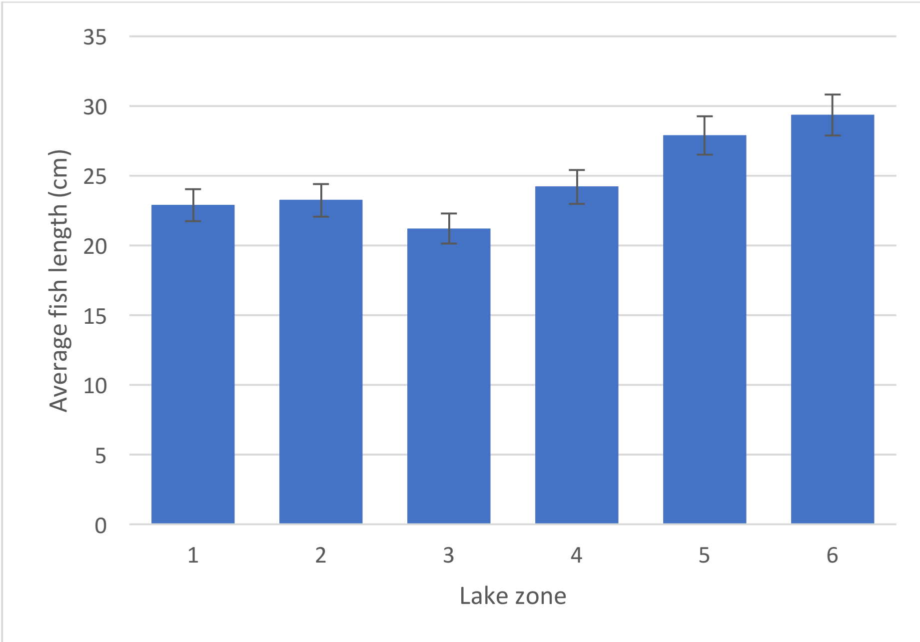

Figure 10 Average fish length (cm) in each zone.

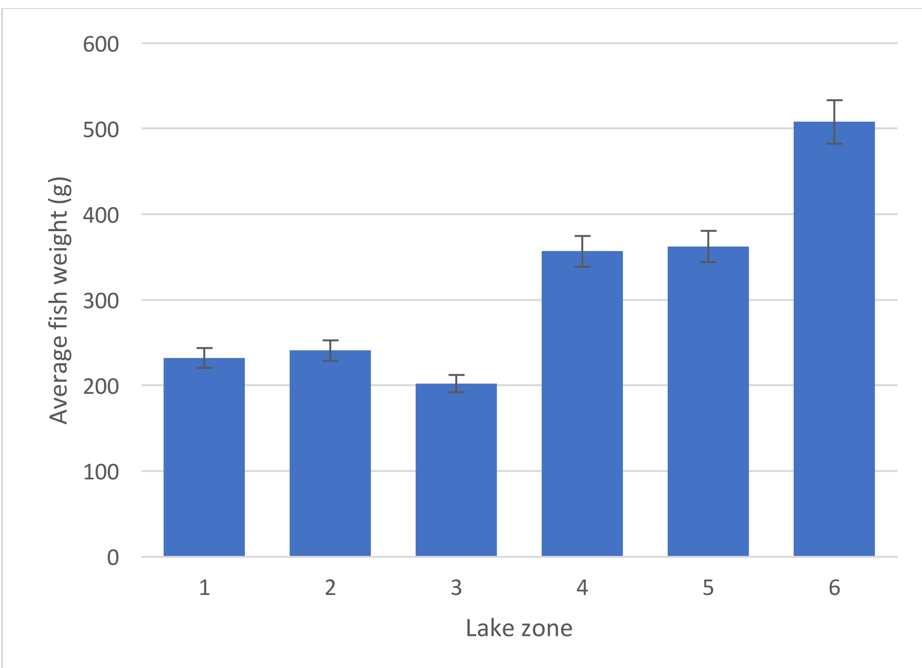

Figure 11 Average fish weight (g) in each zone.

The differences in averages of weight and length between the zones varied in their significance (see *Tables 2 and 3*). Roughly 75% of the locations of the nets used to collect the data in this study were placed along the edges of the lake as opposed to open water environments, although this could vary slightly depending on the location of *P. stratiotes* L., as they move daily depending on wind, rain, and river conditions.

Table 2 Comparison of average weights within 6 zones; Tukey HSD p-values displayed in green when statistically significant ($p \leq 0.05$) and displayed in red when statistically insignificant ($p \geq 0.05$).

Zone	**1**	**2**	**3**	**4**	**5**	**6**
1		0.8999	0.8999	0.2789	0.3552	0.0010
2			0.8999	0.0573	0.1585	0.0010
3				0.0010	0.0104	0.0010
4					0.8999	0.0110
5						0.0764
6						

Table 3 Comparison of average lengths within 6 zones; Tukey HSD p-values displayed in green when statistically significant ($p \leq 0.05$) and displayed in red when statistically insignificant ($p \geq 0.05$).

Zone	**1**	**2**	**3**	**4**	**5**	**6**
1		0.8999	0.8999	0.8999	0.0415	0.0038
2			0.5602	0.8999	0.0058	0.0010
3				0.0260	0.0010	0.0010
4					0.0086	0.0010
5						0.8999
6						

Empirical similarity indices were used to measure the similarity of individuals per species in all 6 zones. They reported that when q=0, Sorensen's similarity was 0.5800 and Jaccard's dissimilarity was 0.1871 (see *Figure 12*). A Bray-Curtis dissimilarity index was used via SpadeR software (Chao et al. 2015) to estimate classic richness-based similarity between all six zones in Limoncocha lagoon. When comparing species absolute abundances, Bray-Curtis reported an estimate of 0.7031. Each zone was also categorized with a similarity value (see *Table 4*) with an overall average pairwise similarity of 0.823.

Table 4 Pairwise similarity matrix of individuals/species generated using SpadeR software.

Zone	**1**	**2**	**3**	**4**	**5**	**6**
1	1.000	0.857	0.79	0.875	0.810	0.753
2		1.000	0.779	0.932	0.787	0.778
3			1.000	0.797	0.815	0.809
4				1.000	0.814	0.954
5					1.000	0.954
6						1.000

SpadeR software (Chao et al. 2015) was used to illustrate a Jaccard similarity index between all 6 zones of the lake as q increased (see *Figure 12*).

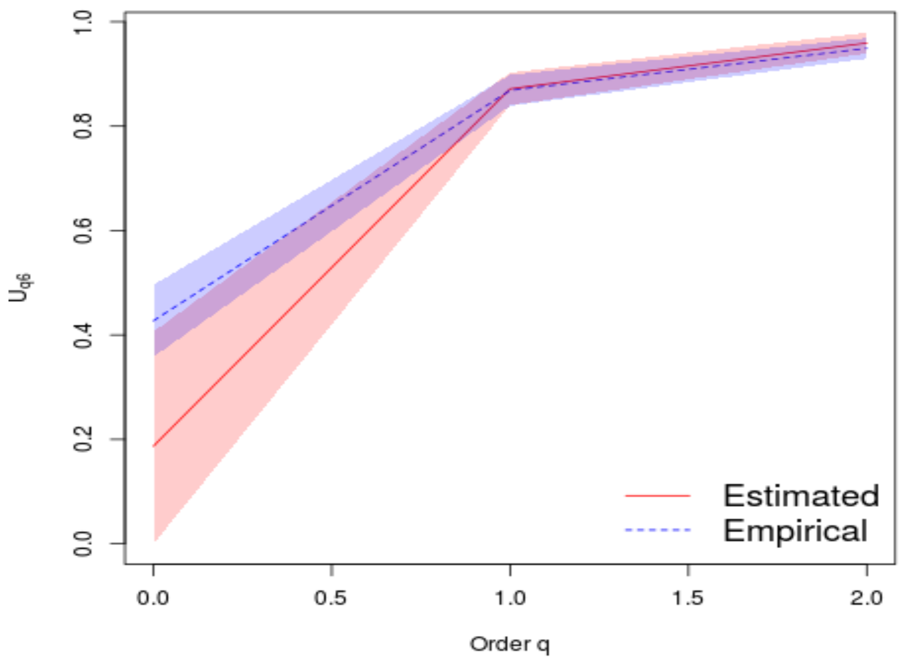

Figure 12 Regional (Jaccard-type) species-overlap measure to show similarity index between all 6 zones. Generated using SpadeR software (Chao et al. 2015).

