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Evaluation of Recreational Fishing Demand for Billfish Resources in Guatemala

Julie Elizabeth Brown
University of Miami, julie.elizabeth.brown@gmail.com

UNIVERSITY OF MIAMI

EVALUATION OF RECREATIONAL FISHING DEMAND FOR BILLFISH RESOURCES IN GUATEMALA

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Julie Elizabeth Brown

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EVALUATION OF RECREATIONAL FISHING DEMAND FOR BILLFISH RESOURCES IN GUATEMALA

Julie Elizabeth Brown

Approved:

Nelson Ehrhardt, Ph.D. Professor of Marine Ecosystems and Society	Elizabeth Babcock, Ph.D. Professor of Marine Biology and Ecology
David Die, Ph.D. Professor of Marine Ecosystems and Society	David Letson, Ph.D. Professor of Marine Ecosystems and Society
David Carter, Ph.D. Economist National Oceanic and Atmospheric Association, Miami, Florida	Guillermo Prado, Ph.D Dean of the Graduate School

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Bycatch mortality from commercial tuna fisheries threatens billfish populations in the Eastern Pacific Ocean, which are also used for lucrative recreational tourism industries. The recreational billfish fishery in Guatemala is characterized by seasonally high daily sailfish catch rates, consistently 2-3 times higher than anywhere else on Earth, and is entirely catch-and-release. The anglers are predominantly tourists, bringing financial contributions to Guatemala. Until now, Guatemala's government and international tuna management organizations could not consider the value of this sustainable use of billfish resources, because previous estimates were poorly defined and estimated. We used an innovative, market-based technique to estimate the value of Guatemala's recreational fishery, which eliminates the hypothetical bias that has plagued previous estimates of other billfish resources. Based on charter fishing client transactions in 2017, we estimate that the value of the billfish resources in Guatemala is approximately $1 Million when used for catch-and-release fishing. We also identify factors and variables that support the demand for these services. The predominant aspect drawing anglers to fish in Guatemala is their expectation of high daily catch rates; over half of the respondents self-reported that this was their motivation for choosing Guatemala. Anglers explicitly seeking high catch rates

were more satisfied following their fishing trip than those who were motivated by other reasons, despite many over-predicting their success rates. Anglers traveling to Guatemala were also highly experienced; on average, they had been fishing specifically for billfish for 13 years. These factors contribute to our theory that anglers traveling to Guatemala are seeking a unique experience that cannot be expected when fishing elsewhere. We also describe the dynamic environmental conditions supporting the high, seasonal catch rates that draw anglers to Central America. Using tournament Catch Per Unit Effort (CPUE) indices, we found support for the theory that local density and habitat compression affect the recreational catch rates. When the habitat was more compressed, Guatemalan anglers fishing in the yearly tournament saw higher catch rates, indicative of increased fish vulnerability to the surface fishing gear. Here, we suggest that catchability is indicative of very localized conditions, and cannot be applied stock-wide. Our evidence suggests that high seasonal catch rates (in recreational tournaments or for-hire fishing) sampled from a peripheral, small portion of the entire stock distribution should not be interpreted as indicators of sailfish abundance. Instead, these catch rates should be viewed as the foundation of valuable tourism industries, and be preserved as such.

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Chapter 1

Introduction

Indo-Pacific sailfish (*Istiophorus platypterus*) and blue marlin (*Makaira mazara*) belong to the billfish family *Istiophoridae.* Billfish are found in all of the world's oceans, and they are highly migratory, passing through several nations' Exclusive Economic Zone boundaries yearly. Catching these large, apex predators is the ultimate prize for many marine anglers, some of whom seek to preserve the stocks for future recreational opportunities. Billfish (and other highly migratory species) are vulnerable as bycatch in lucrative commercial tuna fishing operations (Hall 2013), and are likely experiencing fishing mortality beyond that which is considered sustainable. Billfish harvested mainly as bycatch have little economic value; therefore there is no motivation for the commercial tuna fishing industry to conserve the species. The management of these species in the Eastern Pacific Ocean (EPO), under the authority of the Inter-American Tropical Tuna Commission (IATTC), is contentious due to this conflict and the need to integrate multiple spatial management jurisdictions.

1.1 Commercial Exploitation of Billfish

Although billfish are not the target species, they are a significant portion of the catch in commercial tuna fishing operations (Figure 1.1), which are drawn to the Eastern Pacific Ocean's productive ecosystem. Billfish are either discarded or retained, but practically none are released alive (IATTC 2017). Thus, the commercial exploitation of the large migratory pelagic resources is closely tied to the availability of billfish for other users. The major tuna fleets occupying the Eastern Pacific Ocean (EPO) use purse seine and longline gear, although much smaller artisanal fleets using hook and line, gillnets, and other fishing methods are located near the coast.

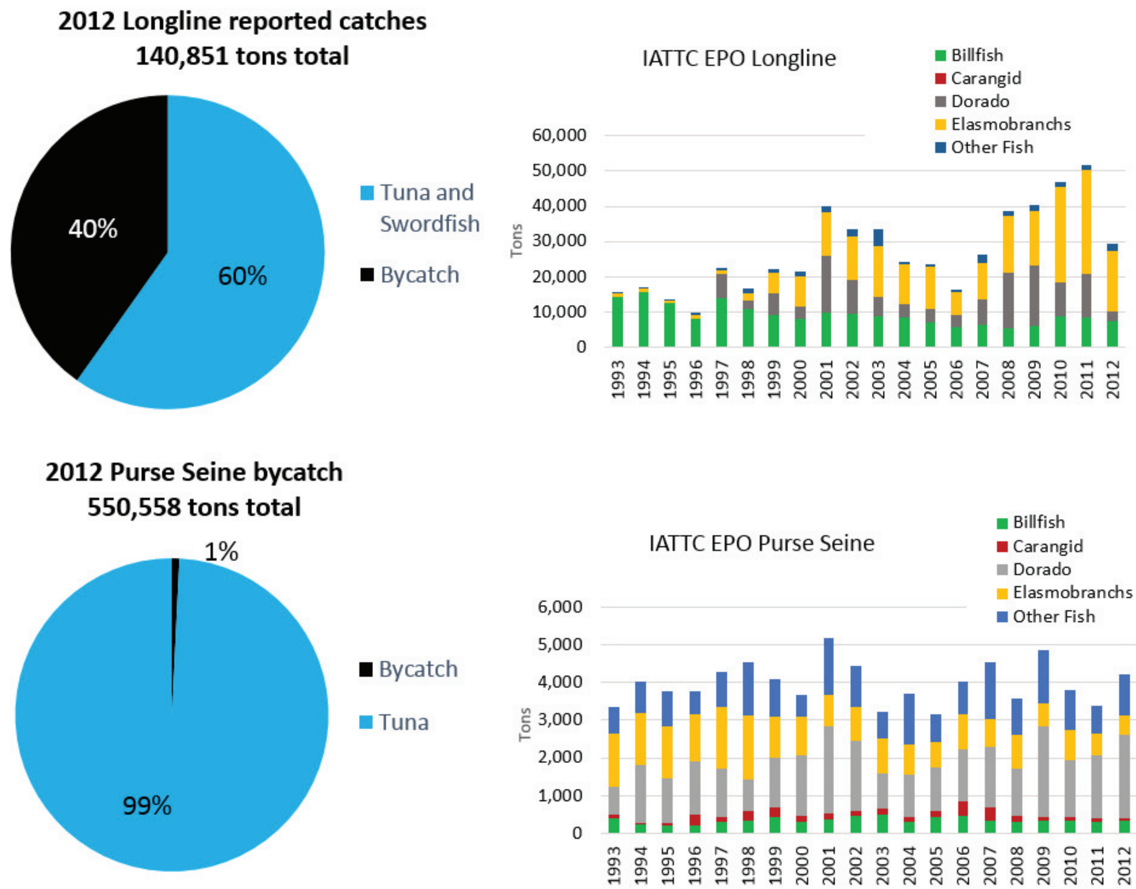

Figure 1.1. Bycatch in the longline (top) and purse seine (bottom) fleets operating in the Eastern Pacific Ocean as reported by IATTC (www.iattc.org/CatchReportsDataENG.htm). Longline estimates are extrapolated from the portion of fleet covered by observers, and has significant uncertainty due to low reporting. Artisanal longline removals are unknown and unrepresented here. Reports by species category ceased to be published after 2012.

Traditional tuna purse seine fishing typically captures very few billfish (Figure 1.1 and 1.3), however, tuna purse seine operations using modern satellite-linked fish aggregating devices, or FADs, capture a significantly higher proportion of bycatch species (Escalle et al. 2019; Lezama-Ochoa et al. 2017; Leroy et al. 2012), like billfish. FAD fishing has the potential to remove 2-3 times more biomass than unassociated or dolphin sets of tuna purse seining (Gerrodette et al. 2012). While the number of dolphin and unassociated tuna purse seine sets in the EPO have remained relatively stable since 2010, the number of FAD sets has steadily increased (Figure 1. 2), raising concerns about the fishing mortality for billfish and other bycatch species.

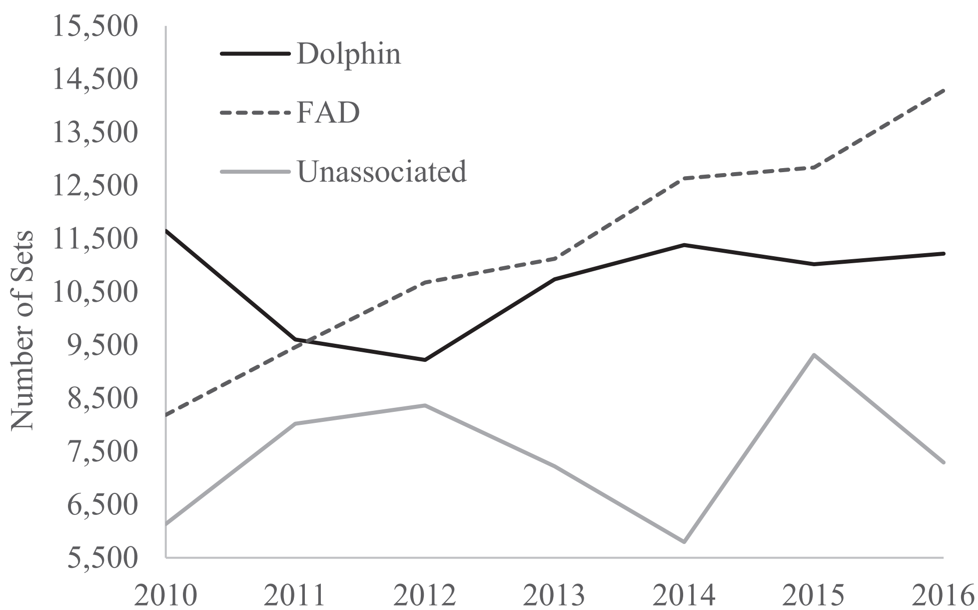

Figure 1.2. Trends in the intensity of Purse Seine fishing by set type. Data from IATTC (www.iattc.org/CatchReportsDataENG.htm).

Modern tuna purse seine fleets are capable of encircling a fish school to depths in the EPO that are well below most species' oxygen minimum threshold, preventing any chance of escape (Hall 2013). Due to conservation concerns for tuna fishing bycatch species, Costa Rica has banned international purse seine operations from the first 45 nautical miles of its Exclusive Economic Zone. Figure 1.3 shows the country's EEZ boundary and the billfish removals (sailfish and marlin) from the most recent year available, 2016. The effectiveness of this gear closure in preventing billfish declines is unknown, because the longline industry, which has higher bycatch than traditional or FAD purse seine fishing (Figure 1.4), is still allowed in the coastal areas.

Longline fishing is the other major commercial fishing method in the region that targets tuna, and has large effects on billfish populations through bycatch. The EPO was fully covered spatially by the Japanese longline fleet operations by the mid 1960's (Suzuki, Tomlinson et al. 1978). Due to the passive nature of this method, the non-target fish/sharks/turtles/seabirds are left hooked on the lines potentially for several hours (soak time), making post-release survival unlikely for many species.

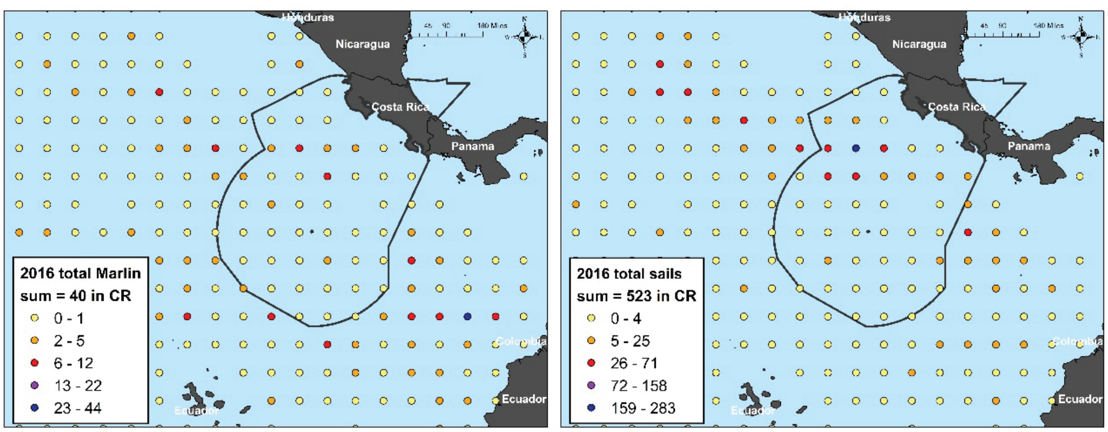

Figure 1.3. Sailfish and Marlin (all species) removals (tons) from the commercial purse seine fleet in 2016 in Costa Rica (EEZ outlined). Data from IATTC (www.iattc.org/CatchReportsDataENG.htm).

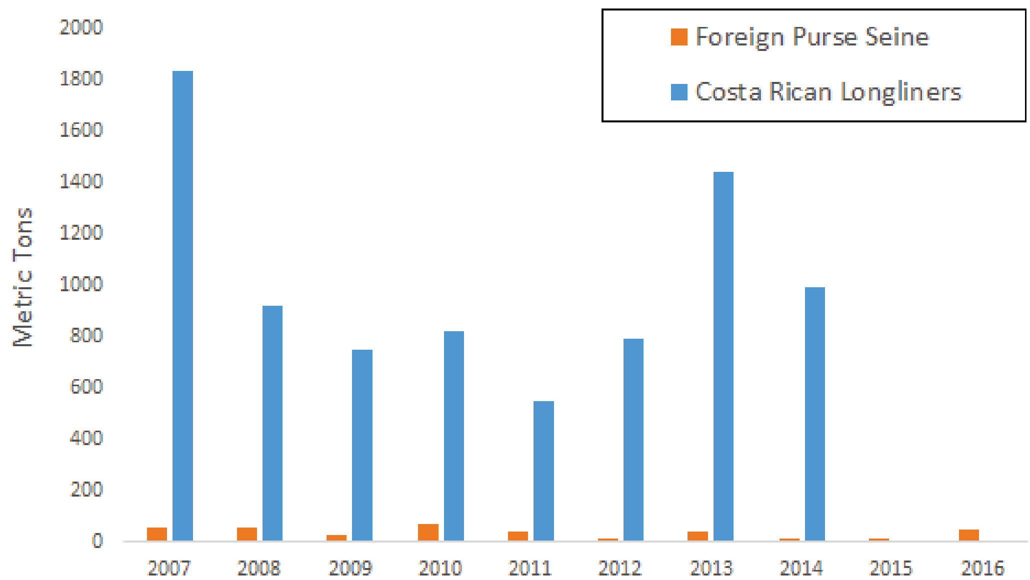

Figure 1.4. Metric tons of billfish (sailfish and marlin) removals from the purse seine and longline industries in Costa Rica for 10 consecutive years. The purse seine ban became effective starting in 2014. Data from IATTC (www.iattc.org/CatchReportsDataENG.htm). Tonnage calculated using conversion factors (Appendix A). Longline removals are estimated from Costa Rica's artisanal fleet (unpublished data sent via anonymous communication from employee at OSPESCA). 2015 and 2016 were unavailable for longline removals.

In 2013, IATTC Resolution C-11-08 requires at least 5% of the fishing effort by each Member's longline vessels greater than 20 m in length to be monitored by scientific observers. Figure 1.5 shows the total estimated effort (in millions of hooks deployed) to the IATTC, by year. These estimations, however, are far from accurate (IATTC 2017), as the sample only includes the largest industrial longline vessels operating on the high seas. The magnitude of fishing effort or catch from the artisanal coastal longline fleets is largely undocumented and unaccounted for by the IATTC estimate.

Figure 1.5. Longline effort (Millions of hooks per year) reported to the IATTC in the EPO (www.iattc.org/CatchReportsDataENG.htm).

1.2 Billfish Mortality Trends

Because the proportion of bycatch in the longline industry is a large portion of the total mortality (significantly higher than the purse seine industry (Figure 1.4 and 1.6)), the longline bycatch mortality that is unaccounted for hinders the IATTC's ability to conduct accurate abundance and fishing mortality assessments for those species (Hinton and Maunder, 2014). Additionally, within the observer data, there is considerable billfish species misidentification, which has injected further uncertainty into stock assessments (Williams et al. 2018). Despite the high uncertainty in IATTC assessments, there is evidence that the abundance of some Indo-Pacific billfish species is declining below an ecologically acceptable level (Kapur et al. 2017; Pons et al. 2017).

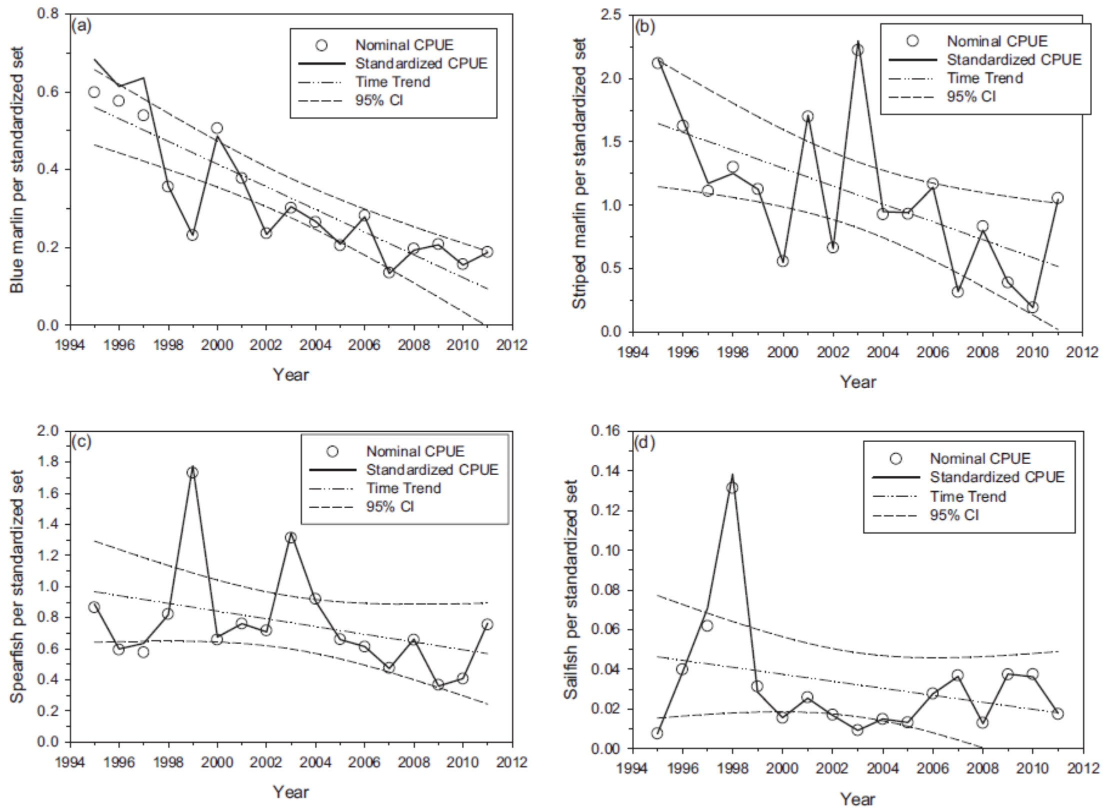

Figure 1.6 CPUE trends for (a) blue marlin, (b) striped marlin, (c) spearfish and (d) sailfish populations from the Hawaiian Longline fishery. NOAA observer data. From Walsh and Brodziak 2015.

Nominal and standardized billfish catch per unit effort (CPUE), or indices of true relative abundance are declining in the region (Figure 1.6 and 1.7), indicating either increases in fishing mortality (F), or persistent sub-optimal recruitment. The most recent IATTC assessment of blue marlin (ISC 2013), which includes data up to 2011, shows that the stock is fully exploited, and preliminary data from more recent years suggests that fishing mortality rates are in fact exceeding that which permits Maximum Sustainable Yield (MSY). The 2013 sailfish assessment failed to reach a conclusion; however, CPUE trends from the two selected fisheries are mostly trending down (Figure 1.7) from the 1990s (IATTC, 2013). The committee reiterates that there are significant unreported catches hindering the stock assessment modeling process. An alternative data source, trophy records from the International Gamefish Association (IGFA), also suggests that the sailfish populations are experiencing depletion. The number of registered trophy size sailfish from this region has decreased by 64% since 1970, despite increased recreational fishing effort (Ehrhardt and Fitchett 2006), most likely due to a depletion of adults in the population (Figure 1.8).

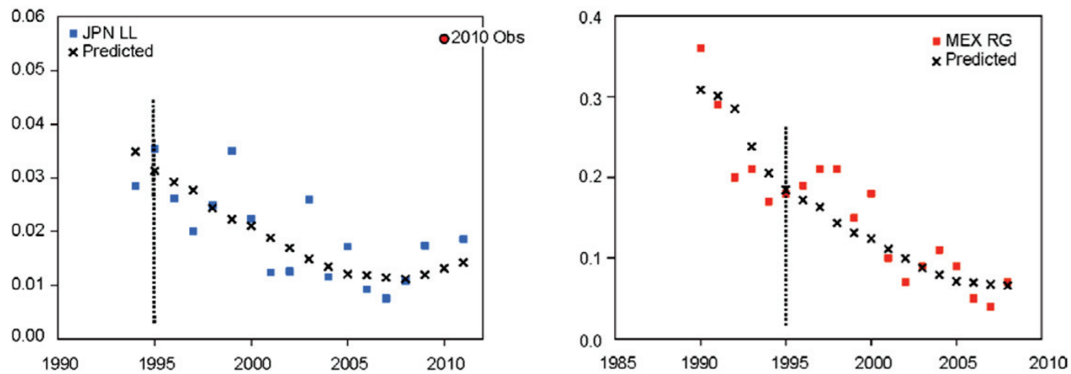

Figure 1.7. Observed and predicted trends in sailfish CPUE from two fisheries in the region (Japanese longline and Mexican recreational fisheries). (IATTC Document 92-04a).

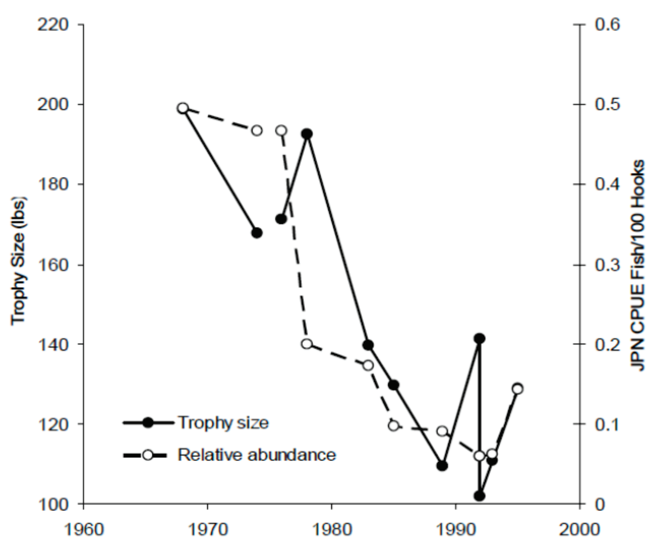

Figure 1.8. Sailfish IGFA trophy records mirror the trends in other regional abundance indices. From Ehrhardt and Fitchett 2006.

1.3 Fisheries Management Organizations

Due to the highly migratory nature of billfish, effective management of these resources requires multi-national cooperation. Historically, IATTC management has minimally included the needs of recreational resource users. Now, the industry has a growing voice in regional politics, and is influencing the legal framework for fisheries management. The needs of these stakeholders are increasingly receiving attention in their local governments, however, funding for the research necessary to support these needs are currently lacking.

In the EPO, complex geographical marine jurisdictions are often unpatrolled where the international tuna fleets operate, and logistics and funding for fisheries enforcement are lacking. Guatemala, Costa Rica, and other countries in the region are signatories to the Inter-American Tropical Tuna Commission (IATTC), committing to manage the highly migratory species by following recommendations from the Commission. The IATTC, created in 1949, has a goal of maintaining populations of tuna and tuna-like species at levels permitting MSY in the EPO. Currently, the IATTC focuses most of its resources on management of target species like tuna and swordfish (*Xiphias gladius*), while marlins and sailfish receive less attention from the Commission and thus less research effort.

Central American countries' HMS fisheries also fall under the regional jurisdiction of OSPESCA (The Organization for Fisheries and Aquaculture in the Central American Isthmus), an international advisory body, which aims to "encourage the development and the coordinated management of regional fisheries and aquaculture activities" (according to the Food and Agriculture Organization of the United Nations). Its members include Belize, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, and

Panama. The extent of their combined Exclusive Economic Zones (EEZ) in Central America are shown in Figure 1.9. OSPESCA has binding resolutions pertaining to sea turtles, whale sharks, shrimp, sharks and lobster, but nothing specifically regulating tuna or tuna-like species.

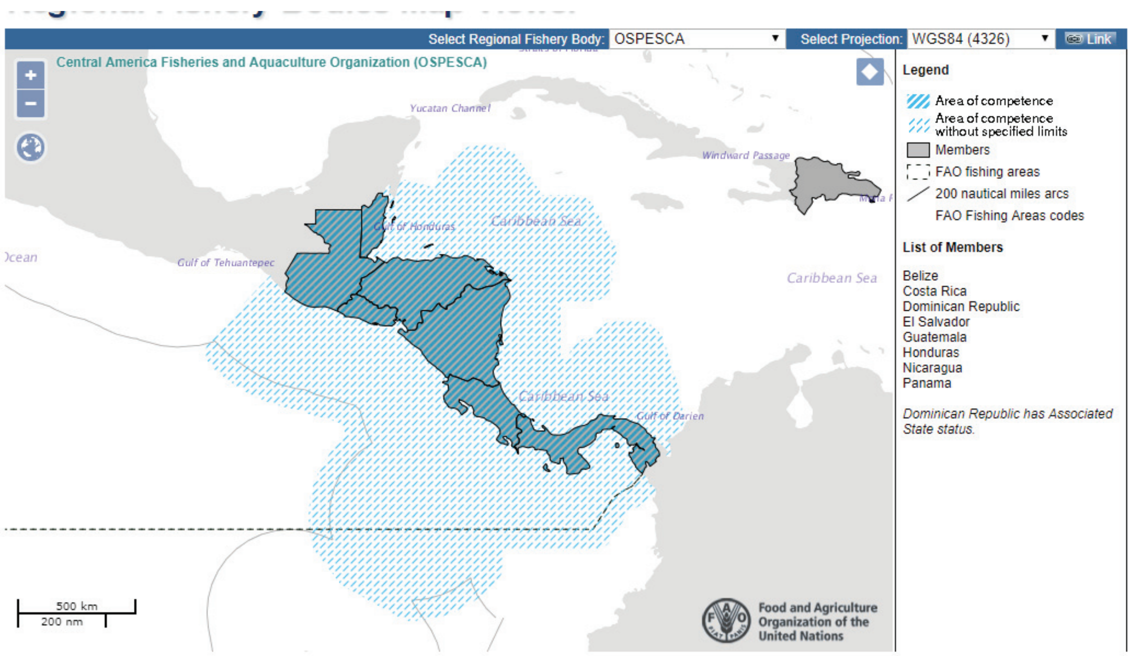

Figure 1.9 Countries and their EEZs participating in OSPESCA

At the national level, fishery management in Guatemala falls under the Fisheries and Aquaculture Management Unit (UNIPESCA). UNIPESCA has the general objective to establish the guidelines that achieve the sustainable and responsible development of national fisheries and aquaculture, has the power to grant fishing permits/licenses, and maintains and evaluates official fishery statistics for the country. In Costa Rica, the national body for fisheries regulation and enforcement is the Costa Rican Institute for Fisheries and Aquaculture (Instituto Costarricense de Pesca y Acuacultura, INCOPESCA), under the Ministry of Agriculture. The Institute is similarly responsible for the coordination, promotion and development of the fisheries and aquaculture sectors. In Panama, the Aquatic Resources Authority of Panama (ARAP) was created to unify responsibilities for coastal and marine resources, fisheries, and aquaculture. For all countries, regulation of offshore pelagic fisheries typically defaults to recommendations provided by OSPESCA and IATTC.

At present, there is virtually no large scale purse seine vessels fishing (Figure 1.10) in the Guatemalan EEZ, however, billfish are highly migratory and they are vulnerable to purse seine and longline effort elsewhere in the Pacific Ocean. The country also has an artisanal longline fleet, the precise magnitude of which is unknown. In 2014, Guatemala became the first country to create an inter-institutional commission for the specific protection of sailfish. The main objective of Governmental Agreement 183-2014 is to "promote the socioeconomic development of the coastal region in the Pacific Coast of Guatemala through sport fishing tourism for sailfish in a sustainable manner." The Sailfish Commission was created at the behest of the recreational industry, to enforce the existing legal regulations (Decree 114-97 and Decree 80-2002), which prohibits the commercial harvest, landings, and sale of sailfish. Sailfish have been and are presently harvested frequently (Ehrhardt and Fitchett, 2006) in artisanal longline fishing operations.

1.4 Billfish Sport Fisheries in the Eastern Pacific Ocean

The marine resources off the Pacific coast of Central America also support several tourism operations, and these stakeholders have interest in the management and conservation of billfish populations. The three major Pacific billfish sport fishing destinations in Central America are Costa Rica, Panama, and Guatemala. Through our research we estimated the number of tournament boat days for each several locations, which is a good approximation of the relative popularity of fishing locations (Figure 1.10), excluding Panama. In Costa Rica, marinas for recreational fishing extend along the entire coast from Guanacaste-Flamingo, the coast of Golfito, to near the border with Panama. The largest operations, estimated to serve more than 400 vessels, occur near the localities of Jaco and Quepos (Fitchett 2015). Panama also has a thriving sport fishing industry, with over 200 vessels associated to numerous hotels and fishing lodges along the coast (Fitchett 2015). Guatemala, conversely, has a much smaller fleet, and sport fishing is limited to one location: Puerto San Jose. Fitchett (2015) estimates a maximum of 38 charter sport fishing vessels actively using this port. The fleets have likely grown in the time since these estimates were collated.

Recreational fishing for billfish is the primary tourist activity for Puerto San Jose in Guatemala, making it a unique location for studying billfish resources. There are no other billfish charter fishing locations on Guatemala's Pacific Coast. Sailfish are the predominant species caught in this fishery, however marlin (mostly blue marlin) are sometimes caught as well. Yellowfin tuna (*Thunnus albacares*) and Dorado (*Coryphaena hippurus*) are also present, but not typically targeted unless customers are satiated with catching billfish, which is rare. Charter boats operating out of the Marina Pez Vela in Guatemala attract tourists seeking the highest catch rates for sailfish in the world (Figure 1.11). According to industry marketing materials, more anglers who had previously frequented Costa Rica and Panama are increasingly making Guatemala their primary fishing destination (pacificfins.com.gt).

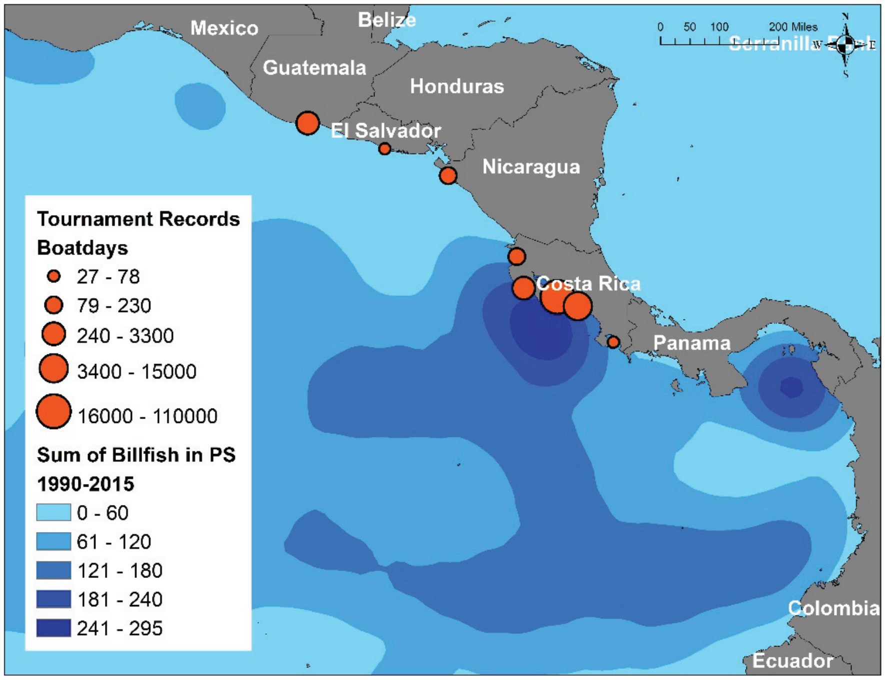

Figure 1.10. The number of total tournament boat days for several locations along the Pacific Coast of Central America. Also shown is an interpolated distribution of billfish removals from the purse seine fleet. Data from IATTC (www.iattc.org/CatchReportsDataENG.htm).

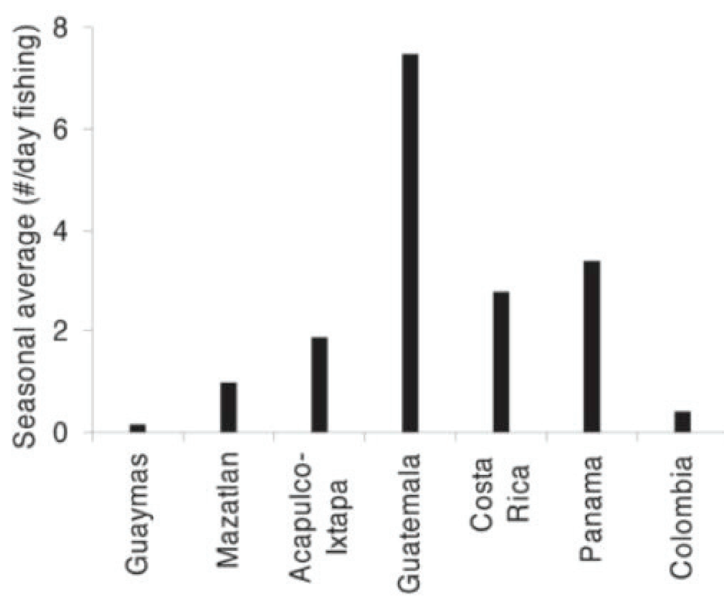

Figure 1.11 Sailfish recreational catch rates in Marina Pez Vela in Guatemala and other popular sport fishing destinations in the region. From Ehrhardt and Fitchett 2006.

1.5 Sustainable Use of Billfish Resources

As worldwide demand for seafood increases and marine resources dwindle, conflicts have arisen over the most efficient use of the shrinking abundance of fish stocks. Stakeholders are becoming increasingly aware of the reality of overfishing, and they are looking for sustainable solutions to continue increasing human wealth and well-being. Increasingly, ecotourism principals are being applied to recreational fisheries like those presently observed in Central America (www.fao.org/fi/oldsite/FCP/en/cri/profile.htm).

By definition (International Union for the Conservation of Nature, The Nature Conservancy, etc.), the ecotourism activities must promote conservation and have low-impact on the natural environment. Many have proposed that catch-and-release sport fishing may serve such a role (Holland et al. 1998; Zwirn et al. 2005; Cisneros-Montemayor and Sumaila 2010). When guided by science and following best practices to minimize at vessel and post release mortality (Brownscombe et al. 2017), catch-and-release fishing can be considered a non-consumptive activity that has minimal impact on fish populations. According to fishing guides and clients we interviewed, most billfish anglers visiting Central America engage in activities that reduce post-release mortality, such as using circle hooks or leaving the fish in the water (Schlenker et al. 2016), even at the expense of having lower catch rates or higher expenses to themselves. The industry also facilitates to scientific studies via in-kind contributions by donating boat time and fishing equipment, although no formal research funding body is available to sustain research in the region.

In addition to having minimal impact (Musyl et al. 2014) on the marine environment when post-release mortality rates are low, catch-and-release sport fishing must meet the economic and social constraints of the ecotourism model, which demands that the activity in question enriches the local community through monetary, educational, or other inputs. One limitation to the Guatemalan billfish fishery in meeting these standards is the fact that much of the transactions and revenue remain in the USA. However, we observe a degree of local spending and employment generated by anglers traveling to catch billfish in Central America, and this arguably qualifies the fishery as ecotourism. Another criticism of the recreational sailfish fishing in Guatemala is that the activity generates inequitable distribution of benefits; the displaced artisanal longline fishermen do not share in the wealth provided by sport fishing, and the fish can no longer be used as a source of food for local consumption (Wood et al. 2013).

Tourists attracted to Central America by billfish, predominantly sailfish, practice exclusively catch-and-release fishing. Such fishing in Costa Rica and Guatemala provide an opportunity to study the role of sport fishing as a driving force in the regional development of ecotourism. These small industries rely almost exclusively on billfish (predominantly sailfish) to attract tourists, and in Central America, catch-and-release is practiced exclusively. Sport fishing stakeholders have collaborated with scientists to provide daily (even hourly) catch statistics and have participated in other scientific endeavors.

1.6 Problem Identification, Purpose, and Objectives

Commercial fishing is the main source of mortality that threatens billfish stocks and the high billfish catch rates that currently support regional recreational fisheries in the tropical areas of the Eastern Pacific Ocean. Some local stakeholders believe the economic value of billfish used in recreational catch-and-release fisheries is high compared to the value of the commercially caught fish in seafood markets, or worse, discarded at sea. However, the economic value of Guatemalan sailfish and marlin resources for recreational fishing is not well-characterized, and therefore cannot be used to support economically efficient management decisions. Billfish conservation and research, which is currently not prioritized at the international level compared to tuna, may be prioritized if this fishery has substantial value. In light of regional population declines, there is an immediate need to estimate the value of these resources to recreational users.

There is also a need to understand the human dimensions that drive anglers to fish for billfish in the EPO off Central America. Understanding the beliefs, motivations, and decision-making process for the anglers who create the demand for this tourism industry is critical to frame studies of the economic value of billfish resources. The aspects of fishing that drives billfish angling in the Eastern Pacific should be identified so that management goals incorporate considerations for all stakeholders.

Lastly, there is a need to consider and understand the role of ecosystem dynamics in creating the conditions necessary for recreational fishing. The seasonality and spatial variability of billfish recreational fishing catch rates is well established, but the underlying environmental mechanisms affecting catchability and habitat use are poorly understood.

Ideally, the physical mechanisms that affect catch rates should be identified and factored in to future management decisions.

The goal of this dissertation is to offer guidance for the sustainable management of billfish fisheries through research on the sport fisheries for billfish in Central America.

Objectives:

1. To estimate seasonal trends in billfish catch rates for tournament and charter fishing in Costa Rica and Guatemala (Chapter 2 and 4).

2. To model habitat characteristics that affect recreational catch rates in the nearshore regions where billfish tournament and charter fishing occurs, which are near the main geographic density of the stocks according to purse seine CPUE (Chapter 2).

3. To characterize billfish recreational users in Guatemala (Chapter 3).

4. To identify factors that contribute to the motivation and satisfaction of anglers who travel to Guatemala for billfish charter fishing (Chapter 3).

5. To quantitatively assess the economic value of Guatemala's sailfish resources using market data provided by lodge managers (Chapter 4).

Chapter 2

Establishing Catchability Regimes for Pacific Sailfish Using Tournament CPUE

2.1 Background

The highly dynamic and seasonal ocean features that characterize the Eastern Pacific Ocean (EPO) off Central America generate areas of high ocean productivity that support important pelagic food webs that include tuna (e.g. yellowfin, *Thunnus albacares*, bigeye, *Thunnis obesus,* and skipjack tuna, *Katsuwanus pelamis)* and billfish. Economically and socially valuable recreational fisheries for these species occur in the region from Panama to Guatemala. Guatemala and Costa Rica have internationally well-known recreational fisheries for sailfish (*Istiophorus platypterus*) and blue marlin (*Makaira mazara*), supported by high catch rates between November – April. The seasonality of billfish fishery resources in the two countries is believed to be directly related to distinct atmospheric and oceanic physical processes. The depth of the thermocline, mixed layer, and dissolved oxygen are tightly associated with each other (Figure 2.1) and correlated with seasonally high catch rates for recreational billfish fisheries. Identifying indices of these seasonal processes may contribute to the understanding of the local catchability component of relative abundance indices for Pacific billfish, indicating the fishing power of the gear used in a specific area at a specific time. Variability in stock abundance is also inherent in the CPUE indices, which is driven by recruitment, survival, and exploitation on a much larger scale. Large-scale environmental mechanisms such as oceanic current regimes are also likely affecting the population abundance through recruitment and survival, which would add to the variability in local CPUE through time. In this chapter, we analyze data to examine sources of observed catch rate variability observed in the recreational fisheries of Guatemala and Costa Rica.

The Eastern Pacific Ocean

The EPO refers broadly to the waters east of 120° W, and between the latitudes 20° N and 15° S. Other authors have defined the region physically: "where the southeast corner of the mean [North] Pacific Gyre does not reach into the large bight between central Mexico and Ecuador" (Kessler 2006). It is bounded in the North and South by the Eastern Boundary currents along the continent, the California and Humboldt currents, respectively. In the 1950s and 1960s, the Scripps Institute of Oceanography initiated comprehensive field studies to describe the physical forces defining this oceanic region. The Scripps researchers, led by Klaus Wyrtki (1975), soon realized that the current patterns and habitat forcing mechanisms such as the thermocline and oxygen minimum boundary are highly dynamic compared to the Central or Western Pacific Ocean. These features follow predictable fluctuations by seasons, corresponding with the strength of the seasonal intercontinental winds crossing from the Gulf of Mexico and the Caribbean Sea into the Pacific Ocean through the low lands (i.e. gap winds) in Mexico (Tehuantepec), Central America (Great Lake of Nicaragua) and the Isthmus of Panama (Panama Canal gap). The winds and resulting Coriolis force cause Ekman transport, which itself causes seasonal upwelling (Ehrhardt and Fitchett, 2006), and biological productivity for marine food webs.

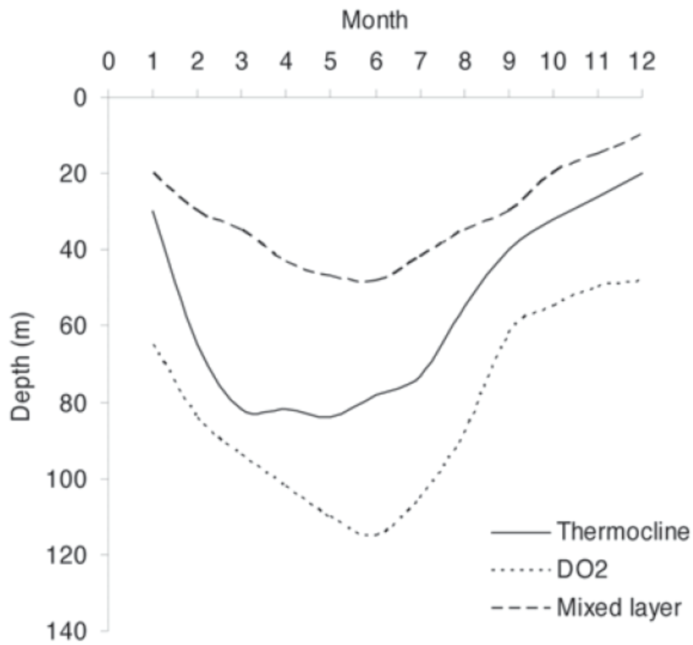

Figure 2.1. Monthly trends in the depth of the thermocline, minimum DO_2 layer (1 ml L-1), and mixed layer, off Guatemala. Figure adapted from NORAD/UNDP/FAO 1988 in Ehrhardt and Fitchett, 2006.

Circulation patterns in the Eastern Pacific Ocean

Atmospheric wind circulation patterns affect all of the major ocean features in the EPO off Central America. The seasonal gap winds, also called the “Nortes”, which blow through low passes in the mountains of Central America, are responsible for the seasonal upwelling along certain areas of the Pacific coast. The gap winds dominate the atmospheric circulation to the east of 110° W (Kessler 2006), relative to the trade wind-dominated region to the west. The winds form when high pressure systems in the Gulf of Mexico force air westward over the continent through gaps in the mountains, and blow over the Gulf of Tehuantepec, the Gulf of Papagayo, and the Gulf of Panama. They are thus named the Tehuantepec Jet (Teh. J.), Papagayo Jet (Pap. J.) and Panama Jet (Pan. J.) (Figure 2.3).

The winds extend at least 500 km over the ocean (Kessler 2006); they are strongest during the Northern Hemisphere winter (Figure 2.2), and push surface waters away from the continent. The wind-generated currents and Coriolis forces generate Ekman transport of deep ocean water to the surface. The deep water replaces the surface water, which has been transported offshore, thus forming seasonal upwelling regions in the EPO off Central America.

Guatemala and Costa Rica have different geographic proximity and position relative to these wind jets and upwelling regions, producing measurably different habitat conditions for fish, despite the two countries' similar location in the EPO. Each wind jet produces two lobes of wind-stress curl to either side of its maxima: negative, anticyclonic curl on the right side, and positive, cyclonic curl on the left side. The wind-stress curl produces Ekman pumping (upwelling or downwelling), and through this mechanism, upwelling occurs to the perpendicular left of each wind jet, and downwelling occurs to the right. Although the coastal waters of Guatemala and Costa Rica are both in a region that is generally described by spatially separated seasonal upwelling, these smaller mechanisms produce highly variable micro-environments for pelagic species.

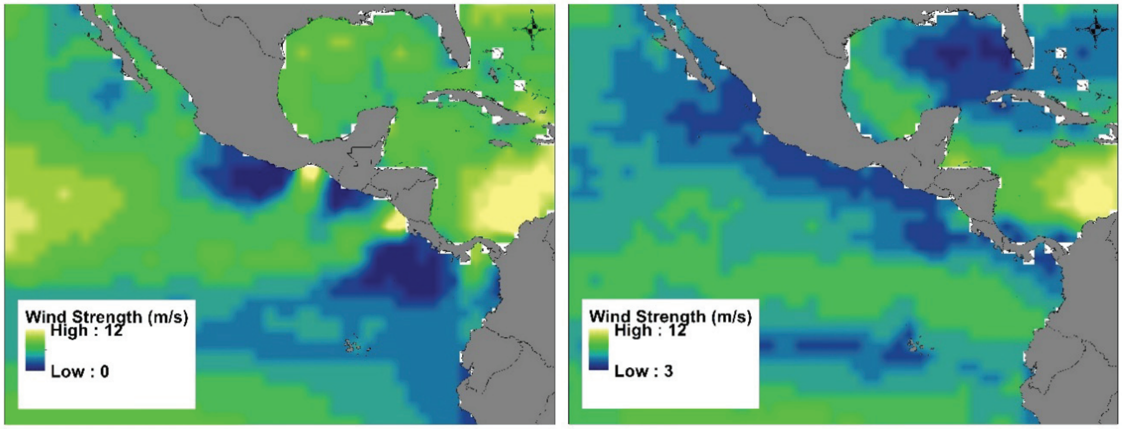

Figure 2.2. Seasonal gap wind strength during January (Left) compared to July (right). 2007 used as an exemplary year. Measurements are meters/second. Monthly averages with wind vector resolution of 25 kilometers, binned on 1 degree grids, NASA QuikSCAT satellite wind data (https://winds.jpl.nasa.gov/missions/quikscat/)

In addition to the semi-permanent upwelling/downwelling, the positive and negative wind-stress curl of the winds produce eddies to either side of the jets. Most eddies in the region are formed by the low-frequency winds and boundary forcing of the gap winds (Reyes-Hernandez et al. 2016). The meso-scale eddies can be long-lived, and can travel thousands of kilometers (Chang et al. 2012).

The size and strength of the eddies are strongest in the Northern Hemisphere summer (Figure 2.3 and 2.4). It has been shown that many species alter their behavior corresponding to the presence of these oceanic features, or seek them out for activities like spawning, or feeding (Pohlot 2019, in review). Cyclonic eddies in particular have been associated with high recreational catches of blue marlin in the areas with strongest fronts and surface thermohaline gradients (Seki et al. 2002), possibly due to temperature preferences or prey availability. Their retention property of convergence zones may also be important for larval transport (Cowen 2002).

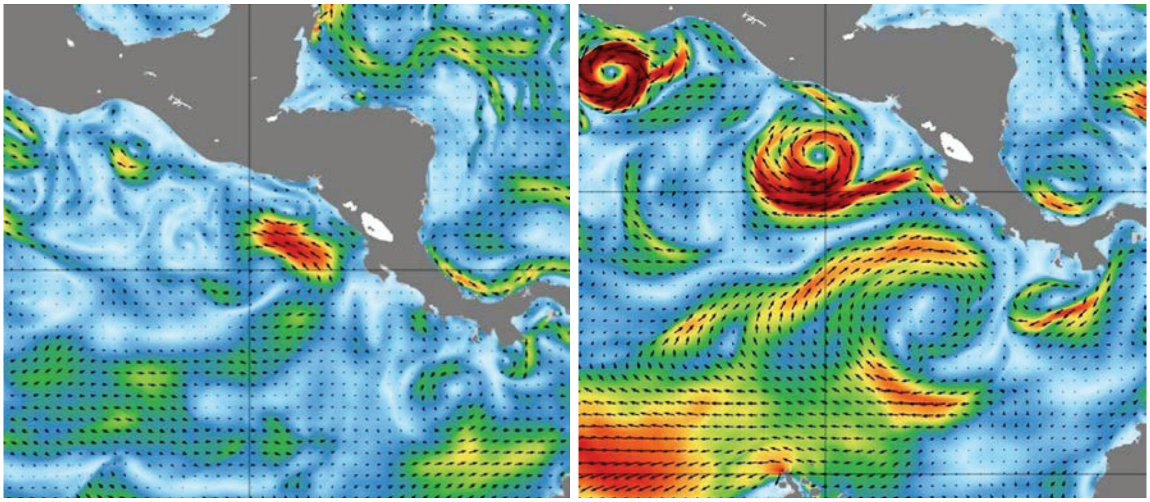

Figure 2.3. Left: eddy environment typical for July. Right: eddy environment typical for Feburary. 2013 is shown as an exemplar year. Sea Surface Height and geostrophic data were collected through AVISO (http://www.aviso.altimetry.fr/) in 0.1 degree resolution.

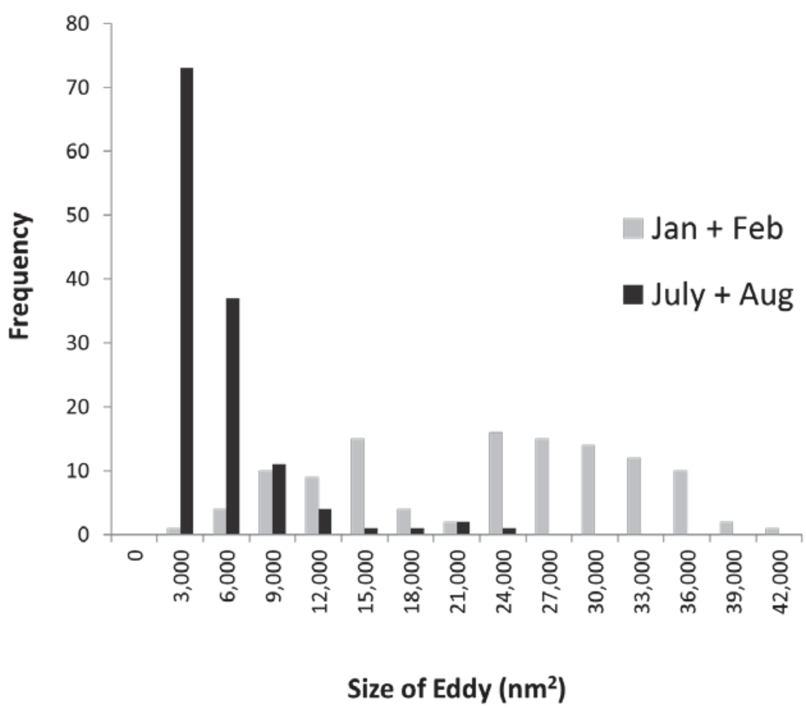

Figure 2.4. The size and frequency of eddies during the northern hemisphere winter and summer months during 2013. Data accessed through AVISO (http://www.aviso.altimetry.fr/)

Currents

In the EPO, ocean currents are similarly driven by the wind (Fiedler and Lavin, 2014). The major boundary currents (Humboldt and California currents) permanently flow along the western continental rim toward the equator (i.e. western boundary currents), and contribute most significantly to the persistent circulation of the equatorial Pacific. To the East of 120° W, however, the Central American sub-continent imposes strong seasonal variability on the winds which force the smaller current systems. The North and South Equatorial Currents (NEC and SEC, respectively), flow to the west (Figure 2.5). In between these equatorial currents, the North Equatorial Counter Current (ECC) flows in the opposite direction, to the east. A strong ECC is associated with increased biological productivity (Dymond and Collier, 1988), which may be beneficial for the pelagic food chain that supports larval billfish. It is a significant feature for many apex predators, such as the tuna-dolphin-seabird assemblages (Ballance et al. 2006). Together, these currents control the magnitude of water flowing away from the continent. The strength and latitude of these currents varies, strongly affecting the net flow of water to/from the coastal regions of Costa Rica and Guatemala, and the net transport of nutrients. The Costa Rican Coastal Current (CRCC) is a relatively small current compared to the western boundary currents and the equatorial currents. It flows poleward over the continental shelf (Figure 2.5). It is much less distinct, due to the frequent disruption by the seasonally varying mesoscale eddies forming in the same region (Fiedler and Lavin, 2017).

Previous research has shown that the presence of sailfish larvae is related to oceanic currents, for instance, proximity to the Loop Current in the Gulf of Mexico (Rooker et al. 2012). Sea surface temperature, salinity and current velocity were also significant. Pacific sailfish larval recruitment may be similarly related to current conditions in the Eastern Pacific (Fitchett 2015). In fact, many species of larval fish aggregate in frontal zones relative to adjacent water masses (Bjorkstedt et al 2002; Okazaki et al. 2002), in areas of convergence. This and other retention mechanisms like eddies and currents are crucial for larval fish that cannot swim against the current.

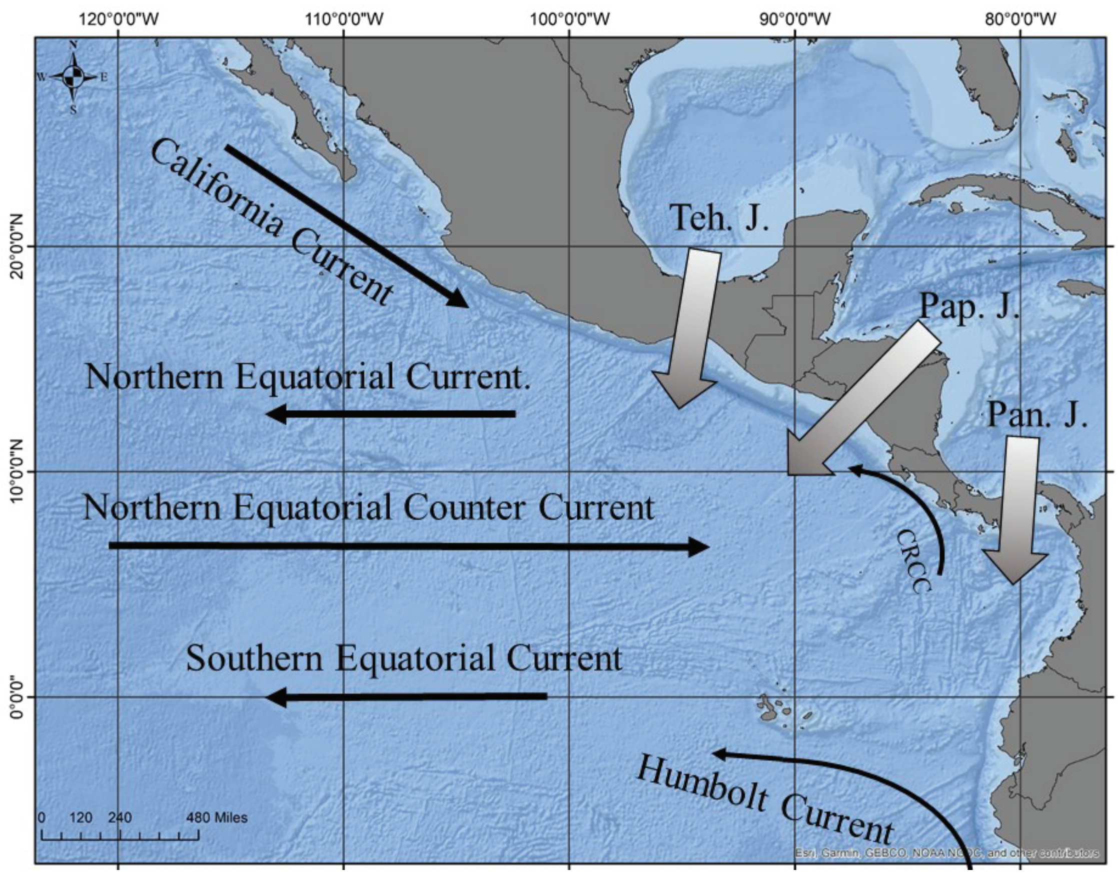

Figure 2.5 Major atmospheric and oceanographic features of the EPO. Tehuantepec Jet (Teh. J) Papagayo Jet (Pap. J) and Panama Jet (Pan. J) are seasonal wind jets. The Costa Rican Counter Current (CRCC) is small in relation to the major equatorial currents and the California and Humboldt boundary currents.

Thermocline and Oxygen Minimum Layer

The atmospheric forcing of ocean circulation creates predictable areas of upwelling, as well as several mobilized eddies per year. The Guatemalan and Costa Rican coasts constitute ocean sub regions, which experience measurably different temporal and geospatial patterns of ocean circulation and seasonal upwelling.

Within the EPO ecosystem dynamics, the depth of the mixed layer is a proxy for the level of upwelling (or downwelling), caused by Ekman pumping. This index is defined as the depth at which water temperature changes from surface temperature by 0.5° C (Levitus, 1983). Upwelling brings limiting nutrients into the photic zone where they are used by primary productivity. The mixed layer depth (MLD) is also highly correlated in time and space with the thermocline and dissolved oxygen levels (Ehrhardt and Fitchett, 2006). The fluctuation in MLD in coastal regions is associated with congruent fluctuations in the minimum DO_2 layer, which is defined as minimum threshold of approximately 1 ml/L believed necessary to sustain most fish species (Ekau et al. 2010). This is considered the absolute lower oxygen limit for billfish. Some scientists contend that they have higher oxygen requirements, approximately 3.5 ml/L for sustained metabolism, and only venture into lower oxygen for brief excursions (Prince et al. 2010; Lam et al. 2015). In other words, the MLD is a proxy for the level of compression of the oxygen habitat, which is especially important for fish like billfish with high metabolic oxygen demands. In Guatemala, there is generally a deeper pocket of habitat near the coast relative to surrounding offshore areas (Figure 2.6). Costa Rica, conversely, generally has more compressed, shallow oxygen habitat nearshore relative to offshore areas (Figure 2.7). Both sub regions vary seasonally.

The cold, deep, hypoxic water that is upwelled regionally in the EPO is a boundary layer for pelagic fish (marlins, sailfish, tuna, etc.). In upwelling regions, the suitable habitat, with sufficient oxygen, is compressed toward the surface, and can be indirectly measured by a very shallow thermocline. Prince and Goodyear (2006) used satellite tags to show that billfish in the EPO, where there is extreme habitat compression, are restricted vertically in the water column. Whereas their counterparts in the Atlantic Ocean, are not bound to the surface due to oxygen-poor upwelling.

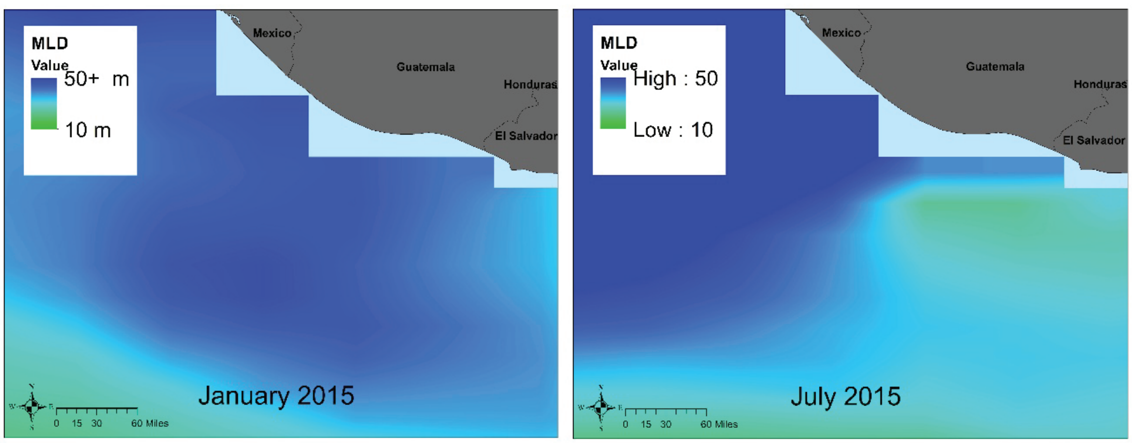

Figure 2.6. MLD distribution in winter and summer off the coast of Guatemala. Monthly mean of ocean mixed layer depth below sea surface. 2015 used as an exemplary year. Data from GODAS (www.cpc.ncep.noaa.gov/products/GODAS)

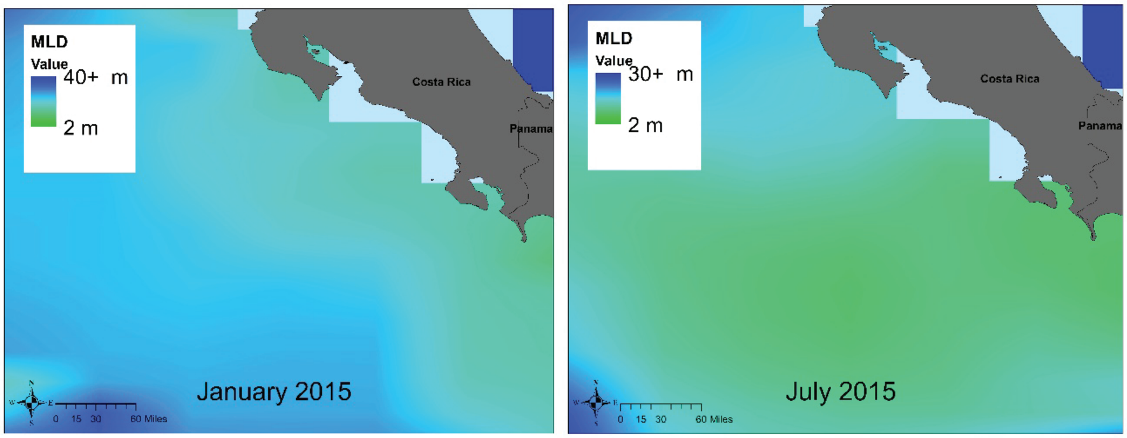

Figure 2.7. MLD distribution in winter and summer off the coast of Costa Rica. Monthly mean of ocean mixed layer depth below sea surface. 2015 used as an exemplary year. Data from GODAS (www.cpc.ncep.noaa.gov/products/GODAS)

El Niño

The El Niño phenomenon has dramatic effects on many of the features discussed above, which subsequently impact marine organisms. El Niño events are triggered as one or several downwelling Kelvin Waves spread east along the Equator, deepening the thermocline and allowing warm, surface water to be retained near the Central and South American coast. In other words, the upwelling of cool water that feeds the Eastern Pacific cold tongue is cut off (Kessler 2006). During El Niño events, the permanent western boundary currents (i.e. California and Humboldt) are greatly diminished, and the corresponding upwelling at the continent is significantly diminished. Along the equator, eastward geostrophic flow is increased, strengthening the Northern Equatorial Counter Current, and weakening (or even reversing) the Southern Equatorial Current (Kessler 2006). The CRCC is enhanced due to the sea level anomalies. The changes in circulation cause corresponding disturbances to the MLD, DO_2, and thermocline patterns. MLD is measurably deeper during El Niño events (Veeranjaneyulu et al. 2016).