Although each fisherman has his top spots for net placement (Residents, 2017), there is a trend wherein the edges of the lake are favored, as well as the mouth of the stream on the northeast end of the lake, just past Zone 6. However, this location is often not available to the fishermen due to high density of *P. stratiotes* L. This closing-off event of the mouth of the lake first occurred in 2008 farther up in the stream, and later the event was intensified in 2014, when the lake closed almost entirely (Vargas, 2017).

The timing of the fishermen collecting their nets was not uniform at any point during the study. However, three trends were notable: 1) More fishermen collected and set their nets on Saturdays due to the prospect of selling extra fish to a market in Pompeya, Ecuador on Saturday mornings; 2) More fishermen collected and set their nets after a large rain event, especially after those lasting multiple days; 3) The highest traffic leaving the lake with fish and nets was between the hours of 6:00am and 8:30am.

DISCUSSION

An iNext analysis was used to estimate the completeness of the sampling methods used (see *Figure 13*). Because the extrapolated line is almost horizontal, it can be assumed that the sample of individuals collected with this set of methods was very close to being complete. This figure also shows that high completeness was achieved early on in the study. This may be due to the honed fishing techniques and routines of the fishermen, which led them to a highly efficient and uniform catch almost every day.

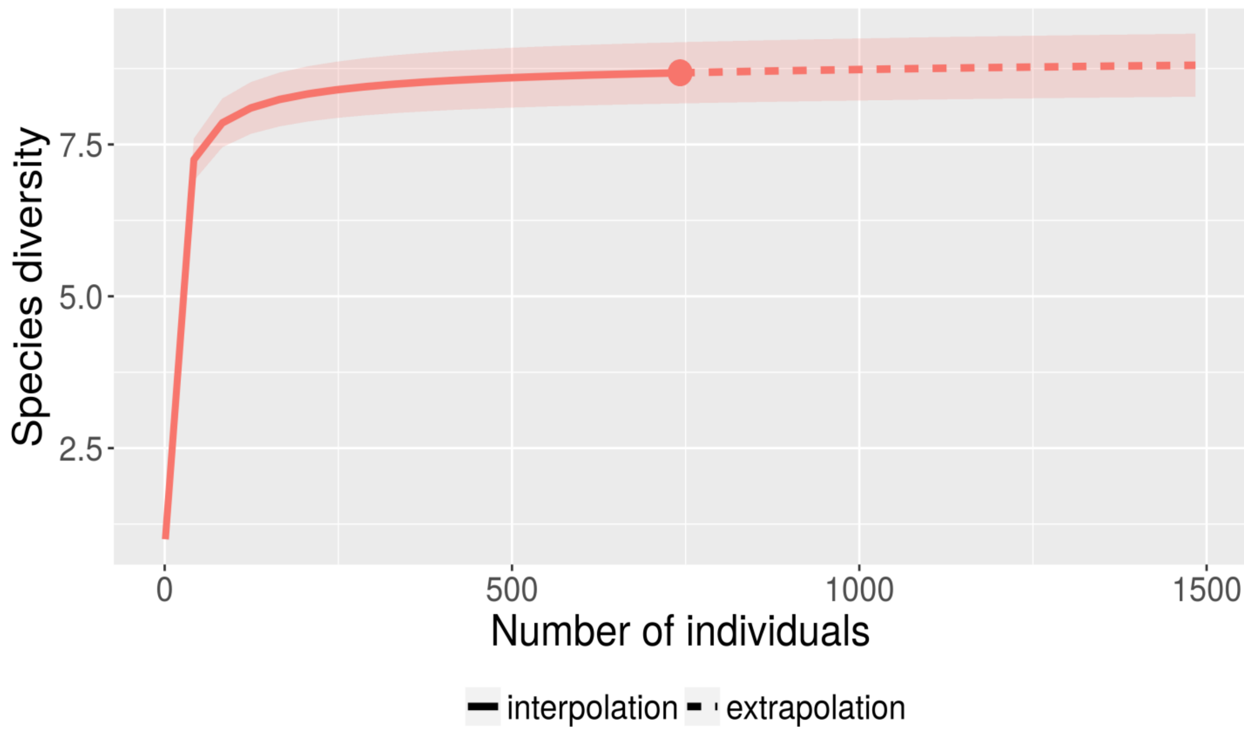

Figure 13 Species accumulation curve: sample-size-based rarefaction and extrapolation sampling curve shows almost complete sample via almost-horizontal extrapolation curve (Chao et al. 2016).

An integral part of this study was to record lengths and weights of each individual in the sample as a way to monitor the health of the fish and the environment. This information was crucial for comparing the composition of each of the six different zones in Limoncocha lagoon as well. Length and weight can be used to track reproductive cycles, energy budgets, growth curves, and evolution of an ecological system (T. M. S. Freitas, Prudente, Fontoura, & Montag, 2014) and therefore provide more insight into the health of the lake, as well as the differences between each of the six zones. There was no significant difference between the mean length to weight ratio of the 2002 census and of the present study. However, when the data from each zone was compared using ANOVA and a Tukey HSD test, the lengths and weights extracted from Zone 6 were significantly different from almost every other zone in the lake. Zone 6 is located at the mouth of the stream connecting the lake to the Napo River. When large amounts of precipitation fall, the water level rises, the lake's connection with the Napo River increases, and more migratory fishes can migrate up into the lake via Zone 6 (Rivera, 2017). More weight suggests greater food availability, and therefore a more balanced system (T. M. S. Freitas et al., 2014). The insignificant difference between the other zones in terms of length and weight of individuals is to be expected due to the small area of the lake. The depth of Limoncocha lagoon varies only by 3 meters from its deepest to shallowest points (Vargas, 2017). There is also little variability in the turbidity and temperature of the water throughout the lake (Anonymous, 2017). Turbidity, water temperature, and water depth all greatly affect the community composition of freshwater fish (Yamamoto et al., 2004). Thus, it is reasonable that the other zones showed little difference in what was used to measure the community composition: length and width of individuals.

Although there is evidence that the channel that feeds Zone 6 supports a community of larger fish, the access to this area is temporary, and seasonal at best. In January of 2017, a yearly flooding event carried millions of *Pistia stratiotes* L. into Limoncocha lagoon. Due to their rapid reproduction and lack of present predators, *P. stratiotes* L. was allowed to invade the lake, creating many small floating islands (Webb, 2017). These islands and individuals move freely on the surface of the lake, propelled by water movement such as heavy rains or the flood as well as air movement such as large winds pulse (Eid, Galal, Dakhil, & Hassan, 2016; Junk et al., 1989). Most of the open water once available for fishing in Zone 6 is now blocked by or filled with dense mats of *P. stratiotes*. Only when the water rises or falls drastically or when a wind storm has passed through are the fishermen able to access Zone 6, hence the small number of samples from that area.

An analysis on the catch per unit effort shows that Zone 4 returns the most biomass per fisherman per net, followed by Zone 6. While this is reflected in the number of fish extracted from Zone 4, it is not reflected in the number of individuals extracted from Zone 6. This is most likely due to the presense of the dense macrophyte mats that tend to congregate in Zone 6.