Through these mechanisms, upwelling-supported primary productivity is reduced during El Niño events. Fish populations that are supported by this food chain either starve or move elsewhere (Barber and Chavez, 1983). The general species composition of the ecosystem changes, favoring more generalist species. Birds, marine mammals, and human fisheries are all affected. For example, the Peruvian anchoveta fishery collapses (Lavin et al. 2006).

In 1997, the world witnessed a very strong El Niño, allowing billfish researchers and others to study the effects on fish populations and fisheries. Ehrhardt and Fitchett (2006) showed a significant decrease in sailfish recreational catch rates in the Guatemala, which coincided with a sharp increase of Mean Sea Level. This resulted from a relaxation of the Papagayo Jet, which typically produces strong upwelling and shallow thermocline off Nicaragua and Costa Rica during non-El Niño winters. Figure 2.8 shows mean sea level anomalies, which correspond to El Niño Southern Oscillation strength (ENSO) and the standardized sailfish catch per unit effort (CPUE) for the recreational fishery in Guatemala. The decreased CPUE is believed to be indicative of a relaxation of the habitat compression, which decreased ocean stratification allowing fish to spread over larger areas, hence generating lower local stock densities. Such habitat dynamics are thought to make billfish less catchable in coastal recreational fisheries.

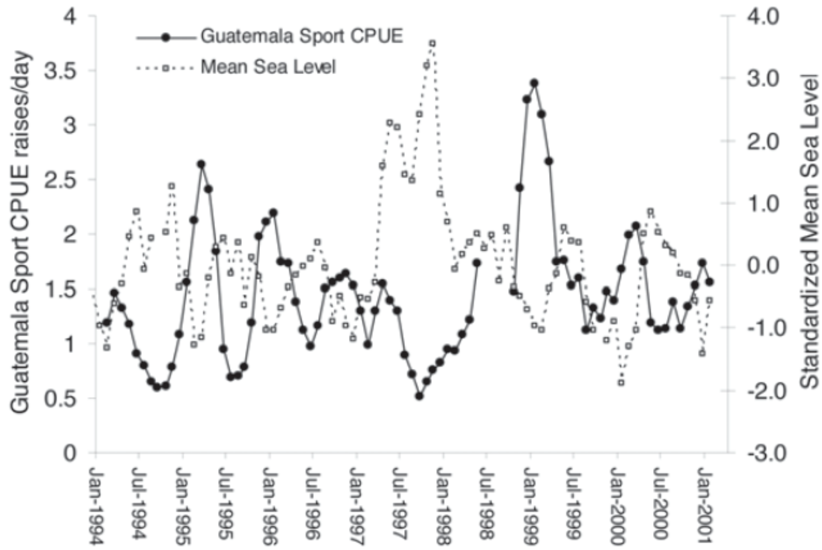

Figure 2.8. Standardized catch per unit effort in Guatemala's recreational fishery for Sailfish and standardized mean sea level. When mean sea level is high, catches are depressed, and vice versa, indicating El Niño-like conditions. From Ehrhardt and Fitchett (2006).

Tournament Catch Rates (CPUE)

In Central and South America, there is a rich history of recreational fishing for sailfish and marlin in the Pacific, beginning with the establishment in 1951 of the Cabo Blanco fishing lodge in Peru. As the popularity of recreational fishing has risen, so too has the prevalence of competitive fishing tournaments in prominent fishing locations. In locations such as Costa Rica, Panama, Nicaragua, and Guatemala, competitive fishing tournaments have been established, and most occur annually. The results of fishing tournaments are often published and distributed broadly in periodicals (Figure 2.9) or the internet, advertising the quality of recreational fishing in a specific location. For example, Marlin Magazine online (www.marlinmag.com/tags/tournament-news) has 32 online pages for billfish tournaments, each containing links to approximately 10 articles at the time of this publication. The articles contain detailed fishing reports, including pictures of the fishing action and the winners. For anglers who consider themselves elite, the publicity and recognition may be worth more than the monetary rewards of winning.

Figure 2.9. Examples of tournament advertisements in Marlin Magazine.

In general, only a few recreational anglers participate in tournaments (Anderson & Ditton 2007), and they have different views about fishing or fishing in tournaments than anglers who do not participate competitively (Loomis & Ditton 1987). Furthermore, their competitiveness, dedication and expertise in recreational fishing practices sets them apart from leisure anglers, and tournament fishing can be considered a type of specialization. Due to the large entry fees and payouts, and the need to strictly adhere to IGFA fishing tournament rules, most anglers who participate competitively in tournaments are highly knowledgeable and experienced. Because of the level of specialization, it is likely that fishing in the tournament mode has different fishing power than fishing in the leisure mode. When considering catch rates for a recreational fishery, it is necessary to account for the specialization effect on fishing power (Zischke et al, 2012). Therefore, in this study, we separate catch statistics between leisure and competitive anglers. Tournament catch rates are the result of comparable fishing effort, and happened in fixed places at similar times of year. This distinguishes tournament catch rates from other recreational and commercial fishery activities. Tournament catch rates for billfish have been used to tune relative abundance estimates in stock assessments of billfish in other regions (Hoolihan et al. 2008; Lauretta and Goodyear, 2018).

Catch rates in recreational fisheries for billfish are seasonal, reflecting the seasonal environmental conditions. Therefore, seasonal CPUE trends in the Central American Pacific coast are likely indicative of environmental processes that affect gear vulnerability and changes of local abundance of billfish. The recreational fisheries for sailfish in Guatemala and Costa Rica experience different proximity to the main geographic density of the sailfish stocks (Figure 2.10), as inferred through purse seine catch and effort statistics, obtained through the Inter-American Tropical Tuna Commission (IATTC). Purse seine billfish bycatch CPUE, aggregated spatially, should reflect the true geospatial abundance of the species because in this fishery, the nets are deployed down to 200 meters, and all fish are caught. Habitat compression, therefore, has no effect on the catchability component of this fishing operation. According to the distribution of purse seine CPUE, Costa Rica is much closer to the main density for the sailfish population in the EPO than Guatemala (Figure 10). Yet, Guatemala consistently has higher recreational catch rates (sometimes an order of magnitude) than Costa Rica during the winter months.

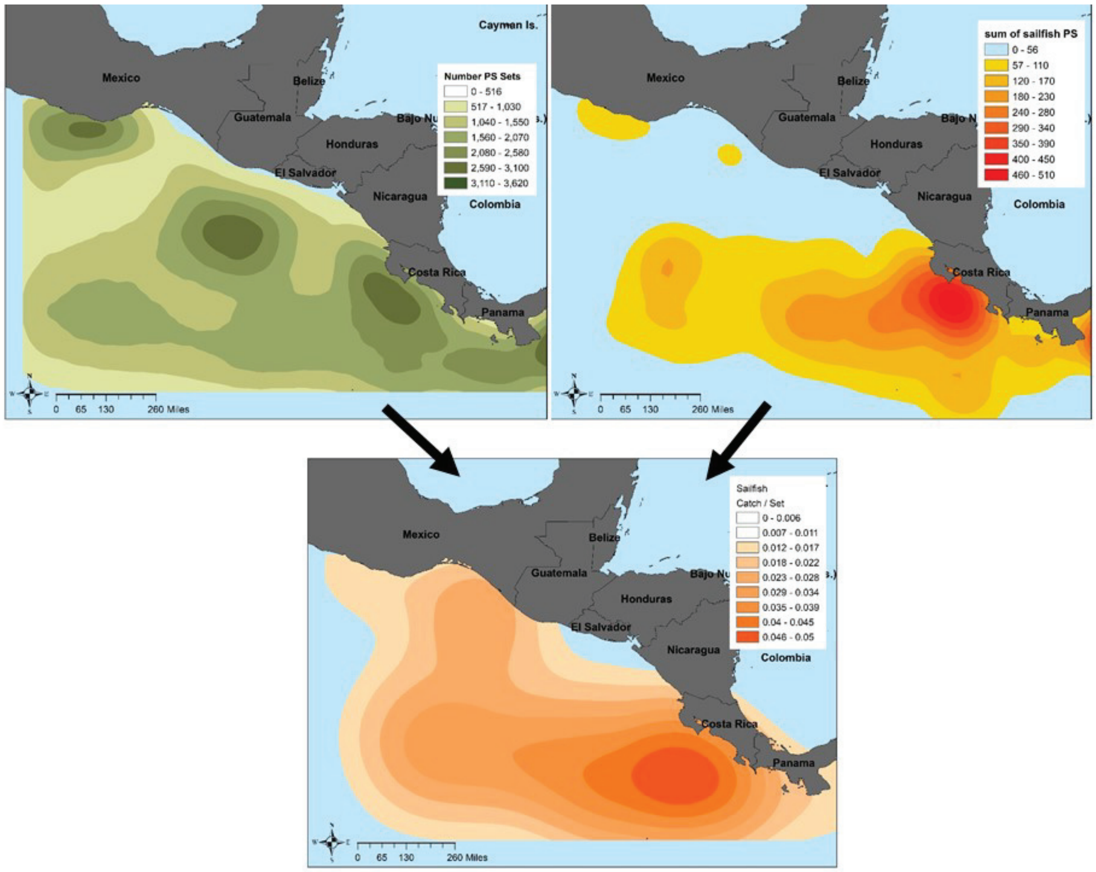

Figure 2.10. Purse Seine effort (top left) and catch (top right), combined to show the approximate geospatial distribution of sailfish CPUE (bottom). Data is interpolated from 1-degree grid estimates provided by IATTC 2010-2012 (https://www.iattc.org/PublicDomainData/IATTC-Catch-by-species1.htm).

2.2 Problem Identification, Purpose and Objectives

For stock assessment purposes, sailfish fisheries in the EPO can be considered "data poor" because there is little information on the age structure of the catch and significant levels of unreported catch, especially from the artisanal and longline fleets. In fact, the latest attempt by IATTC to assess the sailfish population failed due to lack of appropriate catch data (Hinton and Maunder, 2013, IATTC 2013 Sailfish Assessment). In the EPO, minimally regulated coastal artisanal and semi-industrial longline fleets targeting tuna and mahi mahi catch billfish incidentally and most are retained (Fitchett 2015). For billfish, alternative data sources can be used to understand the spatial-temporal dynamics of the species, such as recreational CPUE data, which is increasingly being used to inform billfish fisheries management (Squire 1987, Campbell et al. 2003). The need for additional sources of data is especially great in the EPO, where sailfish stock assessments have failed.

Dynamics of CPUE

The catch rates of a given fishery are dependent on the abundance of the fish population, and the catchability, or proportion of that stock that is captured under given gear or environmental conditions. (Equation 2.1). Standardized indices derived from CPUEs, aim to extract variability in catch rates that is not related to the overall abundance of the stock by accounting for differences in fishing power, as well as location and time period of the observation. Such standardized catch rates are typically used in stock assessments as indicators of abundance (N), but in the highly dynamic environment of the EPO, another source of variability is likely affecting these catch rates. In our model, the catchability (q) component of the equation is not constant. Our q variable fluctuates as a function of environmental conditions, and only applies to the portion of the sailfish population that is temporarily in the sub-region. Under our assumption of uniform fishing practices and fishing power, changes in tournament CPUE reflect changes in catchability at the location and time of the tournament. Here, catchability is described as a combination of local sailfish horizontal density as well as vertical density, both affecting the encounter rate with recreational fishing gear at the surface.

$$CPUE_{i,t} = q_{i,t} * N_t$$ **Equation 2.1**

where CPUE is Catch Per Unit Effort in tournament location i at tournament time t, q is the local catchability, or coefficient of proportionality in the units of fishing effort, and N is the local population abundance in the same units as the catch.

Because our CPUE are nominal indices of localized relative abundance, we are treating catchability (q) not as a parameter that can be applied stock-wide, but as indicative of catchability conditions at a single location at the time of fishing. Most CPUE standardizations do not account for environmentally driven changes in catchability, which may lead to bias in the indices of abundance. Our model is similar to the approach used in geostatistical models, such as the VAST package, which is a tool to estimate spatial variation in density using spatially referenced data. This generalized linear model requires analyst insight to differentiate gear vulnerability (catchability) and density (habitat parameters) across time and space (Thorson 2019). We were not able to use a geostatistical model because the data were not georeferenced. However, our analysis similarly attempts to separate variables that influence localized abundance from those that influence catchability.

Purpose

The purpose of this chapter is to elucidate the influences of environmental conditions that affect tournament CPUE dynamics by altering catchability in recreational sailfish fisheries in the Eastern Pacific Ocean off Central America. In the process, we hope to improve our understanding of environmental mechanisms that define sailfish habitat.

Objectives:

1. Compile a comprehensive dataset of historical catch rates (average sailfish per boat per day) for recreational tournaments operating in the EPO to inform assessments of local sailfish abundance and catchability.
2. Develop indices for variable(s) that potentially represent:
    - large-scale processes that affect regional availability of sailfish for recreational fisheries (ENSO).
    - Physical processes affecting sub-regional catchability of sailfish (MLD).
    - Oceanic conditions that may be related to successful recruitment of sailfish to the adult population (current strength).

3. Determine trends in the CPUE series for Guatemalan and Costa Rican tournaments and the environmental variables thought to influence recreational fishing success.
4. Conduct an ordination procedure representing the interactions of these variables with each other and the tournament catch rates in Costa Rica, to reveal distinct time regimes during which recreational fishing experiences different environmental conditions.
5. Statistically determine which variables significantly contribute to the overall variability of tournament CPUEs to draw inferences about catchability dynamics and interpretation of abundance indices.

2.3 Materials and Methods for Quantitative Analysis

2.3.1 Data acquisition

Tournament CPUE

We compiled a database of billfish tournament fishing results for Costa Rica and Guatemala, spanning from 1990 to 2016. For each tournament, we recorded the number of sailfish caught, number of fishing days, number of participating boats, date and location. We calculated CPUE as the number of sailfish caught per boat per day. The majority of this database was constructed by reading fishing articles on the Internet. Other tournament records were obtained via personal communications with marina/lodge operators, tournament organizers, and fishing clubs. Records from 176 tournaments were obtained with the number of participating vessels in each tournament ranging from 4 – 67 boats.

For the purposes of our analysis, we wanted to use catch rates that were most comparable to each other, to control for factors that are not relevant. Due to potential differences in the fleet (or anglers themselves), tournaments from different countries were not compared to each other. We selected Guatemala and Costa Rica for analysis. Guatemala was chosen because the tournament series consistently took place in the same marina, in the same month, every year. Costa Rica was chosen due to the large number of tournaments available. We excluded tournaments that were from local, leisure-oriented fishing clubs. These tournaments do not draw international anglers. In fact, they are closed to the public, and are therefore less competitive, and thus not considered specialized for the purposes of our analysis. All Costa Rican tournaments from 1990 – 2003 were excluded for this reason. The final dataset for Guatemala was 12 tournaments (2001 – 2014), and the final dataset for Costa Rica included 53 tournaments, from 2004 – 2016.

Mixed Layer Depth

Mixed Layer Depth data was obtained from a real-time analysis and historical reanalysis model; the Global Ocean Data Assimilation System (GODAS), produced by the National Environmental Prediction Center (Behringer and Xue, 2004):

> "*GODAS is based on a quasi-global configuration of the GFDL MOM.v3* [Geophysical Fluid Dynamics Laboratory's Modular Ocean Model version 3]. *The model domain extends from 75°S to 65°N, with a resolution of 1° by 1° and enhanced to 1/3° in the N-S direction within 10° of the equator.*"

The extent of GODAS covers our study area. In the upper 200 meters of the ocean, the model has a 10-meter depth resolution. GODAS assimilates temperature profiles from expendable bathythermographs (XBTs), Tropical Atmosphere Ocean (TAO) array in the tropical Pacific, Triangle Trans-Ocean Buoy Network (TRITON) in the tropical Indian Ocean, Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), and Argo profiling floats (https://www.cpc.ncep.noaa.gov/...):

> *"Additionally, synthetic salinity profiles are computed for each temperature profile using a local Temperature-Salinity climatology* (Conkright et al. 1998)*, which is based on the annual mean fields of temperature and salinity from the NDOC World Ocean Database."*

GODAS data is provided as a NETCDF file (*.nc) by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/. Monthly values of MLD are available starting in January 1980. The variable within this dataset corresponding to the MLD is dbss_obml, and is measured in meters (depth). The NETCDF file was imported into ArcMap (version 10.5) using the tool: Make NetCDF Raster Layer.

To examine the effects of compression of usable habitat for sailfish, we created two indices for each tournament. The first analyzed the horizontal compression of MLD. This we define as the extent to which the nearshore oxygen habitat is vertically compressed compared to the offshore habitat. To measure the available 3-dimensional space of nearshore habitat relative to offshore, we created two geospatial transects perpendicular to the shoreline. For Guatemala, one was to the west of the general fishing area for marina Pez Vela, and the other to the east of the area (Figure 2.11). Nearshore is the area within these transects that is closest to the land, and offshore is on the opposite side of the transect. The width of the transects is based on the limitations of the shape drawing software in GIS, however the width is trivial because the transects are perpendicular to the gradient of the MLD. Using the Zonal Statistics as Table tool in GIS, we obtained summary statistics about the values of the MLD raster within the transect zone, reported in a summary table. Table 2.1 is an example of the output of summary statistics calculated within the southern transect on November 2014.

Table 2.1. Summary statistics for MLD in meters for a single transect in Guatemala during a November 2014 fishing tournament.

Min	Max	Range	Mean	St. Dev
6.48 m	28.30 m	21.82 m	13.80 m	10.25 m

A high MLD value, (i.e. deeper areas of suitable habitat) would indicate more 3-dimensional habitat available to sailfish. We chose the range of values within each of the transect zones to use as an indicator of the amount of shoaling of inhabitable space towards the shore (Figure 2.11) relative to offshore. The average of these two range values was used to build a MLD Shoaling Index for each tournament (Equation 2.2), which was used for comparison with recreational sailfish catch rates. We hypothesize that the compression of habitat horizontally, indicated by a higher MLD Shoaling Index, will increase the average CPUE of sailfish in recreational tournaments.

$$\frac{R_{t1} + R_{t2}}{2} = MLD\ Shoaling\ Index \qquad \textbf{Equation 2.2}$$

where R_{t1} is the range calculated for the northern transect and R_{t2} is the range calculated for the southern transect.

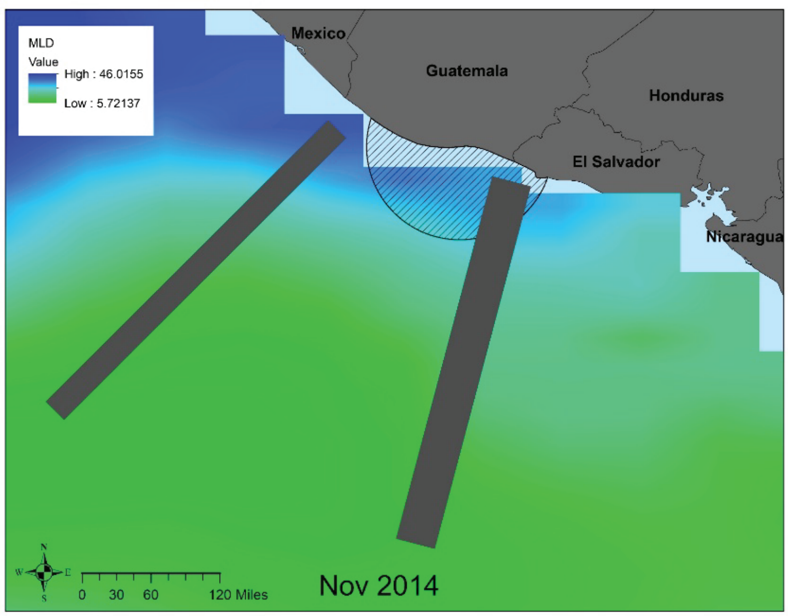

Figure 2.11. Two offshore transects used to calculate Mix Layer Depth range. Fishing zone defined by a 70 nautical mile radius is also shown in relation to the transects.

Similarly, we hypothesize that the compression of habitat vertically (average MLD) in the area of fishing would increase catchability due to an increase in fish density resulting in higher tournament catch rates. To calculate this new index of vertical compression, we first designated a tournament fishing zone (Figure 2.12) that represents an area with a 70-mile radius from the marina. This is estimated to be the maximum distance of potential daily recreational fishing operations during the tournament, because the tournaments require all vessels to be back every night. Vessels are assumed to be fishing anywhere within this shape. Again using the Zonal Statistics tool in GIS, we calculated the average MLD within the fishing zone for each tournament, low MLD values, (i.e. shallower suitable habitat) indicate less 3-dimensional habitat available to sailfish.

For billfish fishing tournaments in Costa Rica, we similarly created a Shoaling Index and Average MLD value for each tournament. We further assume that fishing vessels would not go to fish in inlets or bays, features unique to Costa Rica, as they usually do not show billfish resource presence, so these areas were excluded from the Costa Rican fishing zones. Figure 2.12 illustrates the tournament fishing zones and distribution of the MLD during the month corresponding to two of the Costa Rican tournaments. The fishing tournament names, start dates, number of participating boats, average MLDs, and Shoaling Indexes are available in Appendix A.

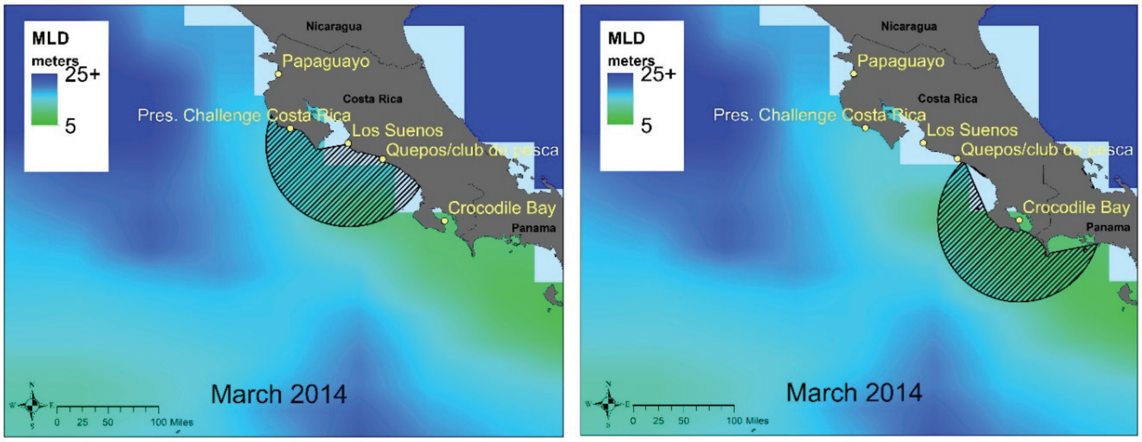

Figure 2.12. The delineation of geospatial fishing zone in Costa Rica. This is used to determine the average depth of the mixed layer (meters).

ENSO and Ocean Current Strength

In the past, the University of Hawaii Sea Level Center (http://ilikai.soest.hawaii.edu/) has collected data and provided monthly summaries of the strength of large scale tropical currents. Archived current strength data that had been previously downloaded was used in this analysis. The northern equatorial current (NEC) and equatorial countercurrent (ECC) indices were made available until 2012. After 2012, the data was no longer made available to the public, so we could not use indices that required years beyond 2012 for their calculation. The NEC index is estimated by the difference in dynamic sea height between the countercurrent trough (~9N) and the north equatorial ridge (~20N), while the ECC index is estimated by the difference in dynamic sea height between the equatorial ridge (2N) and the countercurrent trough (9N) (Wyrtki, 1974). Indices are provided not as anomalies but as absolute measurements. For our analysis, we created a new index using an average of current indices during the winter months, when the gap winds are the strongest (October – March). Because this index is intended to be a predictor of sailfish recruitment strength for the EPO population, reflected in changes to CPUE of sailfish ages 4-6 (Fitchett 2015), we used time-lagged current indices from 4, 5, and 6 years prior to the date of the tournament. The 5 year lagged value received 50% of the weight, while 4 and 6 year lagged values received 25% of the weight, each. Because the winter season straddles two sequential years (i.e. October – April), we defined fishing season as October – April, where October – December are assigned a year + 1 value. This new index yielded tighter coupling with CPUE trends than using the average for any single calendar year by itself. Equation 2.3 describes the averaging of time-lagged values for the NEC index used in analysis.

$$\left(\frac{\sum_{Oct}^{Mar}(NEC_{y-5})}{6} * .50\right) + \left(\frac{\sum_{Oct}^{Mar}(NEC_{y-4})}{6} * .25\right) + \left(\frac{\sum_{Oct}^{Mar}(NEC_{y-6})}{6} * .25\right) = NEC_{y-0}$$

Equation 2.3

where NEC_{y-0} is the NEC value assigned to the tournament held in a given year, y. $\sum_{Oct}^{Mar}(NEC_{y-5})$ is the sum of monthly values of NEC for October – March, 5 years before the year of the fishing tournament. Likewise, $\sum_{Oct}^{Mar}(NEC_{y-4})$ and $\sum_{Oct}^{Mar}(NEC_{y-6})$ are the sums of October – March values of NEC for 4 and 6 years prior to the year of the tournament, respectively.

Similarly, we calculated the 4, 5, and 6 year lagged averages for the ECC data assigned to a given tournament. Equation 2.4 describes this calculation. The strengths of the averaged currents are in Appendix B.

$$\left(\frac{\sum_{Oct}^{Mar}(ECC_{y-5})}{6} * .50\right) + \left(\frac{\sum_{Oct}^{Mar}(ECC_{y-4})}{6} * .25\right) + \left(\frac{\sum_{Oct}^{Mar}(ECC_{y-6})}{6} * .25\right) = ECC_{y-0}$$

Equation 2.4

where ECC_{y-0} is the ECC value assigned to the tournament held in a year, y. $\sum_{Oct}^{Mar}(ECC_{y-5})$ is the sum of monthly values of ECC for October – March, 5 years before the year of the fishing tournament. Likewise, $\sum_{Oct}^{Mar}(ECC_{y-4})$ and $\sum_{Oct}^{Mar}(ECC_{y-6})$ are the sums of October – March values of ECC for 4 and 6 years prior to the year of the tournament, respectively.

We used a ratio of NEC and ECC values (ECC_{y-0}/NEC_{y-0}), standardized to the mean and standard deviation of ratio values used for our time span (0.92 and 0.09, respectively) as a single index for the currents describing the recruitment conditions for sailfish available during a given tournament (Appendix C.) We combined the two current strength values into a single index for two reasons. Firstly, the two currents are linked in space and time, and therefore not independent variables. Secondly, the ratio of the two geographically opposing currents would describe the net water flowing toward or against the continent, depending on which current was stronger at that time. Using a ratio provides an index of the resulting effective total water flow toward or away from the continent. This water movement may influence egg, larval, and juvenile retention. Such proxy for retention may be used as a factor predicting recruitment to the recreational fishery 5 years ahead (Fitchett 2015).

Monthly El Niño Southern Oscillation (ENSO) values are available through NOAA, and are continuously updated. We chose the widely-available MEI index as an indirect indicator of large-scale, regional processes that affect the distribution and catchability of sailfish. To assign an MEI value to each tournament, we again used the average of the winter months corresponding to the year of that tournament (Oct – Mar). The multivariate ENSO Index (MEI.v1, https://www.esrl.noaa.gov/psd/enso/mei.old/) is used to describe regional ocean and atmospheric conditions. It is calculated as the unrotated first principal component of the following six variables: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. (Wolter and Timlin, 1993). Negative values of the MEI represent the cold ENSO phase, (i.e. La Niña), while positive MEI values represent the warm ENSO phase (El Niño). The values are reported as 1/1000 of standard deviations from each season and to the 1950-93 reference period (data accessed in July 2018).

2.3.2 Analysis

We performed the majority of multivariate analysis on the Costa Rican tournament CPUE, as the sample size (12 tournaments) of the Guatemalan dataset was deemed insufficient for multivariate hypothesis testing. For the Guatemalan CPUE, we used first order regression analysis to discern trends with the two indices of habitat compression. We prioritized these variables due to their novelty in the literature relating to billfish behavior.

For cursory exploration of the Costa Rican tournaments, we first executed first order regression analysis between several of the environmental variables with each other and with the tournament CPUE, to discern any interactions. To further explore the relationships of these variables, we implemented a Principal Component Analysis (PCA). In this type of analysis, a dataset with many, possibly correlated variables, is reduced to fewer dimensions. New variables are created (the principal components) that are combinations of the original variables, and these new variables are ordered such that the first few retain most of the variation present in the original variables. PCA can be considered as a rotation of the axes of the original variables to new orthogonal axes, called the principal components. The first principal component coincides with the maximum variation of the spread of the data, and the second principal component coincides with an orthogonal axis that explains the maximum amount of the remaining variation. The derivation and properties of principal components are based on the eigenvectors and eigenvalues of the covariance matrix of the original variables. PCA is used for two cases: one is to look at correlation between the features of the data and second to perform feature reduction. It produces low-dimensional representation of the dataset by finding a sequence of linear combinations of variables that have maximal variance and are mutually uncorrelated.

To perform this analysis, we first standardized all variables to their sample mean and standard deviation (Equation 2.5).

$$Z_{ij} = \frac{X_{ij} - \bar{x}_j}{s_j}$$ **Equation 2.5**.

where X_{ij} is the sample measurement for variable j in tournament I, $\bar{x}_j$ is the sample mean for variable j, and s_j is the sample standard deviation for variable j.