The majority of the fishermen of the Limoncocha community have learned how and where to fish from their fathers. The trade is passed down through generations in the community, which is common in indigenous populations in the Amazon basin (Vargas, 2017). Through this process, fishermen learn the most effective and efficient processes and locations using long gillnets, about 20 meters across ("trasmallos"). The substrate and physical environment that make up different parts of the lakes and rivers in the Amazon basin can have a large impact on the types of freshwater fish communities that live there (Stewart et al., 2002). Stewart et al. (2002) found that the fish communities in the "beach-zone" were mainly dominated by small characins, while in deeper water, there were many more catfishes. However, the similarity indices between zones in this study produced contradictory information to that of Stewart et al. (2002). All values that were produced using the pairwise similarity matrix of individuals per species were greater than 0.75, indicating high similarity despite location of the zone. The community makeup of each of the 6 zones showed no large difference in which species were dominant, especially between characins and catfishes. When examining the data through a more specific filter, catches extracted from coastal "beach-zones" did not show a statistically significant difference from catches extracted from more open water zones, even when comparing catfishes to characins. This could be due to the difference in size and depth of the bodies of water in the study of Steward and coworkers (2002) and the size and depth of Limoncocha lagoon – Limoncocha is a smaller and shallower body of water than some of those described by Stewart et al. Another possible explanation is that the artisanal fishing that takes place in Limoncocha could be exploiting some of these catfish and characin populations, therefore making them less abundant at all points around the lake. Neither characins nor catfishes are listed as "Dominant" in any of the 5 sampling locations from the 2002 census, suggesting that the fishing activity may not have changed drastically in the past 15 years, but that Limoncocha lagoon may have been overfished prior to the 2002 census as well.

As previously mentioned, Limoncocha lagoon is part of a larger floodplain region. This region generally experiences one large annual flood, as well as multiple smaller floods throughout the year; each of the smaller events generally last from 2-4 days (Fisherman, 2017). Each of these flooding events, especially the larger ones, are conducive to migratory fish populations moving into the lake with the mixing nutrients and organisms(Galacatos, Barriga

Salazar, & Stewart, 2004). This is a unique event in which both migratory species and lake species to have access to more food sources, genetic variation, and habitats (Grabowski & Gurnell, 2016; Mortillaro et al., 2015; Osorio et al., 2011). The wide array of habitats supported by the distinctive geomorphology of the floodplains support help to maintain high biodiversity, species richness, and production (Górski et al., 2013). Górski et al. (2013) also states that communities of fish are determined and controlled by abiotic factors (including complexity) of the floodplain system, but that smaller lakes that experience smaller fluctuations in water level with the flood pulse are more endangered in the presence of harsh conditions or overfishing. The census from 2002 found 20 species of migratory fish in Limoncocha lagoon. It reported that individuals may grow to larger sizes in the river, and then travel laterally via rivers into the lake. Multiple species have been found to migrate to the lake at sexual maturity to reproduce, hence the larger sizes of individuals found during floods and rainy seasons (Costa & Freitas, 2013; Garcez Costa Sousa & De Carvalho Freitas, 2011; Granado-Lorencio et al., 2007; Martelo, Lorenzen, Crossa, & Mcgrath, 2008).

Two groups of fish were frequently found migrating to the lake to reproduce (as well as 4 other groups with lower frequencies). These two groups are the Curimatidae ("Boquiche") family and the Prochilodontidae ("Bocachico") family. This behavioral pattern explains the high ratio of juvenile to adult individuals sampled in this present study as well as the especially high frequency of these two main migratory families. Of all the identified individuals throughout this study, only 39% of all individuals were considered "adult" (individuals were classified as "adult" only when they were fully grown), while 61% were still not full grown and therefore considered "juvenile" (individuals were classified as "juvenile" at all stages of development prior to full-grown adult). The present study proposes that there were more individuals in the development stage due to a recent flooding event, thus allowing for more fish to migrate and reproduce in the lake. This is also consistent with information provided by two of the local fishermen of Limoncocha —there had been a larger flooding event one month prior to data collection (Fisherman, 2017).

In a census taken in 2002 at the Limoncocha Biological Reserve, it was reported that two species may act as bioindicators in the lake, representing a stable environment and healthy habitat to support biodiverse and rich population of freshwater fish. These species were named as *Raphiodon vulpinus* (family Cynodontidae) and *Cyphocharax sp*. (family Curimatidae). Neither of these species were found in the present study, nor was there a single individual from the Cynodontidae family. However, two species of Curimatidae were included in the sample, both with relatively high frequency. These species were *Potamorhina altamazonica* and *Steindachnerina bimaculata*. The absence of the family Cynodontidae suggests that the lake environment may not be supporting the same diversity that it was in 2002. However, the strong presence of Curimatidae (albeit only two species) suggests otherwise. Because one of the reported bioindicators was completely absent while the other was so strongly represented lends itself to the idea that the lake may still be supporting high diversity; it is possible that the trophic levels have simply been shifted or rearranged. Multiple studies have found that the trophic levels occupied in the Amazon Basin are more fluid and generalized than previously reported due to the large impact of the flood pulse and seasonality of bodies of water, especially in the case of floodplains and lakes (Albert et al., 2011; Costa & Freitas, 2013; Granado-Lorencio et al., 2007; Mortillaro et al., 2015; Osorio et al., 2011; Portocarrero-Aya & Cowx, 2016; Stewart et al., 2002; Suçuarana, Virgílio, & Vieira, 2016). However, Carvalho et al. (2017) contrasts this argument by stating that because there is a large influx of nutrients, primary production, and available food sources when the water levels rise, animals tend to occupy a more specific trophic level. If absence of the fish mentioned in the 2002 census is not due to fluid community structures within the floodplain surrounding Limoncocha, then the lake is showing signs of lowered species richness and biodiversity. This could lead to the increased probability of species being fished to extinction, proliferating the impact of the initial decrease in biodiversity and species richness. In terms of the indigenous village, the local residents may have to begin monitoring or rationing the fish that they extract from the lagoon, perhaps with the guidelines proposed in the Código de Conducta from the reserve.

The 2002 census lists the top 10 species that were found to be the most desirable by the local fishermen for consumption and sale (see *Table 5*). When this list was compared to the species list of the present study, only five of the named species from 2002 were present in the species list of this study. Five of the most valuable species (i.e. best-suited for consumption) were entirely absent in May/June 2017. Due to the completeness of my research (see *Figure 13*), the claim can be made that these species are no longer present in Limoncocha Lagoon, most likely due to human predation. Artisanal fishing is the only activity allowed by the Reserve, therefore supporting the claim that there are lasting and negative effects of the fishing activity

Table 5 Top 10 species of highest nutritional/sale value as determined by the 2002 census and their presence/absence in the species list of the present study (2017).

Species	**Presence in 2017**
Calophysus macropterus	Absent
Leiarius marmoratus	Absent
Prochilodus nigricans	Present
Pygocentrus nattereri	Present
Serrasalmus rhombeus	Present
Rhamdia quelem	Present
Hypostomus micropunctatus	Absent
Brycon melanopterus	Absent
Plagioscion squamosissimus	Present
Potamorhina latior	Absent

Macrophyte influence

The direct influence of *P. stratiotes* L. on the Limoncocha Biological Reserve has yet to be examined. However, other studies have found that the presence of large macrophytes populations can have measurable impacts, especially on smaller systems such as Limoncocha lagoon. In high quantities, macrophytes lower oxygen content of the water, as well as decrease the available sunlight that passes through the water. Primary productivity is also increased, which supports more macroinvertebrates, and therefore carnivorous fishes as well (Eid et al., 2016; Mortillaro et al., 2015; Röpke, Amadio, Winemiller, & Zuanon, 2016; Suçuarana et al., 2016). Macrophytes also increase habitat complexity, which in turn supports higher biodiversity and species richness (Petry, Bayley, & Markle, 2003). The macrophyte rafts and banks vary greatly on both a daily and seasonal basis, as do the fish populations of floodplains and lakes.