After producing a matrix of standardized measurements of the ENSO value, weighted 5-yr ocean currents ratio (ECC/NEC), Avg. MLD, and Sailfish CPUE for each of the tournaments, we used the prcomp function in R (R Development Core Team. 2018) to perform the exploratory principal component procedure.

Lastly, we performed a multiple regression analysis, using Costa Rican tournament CPUE as the dependent variable. This allowed assessment of the independent variables that may affect CPUE. Unlike most CPUE datasets, the billfish recreational tournament database does not have zeros. However, the distribution is not normal and skewed right. Therefore, we natural log-transformed the CPUE values prior to inclusion for the multivariate analysis. We performed a simple multiple regression using only first order terms for the explanatory variables (Equation 2.6). The model selected for sequential analysis includes the current ratio as the first source of variance, because it is thought to be related to recruitment, which affects the whole population. Next, ENSO is added as this ocean-wide phenomenon affects a larger portion of the population that the local MLD index. The average daily catch rates of sailfish for tournament i, log-transformed ($Log(CPUE)_i$) is estimated through a linear model:

$$Log(CPUE)_i = \beta_0 + \beta_{1,current(i)} X_{1,current(i)} + \beta_{2,ENSO(i)} X_{2,ENSO(i)} + \beta_{3,MLD(i)} X_{3,MLD(i)} + e_i$$

Equation 2.6

where $\beta_{1,\mathrm{current}(i)} X_{1,\mathrm{current}(i)}$ is the coefficient and variable for the 5-year delayed ratio of ECC and NEC currents during the time of tournament i, $\beta_{2,\mathrm{ENSO}(i)} X_{2,\mathrm{ENSO}(i)}$ is the coefficient and variable for the ENSO value at the time of tournament i, and $\beta_{3,\mathrm{MLD}(i)} X_{3,\mathrm{MLD}(i)}$ is the coefficient and variable for the average depth of the mixed layer in the fishing zone at the time of tournament i. Error is defined as N($\widehat{Log(CPUE)}$, σ_Y).

Other, higher order regressions were also performed, but these resulted in miniscule reductions in residual error, and interpretation was convoluted. Similarly, adding interaction terms did not improve the model, as judged by the AIC criterion. We therefore only present the results of the model using only first order terms in Costa Rica.

2.4 Results

Guatemala

Twelve tournaments in Guatemala were used for analysis, all occurring in the month of November. Table 2.2 shows the average sailfish daily releases for Guatemalan billfish tournaments, and the results of the Mixed Layer Depth analysis calculated within the pre-defined 70-nautical mile radius from Marina Pez Vela (Fishing Zone). Also shown are the values of the calculated range for the two transects (East and West) which were perpendicular to the coast, and the average of these two values (Shoaling Index). The values are plotted in Figure 2.13 and 2.14.

Table 2.2. Results of Average MLD and Range for tournaments in Guatemala. No records for recreational billfish tournaments in 2002 and 2003 tournaments were available in Guatemala.

Date of 1st day	Sail CPUE (Releases/day)	Avg. MLD Fishing Zone (m)	WEST Transect Range (m)	EAST Transect Range (m)	Shoaling Index (Avg. E + W) (m)
11/12/2001	8.8	16.3	20.3	22.7	21.5
11/13/2004	9.98	18.4	12.7	9.6	11.1
11/19/2005	10	19.1	13.1	10.2	11.7
11/17/2006	11.3	15.2	10.8	9.5	10.2
11/16/2007	5.6	17.8	10.4	12.7	11.5
11/21/2008	7.8	19.3	17.9	10.1	14.0
11/19/2009	10.0	13.4	14.0	7.9	11.0
11/18/2010	18.8	14.5	9.5	8.5	9.0
11/10/2011	10.5	13.8	9.0	9.2	9.1
11/15/2012	1.8	28.4	24.3	16.6	20.4
11/21/2013	11.2	19.1	12.2	9.3	10.8
11/7/2014	23.5	26.9	26.6	21.8	24.2

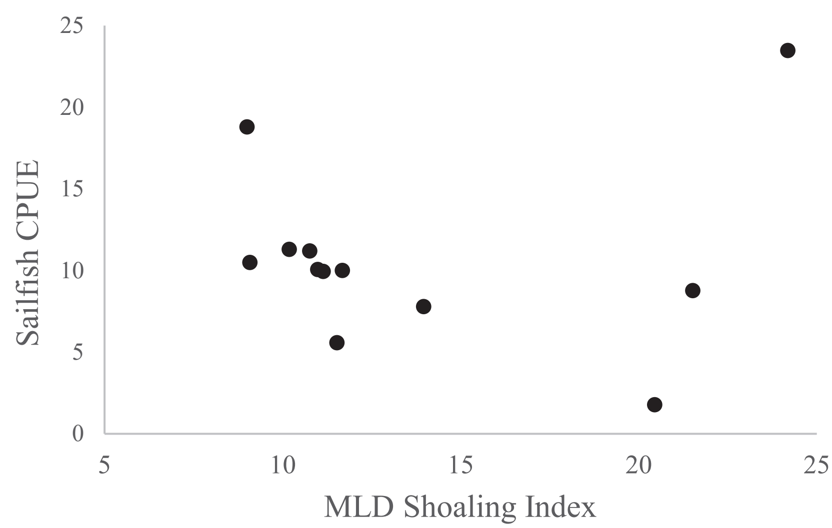

Figure 2.13. CPUE and MLD shoaling Index for all tournaments in Guatemala.

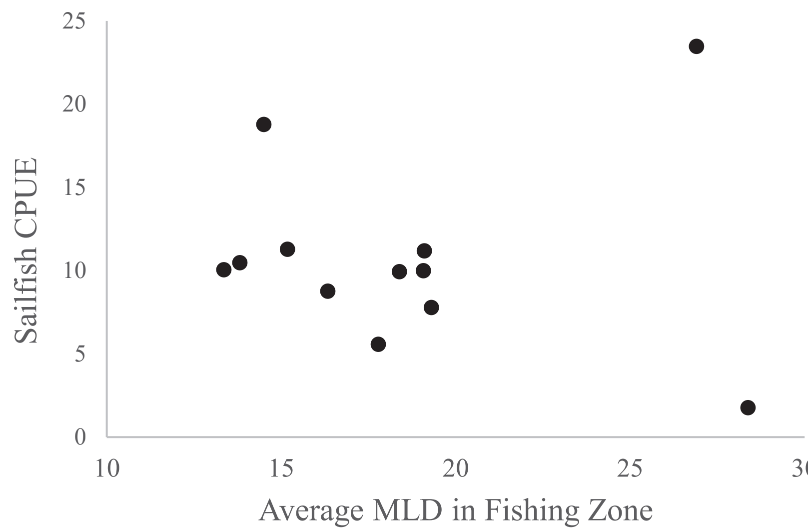

Figure 2.14. CPUE and Average MLD for all tournaments in Guatemala.

We analyzed the relationship between tournament catch rates and indices of habitat compression using linear regressions (Equations 2.7 and 2.8). The 2014 tournament was removed from these analyses as an outlier. Although other years corresponded to positive ENSO values, 2014 was the beginning of a persistent El Niño period (Figure 2.21 and Figure 2.22) in the Pacific (NOAA). Previous research (Ehrhardt and Fitchett 2006) has shown that El Niño effects recreational catch rates in the region. Figure 2.15 shows the relationship of the MLD Shoaling Index with Sailfish CPUE (Equation 2.7), with an R^2 value of 0.39 and P-value of 0.038. Figure 2.16 shows the relationship of sailfish CPUE with the average MLD (Equation 2.8) calculated inside the Guatemalan fishing zone. The R^2 value is 0.50, and P-value is 0.01. The regression equations are:

$$Sailfish\ CPUE = -0.6078 * R + 17.351 \qquad \textbf{Equation 2.7}$$

where R is the average range of MLD values of the two transects (Shoaling Index).

$$Sailfish\ CPUE = -0.702 * Average\ MLD + 22.056$$ **Equation 2.8**

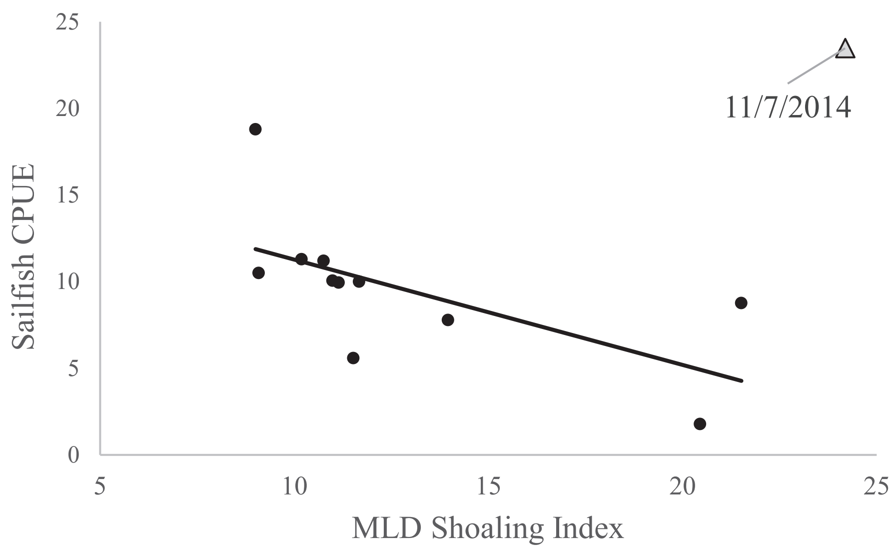

Figure 2.15 The relationship of CPUE and the Shoaling Index in Guatemala. 2014 excluded as an outlier.

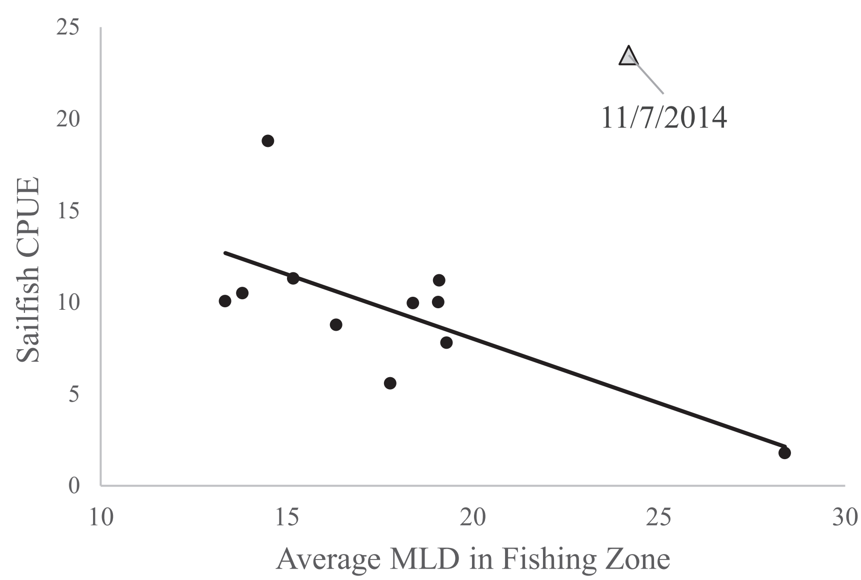

Figure 2.16 The relationship of CPUE and the average MLD in Guatemala. 2014 excluded as an outlier.

Costa Rica

A total of 53 tournaments taking place in Costa Rica were used in the final dataset for analysis. Figure 2.17 shows that an interannual trend in the sailfish CPUE characterized by an era of mid-level CPUEs, followed by an era of low CPUEs, and finally an era with dramatically increasing CPUEs. This trend can be described by a second order polynomial, Equation 2.9, fitted using Least Squares method (Figure 2.15) with an R^2 value of 0.57.

$$Sailfish\ CPUE = 0.000002x^2 - 0.147439x + 2{,}934.145$$

Equation 2.9.

where x is the date of the tournament.

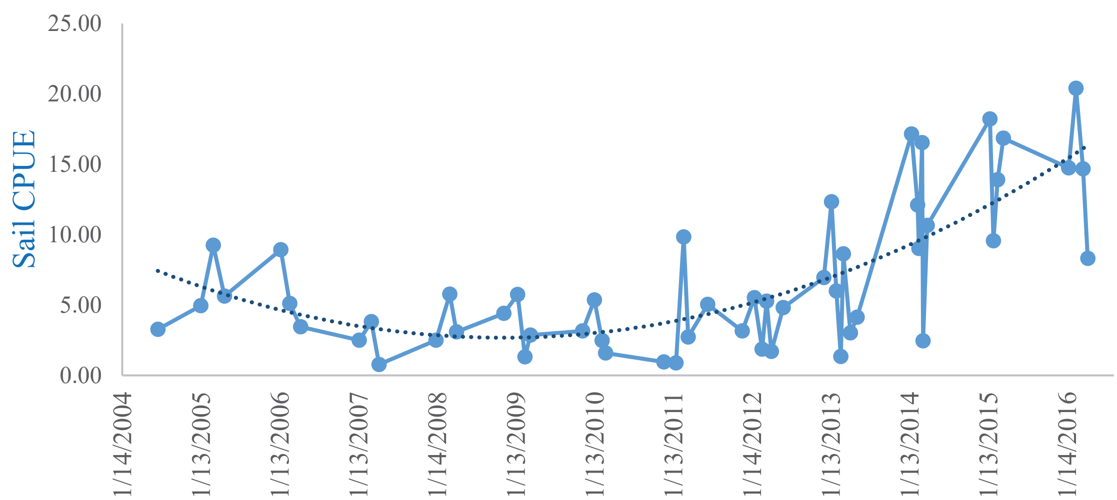

Figure 2.17 Interannual trend of tournament CPUE in Costa Rica.

Mixed layer

The average depth of the mixed layer in the fishing zone for Costa Rican tournaments does not show the same interannual trend as the CPUE. A second order polynomial (Equation 2.10) does not describe well the variation of this variable, with a low R^2 value of 0.11. Figure 2.18 compares the trends between CPUE and MLD. There is a notable increase in the variance between the years of approximately 2009 – 2011, which may indicate a time period with unique environmental attributes, possibly influencing tournament catch rates for billfish.

$$Average\ MLD = 0.00000056x^2 - 0.0439216x + 874.841$$

Equation 2.10.

where x is the date of the tournament.

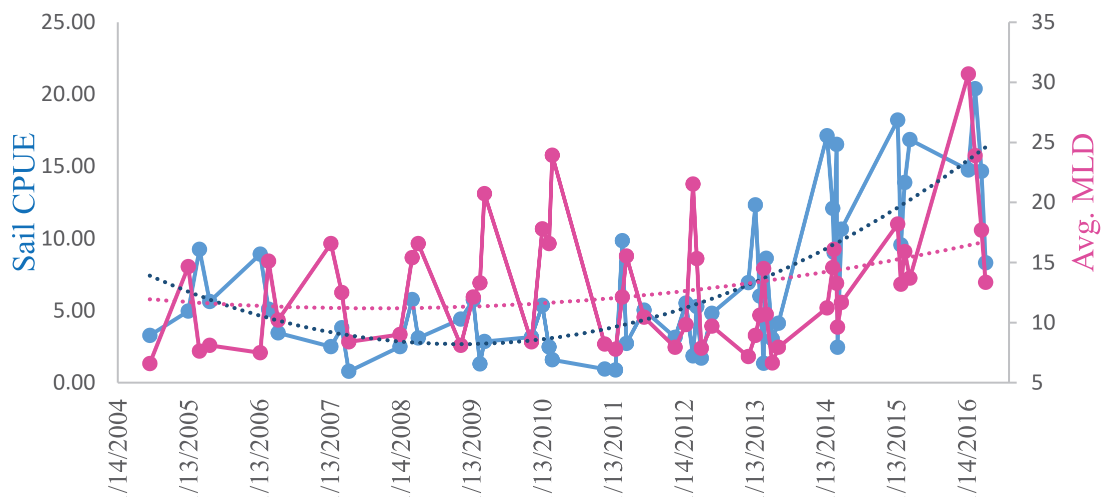

Figure 2.18. The interannual trend of sailfish CPUE in Costa Rica and the corresponding MLD during the month of the fishing tournament.

We also examined the relationship of the average MLD and the Shoaling Index directly to the Costa Rican sailfish CPUE. Unlike the more uniform database for Guatemala, there is no negative relationship between the CPUE and average MLD (Figure

2.19) or the Shoaling Index (Figure 2.20). Contrary to our initial hypothesis, fishing tournaments experiencing the most extreme habitat compression, indicated by very low values for Avg. MLD and Shoaling Index, have very low values for CPUE. There are also very low values, however, through the entire range of evaluated levels of habitat compression.

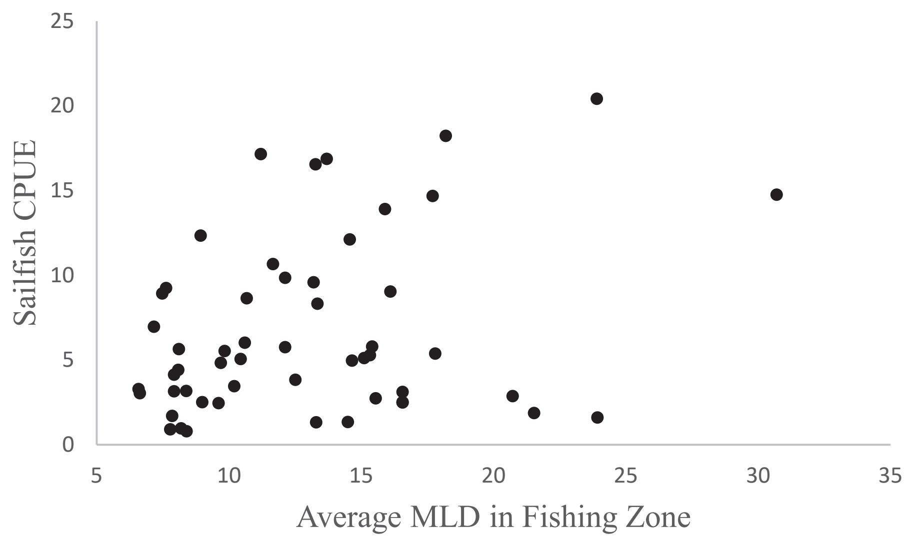

Figure 2.19. The average MLD in the fishing zone during the month of the tournament, and sailfish CPUE for the tournament in Costa Rica.

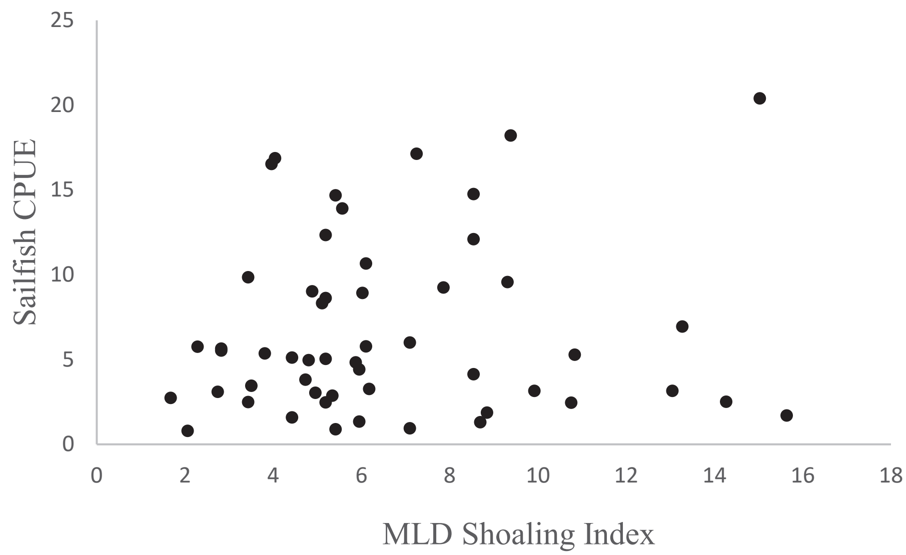

Figure 2.20. The Shoaling Index for the month of the fishing tournaments and the sailfish CPUE for that tournament in Costa Rica.

ENSO

The ENSO index (MEI) shows a similar interannual trend as the Costa Rican CPUE, with three phases. As with the MLD, we see a time period of high variance during the approximate years of 2009 – 2011. Similarly, we produced a second order polynomial (Equation 2.11) to describe the variation of ENSO, with a R^2 value of 0.39. Figure 2.21 compares the trends between CPUE and ENSO. We compared the ENSO index we created using an average of winter months for three consecutive years with the traditional index for all months over a similar time span (Figure 2.21 and 2.22). The light gray rectangle highlights the 2009 – 2011 period of our ENSO index, which used only winter months. Both indices show relatively high variability during this period, most conspicuously the rapid drop in values between late 2010 to early 2011. The dark gray rectangles highlight a period of persistently high ENSO values (El Niño conditions), which were excluded in the Guatemalan analysis.

$$ENSO = 0.0000004x^2 - 0.031977x + 641.1995 \qquad \textbf{Equation 2.11}.$$

where x is the date of the tournament.

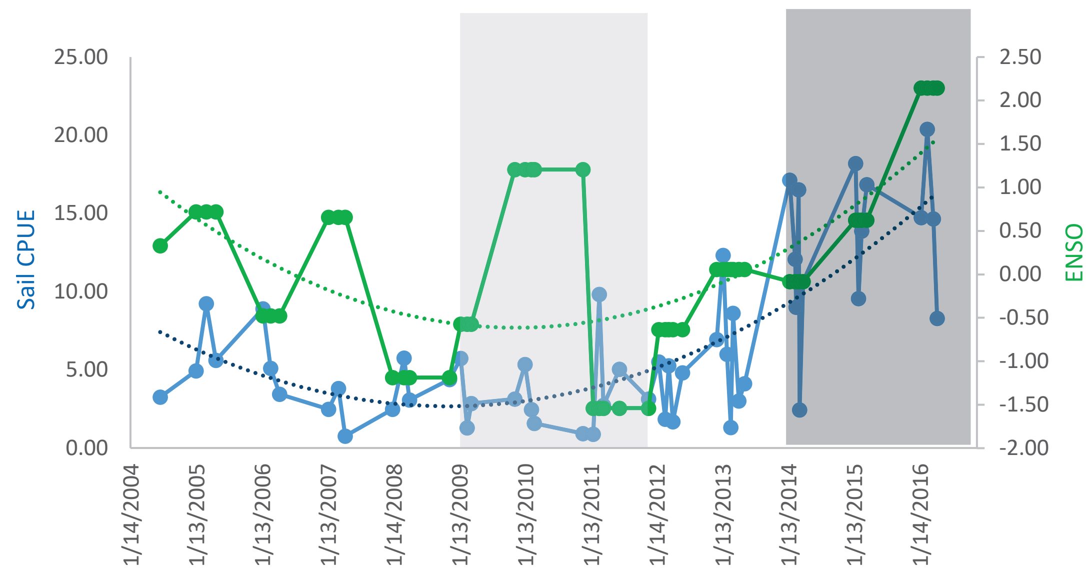

Figure 2.21. The interannual trend of sailfish CPUE and the corresponding average winter El Niño Index (ENSO MEI) during the fishing season of the tournament.

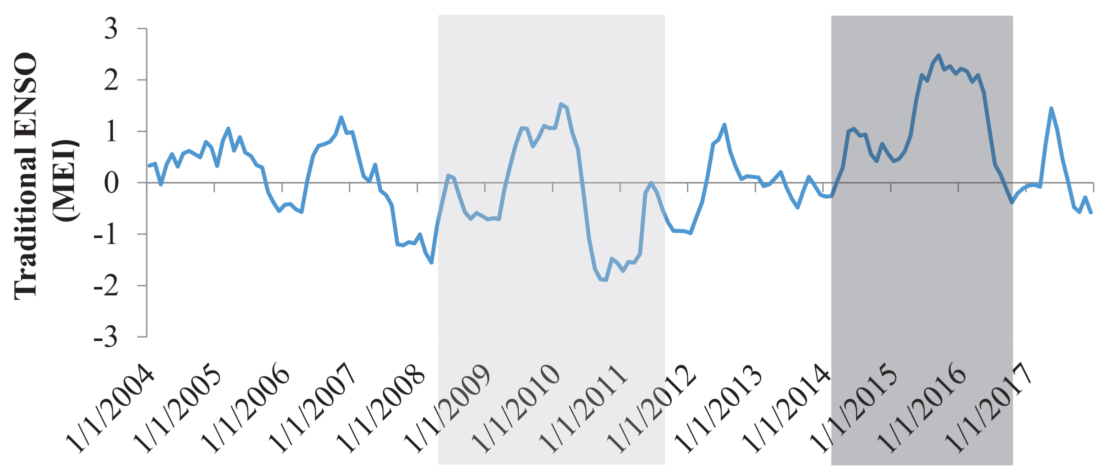

Figure 2.22. Time series of all monthly ENSO values during the time span of the Costa Rican tournament data base.

Currents

The ratio of ECC to NEC currents (seasonal average, 5 year delayed) has a large variance in the most recent 3 years of the dataset relative to the prior years. The lowest values for the data are preceded two years by the highest values for the ratio. This variable does not show an interannual trend that is well-described by a 2nd order polynomial (Equation 2.12, Figure 2.23), however the years between 2006 – 2014 do show a general trend of falling followed by rising values. The R^2 is 0.01.

$$ECC/NEC = 0.00000001x^2 - 0.000614x + 13.3316 \qquad \textbf{Equation 2.12}$$

where x is the date of the tournament.

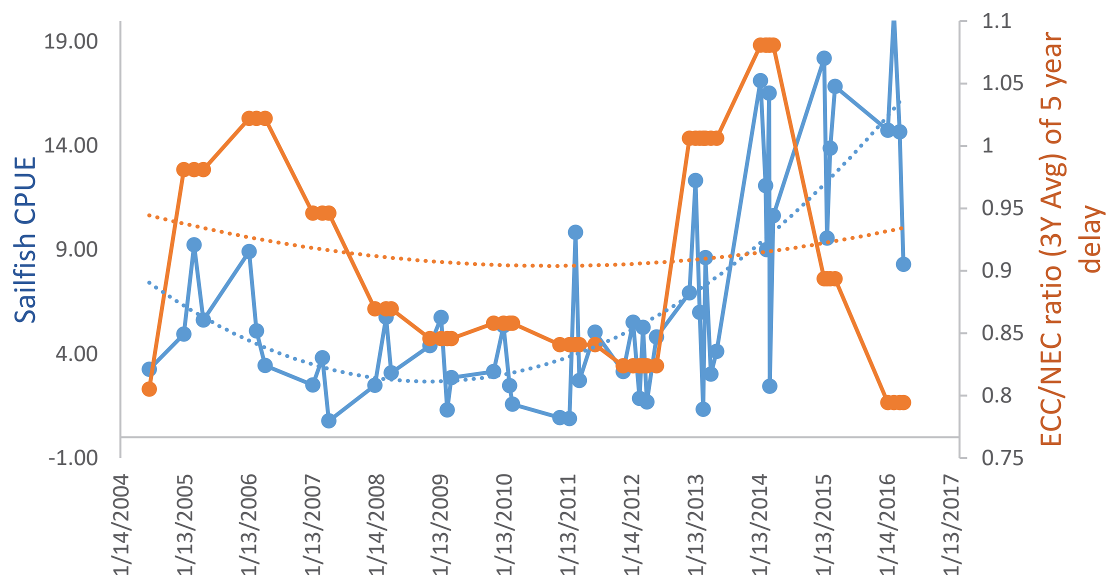

Figure 2.23. The interannual trend of sailfish CPUE and the corresponding 5-year delayed ratio of current strength during winter months (ECC/NEC) Costa Rican tournaments.

Multivariate Analysis

To visualize the structure of the Costa Rican tournament CPUE data and the corresponding environmental variables, we plotted the standardized variables in a scatter matrix (Figure 2.24). There are no obvious correlations between any two of the variables used for analysis.

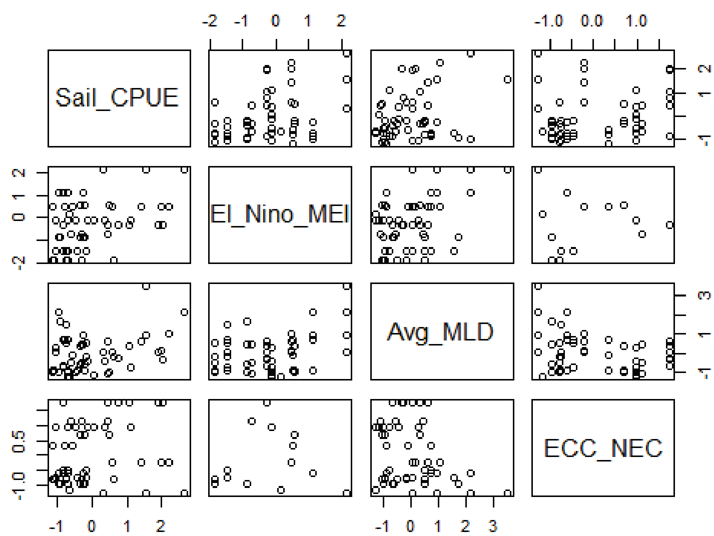

Figure 2.24. Scatter matrix of the Costa Rican tournament CPUE and corresponding environmental variables.

It is possible that some of environmental variables interact with each other. Therefore, we used regression analysis to test for relationships. The two contemporary environmental variables, MLD and ENSO, are likely to covary, because they result from the same oceanographic processes described in the introduction. The MLD, however, is a much more localized measurement, whereas the ENSO MEI is indicative of many ocean-wide processes. Veeranjaneyulu and Colleagues (2016) showed a positive relationship between these two variables. Figure 2.25 shows the covariance of MLD with El Niño. A summary of the analysis of variance of this linear regression (Table 2.3) shows the errors explained by the slope and intercept (Equation 2.13), along with the residual error, and returns a p-value of 0.00506, confirming the positive relationship, albeit weak. The time-lagged current strength ratio (ECC/NEC) should not interact with the contemporary variables, because they are occurring at a different time. There is no evidence that the strength of currents from 5 years ago influences the ENSO index of today. However, the current ratio variable does show a clear relationship (Figure 2.26) with the ENSO values measured at the same time, shown through linear regression of the values for the month of November, 1975-2012. Again, this is because they are the result from similar, linked oceanic processes summarized in the Introduction. Equation 2.14, R squared value of 0.3632, and p-value of regression = 6.237e-05.

Table 2.3. The results of regression of average MLD and ENSO in Costa Rica.

	Estimate	Standard Error	P value
Intercept	-0.90952	0.35186	2e-16 ***
Slope	0.07436	0.02538	0.00506 **
Residual standard error: 0.9267 on 51 degrees of freedom			

$$Average\ MLD = 1.9373 * ENSO + 12.824$$ **Equation 2.13**

$$ECC/NEC = 0.1352 * ENSO + 0.8455$$ **Equation 2.14**.

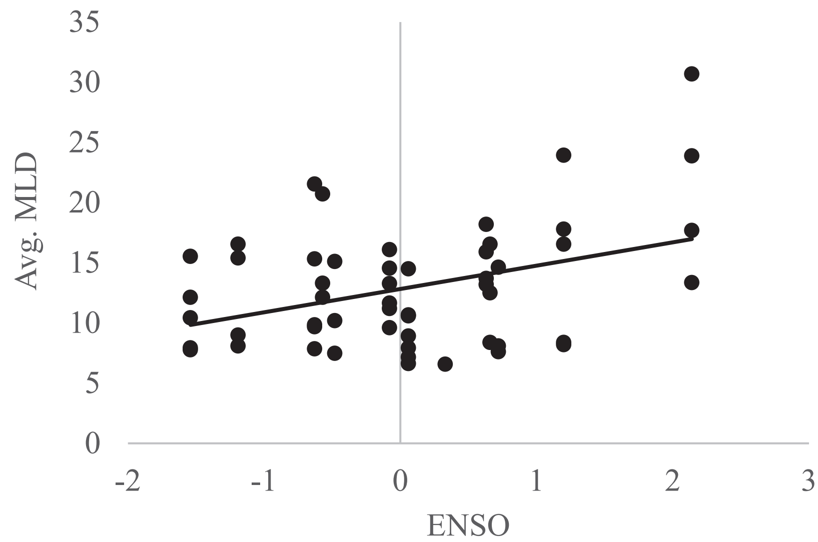

Figure 2.25 The relationship between contemporary variables describing local and regional oceanographic processes, i.e. average winter ENSO and MLD, in Costa Rica.