The dynamics of both populations (fish and macrophytes) were found to be linked in a study examining the trophic structure of fish and macrophytes in the same habitat (Suçuarana et al., 2016). This and other studies also suggest that the increase in biodiversity and species richness is due to the macrophyte rafts transporting aquatic fauna via the root system (Górski et al., 2013; Petesse, Siqueira-Souza, de Carvalho Freitas, & Petrere, 2016; Petry et al., 2003; Schiesari et al., 2003).

The large macrophyte rafts also increase the difficulty and time required for fishing events. The dense populations are challenging to row through in a canoe and the individuals become entangled in the fishing nets. This increases the necessary time retrieving nets because each individual must be removed from the net before they can be collected. The rafts have been reported as acting as a nursery or feeding ground for many species and populations of fish (Petry et al., 2003; Schiesari et al., 2003). When fishermen place their nets in and around macrophyte populations, it is possible that they are catching younger, more vulnerable fish, thus decreasing population sustainability. This contradicts the theory of increased biodiversity. The placement of nets has had an overall shift away from heavy placement in Zone 6 due to inaccessibility. It is difficult to row through the macrophyte rafts in the canoes used to place and collect the gill nets. Further studies with a focus on tracking the biodiversity specifically in the root systems of *P. stratiotes* L. are necessary for drawing conclusions on the direct effects of the species on specific fish communities and species. It is possible that the macrophyte mats are providing a type of protection from the fishermen due to the difficulty that they create for the fishermen in the rowing/locomotion process and net extraction. This may provide a regeneration opportunity for the fish populations that was not previously present.

Anthropological considerations

The "Código de Conducta de Pesca Sustenable en la Reserva Biologica Limoncocha" outlines regulations placed on the fishermen of Limoncocha with regard to frequency and methods of fishing in the lake. These regulations are in place to prevent over-exploitation of the fish in the lake, as well as to guarantee that the only people who are fishing at the lake are local people of the Limoncocha Community. Because the lake is protected by the Limoncocha Biological Reserve, the only permitted fishing activity is artisanal sustenance fishing for local community members. However, the regulations and suggestions listed in this code of conduct are not being enforced by the fishermen nor the park guards/reserve authorities. Therefore, there is a possibility that the lake is being overfished. For example, the *Arapaima sp.* is an iconic fish of the Amazon basin that used to be one of the dominant species in Limoncocha but is threatened in all of the Amazon basin by overfishing and habitat degradation (Carvalho et al., 2017; Castello, Arantes, Mcgrath, Stewart, & De Sousa, 2015). Due to overfishing, there have been zero recent reports (from the fishermen) of this species anywhere in the lake for the past two years (Vargas, 2017). Regulations outlined in this document allow the fishermen two fishing sessions per week. Also, all fishermen and their canoes should be registered with the Limoncocha Biological Reserve and the Ministerio del Medioambiente in Limoncocha. It is mentioned multiple times within the Code of Conduct that the fishermen are responsible for fishing in a "sustainable and just manner". The Code suffests that the fishermen should use methods of extracting fish that will allow the populations to continue surviving and developing into the future. The trouble with this remark is that the fishermen have all already adopted their father's way of fishing that has been passed down for years. In addition, there are no concrete suggestions for specific fishing practices that would be considered "sustainable and just".

Overall, the "Código de Conducta de Pesca Sustenable en la Reserva Biologica" is not enforced regularly, if at all. According to personal communications with some of the local fishermen, the misunderstanding between the local community and the reserve is what prevents some of the fishermen from participating in the research and censuses performed at the Limoncocha Biological Reserve, both by students, foreigners, and local people.

The census taken in 2002 at the Reserve made suggestions for which seasons are least impactful on the populations of fish in Limoncocha lagoon as well as seasons during which fishing should be more limited and strictly-regulated due to lower reproduction rates and slower population growth. Another suggestion that was made was to enforce a minimum length requirement for extracted fish from the lake. If this requirement were adopted into the code of conduct and enforced, juvenile fish would have a greater probability of reaching reproductive maturity and reproducing to replenish and sustain the populations. This may help balance the ratio of juvenile to adult fish extracted from the lake.

The local fishermen have a deep understanding of the flood pulse and population cycles of the fish in Limoncocha lagoon. Understanding and predicting the timing of flood and migratory events is essential to successful fishing due to the high impact of migratory fish and flood pulse effects. A couple of studies in the Brazilian Amazon (Guerreiro, Ladle, & Batista, 2016; Pinto, Mourão, & Alves, 2013) tested local fishermen's knowledge of community composition (such as species) as well as environmental events, such as flooding, desiccation, and seasonality of the system in focus. Guerreiro et al. (2016) found that the important events and species were remembered by almost every single fisherman that was interviewed as a part of the study. The fishermen at Limoncocha are hyper-aware of the flood pulse cycle as well as fish community composition and dynamics due to the amount of time that is spent fishing as well as the importance of the fish to their families and livelihood (Vargas, 2017).

Potential error

This study was largely based on the cooperation of the local fishermen of the Limoncocha community. For this reason, some extracted individuals were not accounted for in the data set of this research. It is also possible that some of the fishermen exited the lake from another location on the lake as opposed to exiting at the main entrance to the reserve, where data was taken daily. It is not possible to know how many catches were excluded from the data set due to these potential sources of error. In catches with large quantities of individuals, fish of the same species and same length were all assigned the same length measurements and weights. This may have slightly diminished the precision of collected data. A longer study period would have increased the robustness of the data from all seasons and floods throughout the year. The data from this study may have been more representative of the populations in Limoncocha lagoon had data been collected over a longer period of time. Finally, a potential source of error in this study is the possible misidentification of individuals, although this was minimized by the involvement of a knowledgeable park guard when recording data.

CONCLUSION

Conservational implications

The Alpha and Beta diversity of floodplains and bodies of water illustrate general trends and preferences of the ichthyofauna and are fundamental to understanding the ecology and conservation biology of an area (Freitas, Siqueira-Souza, Florentino, & Hurd, 2014; Jost, 2007) and are therefore vital to understanding the conservation status and necessary protective measures of Limoncocha Biological Reserve. Alpha diversity is the diversity within a single floodplain system, such as Limoncocha Lagoon, while Beta diversity is the diversity between two or more floodplain systems. Beta diversity provides the prospect of comparing pristine lakes that have not been fished or exposed to pollution such as gasoline used for boat fuel to those that have, such as Limoncocha lagoon. Petesse et al. (2016) developed a system of selecting “reference lakes” that were considered pristine (without contamination or fishing activity) to compare to lakes with anthropogenic impacts. This system has potential to further analyze the conservation status and urgency of Limoncocha lagoon. Laguna Negra, a nearby floodplain lake, is not fished due to local superstitions about the area (Vargas, 2017). Because this lake is not fished or influenced by anthropogenic factors, the conservation status of Limoncocha lagoon could be investigated via the system of reference lakes proposed by Petesse et al. (2016).

Fish species with a high nutritional value have the tendency to be depleted and over-fished, which can cause an unbalanced ecosystem, and therefore can essentially threaten the biodiversity and species richness of an ecosystem (Castello et al., 2015). On days when the fishermen are looking to sell their catch to the Pompeya market, they may aim to collect as many individuals as possible pertaining to a species that is more highly valued as a food source by patrons of the market. Larger species are typically more desirable, which often includes individuals of reproductive age, potentially reducing the prospective for reproduction of certain populations. This poses a risk to species such as *Hoplias malabaricus* and *Prochilodus nigricans* because both of these species produce relatively larger individuals with a high nutritional value (Vargas, 2017). This threat is illustrated in the comparison of the species list of “desired fish” from 2002 and the species list acquired from this study; those with higher nutritional value are being depleted and are in danger of extinction due to human predation. In addition to the nutritionally valued species being depleted, the extraction of many juvenile fish is concerning for future population abundance. The extraction of multiple juvenile fish prevents them from reaching reproductive maturity, and therefore prevents the individuals from reproducing and propagating the species to maintain abundance.