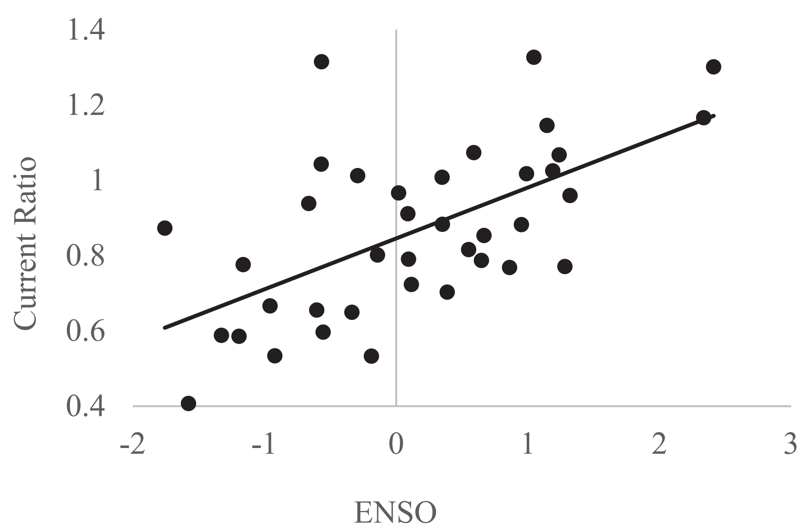

Figure 2.26. November ENSO and the strength of the current ratio during November. These values are not exclusive to a single country.

Next, we performed a principal components ordination procedure to explore the nature of the interactions among variables. Our first principal component accounts for 44% of the variance in the data, and the second accounts for 30% (Figure 2.27). Table 2.4 summarizes the resulting loadings of the Principal Component (PC) analysis, or the relative contribution (weight) that each variable adds to the respective principal component. Along the first principal component axis, the CPUE, ENSO, and MLD variables all correlate in the same direction (positive values) with similar magnitude. Along the second principal component axis, CPUE, ENSO, and the current ratio all correlate along the same axis (negative values). Figure 2.28 shows the original variables projected onto Principal Components 1 and 2. Anything in the right half of the space will have a positive value for PC 1, and thus the original values for CPUE, ENSO, and MLD will also be positive. Along the vertical axis, any tournament that is in the upper half of the space will have a positive value for PC 2, and only MLD, of the original variables, will be positive for this tournament. Sailfish CPUE and ENSO values are drawing in a similar direction, into the same quadrant of the principal component space, and thus have similar standardized values for along the axis of both PC1 and PC2. The numbers refer to the order of the tournaments in time, i.e. #1 is the first tournament, which occurred on 6/27/2004.

Table 2.4 Loadings between the original variables and the principal components for Costa Rican tournaments.

	PC1	PC2	PC3	PC4
CPUE	0.5134	-0.3237	0.6190	-0.4984
ENSO	0.6913	-0.1191	-0.7071	-0.0886
Avg. MLD	0.5061	0.4137	0.3406	0.6757
ECC/NEC	-0.0464	-0.8425	0.0294	0.53584

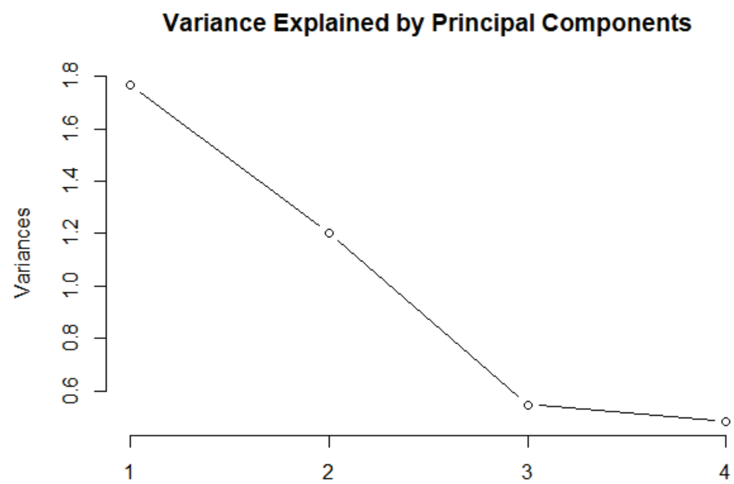

Figure 2.27. Screeplot of the variance explained by the principal components for Costa Rican CPUE analysis.

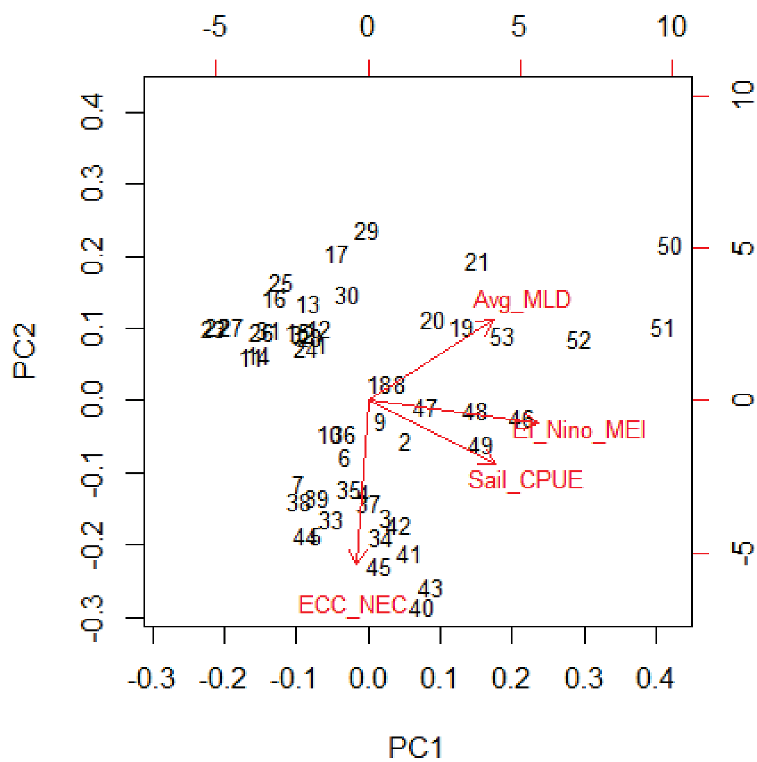

Figure 2.28. Values of PC1 and PC 2 for each Costa Rican tournament (numbers), along with the projection of CPUE, MLD, El Niño, and ECC/NEC (red arrows).

There are several subjective interpretations of the clustering of points in the principal component visualization. In Figure 2.29, we have defined two clusters onto the dataset based on their relation to principal components 1 and 2, which combined contribute to 74.27% of the total variance. Figure 2.30 shows each tournament organized according to these two groups, visualized with color, plotted against time. A pattern emerges after this post-hoc grouping. The dataset can generally be described by three periods. One period of mid to high levels of CPUE (High), transitioning to a period with low levels of CPUE (Low), and a final period of rapidly rising CPUE (High). There is only one outlier from this description, the first documented tournament in this analysis. This point is detached in time from other points, which behave similarly according to the principal component analysis.

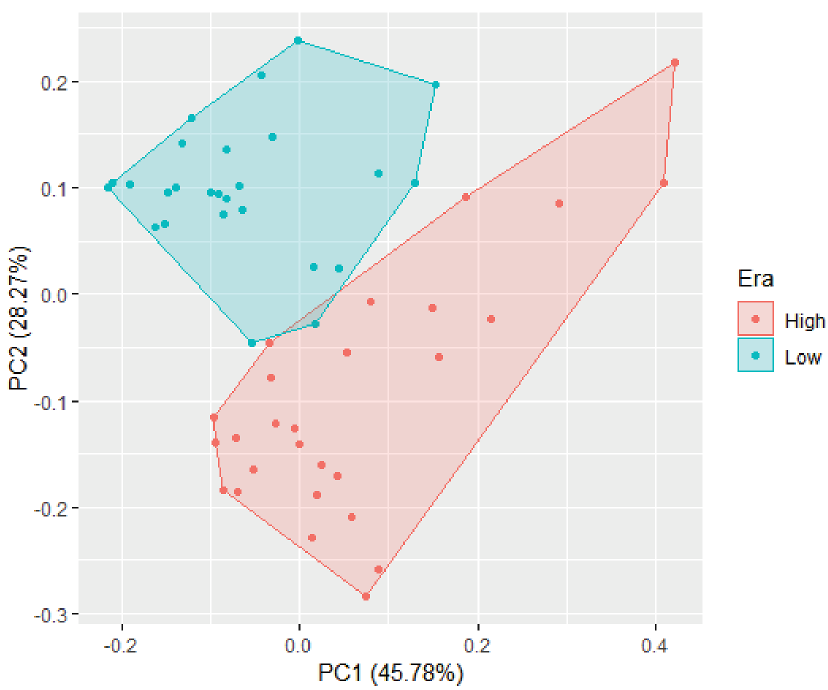

Figure 2.29 Clustering imposed according to eras of high and low Costa Rican tournaments CPUE.

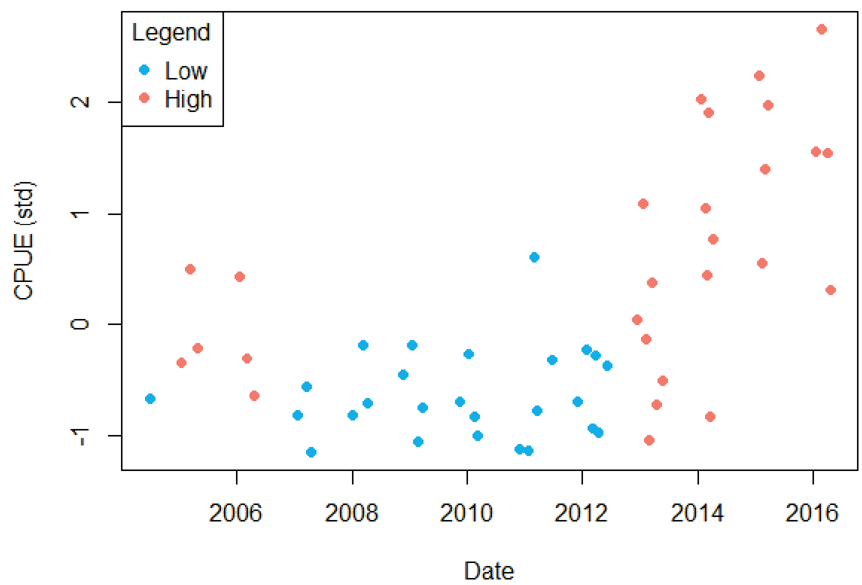

Figure 2.30 The two clusters (High and Low) generally correspond to time periods of mid-level CPUE, low CPUE, and rapidly rising CPUE in Costa Rican tournaments.

Due to the temporal clustering of tournaments according to the newly-defined groups (High and Low), we investigated the nature of these two groups by comparing the environmental variables. Figure 2.31 compares the density of values for standardized variables. Each population is scaled to a unit area. The density of CPUE values confirms visually the two clusters of points, one cluster defined by relatively high CPUE, and another cluster defined by relatively low CPUE, although there is overlap. The ENSO index and ECC/NEC also show markedly different distributions according to the new grouping; however, the MLD variable shows large visual overlap. Using a Shapiro test, we found that these populations of measurements are not all normally-distributed (Table 2.5). Therefore, we used a non-parametric two-tailed Wilcoxon Rank Sum test to determine if the mean values of each variable for these two populations are different (Table 2.6). This test replaces the actual values with their ranks, in ascending order, and compares the sums of these ranks between the two populations. For three of the variables, the CPUE, ECC/NEC, and ENSO, the Wilcoxon test confirmed a significant difference between the two eras. Measurements for the average MLD, however, were similar between the two eras.

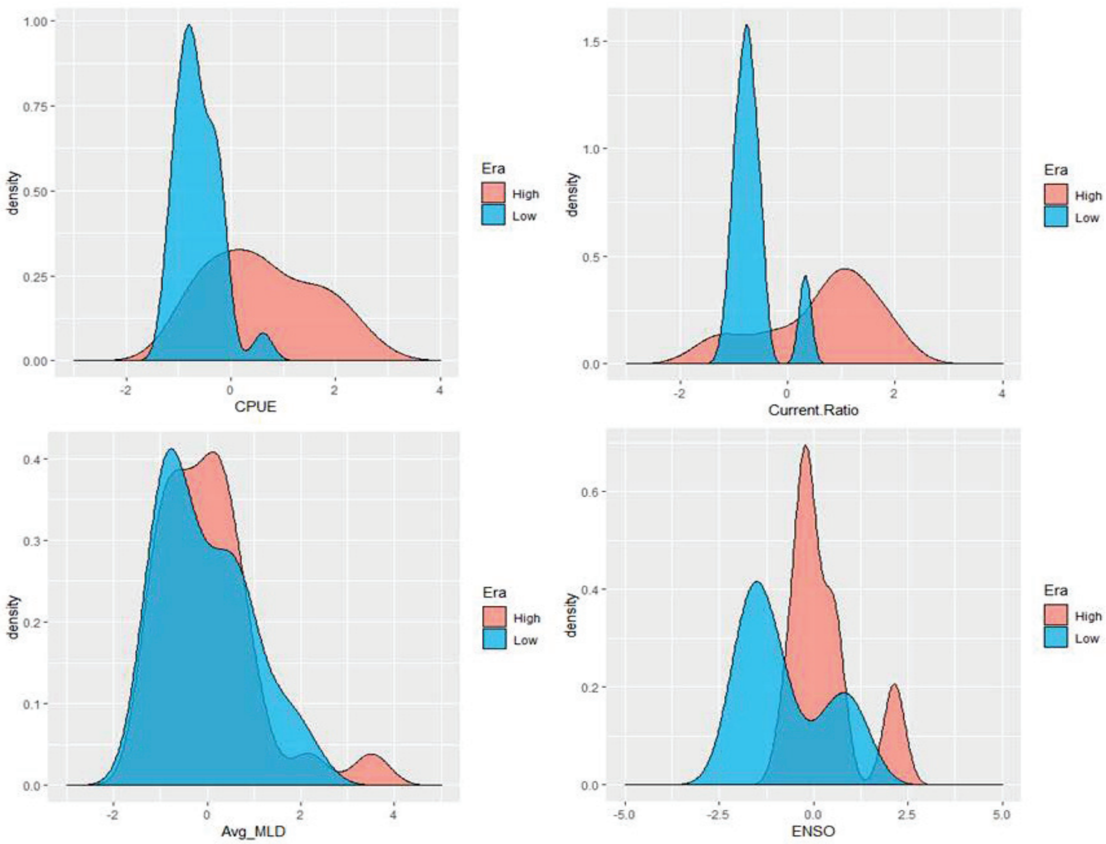

Figure 2.31. Distribution of Costa Rican sailfish CPUE and the three environmental variables between the two imposed clusters (pink and blue) generated by Principal Components 1 and 2.

Table 2.5. Results of Shapiro test on the newly-defined populations of variables.

Variable	High Shapiro W	High p-value	Low Shapiro W	Low p-value
Current Ratio	0.84868	0.001085	0.7746	6.712e-05
ENSO	0.78942	9.027e-05	0.81673	0.0003438
Average MLD	0.87139	0.003147	0.91301	0.03092
CPUE	0.96067	0.3827	0.91004	0.02642

Table 2.6 The results of four Wilcoxon tests comparing the means of each of the four variables between the two newly-defined populations of Costa Rican tournaments.

Variable	Wilcoxon W statistic	Pr (>F)
Sailfish CPUE	604	1.744e-06 **
ECC/NEC	586	2.798e-05 **
ENSO	534	0.001102 **
Avg. MLD	349	0.9787

Lastly, we tested the relationship between the two contemporary environmental variables to determine whether this relationship is different between the two populations of tournaments. Figure 2.32 compares the relationship of MLD to ENSO between the two populations. We compared these two relationships using ANCOVA, to test three hypotheses. Firstly, we confirmed that there is a significant (positive) correlation of the MLD variable and ENSO (Figure 2.25). Secondly, we compared the intercepts of the High and Low era, to determine if there is a group effect. Lastly, we compared the slopes of the two groups to determine if there is an interaction between the MLD and the group. If there is an interaction of the linear relationship with the factor (High or Low), then the slopes are different. Table 2.7 shows the results of an ANCOVA, which revealed that the two populations have a different intercept, and that there is a significant interaction of the population factor (High or Low) with the ENSO.

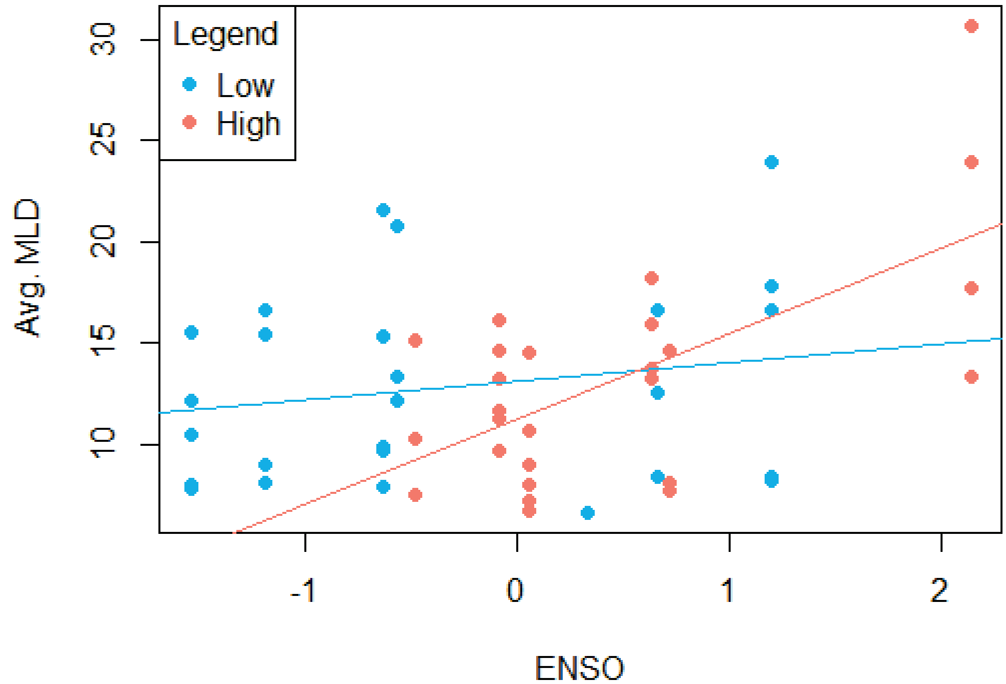

Figure 2.32 The relationship between MLD and ENSO of the two newly-defined Costa Rican tournament populations are compared.

Table 2.7. Results of an ANCOVA comparing the regressions of the two, newly created populations of Costa Rican tournaments. There is a significant interaction of the ENSO index with the Era factor (High or Low), which describes the CPUE.

	DF	Sum Sq	F value	Pr (>F)
ENSO	1	192.05	9.3716	0.003572 **
Era Factor (High or Low)	1	23.77	1.1601	0.286725
Interaction	1	113.19	5.5232	0.022837 *
Residuals	49	1004.15		

The distribution of values of Costa Rican Tournament CPUE failed a Shapiro test (p = 6.472e-05) and are skewed to the right (Figure 2.33). Therefore, we transformed them using the natural log for the analysis of variables contributing to the total variance of CPUE (Figure 2.34) for the multiple regression analysis. The log-transformed sailfish CPUE passes the requirements of normality, tested with a Shapiro test (p = 0.2758), an assumption for the analysis of variance. The results of an analysis of variance on multivariate regression are reported in Table 2.8. The ratio of the 5-year delayed current strength (ECC/NEC) significantly contributes to the variance of tournament CPUE in Costa Rica, with a p-value of 0.0204. The estimate is positive (2.953), confirming previous results that a prevailing ECC contributes positively to tournament catch rates. We did not find a significant result of the effect of ENSO on the catch rates in the analysis of variance. Similar to earlier analysis, and the Wilcoxon test results, the ANOVA here shows that MLD was not a unique factor contributing to the variance of CPUE in Costa Rica (p-value 0.4078). There is also no significant interaction between the two contemporary variables, MLD and ENSO (p-value 0.1536). The residuals from this ANOVA are plotted against the transformed CPUE in Figure 2.35. The residuals do not have systematic distribution and show no obvious trends, indicating that the assumption that the residuals are normal with equal variance is valid.

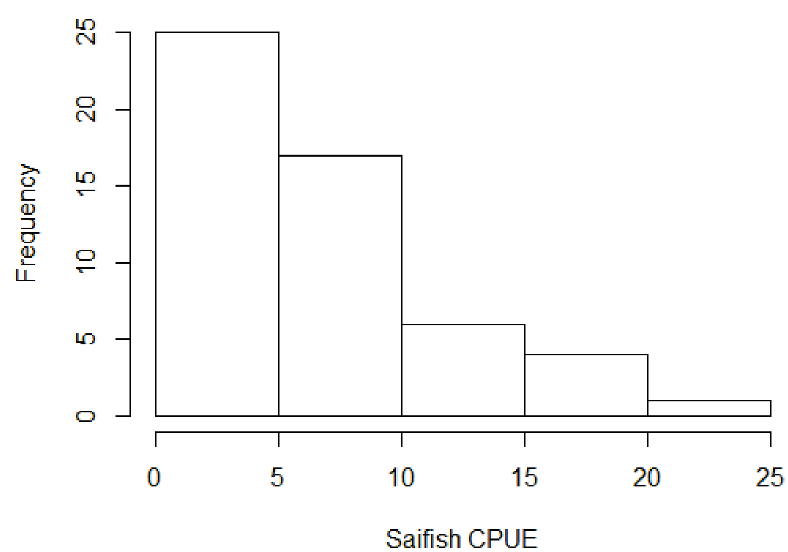

Figure 2.33. Distribution of tournament CPUE in Costas Rica. X-axis indicates the bin size range according to average sailfish CPUE during the tournament and the Y-axis is the frequency of tournament having a CPUE value within that range.

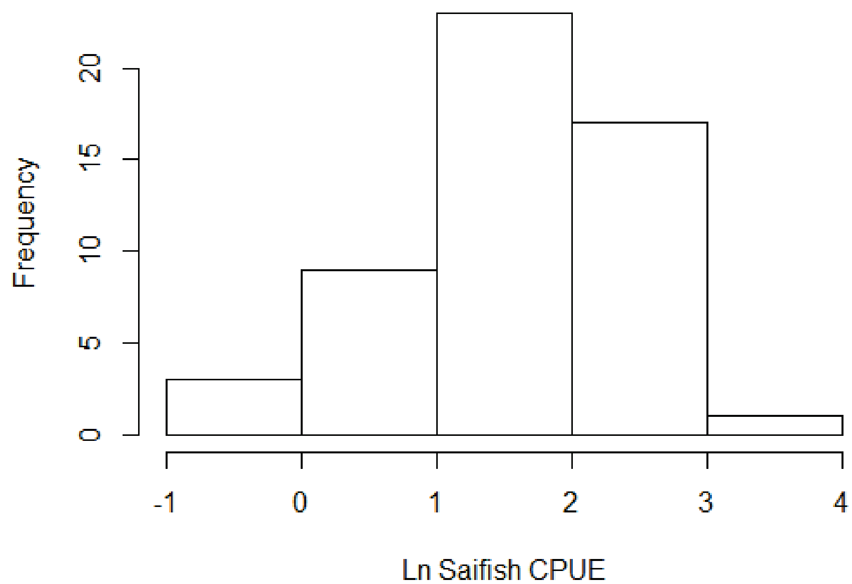

Figure 2.34. Histogram of transformed Costa Rican CPUE used for analysis.

Table 2.8. Estimated parameters from Equation 2.6 for Log(CPUE) as a response variable.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.267	1.243	-1.019	0.313
ECC/NEC	2.566	1.214	2.112	0.039 *
MLD	0.039	0.024	1.586	0.119
ENSO	0.165	0.119	1.378	0.174

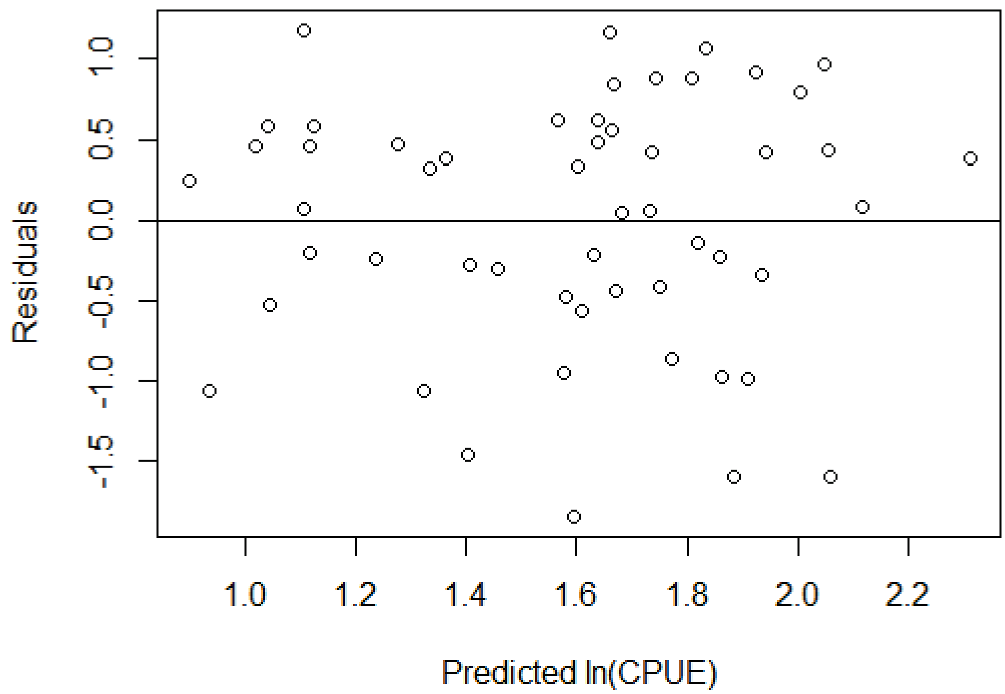

Figure 2.35. Residuals from multiple regression and the predicted log-transformed Costa Rican CPUE from the model.

2.5 Discussion

To answer the question of why recreational sailfish catch rates are different across time and space, we must consider three categories of factors. Firstly, changes in fishing techniques may cause changes in catchability. This issue is not considered in our analysis due to the uniform fishing power of the recreational vessels over the defined time span, and among the tournaments. Secondly, we consider factors inducing spatial changes in the vertical and horizontal distribution of adult sailfish, altering the catchability of the population. We have defined several variables that relate to the compression of preferred habitat of adult sailfish. Lastly, we consider real changes in stock abundance, specifically, recruitment success in years prior to recreational fishing activities.

Guatemala

In Guatemala, we focused our analysis on understanding the effect of habitat compression, approximated by the depth of the mixed layer, on sailfish catchability. Through the analysis of the depth of the mixed layer in Guatemala, we found evidence to support our hypothesis that habitat compression positively influences the catch rates for tournaments. The average depth of the mixed layer within the fishing zone significantly correlated with tournament catch rates for sailfish ($P = 0.016$) after removing the anomaly expressed by a point corresponding to a persistent El Niño year. When the MLD was shallow in the fishing area, this resulted in higher catch rates in Guatemalan tournaments, supporting our hypothesis that compression of habitat vertically forces billfish to remain near the surface, increasing their catchability in recreational fisheries. We found a different horizontal tendency when using the habitat shoaling index, developed from offshore transects. High index values corresponded to significantly lower catch rates ($P = 0.038$). A high index value would indicate that the habitat is either much deeper or shallower near shore relative to the offshore area, thus the higher range of values. We found that catch rates in Guatemala improved when the depth of this layer was homogenous.

Costa Rica

The Costa Rican dataset of 176 tournaments is the largest collection of tournament CPUEs for billfish-targeted tournament fishing in this country. There is considerable variance in the CPUE for tournaments in Costa Rica. It can generally be described in three time periods: a period of mid-level CPUEs, followed by a period of low CPUEs, and lastly a period of rapidly rising CPUE.

We chose MLD, ECC/NEC current strength ratio (5 years delayed), and ENSO as indicators of catchability, recruitment, and sub-regional and regional availability, respectively. The mixed layer depth, as in Guatemala, was further split into a vertical and horizontal component. Of these variables, ENSO is the only variable that also follows a general trend of mid-level values, low-values, and rapidly rising values between the years of 2004 - 2016. The ENSO value is indicative of broad, ocean-wide processes (described in the Background) and many mechanisms that affect billfish populations through their recruitment, mortality, or behavior. The strength of upwelling is a prominent feature that varies with the ENSO index, and we validated the correlation with our average MLD variable, used as an index of upwelling. Predictably, when the ENSO index is high (El Niño-like conditions), the level of upwelling is depressed in the coastal shelf of Costa Rica. The average MLD is consequently high (Figure 2.25). Additionally, the strength/location of currents (Figure 2.26), and frequency/direction of eddy formation/propagation also fluctuate along with the ENSO index, and any one of these other mechanisms may be influencing the adult sailfish population in Costa Rica.

The ENSO index showed partially significant influence on the variation of Costa Rican tournament CPUE. For instance, ENSO had significantly different values when comparing the dates of High and Low CPUE classified tournaments. When the ENSO index was high, the tournament date was more likely to be in the High era for CPUE values. In the analysis of variance, the ENSO variable did not significantly contribute to the variability in tournament CPUE. These results, plus the broad scale trends described by the polynomials (Equation 2.9 and 2.11) were counter to our hypothesis, that high ENSO values would have a negative effect on catch rates through the relaxation of seasonal habitat compression. Our results suggest that when upwelling is depressed, as in years with a high ENSO index, Costa Rica's recreational fisheries have higher catch rates for sailfish. El Niño-like conditions appear to favor recreational anglers in Costa Rica, potentially through altering the catchability (q) of adult sailfish.

It is possible that the ENSO index is indicative of vertical habitat compression on a larger scale than the average MLD measured within the fishing zone, which did not contribute to the variability of Costa Rican Catch rates. It is also likely that the ENSO index is revealing mechanisms affecting the horizontal distribution of sailfish populations. ENSO is demonstrated to correlate with the strength of major currents in the EPO, and these currents may be transporting water of varying preference for billfish or their prey, due to oxygen, nutrient richness, or water temperature. Other researchers (Braun et al. 2015) have suggested that temperature may be the main factor controlling the movement of billfish. Satellite tagging studies show that most billfish thrive in a narrow temperature range, approximately 22° – 24° C. ENSO is also known to affect eddy formation/propagation, which act as enrichment and retention mechanisms for fish. An increase or decrease in the frequency of eddies propagating close to the coast may disrupt normal sailfish behavior.