Contamination due to water pollution also may play a part in the changing biodiversity of Limoncocha Lagoon (Soria Fregoso et al., 2000; Viana & Lucena Frédou, 2014). The Limoncocha Biological Reserve use motors for their larger canoes, adding a source of pollution to the waters. One of the fishermen reported that he saw more diverse and abundant catches before the introduction of these motors (2017).

Overall, Limoncocha Lagoon is still supporting high levels of ichthyofaunal biodiversity. However, the changes in population composition when compared to the census of 2002 may indicate that the populations of the lake are being diminished. Thus, the lagoon should continue to be monitored to determine if the numbers of individuals and species diminish over the course of the next few years. The presence of one of the two bioindicator families described in the 2002 census combined with continually high numbers of individuals caught each morning suggests that the lagoon will continue to be able to provide for the people of Limoncocha, Ecuador. The presence of one or more bioindicator species in an environment can provide insight into the environmental quality and overall biodiversity of an environment. In the case of the absence of such species in Limoncocha Lagoon, it is possible that the lagoon is no longer supporting the high levels of biodiversity and environmental health that it used to support. While it is convenient for the fishermen to be in tuned with the weather and fish population patterns, it poses an increased risk to the ichthyofauna because the fishermen target larger population movements with higher catch success. The conflict between the park guards at the entrance to the lagoon and the fishermen may need to be surpasses and overcome if the populations visibly decrease in order to monitor the extraction of individuals. Currently, the rate of extraction is dangerously close to overfishing for the size of the lagoon, causing the gradual change in trophic and population dynamics.

Future studies

Due to the seasonality of the fish populations within Limoncocha, it is suggested that data are collected for a full year to completely analyze the population development and change over time. Galacatos et al. (2004) found that multiple abiotic factors were significantly influenced by the seasonality of the flood pulse. Such abiotic factors include: dissolved oxygen, temperature, turbidity, and pH. Changes have also been reported in species richness and biodiversity in response to seasonality and flood pulse (Galacatos et al., 2004; Galacatos, Stewart, & Ibarra, 1996; Junk et al., 1989). Sampling fish populations over the course of multiple seasons would also provide sufficient information to track fishing trends over time. A study performed in 2011 showed indications of a lack of fishing pressure on the lower age groups of *P. nigricans* in the lower stretch of the Amazon River (Santana & Freitas, 2013). This proposal is supported in the data of the present study because *P. nigricans* was the most frequent individual in the current study, indicating that the population was allowed to develop and grow during the younger ages of the fish life history. Future studies may be done on tracking specific populations and species of fish for longer periods of time so as to track the developments through all seasons of the year. With more information on the development of different species and populations, the ichthyofaunal relationships and trophic levels could be analyzed to illustrate specific bioindicators (Viana & Lucena Frédou, 2014) and therefore the overall productivity and health of the ecosystem. Future studies should be focused on the seasonality of fish populations over time in order to fully analyze the effects of sustenance fishing on biodiversity and species richness of the floodplain system in the Ecuadorian Amazon.

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REFERENCES

Albert, J. S., Carvalho, T. P., Petry, P., Holder, M. A., Maxime, E. L., Espino, J., … Reis, R. E. (2011). Aquatic biodiversity in the Amazon: Habitat specialization and geographic isolation promote species richness. *Animals*, *1*(2), 205–241. https://doi.org/10.3390/ani1020205

Barros, D. F., Albernaz, a L. M., Zuanon, J., Espírito Santo, H. M. V, Mendonça, F. P., & Galuch, V. (2013). Effects of isolation and environmental variables on fish community structure in the Brazilian Amazon Madeira-Purus interfluve. *Brazilian Journal of Biology*, *73*(3), 491–499. https://doi.org/10.1590/S1519-69842013000300005

Carvalho, F., Power, M., Forsberg, B. R., Castello, L., Martins, E. G., & Freitas, C. E. C. (2017). Trophic Ecology of *Arapaima* sp. in a ria lake-river-floodplain transition zone of the Amazon. *Ecology of Freshwater Fish*, (January), 1–10. https://doi.org/10.1111/eff.12341

Castello, L., Arantes, C. C., Mcgrath, D. G., Stewart, D. J., & De Sousa, F. S. (2015). Understanding fishing-induced extinctions in the Amazon. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *25*(5), 447–458. https://doi.org/10.1002/aqc.2491

Chu, C., Minns, C. K., Lester, N. P., Mandrak, N. E., & Rosenfeld, J. (2015). An updated assessment of human activities, the environment, and freshwater fish biodiversity in Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, *72*(1), 135–148. https://doi.org/10.1139/cjfas-2013-0609

Costa, I. D., & Freitas, C. E. D. C. (2013). Trophic ecology of the ichthyofauna of a stretch of the Urucu River (Coari , Amazonas , Brazil), *25*(1), 54–67.

Costa, I. D., & Freitas, C. E. de C. (2015). Factors determining the structure of fish assemblages in an Amazonian river near to oil and gas exploration areas in the Amazon basin (Brazil): establishing the baseline for environmental evaluation. *Zoologia (Curitiba)*, *32*(5), 351–359. https://doi.org/10.1590/S1984-46702015000500004

Eid, E. M., Galal, T. M., Dakhil, M. A., & Hassan, L. M. (2016). Modeling the growth dynamics of Pistia stratiotes L. populations along the water courses of south Nile Delta, Egypt. *Rendiconti Lincei*, *27*(2), 375–382. https://doi.org/10.1007/s12210-015-0492-4

Freitas, C. E. C., Siqueira-Souza, F. K., Florentino, a. C., & Hurd, L. E. (2014). The importance of spatial scales to analysis of fish diversity in Amazonian floodplain lakes and implications for conservation. *Ecology of Freshwater Fish*, *23*(Wilsey 2010), 470–477. https://doi.org/10.1111/eff.12099

Freitas, T. M. S., Prudente, B. S., Fontoura, N. F., & Montag, L. F. A. (2014). Length-weight relationships of dominant fish species from Caxiuanã National Forest, Eastern Amazon, Brazil. *Journal of Applied Icthyology*, *30*, 1–3. https://doi.org/10.1111/jai.12436

Galacatos, K., Barriga-Salazar, R., & Stewart, D. J. (2004). Seasonal and habitat influences on fish communities within the lower Yasuni River basin of the Ecuadorian Amazon. *Environmental Biology of Fishes*, *71*(1), 33–51. https://doi.org/10.1023/B:EBFI.0000043156.69324.94

Galacatos, K., Stewart, D. J., & Ibarra, M. (1996). Fish Community Patterns of Lagoons and Associated Tributaries in the Ecuadorian Amazon. *Copeia*, *1996*(4), 875–894. https://doi.org/10.2307/1447650

Garcez Costa Sousa, R., & De Carvalho Freitas, C. E. (2011). Seasonal catch distribution of tambaqui (Colossoma macropomum), Characidae in a central Amazon floodplain lake: Implications for sustainable fisheries management. *Journal of Applied Ichthyology*, *27*(1), 118–121. https://doi.org/10.1111/j.1439-0426.2010.01521.x

Górski, K., Buijse, A. D., Winter, H. V., De Leeuw, J. J., Compton, T. J., Vekhov, D. A., … Nagelkerke, L. A. J. (2013). Geomorphology and flooding shape fish distribution in a large-scale temperate flood plain. *River Research and Applications*, *29*(10), 1226–1236. https://doi.org/10.1002/rra.2610

Grabowski, R.C.; Gurnell, A. M. (2016). Hydrogeomorphology- Ecology Interactions in River Systems. *River Research and Applications*, *22*(March 2014), 1085–1095. https://doi.org/10.1002/rra

Granado-Lorencio, C., Cerviá, J. L., & Lima, C. R. M. A. (2007). Floodplain lake fish assemblages in the Amazon River: Directions in conservation biology. *Biodiversity and Conservation*, *16*(3), 679–692. https://doi.org/10.1007/s10531-005-3742-4

Guerreiro, A., Ladle, R., & Batista, V. (2016). Riverine fishers' knowledge of extreme climatic events in the Brazilian Amazonia. *Journal of Ethnobiology and Ethnomedicine*, in press. https://doi.org/10.1186/s13002-016-0123-x

Jost, L. (2007). Partitioning diversity into independent alpha and beta components. *Ecology*, *88*(10), 2427–2439. https://doi.org/10.1890/06-1736.1

Junk, W. J., Bayley, P. B., & Sparks, R. E. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences*. https://doi.org/10.1371/journal.pone.0028909

Junk, W. J., & Wantzen, K. M. (2002). The flood pulse concept: new aspects, approaches and applications-an update. In *The Second International Symposium on the Management of Large Rivers for Fisheries* (Vol. 2, pp. 117–140).