Results of our analysis of tournament catch rates in Costa Rica corroborated other studies which found a degree of influence with ENSO and billfish catch rates (Ehrhardt and Fitchett, 2006), in accordance to the vast literature exploring the link between El Niño phenomenon and fisheries productivity. In fact, commercial tuna fishers have long known about the changes in stock distribution and catchability of these top pelagic predators associated with El Niño (Lehodey et al, 1997). The analysis using principal components was consistent with this mechanism, implying that disturbances to the average state of the ocean creates winners and losers in the ecosystem and contingent fisheries.

It is probable that CPUE is affected by El Niño through a mechanism which affects the catchability (q) of adult sailfish. It is likely that spatial migrations are affecting the portion of the stock that is captured by a single fishing effort unit in a given location, in accordance with the hypothesis of Lehodey and colleagues (1997). However, CPUE is additionally dependent on the current abundance (N) of the fully-recruited adult population. Present ENSO status cannot affect the population abundance of adults (average age: 5) through recruitment processes, however it may be affecting the survival of adults, which would also be reflected in the catch rates. Although it is possible that present El Niño conditions simultaneously affect the catchability and mortality of adult sailfish, its influence on true abundance is not incorporated into our statistical analysis. Other billfish researchers have been unable to detect an El Niño influence (Ortega-García, et al. 2003) on tuna distribution for a different region of the EPO (Mexican Baja Peninsula).

Interestingly, the two indices created from MLD were not strong variables influencing the catch rates for Costa Rican tournaments. Average MLD is arguably a better indicator of local, vertical habitat compression than ENSO, because it is apportioned in the specific fishing area, and not on an ocean-wide basis. We were also unable to show evidence for horizontal habitat compression in Costa Rica, using the Shoaling Index, as we demonstrated in the analysis of Guatemalan MLD ranges. This non-significant result was surprising because the MLD is tightly coupled in time with fluctuations in the thermocline and Oxygen Minimum Zone (Ehrhardt and Fitchett, 2006), hypothesized to be limiting features for preferred sailfish habitat.

MLD is also known to be coupled with fluctuations in El Niño strength, which was a significant factor in the principal component analysis of Costa Rican tournament CPUEs. Therefore, the two variables are conceptually linked. The combined results of the analysis pertaining to both ENSO and MLD provide insight into the effect of upwelling on adult sailfish populations in Costa Rica. Throughout the Costa Rican analysis, the ENSO values influenced CPUE in a manner that was counterintuitive to the proposed mechanism of upwelling intensity and catchability. The MLD indices (vertical and horizontal) were consistently insignificant for Costa Rican billfish tournaments. We hypothesize that in our case, ENSO is representative of other additional mechanisms that are affecting the catchability of sailfish. El Niño is associated with large scale, regional processes, and it has been shown to correlate with many physical and biological features in addition to upwelling intensity, such as eddy formation frequency (Bakun et al, 1996). Eddies play an important role in the vertical and horizontal transport of heat, mass and the chemical constituents of seawater, such as oxygen and nutrients (e.g., Klein and Lapeyre, 2009), with the ability to enhance biophysical conditions for survival and reproduction of marine organisms. Eddies, ocean currents, and other physical features may be affecting sailfish behavior, or the behavior of their prey, subsequently changing their spatial distribution and abundance (Lea and Rosenblatt, 2000, Bakun and Broad, 2003) in synch with the El Niño oscillations.

Although we were unable to show a significant influence of vertical or horizontal habitat compression for Costa Rican billfish tournament catch rates, we do not believe that the billfish in this area are behaving independently of this mechanism, due to their yearly catch rate fluctuations coinciding in time with the seasonal upwelling. The majority of our tournament samples occurred during the high season for sailfish fishing. It is possible that we did not obtain the contrast in time to measure the effect. Tournaments are not held during the summer for good reason; local knowledge indications that there are very low catch rates during this time. The data of opportunity limited our analysis because these samples could not be obtained

Another limitation of our analysis of habitat compression is the resolution of the MLD data, which may have been insufficient to track sailfish interactions with habitat compression. The GODAS model assigns a value of the average MLD to the center of each 1X1 degree square in the Pacific Ocean based on measurements taken anywhere within the 1X1 square. Our use of a 70-nm radius for the tournament fishing zones necessitated the interpolation of the points in between these assigned values. Although is a usual method for inferring the finer scale values necessary for our analysis, it is important to note that the original data has been first compressed, and then expanded based on assumptions that are likely violated to some unknown extent. (Jin Li, 2008). The fishing zone also highlighted another complicating factor for the MLD variable: the lack of interpolated values close to shore (Figure 2.36). This is due to the limitations of the GIS software to assign values outside of the spatial extent of the GODAS model. These nearshore values may be, in reality, quite different from the nearest interpolated value in the model, and likely have a high degree of influence in the catch rates of those fishing nearshore; however we were unable to include them for analysis. Real time measurements of the depth of the mixed layer in the fishing zones would provide the data necessary to test our hypothesis.

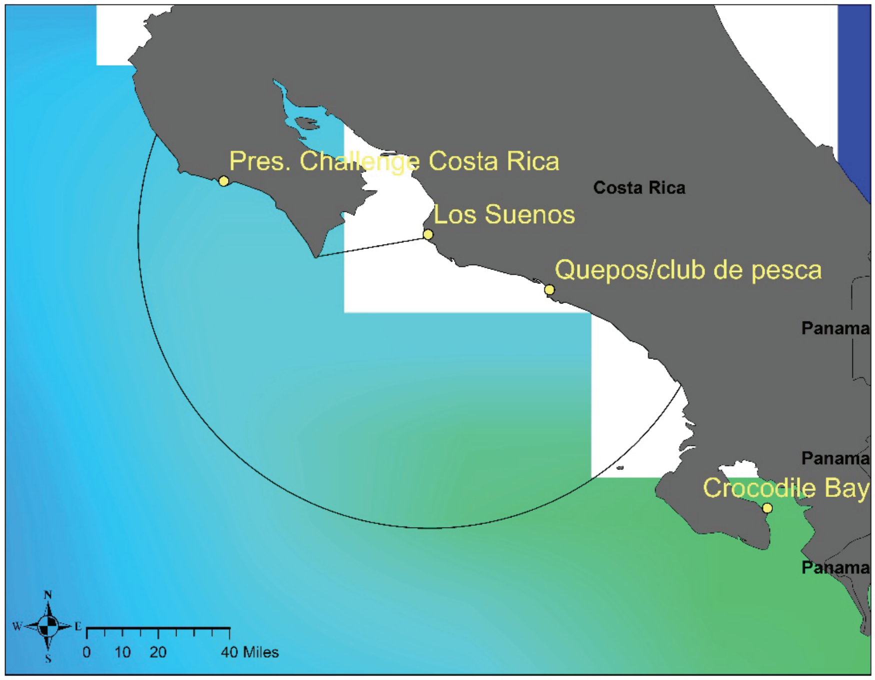

Figure 2.36. The lack of available MLD values (white) in the Los Suenos fishing zone.

In the Costa Rican tournament analysis following the ordination procedure with principal components, we also found evidence for a delayed effect on recreational catch rates of an index of current strength (ECC/NEC). When we compared the values of the current ratio between the two newly-defined populations of tournaments (eras of High and Low CPUE) the current index also showed two distinct populations. In other words, when the ECC prevailed and the ratio was high, a tournament approximately 5 years in the future would be more likely to have high CPUE values. The importance of this index was verified in the analysis of variance. The prevailing ECC within the current ratio significantly and positively influences Costa Rican tournament catch rates approximately 5 years in the future. Based on the results of Fitchett (2015) that age 5 predominate catches, we interpret these results as a signal that successful sailfish recruitment may be favored by a particular set of ocean current conditions.

By combining the strength of the two currents into one index, we are describing the bulk volume of water moving either toward or away from the continent, which may be an important factor for recruitment. When this ratio is high, the ECC current prevails, pushing water toward the continent. This net flow may bring larval and juvenile sailfish closer to the coastal regions. Currents such as these two may be responsible for transporting young fish to the preferred habitat of adult sailfish (Cowen 2002). Previous studies have shown that zonal current strengths in the EPO could be linked to better larval sailfish recruitment, and that this is evident as increased abundance of age 5 fish (Fitchett 2015). This study, however, concluded that a strong NEC was linked to high recruitment. The mechanism linking these currents to larval retention and successful recruitment is still unclear. Additionally, these currents are responsible for some of the eddy formation in the region, and Bakun (2006) suggests that these features provide resources for larval fish. The Northern Equatorial Counter Current (ECC) and the Northern Equatorial Current (NEC) are major water transport mechanisms in the EPO, and it follows that they are likely to affect spawning success, larval survival, and recruitment to the adult population. The nature of these affects, however, are only beginning to be studied and understood.

In contrast with the contemporary environmental variables pertaining to the catchability (q) portion of the localized catch equation (Equation 2.1), the recruitment mechanism of the current ratio index pertains to the true abundance of the sailfish population (N). The time-delay of this index allows us to rule out potentially confounding impacts on catchability of adult sailfish. The currents may be useful to define eras of high or low recruitment. It is likely that these currents affect other fisheries as well.

If CPUE is used to calculate an index of abundance for assessments, variability created by the dynamics of catchability will confound the methodology and conclusions if not adequately modeled. For example, in other billfish assessments, there has been some effort to standardize the CPUE of such interference, according to the nature of fishing effort (gear, depth, area, etc.). Habitat Standardization methodology (Hinton and Nanako, 1996) modifies the effort component of CPUE indices to account for the proportion of the effort that occurs in the fish's preferred habitat, in their case, blue marlin. This implies that CPUE samples fully cover the spatial extent of the fishery, which was not possible for our analysis. They assume that the vertical distribution of blue marlin is solely a function of the temperature relative to the surface. In our analysis, we do not define habitat as a matter of fish population preference, but rather as a variable affecting the localized catchability. In both types of analyses, however, the power of a fishing effort unit changes depending on the time and location.

This research illuminates several environmental mechanisms that affect recreational fishing in Central America. Two of our variables were intended to address the catchability component of the catch equation, MLD and ENSO. We found varying degrees of influence of these variables on the tournament catch rates in Guatemala and Costa Rica. Our other variable, ECC/NEC, was intended to address the abundance component through recruitment processes. We determined that a prevailing ECC current may contribute to positive recruitment and thus higher indices of relative abundance. In our Costa Rican CPUE database, we saw a positive trend in the CPUE values starting in the mid-2000s, which corresponds to rising values in the Japanese Longline CPUE data from the 2017 IATTC status of the stocks report during that same time period (Figure 1.8). Although the recreational fisheries are only sampling a small, peripheral portion of the main geographic density of sailfish stock, it is possible that these trends are indicating a modest recovery for sailfish stocks in the EPO, which have been trending down for several decades. This time period also corresponds to a relative drop in commercial longline effort in the EPO, evidenced by the reduction in millions of hooks reported by the IATTC (Figure 1.5). This evidence supports the idea that the industrial longline industry is directly linked to the sailfish mortality through its large amount of bycatch. The effort represented by artisanal longline operations, however, is thought to be substantial and is unaccounted for in these estimates. It is therefore impossible to estimate the changes in abundance that may be related to changes in fishing mortality.

Chapter 3

Angler Motivation and Satisfaction in Guatemala’s Recreational Fishery for Billfish

3.1 Background

Guatemala has consistently high recreational catch rates for sailfish (sportfishingmag.com), and it is considered by some to be the “Sailfish Capital of the World.” Guatemala’s recreational fishery for billfish draws international anglers to the small coastal community Puerto San Jose (Figure 3.1) and the adjacent colonial town Antigua. Expenditures from anglers and their families support a major industry for these towns. For this reason, the government and for-hire fishing industry alike are interested in preserving the marine resources that support this tourism in the face of growing commercial exploitation of pelagic fisheries in the region (IATTC, Chapter 1).

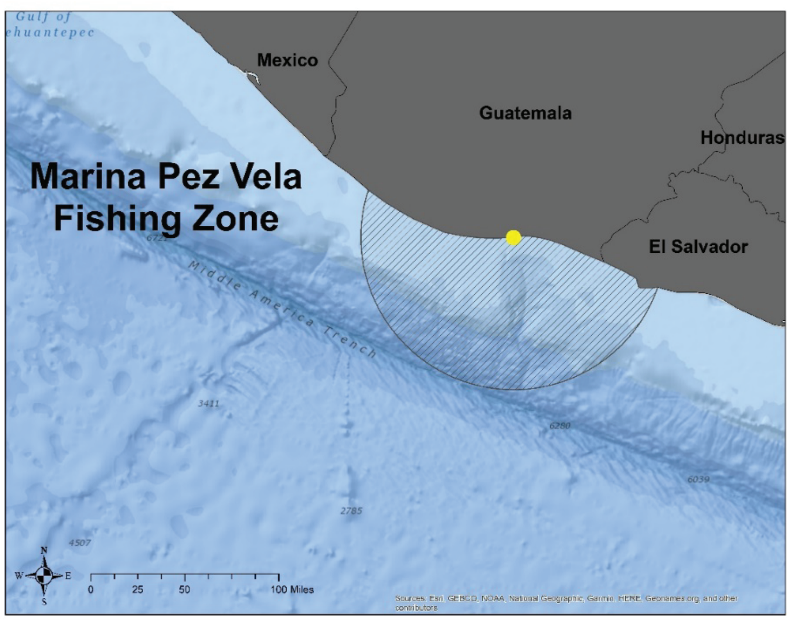

Figure 3.1. 70-mile radius from Marina Pez Vela, in Guatemala, where recreational fishing takes place.

Angler preferences

Identification and protection of the aspects of fishing that attract and satisfy recreational anglers is necessary for fishery managers as well as industries which rely on recreational fisheries. In economic terms, the aspects of a recreational for-hire fishing trip may be considered attributes, and a charter fishing package may be considered a differentiated good which contains several attributes. For instance, the species being targeted, or length of trip may be considered different attributes of a single good (the fishing package). Although consumers can choose their preference of attribute combinations, they are all similar enough in the consumer's mind to be considered one commodity. Furthermore, the purchase of a fishing package is a single financial transaction.

Both catch and non-catch related attributes of fishing contribute to the perceived value of recreational fishing trips or for-hire charter trips. Daily catch rates are an example of a catch related attribute. Conversely, vessel size would be considered non-catch. Some attributes can be guaranteed to a degree: the lodge and accommodations for example. However, other components cannot be guaranteed, such as successful fishing. For these attributes, anglers make their choices based on expectations, which can be based on researching internet and literature sources, word of mouth from other anglers, or prior experience. In this way, features which motivate (ex ante) and subsequently satisfy (ex post) anglers are necessary considerations to optimize human benefit of recreational fisheries.

Many researchers in the field of human dimensions have devised surveys to elucidate factors contributing to angler motivation and satisfaction. Early studies on recreational fisheries relied on stated preference survey designs to reveal differences when anglers are divided by specialization and experience (Fisher 1997, Salz, Loomis et al. 2001). Other studies have used the choice experiment design to determine the rational preferences of anglers according to their specialization categories (Aas, Haider et al. 2000, Oh and Ditton 2006). Demographic factors such as race, ethnicity, and income also contribute to participation patterns among recreational anglers (Lee, Scott et al. 2016) in addition to their motivations, preferences, and satisfaction (Brinson and Wallmo 2017).

As an aggregate group, recreational anglers often report that non-catch oriented aspects of the fishing experience are more important than catch related aspects (Fedler and Ditton 1994). For certain management purposes, this description may be adequate, however many authors have found differing results when anglers are divided into subgroups based on the context of the fishing trip. The characteristics of the fishing experience (i.e. expectations and outcomes) as well as the anglers themselves can usually be divided into categories that are catch oriented and non-catch oriented. For instance, the desire to be outdoors in nature is a major motivation factor for most anglers (Spencer 1993) as well as social aspects of fishing, like solitude, or conversely, companionship (Falk, Graefe et al. 1989) regardless of catch expectations or success. A study on a broad group of Texas recreational fishing permit holders found low correlation with any catch oriented factors such as size or number to other motivation factors (Anderson, Ditton et al. 2007).

As anglers become more specialized, however, either by experience or species being targeted, catch oriented aspects become more important to the motivation of the anglers (Beardmore, Haider et al. 2011, Beardmore, Hunt et al. 2014, Dabrowksa, Hunt et al. 2017). Oh and Ditton (2006) measured specialization with 8 different variables, resulting in the classification of anglers into three groups: advanced, intermediate, and casual. The groups showed notably different patterns in their preference for catch oriented management conditions. In another study, anglers who had previously experienced “bad fishing” placed more importance on catch (number of fish and size) when considering their motivations than counterparts who recently experienced “good fishing” (Finn and Loomis 2001). Norwegian freshwater anglers preferred bigger fish, but not more fish (Aas, Haider et al. 2000). Olaussen (2016) found a higher willingness to pay for fishing trips when salmon anglers expected higher catch rates. These anglers had a strong aversion to management regulations mandating catch and release, suggesting a degree of importance relating to harvesting salmon for consumption as a motivation.

Not surprisingly, catch related aspects of fishing success (e.g. number of fish and size), influence not only the motivation of anglers, but the post-trip satisfaction as well. Likewise, the degree of fishing specialization also plays an important role in shaping the anglers’ perception of how successful their trip was. Anglers who identified as targeting one or few species were generally less satisfied after their trip than those targeting diverse species (Beardmore, Hunt et al. 2014). McCormick and Porter (2014) found that younger, less specialized, and less experienced anglers tended to be overall more satisfied, although all groups showed some correlations between fishing success and satisfaction. It is clear that for some recreational fisheries, measurements of anglers’ motivations and subsequent satisfactions are multi-dimensional. Additionally, context-specific specialization can influence the importance of catch oriented attributes to the angler's perception of their fishing experience.

Billfish Anglers

Because of the relative homogeny in species targeted, socioeconomic factors, and the commitment to practicing catch-and-release, anglers who target billfish can be considered highly specialized among recreational fishers. Thus, they are an ideal subgroup to study motivations and satisfactions. Recreational fisheries for billfish in the United States and elsewhere are almost exclusively catch-and-release (Ditton and Fisher 1990, Ditton and Fisher 1992), and there is considerable taboo in bringing a sailfish (*Istiophorus platypterus*) or blue marlin (*Makaira mazara*) to a dock unless it is large enough to potentially qualify for an International Game Fish Associating (IGFA) record. Even fishing tournaments with millions of US dollars in prizes have very few billfish that are not released (Ditton and Stoll 2003). Furthermore, marlin and sailfish are banned from sale in the continental USA (Billfish Conservation Act of 2012) and there is virtually no market for them as seafood in the United States. Anglers who specialize in billfish are almost entirely motivated by non-consumption aspects of billfish fishing, and many travel worldwide to seek these fish (Hanley, MacMillan et al. 1998).

Economically lucrative industries catering to international billfish anglers have developed in countries such as Mexico, Costa Rica, Panama, and Guatemala. The tourism dollars spent in these locations generate high economic activity, and in fact, entire towns and economies have grown around recreational fisheries (López-López et al. 2006). In those locations, other types of fishing experiences in addition to offshore trips targeting billfish are offered. For example: trips targeting tarpon, bonefish, roosterfish, or tuna may be as popular as billfish fishing. Fishing charter companies operating out of Marina Pez Vela in Guatemala, however, are specialized in targeting almost exclusively billfish.

Fishing in Guatemala

Many of the billfish fishing trips sold in Central America, including Guatemala, are all-inclusive packages, and they can be considered differentiated goods insofar that they contain multiple attributes, at different levels. For our purposes, daily catch expectations are considered an attribute because international anglers can choose between packages at different locations in the world, or during different times of year, which offer different "typical" catch rates. For example, an angler might see 1 or 2 billfish on a typical day in Florida, USA. Anglers traveling to Costa Rica can expect to see even more on a typical fishing trip. Anglers in Guatemala consistently see the highest numbers of sailfish of any known recreational fishing location during the high season, November – April (Chapter 4). NOAA's billfish tagging program also ranks fishing locations (Table 3.1) by catch rates (not separated by species) according to the Billfish Angler Survey. Guatemala comes in at the top of the list with an average of 7.00 billfish per fishing day, while the next runner-up, Costa Rica, has 2.65. Furthermore, many fishing enthusiast magazines and online blogs/reports claim that Guatemala has the highest catch rates for sailfish of any destination in the world (www.fishfishme.com; www.marlinmag.com).

Table 3.1. Average billfish catch rates for comparable fishing locations from NOAA's Billfish Angler Survey (https://swfsc.noaa.gov/BillfishTagging/)

Location	Angler Fishing Days	Number of Billfish	Billfish per Fishing Day	Major Species
Pacific Ocean				
Hawaii	898	379	.42	Blue Marlin
Southern California	670	141	.21	Striped Marlin
Baja California	247	222	.90	Striped Marlin
Acapulco/Ixtapa	115	202	1.76	Sailfish
Australia	75	42	.56	Black Marlin
Panama	68	48	.71	Sailfish
Costa Rica	62	164	2.65	Sailfish
Tahiti	52	15	.29	Blue Marlin
New Zealand	48	10	.21	Striped Marlin
Manzanillo, Colima	27	11	.41	Sailfish
New Guinea	20	5	.25	Blue Marlin
Mazatlan, Sinaloa	20	14	.70	Sailfish
Guatemala	13	91	7.00	Sailfish
Puerto Vallarta	10	8	.80	Sailfish
Samoa	10	2	.20	Blue Marlin
Galapagos Islands	5	2	.40	Striped Marlin
Fiji	4	0	.00	-
Huatulco, Oaxaca	4	1	.25	Sailfish
Kiribati	1	0	.00	-
Atlantic Ocean				
Dominican Republic	16	12	.75	White Marlin
Bermuda	10	18	1.8	Blue Marlin
Cape Verde Island	5	1	.20	Blue Marlin
Florida	3	3	1.00	Sailfish
Florida Keys	1	1	1.00	Blue Marlin
Cayman Islands	1	0	.00	-

The experience of billfish fishing in Guatemala has many qualities that are universal to all recreational billfish fishing experiences; it is enjoyed in many places in the world's oceans, and provides the opportunity for anglers to enjoy nature, the relative solitude away from land, companionship with friends/family, and the chance to interact with large, charismatic animals (Figure 3.2). The one exception – Guatemala's remarkably high seasonal catch rates, can be said to set this fishery apart from other billfish fishing destinations. In one instance, in 2013, an American angler fishing in Guatemala caught and released 91 sailfish in one day, while his counterparts fishing in the US average two or three on a good day of fishing. In January 2016, the boat *Rum Line* in Guatemala released 89 sailfish in one day. Consequently, there are few, if any substitute fishing locations for anglers seeking such high catch rates.

Figure 3.2. Recreational anglers often participate in scientific data collection, like satellite tagging studies. From marlinmag.com.

The uniquely high seasonal catch rates are due to the high density of the sailfish locally, during the months of November through April (Ehrhardt and Fitchett 2006). During this time, sailfish and other pelagic predators are compressed to the near-surface layers of the ocean as a result of the upwelling of anoxic waters. This is known as habitat compression, and results in the high density which permits billfish anglers to utilize atypical techniques such as fly fishing, which is more difficult and usually results in fewer catches.

As previously stated, anglers drawn to the seasonal high density of billfish in Guatemala are believed to represent significant economic stimulation and employment for the small coastal community by the lodge operators. A review of websites reveals that the average cost of a Guatemalan fishing package is $1,139 per person per day (US dollars 2016), with the majority of packages sold as three day bundles (3 days fishing, 4 nights lodging.) Prices vary by season, boat size, room type, and number of additional anglers on the boat. Following Holland, Ditton, et al. (1998), the commitment to catch-and-release practices, as well as the economic contributions to local communities, qualifies this fishery as a form of ecotourism. Furthermore, expenditures represent only a portion of the total economic value of the fishery. In fact, there is additional value unrepresented in the price of packages, which is the angler's willingness to pay additional money before foregoing the fishing trip (consumer surplus). Previous studies have shown that Central American recreational fisheries in the Pacific have higher aggregate economic value (expenditures plus consumer surplus) than comparable fleets in the United States (Ditton and Stoll 2003), however no valuation studies have been attempted for Guatemala. Identification and protection of Guatemala's unique recreational fishing characteristics is necessary to ensure that this important fishery continues to thrive.

3.2 Problem Identification, Purpose, and Objectives

Factors contributing to the demand for recreational fisheries have been studied broadly, surveying a general population of anglers and within the context of a non-specific fishing experience. However, when either the anglers or the fishing experience is highly specialized, the influence of these factors may be different. It is unknown what motivates the anglers who travel to fish for billfish in Guatemala, their experience or specialization level, and the factors contributing to their satisfaction. This information is crucial to understand the foundation of the economic value of this recreational fishery.

Purpose

It is believed that the expectation of catching extremely high numbers of billfish is the main motivation for international anglers to fish in Guatemala's waters. This paper examines the demographics and opinions of these anglers, and factors influencing their motivation and satisfaction. The results may provide a better understanding of the nature of the demand for billfish fisheries services, which could be used to justify conservation measures in Guatemala's exclusive economic zone.

Objectives

1. Quantify the billfish catch rate expectations of anglers fishing during Guatemala's main fishing season.
2. Examine the degree to which this factor motivated their decision to fish in Guatemala instead of elsewhere.
3. Examine the extent to which their motivations, expectations, and fishing outcomes influenced their satisfaction.
4. Investigate the influence of other demographic factors, such as specialization and experience, which have been shown in other studies to influence motivation and satisfaction.

3.3 Materials and Methods

Survey Protocol

We developed this survey with the cooperation of Guatemala's billfish fishery stakeholders (recreational fishing lodge operators and captains), using conceptual protocols from previous surveys in the literature (Beardmore et al. 2014; Arlinghaus 2006). The survey gathered information about anglers' demographics, knowledge and commitment to recreational fishing, motivations, opinions about conservation issues, gear preference, trip expectations and outcomes, and lastly, satisfaction. Most questions related specifically to perceptions and expectations of Guatemala's billfish fishery, with few broader questions such as the angler's country of origin. Whereas other surveys have inquired about angler's motivations or knowledge of recreational fishing in general, this survey focused on their decisions to fish for billfish in Guatemala instead of elsewhere, operating under the assumption that these anglers would have fished for billfish somewhere, as opposed to foregoing fishing in lieu of another activity. In coordination with lodge managers and staff, we decided that the survey should fit on one sheet of standard size printer paper, front and back, and certain questions were altered in the interest of brevity.

Although there are several fishing charter companies operating out of Guatemala's Marina Pez Vela, two lodges represent the majority of clients for all-inclusive fishing packages. We surveyed visitors of Casa Vieja and Pacific Fins during the months of February through April in 2017. Lodge staff administered the 1-page survey, either through a web document or a sheet of paper. Clients were surveyed during leisure time at the lodge, before or after the day's fishing activities. Each survey included instructions that participation was completely voluntary, answering all questions was encouraged but not necessary, and responses would be kept anonymous. SEE APENDIX for survey sample.

Angler Demographics, Gear Preference and Avidity

A portion of the survey served as an instrument to collect demographic and fishing information from the anglers. Information of particular importance is the commitment to fishing. The most straightforward measure of commitment is the number of years spent fishing for billfish specifically. Secondly, fishing magazine or IGFA subscription was used as an indicator of overall commitment or avidity to sport fishing and learning about sport fishing current events. We focused magazines/newsletters that appeal to billfish anglers, Marlin magazine being the most notable, or more broadly to saltwater anglers. Lastly, we asked participants if they checked one or more fishing reports prior to booking a trip. This analysis is important to identify characteristics common to clients for these services and to identify potential future demand for the billfish recreational fishing experience. We also asked anglers if they preferred to fish alone or with fellow anglers and why.

Angler Opinions

A section of the survey asked respondents to rank their level of agreement to statements relating to billfish conservation issues. These statements provided us with a better understanding of anglers' beliefs and knowledge about the fishery. Responses to these questions are defined here as categories, therefore modes are calculated. This is in contrast to previous studies (Fedler and Ditton 1994, Brinson and Wallmo 2017) that treated rankings as numerical measurements.

Angler Motivations, Expectations and Satisfaction

This survey assumes a fair degree of knowledge about fishing for billfish specifically. For instance, we asked anglers questions about how many billfish they expected to raise per day of their fishing trip. A raise refers to a fish that has been visibly drawn to the surface by teasers or bait. A catch refers to a fish that has been caught, reeled to the boat, and released alive. Raises per day is a better indicator of relative billfish abundance than catch per unit effort (CPUE) in this instance because the issue of individual angler skill (an element of catchability) is removed. Anglers who seek to catch a billfish using a fly rod have a much lower probability of hooking and subsequently releasing a billfish compared to anglers using conventional gear. The number of raises seen by both angler types, however, is comparable (Figure 1). The number of raises and catches are identified, logged, and reported by the captains during fishing activities, shared with other clients staying at the lodges, and reported on the websites. Some lodges have a scoreboard posted in common areas like the bar to encourage friendly competition and interaction among visitors. For these reasons, we assume that survey respondents are familiar with these terms.

Motivation was a fill-in question, as opposed to many other surveys which ask respondents to rank components of motivation on a scale. This was done for two reasons. First, the possibility that other unidentified aspects were motivating anglers was considered. Secondly, the instructions needed to be extremely simple, due to the fact that there was no trained professional administering the survey to explain the ranking system. Similarly, the question regarding satisfaction, here defined as the degree to which expectations were met, was also designed to be simple to understand. Respondents were asked if the trip either failed to meet expectations, met expectations, or exceeded expectations. Thus, the satisfaction was ranked as scale with three categories. We also asked respondents to report their main motivation to fish in Guatemala instead of elsewhere. This is in contrast to most studies that aim to measure the decision to simply fish or not fish. This is appropriate to describe the qualities drawing international anglers to Guatemala, because they have many options for locations to fish for billfish. These anglers are, for the most part, not limited by travel expenses. These questions were fill in the blank and categorized once all surveys were collected.

We used several parametric and non-parametric methods to test the correlation between the motivation, success, and satisfaction variables. The satisfaction ranking was transformed into a probability of reporting that “expectations were exceeded,” (score of 3 on the scale) by grouping participants based on their daily catch rates. We next tested the robustness of the linear relationship between these two variables (catch success and probability) using bootstrapping resampling methods. By resampling the estimates from this regression many times, this analysis allows us to estimate confidence for the correlation coefficient of the estimated linear parameters (slope and intercept). We also produce estimates for the distribution of parameters produced by the bootstrapping procedure. This process assumes that our sample is a randomly sampled and unbiased portion of the population of anglers in Guatemala. To ensure meaningful statistics, we resampled 550 times.

Multivariate Analysis

We modeled self-reported satisfaction as a function of 6 variables: whether the angler mentioned quantity as their motivation (y/n), number of years of experience fishing for billfish, number of billfish-oriented magazines the angler subscribed to, measurement of willingness to pay to fish with lodges enacting conservation measures, whether they check reports prior to booking a billfish fishing trip (y/n), and the average number of fish they raised during their trip. Because only two anglers reported that the trip failed to meet their expectations, these answers were treated as outliers. Only surveys reporting that expectations were either met or exceeded (52 total) were used for this model, and a probit model (Equation 3.1):

$$\Pr(y_i = 1) = \pi_i = \Phi\,(X_i'\beta\,) \qquad \textbf{Equation 3.1}$$

where $y_i = 1$ indicates that the angler's expectations were *EXCEEDED.* Φ is the cumulative distribution function (inverse normal), X is a vector of regressors that influence the probability of reporting "exceeded", and β is a vector of the coefficients. The Regressors and coeffecients are defined as,

$$X'_i\beta = X_1\beta_{mention\_quantity} + X_2\beta_{years\_fishing} + X_3\,\beta_{magazine\_count} + X_4\,\beta_{WTP\_conserv.} + X_5\,\beta_{check\_reports} + X_6\,\beta_{actual\_raise}$$

Equation 3.2.

where X_1 (Y/N) indicated whether the angler mentioned quantity as their motivation, X_2 is the number of reported years the angler has been fishing, X_3 is the number of fishing related magazines that the angler subscribes to, X_4 is the rank the angler reported with their willingness to pay to fish with a lodge that commits to conservation, X_5 indicated whether the angler checks fishing reports (Y/N), and X_6 is the number of billfish the angler raised per day of their fishing trip.

We evaluated models with different combinations of variables from the survey using R statistical software. Due to restrictions in sample size, many models did not converge on a solution. Of those that did, we chose the final model using the AIC criterion.

Lodge Occupancy and Fishing Reports

Both Casa Vieja and Pacific Fins have made detailed fishing reports available to the public, archived on their websites. In recent years, the lodges began reporting all of the fishing logs, not just the notable ones. Using the assumption that the majority of anglers are fishing in groups of three for three days, we calculated a monthly occupancy rate. The fishing reports also contain detailed descriptions of raises and catches per fishing day, which are used here as indices of relative abundance or density.

3.4 Results

Using the two lodges' websites and personal communications with captains, we obtained 2,867 records of fishing days where both raises (Raise/Boat/Day) and releases (Catch/Boat/Day), and fishing mode (Fly fishing or Conventional) were recorded. Figure 3.3 shows the relationship between these two variables, split by fishing mode. These records are widely available on the internet and in magazines for anglers.

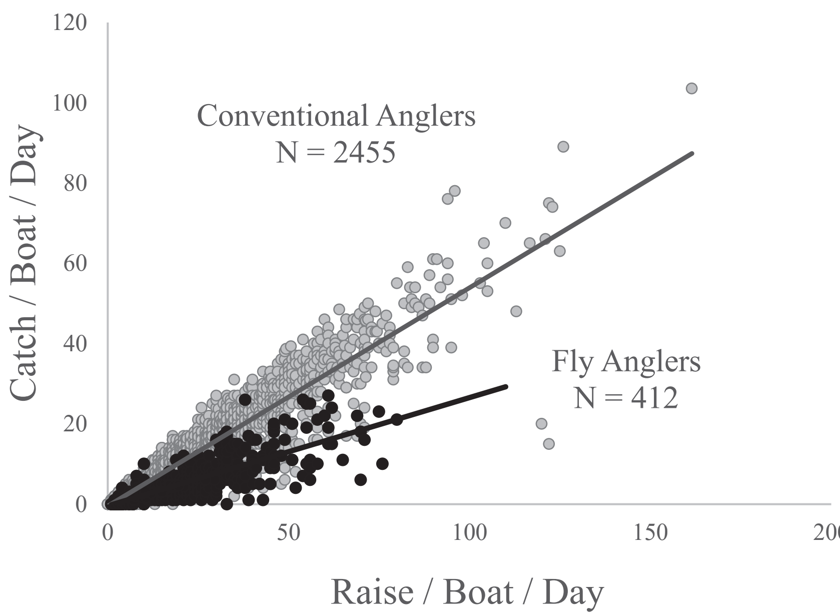

Figure 3.3. The relationship between raises and catches for billfish fishing in Guatemala. Anglers prefer to fish using either conventional gear (gray) or fly fish (black).

Angler demographics

75 surveys were completed and returned between the months of February – April 2017, encompassing most of the main fishing season for Guatemala. We did not calculate a response rate because lodge staff did not record the anglers who declined to participate.

As expected, the majority of survey participants were from the United States (89%), and had a high amount of specialized fishing experience (mean = 13 years fishing specifically for billfish). All respondents said they preferred to fish with other anglers. Most preferred to use conventional fishing gear, but many were interested in trying fly fishing for billfish. Also, many anglers subscribed to billfish-oriented fishing literature sources. Table 3.1 summarizes the response rate, and responses for these questions.

Table 3.1. Angler demographics, gear preference, and magazine/newsletter subscriptions.

Question	Responses	Mean	Count	Percent
Years fishing for Billfish	72	13		
Country of Origin = USA	75		67	.89
Preferred to use Fly fishing gear	69		15	.22
Preferred to use conventional fishing gear	69		28	.41
Usually use conventional, but interested in trying fly	69		27	.39
Usually use fly, but interested in trying conventional	69		0	0.0
Subscribe to Marlin Magazine	71		20	.28
Subscribe to Guy Harvey	71		5	.07
Subscribe to IGFA	71		11	.15
Subscribe to Saltwater Sportsman	71		28	.40

Angler opinions

From a conservation standpoint, we were interested in the knowledgeability of the anglers regarding the health of and threats to billfish populations in Guatemala. For these questions, anglers were asked to rank how much they agreed to the statements, summarized in Table 3.2. A rank equal to 1 = “Agree Strongly”, 2 = “Agree Somewhat”, 3 = “Neutral or No Opinion”, 4 = “Disagree Somewhat”, and 5 = “Disagree Strongly”. Generally, most respondents agreed that sailfish and marlin populations were healthy, and thought that sport fishing is relatively harmless to the populations.

Table 3.2. Reported ranking of agreement to statements pertaining to billfish conservation issues (n=75)

Statement	Responses	Mode Rank
The sailfish population in Guatemala is healthy.	66	1
The blue marlin population in Guatemala is healthy.	69	2
Commercial fishing is harmful to billfish populations.	70	1.5
Sport fishing, including catch and release, is harmful to billfish populations.	70	4
Sailfish are highly migratory with large migrations.	70	3
Blue Marlin are highly migratory with large migrations.	69	3
I would be willing to pay more to fish with a lodge with strong commitment to conservation and science.	68	2

Abundance expectations

Anglers also reported an estimate of the relative abundance of billfish they expected to see on their trip (average raises per day). They also reported how many total billfish were actually raised during their trip, and the number of fishing days. Similarly, they reported how many of these were caught and released (Table 3.3). 75 anglers were surveyed, but several omitted these questions.

Table 3.3. Two different density indices (expected to raise, actually raised) and one index of success (actual catch) reported by anglers.

Relative Density Index	Responses	Mean
Expected to raise per day	64	19.06
Actual raises per day	54	14.81
Actual catches per day	61	8.39

Angler specialization, motivation, and satisfaction

We hypothesized that anglers with the highest levels of experience would be most likely to agree with the statement concerning willingness to pay to fish with a lodge that has strong commitment to science and conservation. The answer to this question was also scored on a scale of agreement. 1 = strongly agree, 2 = agree, 3 = neutral or no opinion, 4 = disagree and 5 = strongly disagree. Experience level was divided into bins of equal size: those fishing for a year or less, those fishing less than 8 years but more than 1, Those fishing between 8 and 21 years, and those fishing more than 21 years.

Figure 3.4 shows the responses to the question asking if they were willing to pay extra to fish with a lodge that participates in conservation. All age bins had the majority of respondents answer “strongly agree” except the third bin ($8 < Y < 21$). Anglers with this level of prior experience had the majority responses report “agree”. Chi square analysis determined that there is no difference between experience level bins in the responses given to this question ($P = 0.61$). We also hypothesized that anglers with more prior experience fishing for billfish would be show more dedication to learning about billfish current events (avidity). Avidity was measured by the number of magazines/newsletters that the angler subscribed to. Anglers were divided into 4 bins according to their reported number of years of experience fishing for billfish (Table 3.4). Chi square analysis detected no level of dependence between experience and avidity, as measured by magazine/newsletter subscription ($P = 0.82$).

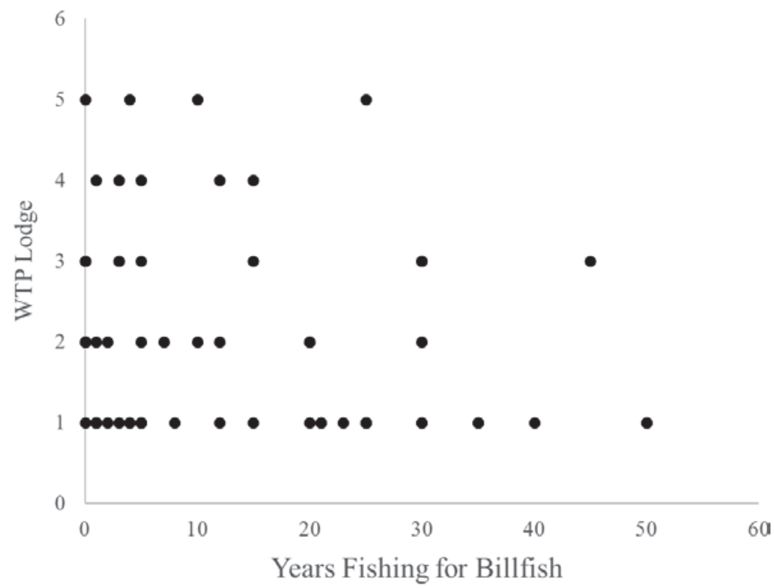

Figure 3.4. Most people answered either agree (scored as 2) or strongly agree (scored as 1) to the following statement: "I would be willing to pay more to fish with a lodge that has a strong commitment to science and conservation of billfish." Four respondents answered that they strongly disagreed (scored as 5).

Table 3.4. The number of anglers, divided by experience bins, who answered that quantity of fish was their main motivation to fish in Guatemala.

Experience fishing for billfish	Quantity motivated	Other motivations
Y≤1	1	16
1<Y≤8	6	9
8<Y≤21	4	11
Y>21	10	8

Motivations

We divided respondents into two groups based on their self-reported answer to the motivation question. The two groups that became apparent upon analysis are: those who specifically mention quantity-related aspects of fishing, and those who answered with other qualitative aspects of the trip, including vague answers such as "good fishing." We cannot rule out the possibility that some of these anglers intended to describe the quantity, however they were unable to convey that in their written answer. As expected due to the specialized nature of these anglers, most mention a fishing-related aspect of motivation compared to previous studies where non-fishing aspects were the most important. Only 7 respondents answered that their main motivation was due to non-catch or non-fishing related motives only. Such answers were related to either the reputation and hospitality of the lodge, or that the trip was due to a family member's wish. Some anglers responded with several aspects of their motivation.

- 22/73 mention billfish quantity, numbers, abundance, or something similar.
- 20/73 mention the quality of fishing, such as "great" or "the best" but not specific about any particular aspect.
- 13/73 mention the lodge reputation, service, or people (Hospitality)

We expected that anglers who were mainly motivated by quantity-related aspects of fishing to have different expectations about the relative billfish abundance in Guatemala. To test this, we used a t-test to compare the mean expected raises of the two groups. The average expected raises for quantity motivated anglers was 16.6 billfish per day. Anglers in the second group, who reported other motivations, expected to see 20.2 billfish raised per day, on average. There was no significant difference from the quantity-motivated anglers ($P = 0.1634$). To discover if gear preference influenced the motivations of billfish anglers, we used a chi-square analysis to test if the two variables were independent. Motivation was again scored as two groups: either quantity motivated or other motivated.

Gear preference was scored also as two groups: those who preferred fly-fishing, and those who preferred conventional gear. We did not find a significant level of dependence between the two factors (P = 0.099).

In accordance with the results from previous studies (McCormick, Porter 2014), we hypothesized that the amount of specialization and prior experience would influence the motivations of anglers. All but one person in the experience category of one year or less reported reasons other than quantity of fish as their main motivation to come to Guatemala instead of elsewhere (Table 3.4). Anglers with the most experience (over 21 years) were much more likely to report quantity as their main motivation. Chi square analysis detected a significant level of dependence between these two factors (P = 0.014) Anglers with more experience were the most likely to report that the quantity of fish was their main motivation to fish in Guatemala instead of elsewhere.

We also wanted to examine how accurately anglers were able to foresee the fish density they would experience on their fishing trip. Figure 3.5 shows fish density (raises) expectations and outcomes for the anglers we surveyed and compares this to historical fish density for the 2015-2016 season, approximately one year before our survey. Anglers motivated by quantity of fish expected on average 16.60 (SD = 4.39) raises per day, while anglers motivated by other reasons expected to raise 20.21 (SD = 15.03) fish per day. A two-tailed student's t-test determined that the reported densities (expected) from these two groups are statistically the same (P) = 0.153). The estimates reported by the 2017 anglers were less than the observed raises (mean = 33.49, SD = 22.09) from the prior year, however they expected higher fish density than what they actually observed (mean = 14.83, SD =

6.54) on their 2017 fishing trip. The surveyed anglers were fairly successful in catching most of the fish they raised (mean = 8.92, SD = 4.22).

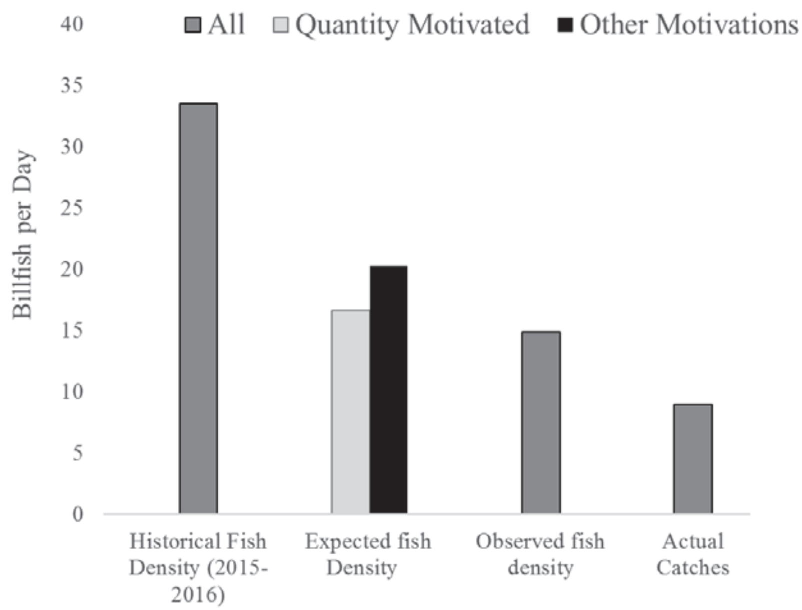

Figure 3.5 Fishing expectations and outcomes from surveyed anglers fishing in 2017, compared to outcomes from the previous year.

Satisfaction

Anglers reported their level of satisfaction with the fishing trip by responding that the trip either failed to meet expectations, met expectations, or exceeded expectations. Only two anglers reported that the trip failed to meet their expectations. For some of the following analysis, satisfaction was scored as a measurement of level 1, 2, or 3 (Table 3.5).

Table 3.5. Responses for satisfaction following fishing activities.

Satisfaction Category	Left blank	Count	Percent
Failed to meet expectations (1)	21	2	.04
Met expectations (2)	21	35	.65
Exceeded expectations (3)	21	17	.31

Only two respondents stated that the fishing experience failed to meet their expectations. These anglers did not report atypical expectations or actual raises/catches. One angler said that he/she expected to raise 30 fish per day on average, but in reality he/she only raised 20. The other angler actually raised more fish than he/she expected to (19 and 15 respectively). Both are well-within the average reported numbers from other anglers. Similarly, both of the unsatisfied anglers reported vague, qualitative motivations for fishing in Guatemala, as did many of their peers. They did, however, have significantly less prior experience than the average angler (0 and 3 years) and each only subscribed to one magazine/newsletter. This observation is contradictory with results from previous authors (McCormick and Porter 2014), who showed that less experienced or specialized anglers generally reported higher satisfaction. However, the sample size for this satisfaction category is extremely small.

We predicted that angler motivation, avidity, experience, as well as fish expected abundance, observed abundance, and fishing success would influence the satisfaction of billfish anglers in Guatemala. The Probit analysis revealed two significant factors that influenced the likelihood that an angler would report that his/her expectations were exceeded (Table 3.6). The model predicts the likelihood of reporting "Exceeded Expectations" of two significant variables. The number of billfish caught per day, and whether the angler was motivated by quantity, significantly affect the likelihood, shown in Figure 6, with 95% confidence intervals. Table 3.7 shows the deviance explained by the probit model.

Table 3.6. Results from the probit model of satisfaction following fishing activities. Coefficients (β) are the rate of change in log odds of an angler reporting that expectations were exceeded for the corresponding variable (e^{β_x}).

Variable	Coefficient (SE)	P value
Motivated by quantity	-1.59278 (0.5596)	0.00443 **
Years of experience	-0.03401 (0.1996)	0.08836
Number of magazines	-0.26500 (0.24884)	0.28689
WTP for conservation	-0.05032 (0.19122)	0.79245
Check fishing reports	0.75303 (0.43861)	0.08601
Actual raise per day	0.10034 (0.04445)	0.02399 *

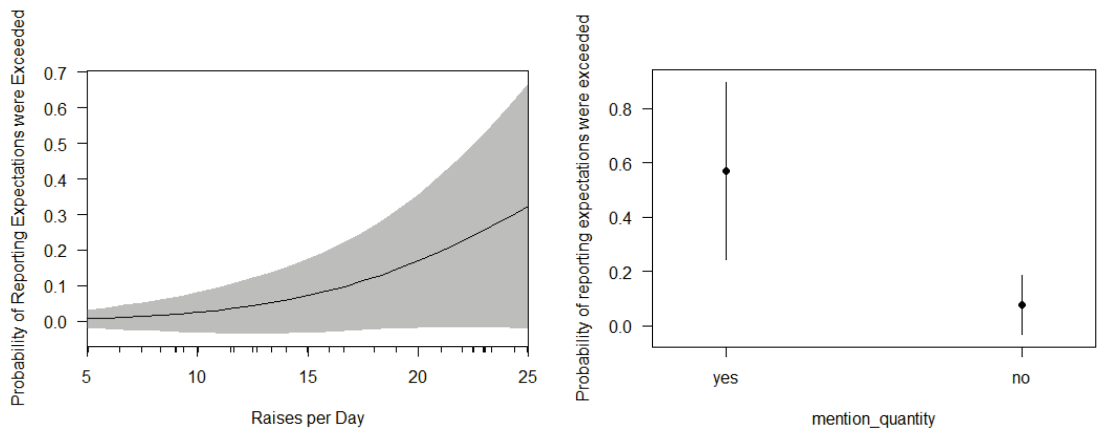

Figure 3.6 The probability of a respondent reporting that their expectations were exceeded, with 95% standard errors.

Table 3.7 Deviance explained by the probit model and Chi_squared P values.

	Df	Deviance	Residual DF	Residual Deviance	P
NULL			51	65.726	
Motivated by Quantity	1	4.5895	50	61.136	0.03217 *
Years of Experience	1	3.5522	49	57.584	0.05947
Number of Magazines	1	1.5433	48	56.041	0.21413
WTP for Conservation	1	0.1887	47	55.852	0.66397
Check Fishing Reports	1	3.5593	46	52.293	0.05921
Actual Raise per Day	1	5.7709	45	46.522	0.01629 *

The probit model required more data points than we obtained to converge on a solution for models that included additional independent variables. Therefore, to determine whether other variables could influence the stated satisfaction, we used simpler non-parametric tests. We used a chi square analysis to test if the satisfaction levels were different for those anglers who intended to use fly fishing gear (8 anglers) than anglers using conventional gear (54 anglers) to fish for billfish. This procedure included the anglers who reported that their expectations were not met. Although both groups responded most frequently that their expectations were met, the analysis determined that the two groups of anglers have statistically different ($P = 0.008$) satisfaction levels from each other. The gear preference of the angler influences their satisfaction following fishing activities. Anglers using conventional gear were more likely to report that the trip met or exceeded their expectations.

We also examined whether the fishing success of the angler influenced their satisfaction levels. We predicted that anglers who successfully hooked and released more of their raised billfish would report higher satisfaction levels than those who were less successful. We used a Spearman's rank correlation test with the null hypothesis that there is no correlation between catch success and satisfaction. There is a significant positive correlation between the number of billfish caught per day and the reported satisfaction of billfish anglers ($P = 0.0079$). It is worth noting that there were very few daily catch rates below five billfish per day, and no one failed to catch any billfish at all. To further study this relationship, we tested several relationship models of billfish CPUE's influence on the probability of reporting that expectations were exceeded following the fishing trip. This analysis provides an estimate of the approximate number of daily catches needed to elicit any responses that expectations were "exceeded." Anglers were assigned a probability of reporting "exceeded" by grouping the anglers into bins according to the number of billfish they caught, each bin has a range of two. For example, there were 6 anglers who caught between one and three billfish, and none of them reported "exceeded." Therefore, all anglers were assigned a zero probability. Figure 3.7 shows the probability of reporting that expectations were exceeded as a logarithmic function of billfish caught per day. Equation 3.3 describes this relationship, and has an r value of 0.69. The residuals about this regression may suggest a linear fit.

$$P(y_i = 1) = 0.229\ln(C/B/D) - 0.2124 \qquad \textbf{Equation 3.3}$$

where C/B/D is the average catch of billfish per boat per day.

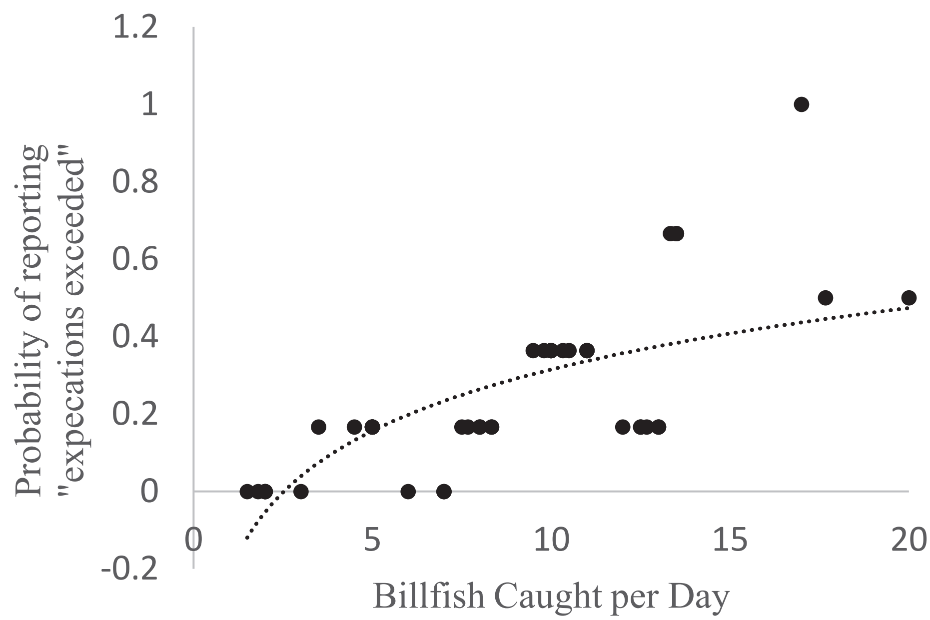

Figure 3.7. The probability of responding that expectations were exceeded and the number of billfish successfully caught per fishing day.

The linear model of this relationship (Figure 3.8) has an r value of 0.749 (Equation 3.4). To understand the variance of our sample and compensate for outliers, we resampled this model with replacement (bootstrap). We performed the resampling procedure 550 times, and estimated a new linear regression for each permutation. With this procedure, we can estimate an approximate sampling distribution for to our model estimates, which we assume is representative of the sampling distribution for the parameters across the whole population of anglers fishing in Guatemala. Thus, we may calculate confidence intervals and bias-corrected means from the bootstrap sampling distribution for each parameter. The average estimates from this procedure are given in Table 3.8, and they are nearly identical to the values in Equation 3.4, indicting a lack of bias in the regression estimates. The distribution to the correlation coefficient of our regression between catches and satisfaction (Figure 3.9) and its confidence intervals (Table 3.9) indicate that the positive correlation between these two variables is robust to sampling error. Figure 3.10 shows the relationship of slopes and intercepts estimated by the bootstrapping procedure, which shows the expected negative correlation

$$P(y_i = 1) = 0.037(C/B/D) - 0.077 \qquad \textbf{Equation 3.4}$$

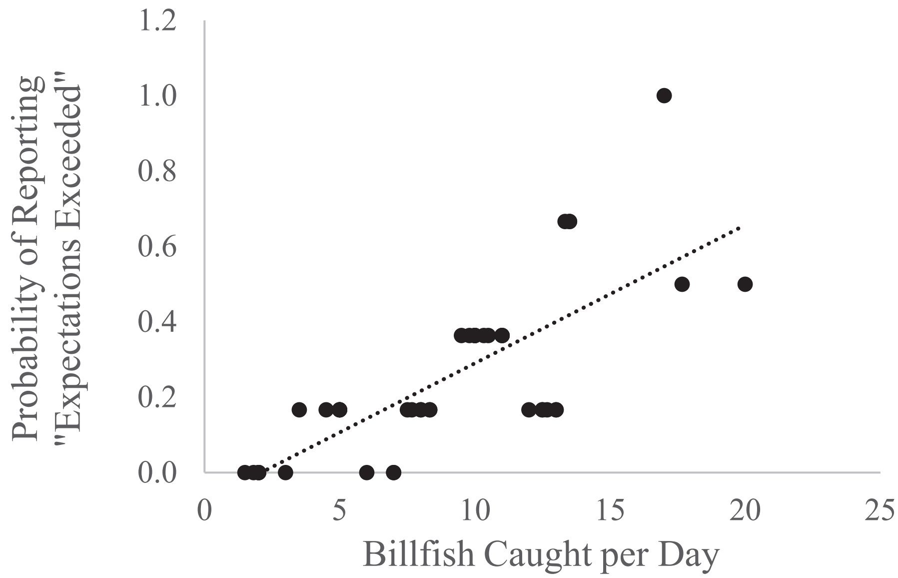

Figure 3.8. The probability of responding that expectations were exceeded and the number of billfish successfully caught per fishing day. We estimate that approximately 5 fish is the minimum needed to elicit any "exceeded" responses.

Table 3.8. Estimates from resampled regression using bootstrapping

	Slopes	Intercepts	r
Average	0.041	-0.133	0.689
Standev	0.0078	0.0687	0.0530

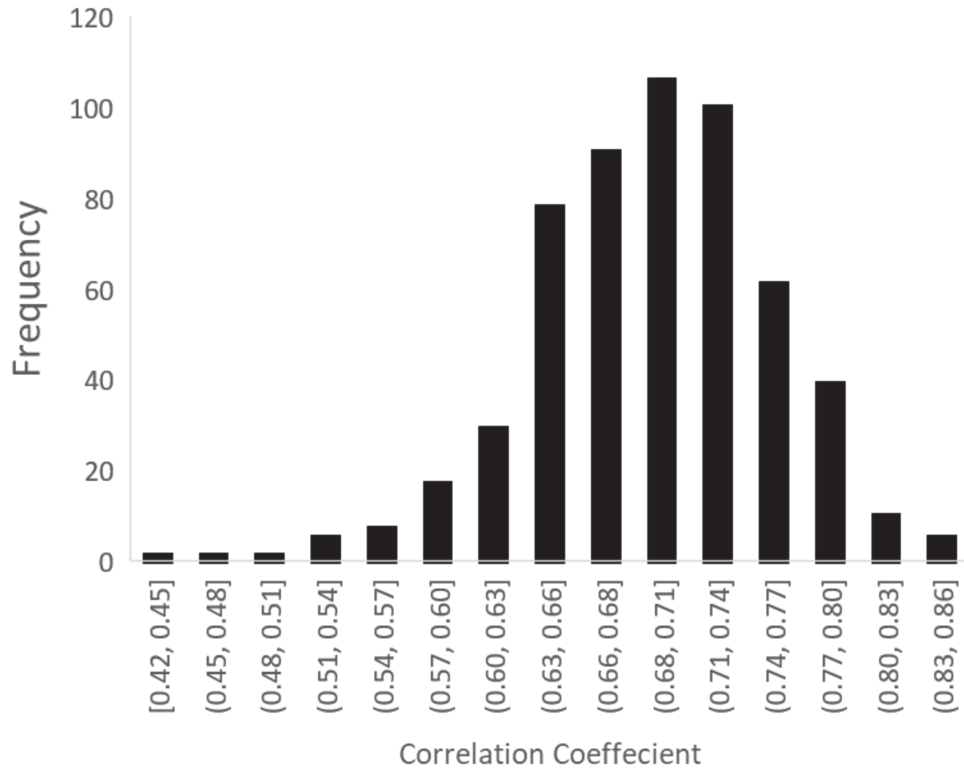

Figure 3.9 Distribution of the correlation coefficients estimated by bootstrapping sample.

Table 3.9 Confidence intervals for bootstrapped r values of regression.

Confidence Level	Lower Confidence Value	Upper Confidence Value
95%	0.687	0.696
50%	0.690	0.693
10%	0.691	0.692

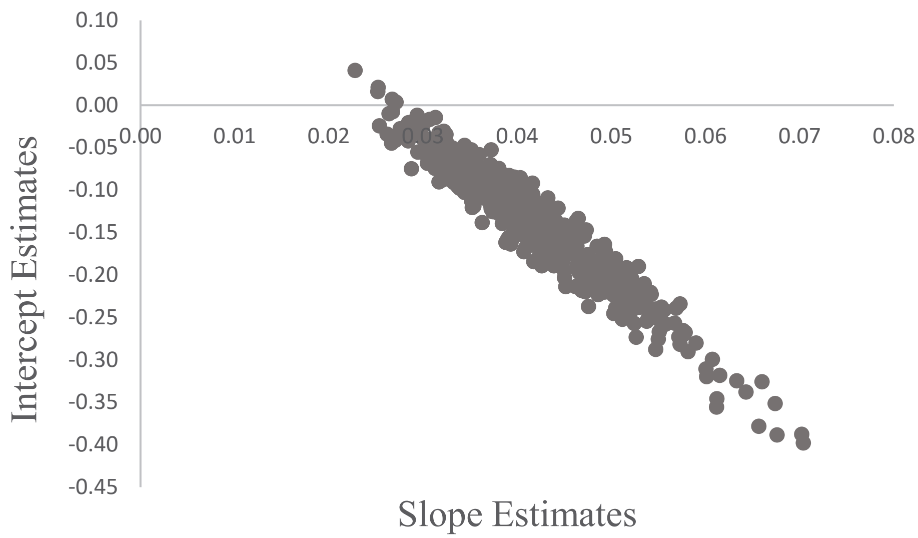

Figure 3.10 The distribution of slope and intercept estimates from resampling procedure of catch success and satisfaction probability

We postulate that there is a threshold embedded into this relationship, i.e. there is a minimum number of fish caught necessary to elicit any "exceeded" responses. No anglers who caught two or less billfish per day reported that their expectations were exceeded. A single angler out of 6 who caught between 3.1-5 fish per day reported that his expectations were "exceeded" (Figure 3.11). The anglers who caught between 4-6 billfish per day also showed a zero probability of reporting that their expectations were exceeded. Therefore, based on the initial regression, we infer this threshold is approximately 5 billfish caught per day. Figure 3.12 shows a similar linear regression. Equation 3.5 shows the linear model estimated after removing these individuals, and has an r value of 0.669. Although our regressions cross the X axis at less than 5, we assume that the single angler who reported "exceeded" is an anomaly (Figure 3.9).

$$P(y_i = 1) = 0.046(\text{C/B/D}) - 0.193 \qquad \textbf{Equation 3.5}$$

We similarly resampled the dataset after removing all survey respondents who caught 5 or less billfish per day, with replacement (bootstrapping). The average estimates from this procedure, along with standard deviations for each estimate, are reported in Table 3.10, and confidence intervals for the correlation coefficient are in Table 3.11. The frequency of bootstrapped estimates of the correlation coefficient are in Figure 3.113, and the distribution of slope and intercept estimates from resampling procedure of catch success and satisfaction probability are in Figure 3.14. To compare the estimates of the models before and after removing individuals catching 5 or less billfish, we used student's t-test to compare the average estimates from the two bootstrapping procedures (Table 3.12). Removal of the participants who caught less than 5 billfish per day significantly changed the population of bootstrap estimates for linear regression parameters (slope, intercept, and correlation coefficient).