Martelo, J., Lorenzen, K., Crossa, M., & Mcgrath, D. G. (2008). Habitat associations of exploited fish species in the Lower Amazon river-floodplain system. *Freshwater Biology*, *53*(12), 2455–2464. https://doi.org/10.1111/j.1365-2427.2008.02065.x

Mortillaro, J. M., Pouilly, M., Wach, M., Freitas, C. E. C., Abril, G., & Meziane, T. (2015). Trophic opportunism of central Amazon floodplain fish. *Freshwater Biology*, *60*(8), 1659–1670. https://doi.org/10.1111/fwb.12598

Osorio, D., Terborgh, J., Alvarez, A., Ortega, H., Quispe, R., Chipollini, V., & Davenport, L. C. (2011). Lateral migration of fish between an oxbow lake and an Amazonian headwater river. *Ecology of Freshwater Fish*, *20*(4), 619–627. https://doi.org/10.1111/j.1600-0633.2011.00511.x

Petesse, M. L., Siqueira-Souza, F. K., de Carvalho Freitas, C. E., & Petrere, M. (2016). Selection of reference lakes and adaptation of a fish multimetric index of biotic integrity to six amazon floodplain lakes. *Ecological Engineering*, *97*, 535–544. https://doi.org/10.1016/j.ecoleng.2016.10.046

Petry, P., Bayley, P. B., & Markle, D. F. (2003). Relationships between fish assemblages, macrophytes and environmental gradients in the Amazon River floodplain. *Journal of Fish Biology*, *63*(3), 547–579. https://doi.org/10.1046/j.1095-8649.2003.00169.x

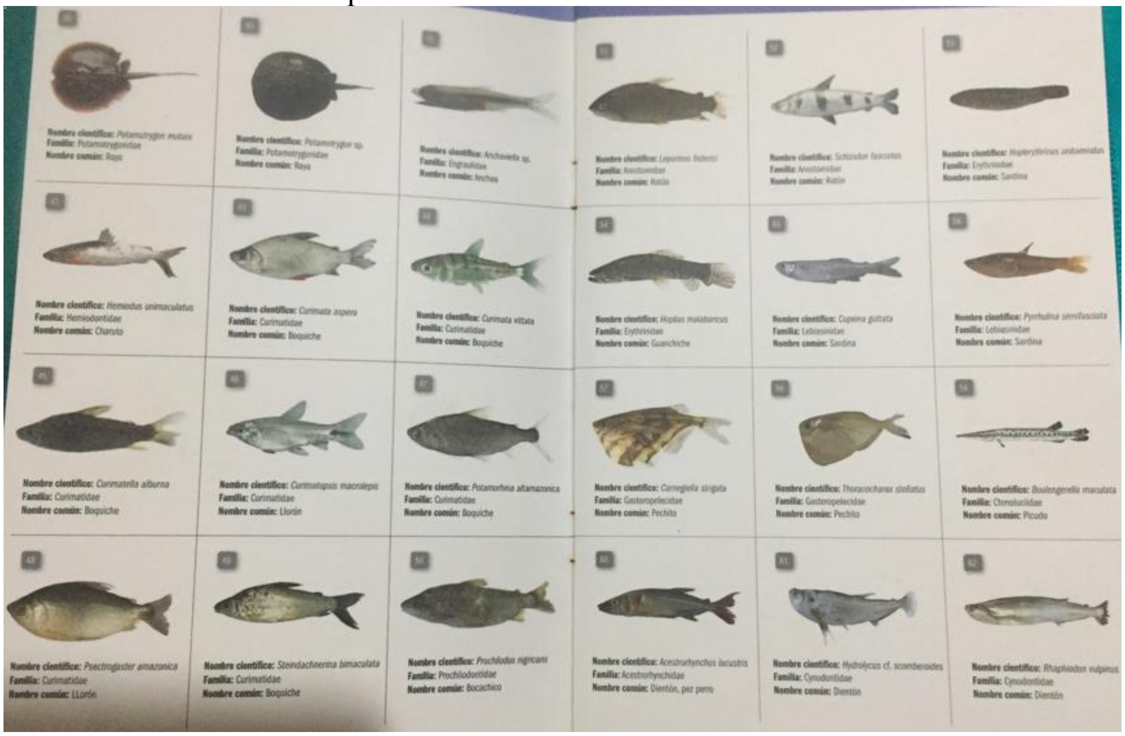
Pinto, M. F., Mourão, J. D. S., & Alves, R. R. N. (2013). Ethnotaxonomical considerations and usage of ichthyofauna in a fishing community in Ceará State, Northeast Brazil. *Journal of Ethnobiology and Ethnomedicine*, *9*, 17. https://doi.org/10.1186/1746-4269-9-17

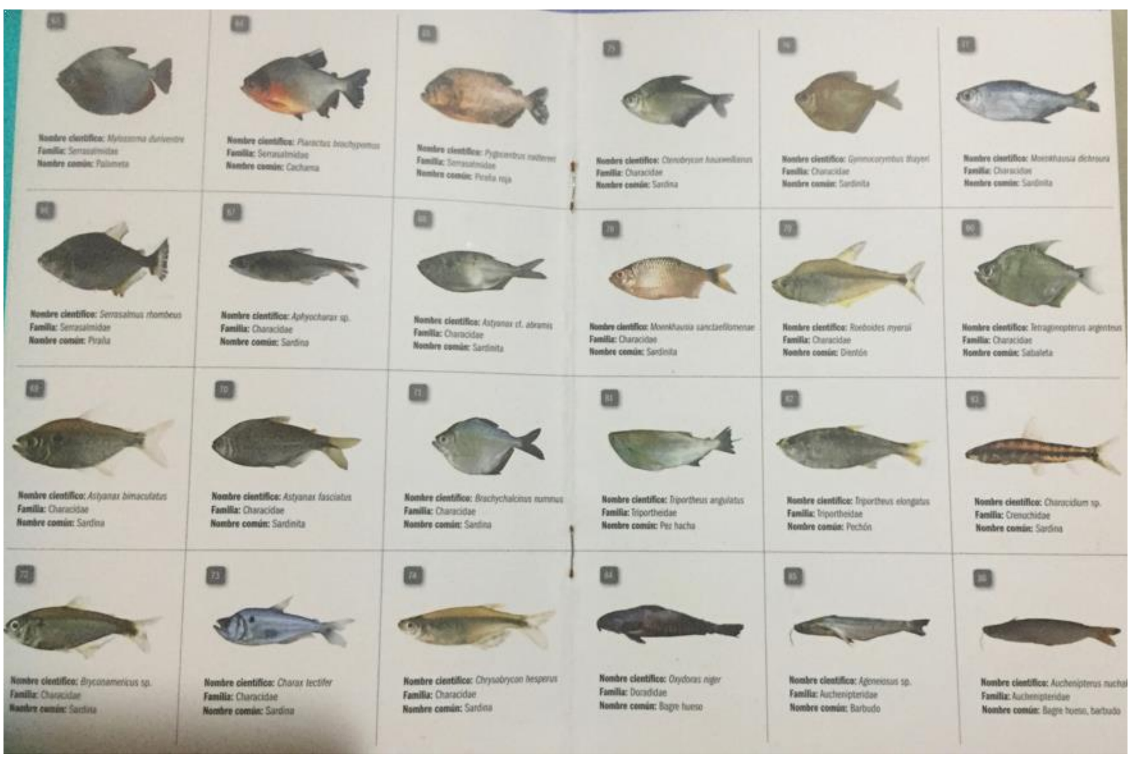
Portocarrero-Aya, M., & Cowx, I. G. (2016). Conservation of freshwater biodiversity in key areas of the Colombian Amazon. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(2), 350–363. https://doi.org/10.1002/aqc.2582

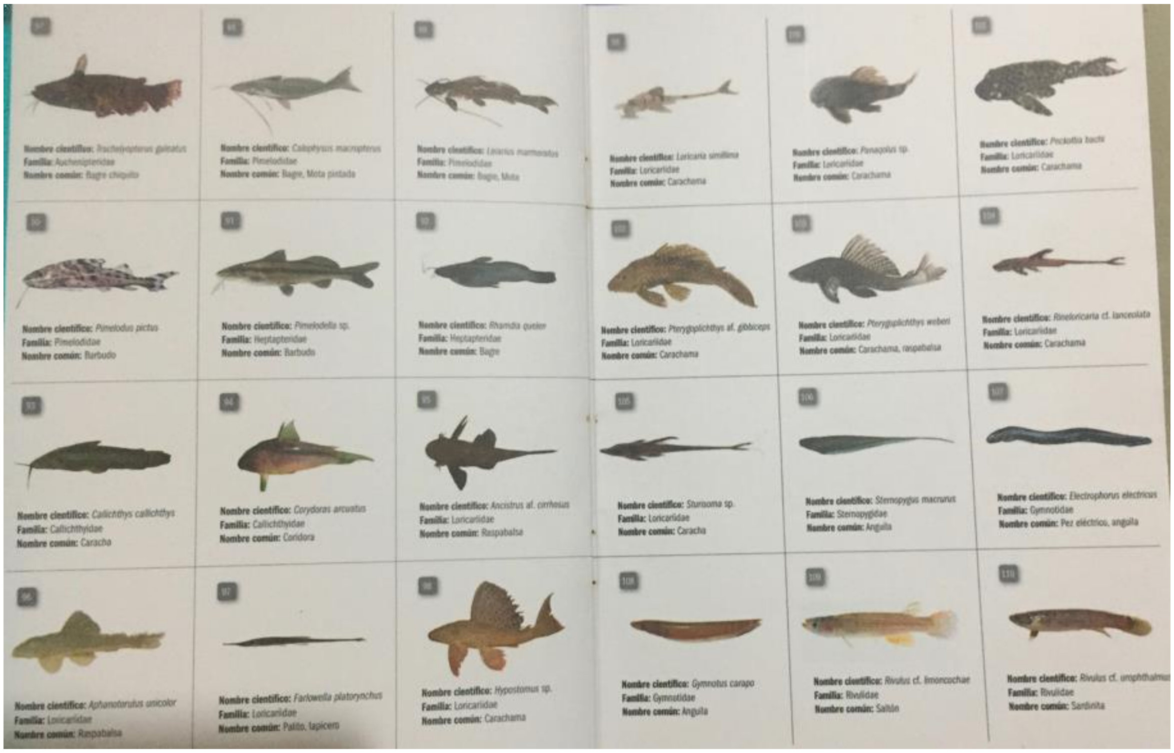
Röpke, C. P., Amadio, S. A., Winemiller, K. O., & Zuanon, J. (2016). Seasonal dynamics of the fish assemblage in a floodplain lake at the confluence of the Negro and Amazon Rivers.

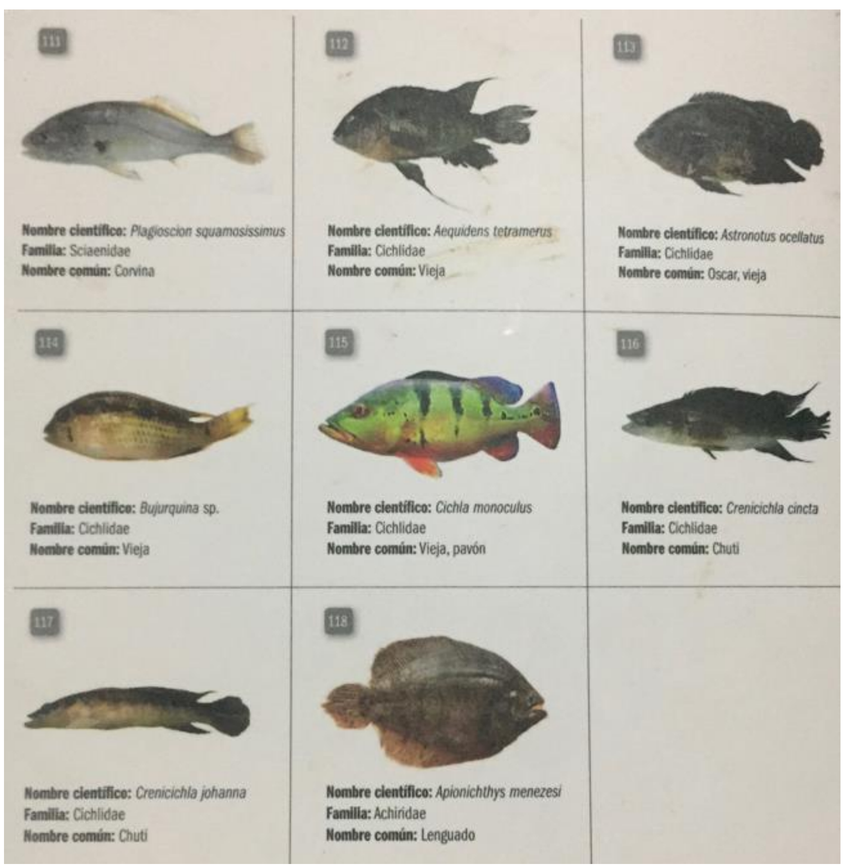
Journal of Fish Biology, *89*(1), 194–212. https://doi.org/10.1111/jfb.12791
Santana, I. F., & Freitas, C. E. C. (2013). A time series analysis of Prochilodus nigricans landings caught by small-scale fisheries in the lower stretch of the Amazon River. *Brazilian Journal of Biology = Revista Brasleira de Biologia*, *73*(1), 53–9. https://doi.org/10.1590/S1519-69842013000100007
Schiesari, L., Zuanon, J., Azevedo-Ramos, C., Garcia, M., Gordo, M., Messias, M., & Monteiro Vieira, E. (2003). Macrophyte rafts as dispersal vectors for fishes and amphibians in the Lower Solimes River, Central Amazon. *Journal of Tropical Ecology*, *19*(3), 333–336. https://doi.org/10.1017/S0266467403003365
Soria Fregoso, M. J., Ferrera Cerato, R., Etchevers Barra, J., Alcántar González, G., Trinidad Santos, J., Borges Gómez, L., & Pereyda Pérez, G. (2000). Produccion De Biofertilizantes Mediante Biodigestion De Excreta Liquida De Cerdo . *Publicado En Terra*, *19*, 1–10.
Sousa, R. G. C., & Freitas, C. E. D. C. (2008). The influence of flood pulse on fish communities of floodplain canals in the Middle Solimões River, Brazil. *Neotropical Ichthyology*, *6*(2), 249–255. https://doi.org/10.1590/S1679-62252008000200013
Stewart, D. J., Ibarra, M., & Barriga-Salazar, R. (2002). Comparison of Deep-River and Adjacent Sandy-Beach Fish Assemblages in the Napo River Basin, Eastern Ecuador. *Copeia*, *2002*(2), 333–343. https://doi.org/10.1643/0045-8511(2002)002[0333:CODRAA]2.0.CO;2
Suçuarana, M. D. S., Virgílio, L. R., & Vieira, L. J. S. (2016). Trophic structure of fish assemblages associated with macrophytes in lakes of an abandoned meander on the middle river Purus, brazilian Amazon. *Acta Scientiarum. Biological Sciences*, *38*(1), 37. https://doi.org/10.4025/actascibiolsci.v38i1.28973
Viana, A. P., & Lucena Frédou, F. (2014). Ichthyofauna as bioindicator of environmental quality in an industrial district in the amazon estuary, Brazil. *Brazilian Journal of Biology*, *74*(2), 315–324. https://doi.org/dx.doi.org/10.1590/1519-6984.16012
Yamamoto, K. C., Soares, M. G. M., & Freitas, C. E. D. C. (2004). Alimentação de Triportheus angulatus (Spix & Agassiz, 1829) no lago Camaleão, Manaus, AM, Brasil. *Acta Amazonica*, *34*(4), 653–659. https://doi.org/10.1590/S0044-59672004000400017

APPENDIX A – Identification plates.






Nombre científico: Trachelyopterus galeatus
Familia: Auchenipteridae
Nombre común: Bagre chiquito
Nombre científico: Calophysus macropterus
Familia: Pimelodidae
Nombre común: Bagre, Mota pintada
Nombre científico: Leiarius marmoratus
Familia: Pimelodidae
Nombre común: Bagre, Mota
Nombre científico: Pimelodus pictus
Familia: Pimelodidae
Nombre común: Barbudo
Nombre científico: Pimelodella sp.
Familia: Heptapteridae
Nombre común: Barbudo
Nombre científico: Rhamdia quelen
Familia: Heptapteridae
Nombre común: Bagre
Nombre científico: Callichthys callichthys
Familia: Callichthyidae
Nombre común: Caracha
Nombre científico: Corydoras arcuatus
Familia: Callichthyidae
Nombre común: Coridora
Nombre científico: Ancistrus af. cirrhosus
Familia: Loricariidae
Nombre común: Raspabalsa
Nombre científico: Aphanotorulus unicolor
Familia: Loricariidae
Nombre común: Raspabalsa
Nombre científico: Farlowella platorynchus
Familia: Loricariidae
Nombre común: Palito, lapicero
Nombre científico: Hypostomus sp.
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Loricaria simillima
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Panaque sp.
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Peckoltia bachi
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Pterygoplichthys af. gibbiceps
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Pterygoplichthys weberi
Familia: Loricariidae
Nombre común: Carachama, raspabalsa
Nombre científico: Rineloricaria cf. lanceolata
Familia: Loricariidae
Nombre común: Carachama
Nombre científico: Sturisoma sp.
Familia: Loricariidae
Nombre común: Caracha
Nombre científico: Sternopygus macrurus
Familia: Sternopygidae
Nombre común: Anguila
Nombre científico: Electrophorus electricus
Familia: Gymnotidae
Nombre común: Pez eléctrico, anguila
Nombre científico: Gymnotus carapo
Familia: Gymnotidae
Nombre común: Anguila
Nombre científico: Rivulus cf. limoncochae
Familia: Rivulidae
Nombre común: Saltón
Familia: Rivulidae
Nombre común: Sardinita


111
Nombre científico: Plagioscion squamosissimus
Familia: Sciaenidae
Nombre común: Corvina
112
Nombre científico: Aequidens tetramerus
Familia: Cichlidae
Nombre común: Vieja
113
Nombre científico: Astronotus ocellatus
Familia: Cichlidae
Nombre común: Oscar, vieja
114
Nombre científico: Bujurquina sp.
Familia: Cichlidae
Nombre común: Vieja
115
Nombre científico: Cichla monoculus
Familia: Cichlidae
Nombre común: Vieja, pavón
116
Nombre científico: Crenicichla cincta
Familia: Cichlidae
Nombre común: Chuti
117
Nombre científico: Crenicichla johanna
Familia: Cichlidae
Nombre común: Chuti
118
Nombre científico: Apionichthys menezesi
Familia: Achiridae
Nombre común: Lenguado

APPENDIX B – Worksheet provided by Limoncocha Biological Reserve for data collection.

7. Anexo 2

HOJA DE CAMPO PARA MONITOREO PARTICIPATIVO ICTIOFAUNA

HOJA DE CAMPO PARA MONITOREO PARTICIPATIVO ICTIOFAUNA

Laguna / Humedal:
Localidad / Cantón:

Nombre de los pescadores:

Localización (GPS) UTM_X:
UTM_Y:
Artes de pesca usadas: Redes agalleras ☐ Retel ☐
Atarraya ☐ Trasmallo ☐ Línea de anzuelos ☐
Caña de pescar ☐ Otras ☐ ....

Fecha:
Clima: Soleado ☐ Nublado ☐ Lluvioso ☐ Niebla ☐
Hora de inicio:
Hora de finalización:

Especie	Longitud (mm)	Peso (g)	Foto	Juvenil / Adulto	Sexo	Observaciones (ulceraciones, parásitos, heridas,....)

APPENDIX C – Complete species list (23 species) with total number of individuals reported.

Pterygoplichthys weberi	49
Serrasalmus rhombeus	25
Pygocentrus nattereri	76
Steindachnerina bimaculata	98
Prochilodus nigricans	225
Roeboides myersii	21
Potamorhina altamazonica	113
Bujurquina sp.	15
Crenicichla johanna	4
Hoplias malabaricus	49
Mylossoma duriventre	48
Aequidens tetramerus	3
Rhamdia quelen	1
Crenichla cincta	1
Schizodon fasciatum	3
Ctenobrycon hauxwellianus	4
Astyanax bimaculatus	1
Astyanax cf. abramis	1
Hoplerythrinus unitaeniatus	1
Prochilodus lineatus	1
Plagioscion squamosissimus	1
Astronotus ocellatus	2
Potamotrygon sp.	1

APPENDIX D – Complete families list (11 families) with total number of individuals reported.

Loricariidae	49
Serrasalmidae	149
Curimatidae	210
Prochilodontidae	227
Characidae	40
Cichlidae	25
Erythrinidae	50
Heptapteridae	1
Anostomidae	3
Sciaenidae	1
Potamotrygonidae	1

APPENDIX E – Number of individuals of each species, separated by zone.

Species	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Pterygoplichthys weberi	2	5	21	6	8	7
Serrasalmus rhombeus	4	3	1	14	2	1
Pygocentrus nattereri	7	16	15	19	11	8
Steindachnerina bimaculata	4	23	7	64	0	0
Prochilodus nigricans	5	27	25	84	47	40
Roeboides myersii	1	0	12	9	4	7
Potamorhina altamazonica	8	16	11	60	11	6
Bujurquina sp.	0	0	15	0	0	0
Crenicichla johanna	0	2	2	0	0	0
Hoplias malabaricus	0	10	6	17	3	5
Mylossoma duriventre	2	3	8	21	11	3
Aequidens tetramerus	0	0	2	1	0	0
Rhamdia quelen	0	0	0	0	0	1
Crenichla cincta	0	0	1	0	0	0
Schizodon fasciatum	1	0	1	0	1	0
Ctenobrycon hauxwellianus	0	0	1	3	0	0
Astyanax bimaculatus	0	0	0	0	0	0
Astyanax cf. abramis	0	0	1	0	0	0
Hoplerythrinus unitaeniatus	0	0	0	1	0	0
Prochilodus lineatus	0	0	0	0	0	1
Plagioscion squamosissimus	0	0	0	1	0	0
Astronotus ocellatus	0	0	1	1	0	0
Potamotrygon sp.	0	0	0	0	1	0

APPENDIX F – Complete data as recorded in Excel (*available upon request).*