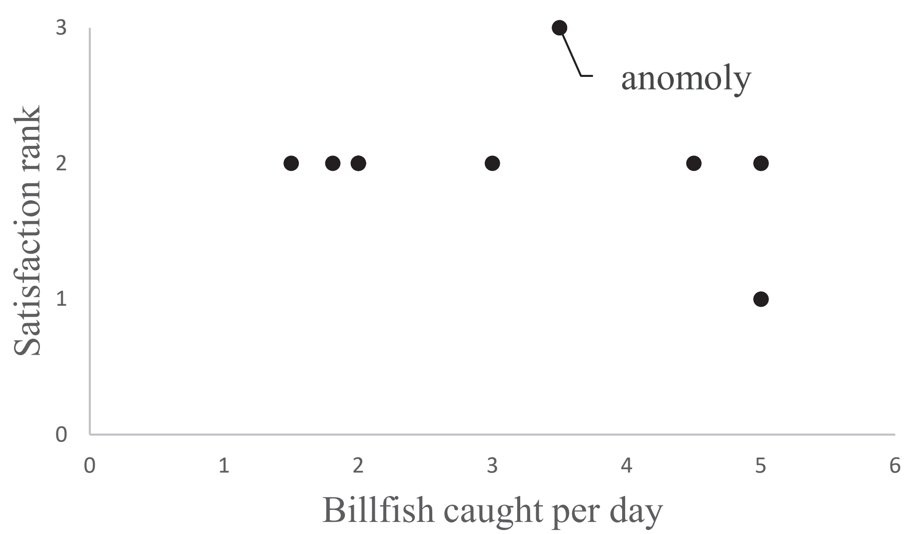

Figure 3.11. The anglers who caught 5 or less billfish per day and their reported satisfaction. Only one angler reported the highest satisfaction level (3).

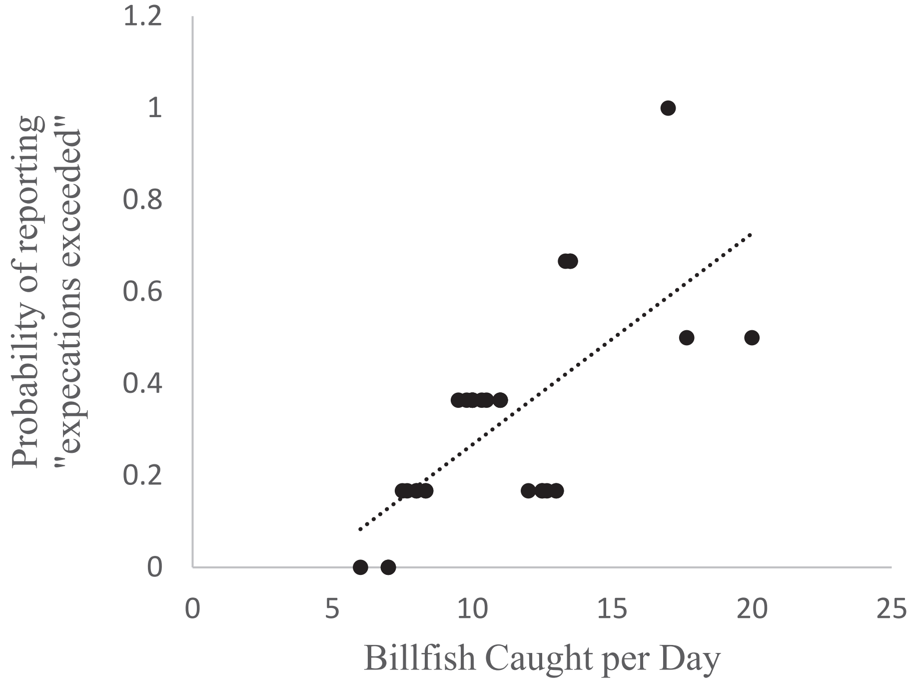

Figure 3.12 The probability of responding that expectations were exceeded and the number of billfish successfully caught per fishing day. We estimate that approximately 5 fish is the minimum needed to elicit any "exceeded" responses, and removed those individuals who caught 5 or less.

Table 3.10. Estimates from resampled regression using bootstrapping after removing anglers who caught below the threshold of 5 billfish per day

	Slopes	Intercepts	r
Average	0.047	-0.206	0.666
Standev	0.0134	0.1282	0.0916

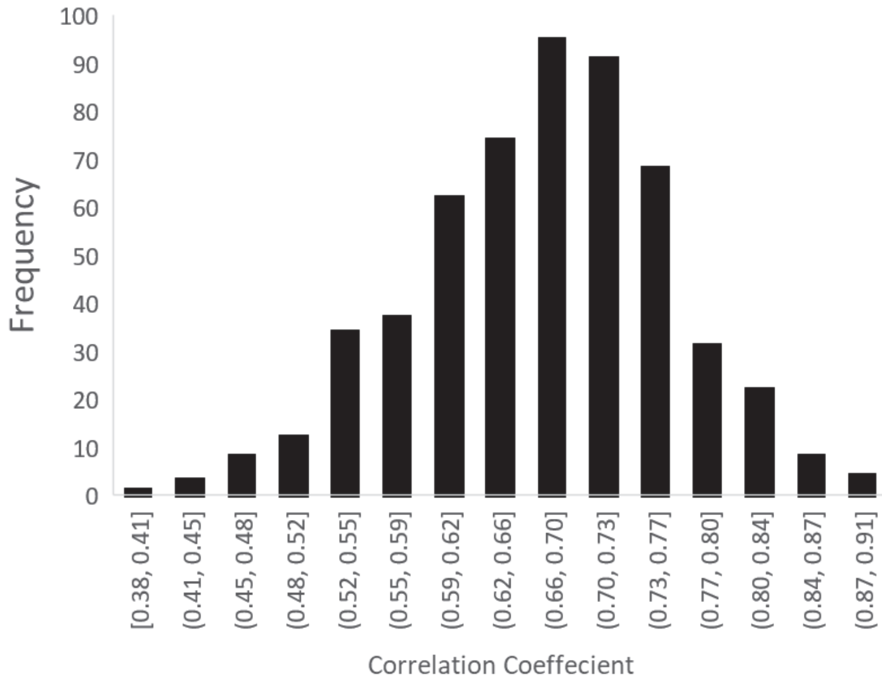

Figure 3.13. The frequency of bootstrapped estimates of the correlation coefficient from resampling procedure of catch success and satisfaction probability, in 0.05 bins, after removing anglers who caught below the threshold of 5 billfish per day.

Table 3.11 Confidence intervals for bootstrapped r values of regression after removing anglers who caught below the threshold of 5 billfish per day

Confidence Level	Lower Confidence Value	Upper Confidence Value
95%	0.659	0.674
50%	0.664	0.669
10%	0.666	0.667

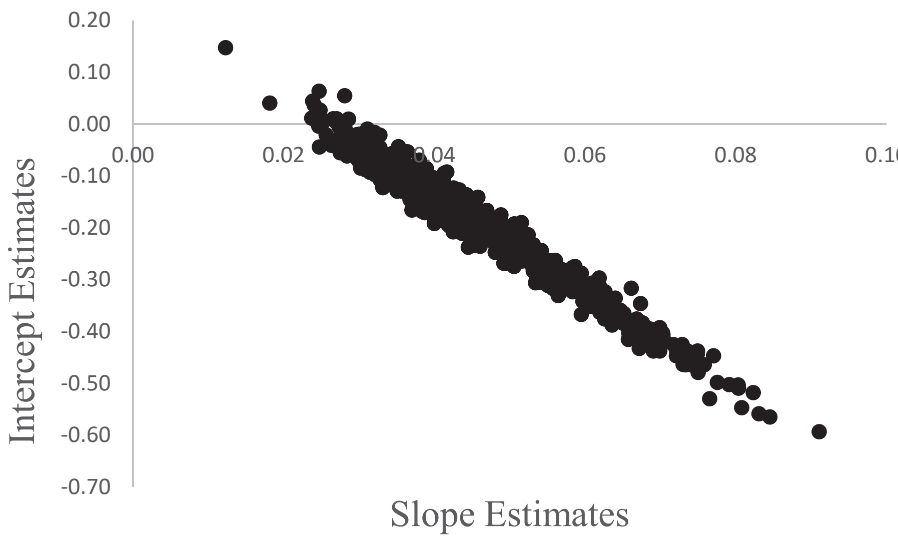

Figure 3.14. The distribution of slope and intercept estimates from resampling procedure of catch success and satisfaction probability after removing all anglers who caught less than 5 billfish per day.

Table 3.12 Results of t-tests comparing the averages estimates from the bootstrap procedure before removing individuals catching less than 5 billfish per day (Equation 3.4), and after (Equation 3.5)

	Mean Before	Mean After	P value
Slope estimates	0.041	0.047	1.077E-15
Intercept estimates	-0.133	-0.206	2.441E-24
Correlation coefficient	0.689	0.666	8.642E-08

To select compare the logarithmic and linear model using all respondents, we used the AIC criterion. The AIC values for the logarithmic model is -32.9 and the linear model is -40.8. This indicates that the linear relationship best describes the influence of catch rates on satisfaction of our participants.

Another factor that possibly influences satisfaction is the degree to which anglers were able to accurately predict the fish density seen on their trip. To measure this prediction accuracy, we used the difference between predicted raises and actual raises for each angler.

An angler who predicted that they would see 20 fish raised per day and only saw 10 fish raised per day would be given a value of -10. We compared these values to the reported satisfaction of the anglers after their fishing activities (Figure 3.15). We also used a Spearman's rank correlation test to determine whether a significant relationship exists between the two variables. A positive relation approaching significance (P = 0.0568) exists between an angler's ability to accurately predict fish density and his/her satisfaction levels. The results are similar if the outlier is removed.

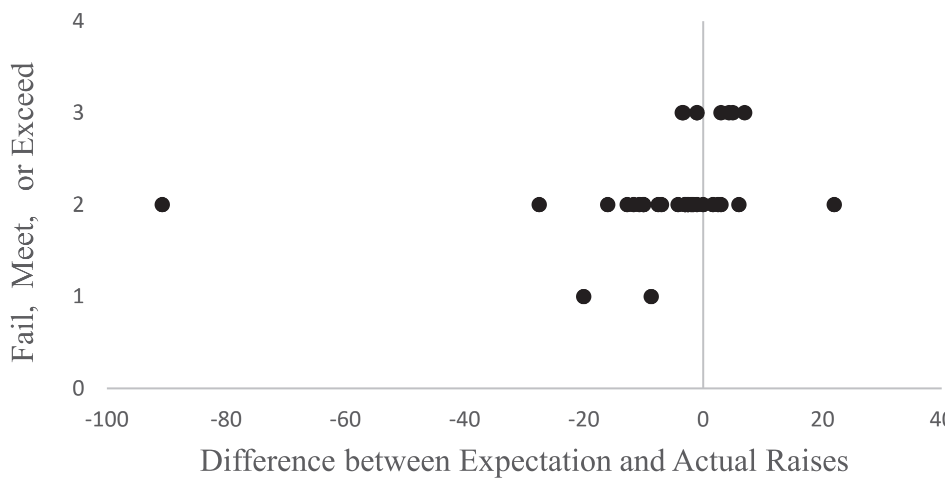

Figure 3.15. The relationship of the satisfaction rank variable, with the difference between the anglers expected raises and actual raises. A positive difference means that they raised more than they expected.

Figures 3.16 and 3.17 show the hotel/lodge monthly occupancy, and actual raises per day (respectively) for the two lodges in the years prior to administering this survey. The trend in room occupancy reflects the seasonal trend in fishing quality. The raises per day are publicly available in fishing logs through the lodges' websites. Anglers may use this information to gauge their fishing expectations, and subsequently choose a fishing date to suit their needs.

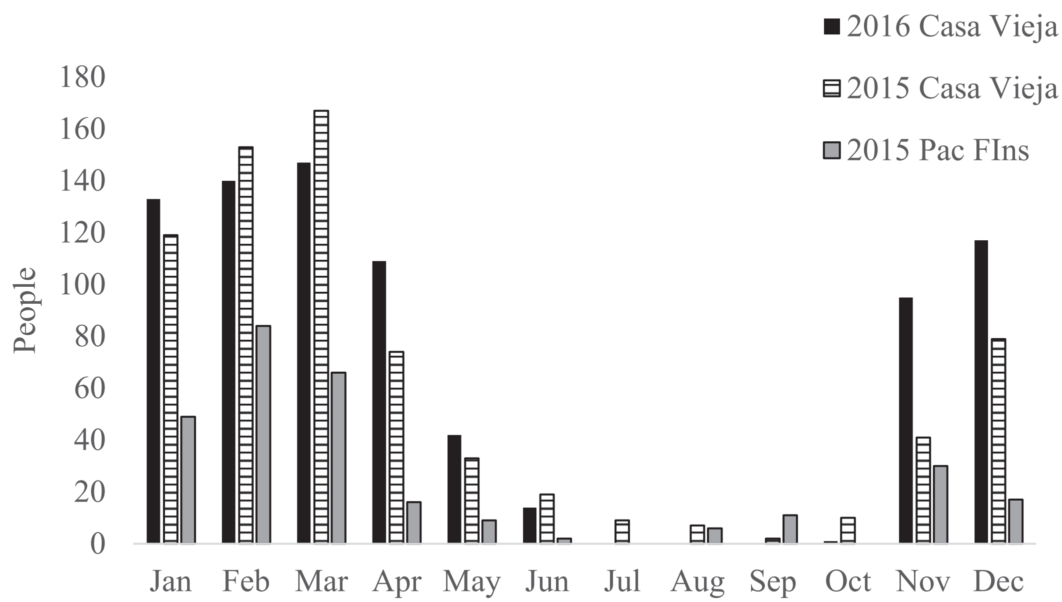

Figure 3.16. 2015 and 2016 occupancy for Pacific Fins and Casa Vieja, the two main operators for billfish fishing in Marina Pez Vela.

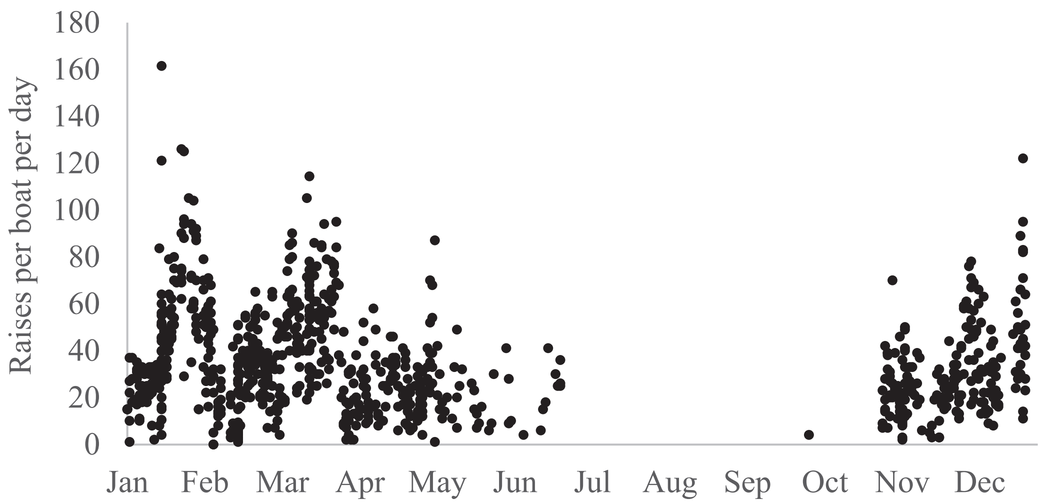

Figure 3.17. Seasonal sailfish density (raises per day) reported in the 2015-2016 fishing season in Guatemala.

3.5 Discussion

The results of our survey are applicable for recreational fishing industries which cater to a specialized subset of recreational anglers. Fisheries which offer unique experiences may represent a small portion of the demand for recreational fishing trips taken, however there are few alternatives for anglers seeking very specific qualities in a fishing trip. The imperfectly competitive nature of highly specialized fisheries may allow a few individual producers to exercise control over prices for fishing services, creating winners and losers in the marketplace. Therefore, it is in the interest of developing communities like Marina Pez Vela to improve the quality of their fishery to capitalize on the high profits and employment resulting from ecotourism. Thus, factors which make a fishery unique should be identified and protected to serve the interest of the local community.

Anglers fishing for billfish in Guatemala are targeting two species primarily (Pacific sailfish and blue marlin). Of those anglers who reported to be motivated by the catch aspects of fishing, all are seeking a high quantity of fish, as opposed to size or diversity. Furthermore, billfish anglers in Guatemala have on average a high degree of prior experience targeting billfish (Table 3.13), comparable to tournament anglers (typically very experienced) fishing in other locations. For these reasons, we believe that the relatively small annual number (Table 3.14) of anglers fishing from Marina Pez Vela, Guatemala can be considered specialized compared to other recreational fishers and even other recreational billfish anglers.

Table 3.13. Experience level of leisure billfish anglers in Guatemala, compared with tournament anglers in Puerto Rico and the US Atlantic coast.

Location	**Mean Number Years Fishing for Billfish**	**Reference**
US Puerto Rico (tournament anglers)	10	A
US Atlantic coast (tournament anglers)	16	A
Guatemala (charter clients)	13	This study

A: Fisher and Ditton 1992

Other studies examining anglers' perspectives have produced significantly more survey responses (Brinson and Wallmo 2017), however the authors used an extremely broad sample frame, and the results should not be extended to a small subgroup of specialized anglers targeting a single species in a single location. Our response rate was high relative to other surveys (Cox 2010) (26) which targeted billfish anglers who had traveled to Central America. The 75 surveyed anglers in our study represent about 12% of the estimated anglers traveling to Guatemala to fish in 2017. Table 3.14 compares studies estimating the number of annual users for recreational billfish fisheries to comparable foreign locations for US anglers.

Table 3.14 Annual demand for recreational fishing in locations known for billfish.

Location	Annual demand	Year	Reference
Cabo San Lucas, Mexico	354,013 recreational anglers	2007-2008	A
Cabo San Lucas, Mexico	94,218 recreational anglers	2010	B
Costa Rica	10,000 directed billfish trips	1994	C
Costa Rica	2899 billfish anglers	1995	D
Mexico	16542 billfish anglers	1996	D
US Atlantic	7915 billfish anglers	1990	D
Puerto Rico	1627 billfish anglers	1994	D
US Mid-Atlantic	2,572 directed billfish trips (USA anglers)	2016	E
US South Atlantic	4,497 directed billfish trips (USA anglers)	2016	E
US Hawaii	1,151 directed billfish trips (USA anglers)	2016	E
Caribbean	2,712 directed billfish trips (USA anglers)	2016	E
Marina Pez Vela, Guatemala	627 billfish anglers	2017	F

A: Southwick, Nelson et al. 2010
B: Hernández-Trejo, Germán et al. 2012
C: Ditton, Finkelstein et al. 2005
D: Ditton and Stoll 2003
E: Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division November 14, 2017
F: Personal communications with lodge operators

Our survey revealed a diversity of motivations for anglers traveling to Guatemala to target billfish. Many anglers reported vague, qualitative motivations for traveling to Guatemala instead of elsewhere. It cannot be ruled out that these anglers were motivated by the fish density, however they did not use these specific words. We chose to leave this question as a fill in the blank to potentially capture any unforeseen responses that may be important for identifying unique factors for this fishery. Another survey with pre-scripted responses to choose from may illuminate more nuanced motivations or reveal stronger relationships between motivation and other factors.

Anglers who had higher levels of experience were more likely to mention quantity as their main motivation for choosing to fish in Guatemala instead of elsewhere. This confirms previous studies that report specialization and experience are important factors in determining anglers' motivation for fishing. Very experienced anglers are almost certainly the most informed about billfish abundance elsewhere in the world, and thus able to recognize the distinctiveness of Guatemala as a fishing location in regard to abundance. The vast majority of billfish caught in Guatemala are sailfish, and therefore an angler seeking to release a very large billfish, such as a grander marlin (>1,000 lbs.) would not likely achieve this goal in Guatemala. Another common goal, the IGFA Billfish Grand Slam (3 species of billfish in one day) would also be very unlikely in Guatemala. An angler seeking record numbers, however, would have that opportunity. Guatemala regularly has long-standing records for numbers of sailfish released in one day without employing the use of Fish Aggregating Devices (FADs), which are gaining popularity in alternative fishing locations.

Anglers traveling to Guatemala to fish for billfish reported high satisfaction levels. Only two people reported that their trip failed to meet their expectations. Most people reported that the fishing trip either met or exceeded their expectations, regardless of their experience, stated motivation, gear preference, number of expected raises, or actual raises. Angler motivations and specialization influenced satisfaction in interesting ways. Contrary to some previous studies (McCormick and Porter, 2014), we found that anglers with relatively less specialization reported lower satisfaction levels than their counterparts. Anglers who had specialized motivations (seeking high density of fish), however, had a significantly higher likelihood of reporting that their expectations were exceeded. Similarly, anglers who had specialized gear preference were significantly likelier to report high satisfaction levels. The Probit model did not reveal a significant influence of prior experience on satisfaction, however, we documented only two anglers with failure satisfaction levels, and these two anglers had very little prior experience or familiarity with billfish. These results support the idea that trip context influences the satisfaction of recreational anglers. Highly specialized anglers may be comparatively more satisfied when the fishing activities are similarly specialized, versus fishing activities that broadly target several species or sizes of fish, or activities that use less challenging fishing gear. In other words, highly experienced/specialized anglers may be better able to recognize and appreciate unique fishing experiences. The model supports anecdotal evidence that there are few, if any, rival fishing locations where it is viable to catch and release billfish using fly fishing gear without employing the use of FADs.

Diminishing marginal utility for fish density and successful catches

Both fish density and catch success affected satisfaction in a predictable, positive manner. In accordance with other authors (McCormick and Porter, 2014) we demonstrate that a logarithmic relationship (Figure 3.7) of these variables is one potential conceptual model for angler satisfaction. Although it was not the best model selected using the AIC, conceptually there is an expected asymptotic level of fish density and catch success where most anglers will feel completely satisfied, and will gain no additional value from seeing or catching more billfish. It would not be logical for satisfaction to continue increasing indefinitely, as implied by the linear models. Economic theory states that the marginal utility (MU) obtained by consuming a good diminishes as the consumer purchases more of that good (Equation 3.6). It is likely that this is the case for billfish anglers who travel internationally seeking billfish. In this scenario, raise or catch rate expectations may be considered the good, or an attribute of a good (the fishing package). The aggregate satisfaction with the entire fishing trip may be considered the utility.

$$MU_1 > MU_2 > MU_3 ...... > MU_n$$ **Equation 3.6**.

where the consumption of each subsequent item (1, 2, 3…n) produces less additional marginal utility than the last item.

Our data reflected linear relationships (Figure 3.8 and Figure 3.12). Depending on whether a threshold was assumed or not, the slope of these models are very similar (0.041 and 0.047, respectively) with low variance measured by the resampling procedure, suggesting that the marginal increase in satisfaction as catch rates increase is similar whether a threshold is assumed or not. The intercepts and correlation coefficients were also similar for the two models, however all estimates were statistically different between the two samples after resampling. This proves that the removal of anglers who caught few fish changes the nature of the relationship between catch rates and satisfaction, although not by much.

Few (approximately 4%) of the anglers surveyed in Guatemala responded that the trip failed to meet their expectations, and therefore we estimate that the average billfish raises and catches (14.82 and 8.92, respectively) are approaching this asymptotic high satisfaction level for these recreational anglers. The fact that the strength of our logarithmic is similar to the linear models (AIC is between the two linear model AICs) may be explained by the lack of adequate regression range. Only six anglers caught less than five billfish per day aboard their vessel, and no one caught zero. It is probable that the relative abundance seen by anglers fishing in Guatemala in 2017 is very high when scaled to expectations for other locations, and thus they have very high probability of being satisfied, even when catch rates are below average for Guatemala. It is likely that observations of lower catch rates would improve the predictive power of this relationship. Other authors who were able to measure a large range of actual catch rates (McCormick and Porter 2014) found a logistic relationship (Figure 3.18) to catch rates and probability of reporting high satisfaction, conforming to the expectation of diminishing marginal utility. Our probit model was unable to reveal an upper limit to the number of fish raised per day and the satisfaction level. Figure 3.6 shows no such asymptote. It is possible that some of the anglers fishing in Guatemala are extremely competitive in the catch or raise rates they are pursuing.

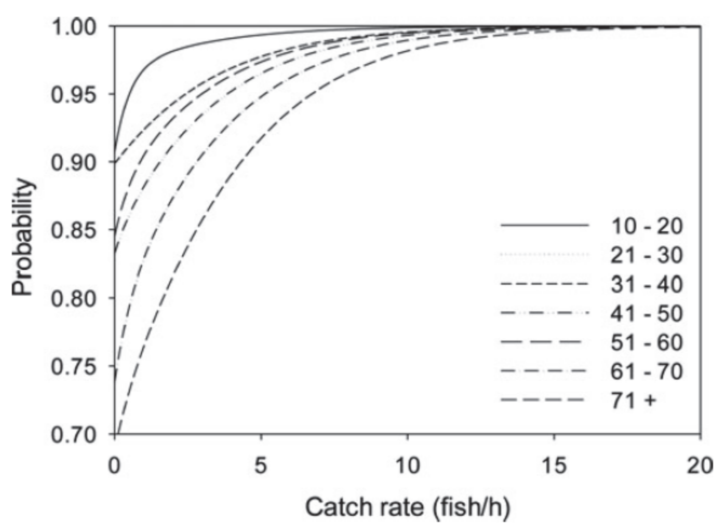

Figure 3.18. Probability of high satisfaction is highly contingent on the catch rates for Oregon Rainbow Trout and also age of angler. Figure from McCormick and Porter (2014).

In the same way, prediction accuracy, measured by the difference between expected and actual raises, influenced satisfaction. The survey responses indicated a fair degree of variance in the influence of expected and actual catch rates on demand for fishing packages. Anglers who saw higher density of billfish than expected were more satisfied than anglers who saw lower than expected. In other words, anglers are satisfied when their fishing trip accurately reflects or exceeds what is being marketed through various channels. There was a wide range of sources reported by the anglers for obtaining information about fishing in Guatemala. Some reported regularly reading sport fishing magazines, including one that is specifically geared to billfish. Others read none. Some anglers reported checking several fishing reports before booking a trip, others one, and some checked zero. These sources are likely persuasive in shaping anglers' expectations about the population density of billfish in Guatemala compared to elsewhere, and thus their preference for fishing times or locations. Examination of lodge occupancy (Figure 3.16) shows seasonal fluctuations corresponding to local indices of relative abundance, or raises per boat per day (Figure 3.17).

Potential measurement error

We assumed that all anglers spoke English to the extent that they could accurately decipher the questions being asked. Most anglers were from the United States of America, a predominantly English speaking country. Others were from Europe, where English is commonly spoken, if not the primary language. Due to the fill in nature of several questions, subjective interpretation was necessary occasionally (See Appendix E).

Handwriting needed to be deciphered, and some answers were ambiguous. When these answers were interpreted, we asked independent colleagues to validate the decision in the interest of objectivity. Some answers simply could not be interpreted, and were not used for analysis. Respondents were informed about their right to refrain from answering any or all questions, and many left portions of the survey blank. Because of these gaps in the data, multivariate techniques, such as multinomial logistic regressions were not performed.

Other self-reported answers were unexpected. For instance, one person reported that they anticipated raising 100 billfish per day. This estimate, in relation to the records being set in Guatemala, is possible, but highly unlikely. Therefore this number was not removed as an error. Several respondents reported a range of expected raises. For these cases, we used the average of the two numbers. It could, however, be interpreted to mean "at least" the lowest number given. In that case, actual raises were even closer to expected raises.

Ranking schemes are standard practice in surveys for elucidating opinions and preferences. There is always the possibility of confusion or misinterpretation. Several people gave the opposite response of what we would expect for questions thought to be uncontroversial for these clients. For example, they "strongly agreed" that sport fishing, including catch and release, was harmful to billfish populations. Conversely, they "strongly disagreed" that commercial fishing is harmful to billfish populations. Despite the few surprising responses, we believe the majority of responses reflected the true perceptions of the anglers fishing in Guatemala.

An increasingly common management strategy is promoting or even mandating catch and release in fisheries where high catch rates are important to the utility and demand for angling activities (Camp, Poorten et al. 2015). In Guatemala, the Sailfish Commission is tasked with enforcing mandatory release of sailfish for this reason. This may be a useful management tool for other highly specialized fisheries similar to the recreational fishery for sailfish and marlin in Guatemala. Future research should investigate anglers' attitudes regarding this regulation in Guatemala. Previous studies (Graefe and Ditton, 1997) have suggested that the more avid anglers (not specifically targeting any species) are likelier to keep a fish, as opposed to voluntarily releasing it. However, age and wealth had the converse effect on the angler's likelihood of keeping a billfish. Attitudes about fishing also affected the likelihood of harvesting a billfish. The demographic of anglers fishing for billfish in Guatemala are typically experienced, specialized, with relatively high income. They also show unique attitudes/motivations about fishing insofar that they have no intention of compared to anglers fishing elsewhere, or for different species. A survey comparing Guatemalan anglers to less specialized anglers, or anglers targeting other species is likely to reveal significant shifts in attitudes about catch-and-release fishing.

This survey illuminates aspects of Guatemala's billfish fishery that drive the demand for ecotourism to Marina Pez Vela. We documented a strong preference for catching high numbers of predominantly sailfish, with a high degree of satisfaction following the fishing experience in Guatemala. This research could guide management decisions that simultaneously conserve the resource for future generations, and motivate and satisfy anglers in the present.

Chapter 4

Determining the Value of Guatemala's Recreational Billfish Fishery

4.1 Background

Recreational fisheries for billfish must compete for the use of billfish resources that are largely open-access, and diminishing. Much of today's sailfish and marlin conservation efforts are focused on demonstrating the value of billfish recreational fisheries, because recreational users often generate more economic activity while using less of the resource (National Marine Fisheries Service 2010). Worldwide, there is high demand for services related to recreational billfish fishing, and billfish fishing destinations must compete globally to attract anglers.

Here, we consider billfish recreational fishing practices to be a form of ecotourism (Holland et al. 1998). Because most anglers practice catch-and-release, lower fishing mortality is imposed on billfish compared to recreational fisheries for species that are kept for consumption (Skomal, 2007, Beerkircher et al. 2009, Holland et al. 1998). Billfish anglers regularly, voluntarily participate in science and conservation programs, such as tagging, at a cost to themselves (Ortiz et al, 2003), and post-release mortality is less than 15% (Musyl et al. 2014). Generally, recreational fishing provides a multitude of benefits to users; anglers fish for leisure, competition, or sustenance. Billfish anglers will often travel large distances or cross international boundaries to target specific billfish species or exceptionally large fish, spending large amounts of money on travel and accommodations (Ditton and Stoll, 2003). Billfish are an examples of fish stocks that provide large economic value, i.e., consumer surplus, through recreational fishing, that is lost when fish are harvested for sale as seafood (Ditton and Stoll, 2003).

Recreational fishing also provides further economic benefits in the form of employment. For-hire charter fishing operations often employ several crew members per fishing boat. For top billfish fishing destinations, this employment may be more reliable, safer, and more lucrative than employment in the commercial fishing industry (Barnett et al. 2016). In personal communications with crew members, we have also documented that the billfish fishing provides an incentive to learn English, which locals believe will open other educational or employment opportunities. Ideally, in an ecotourism economy, there are several avenues for locals to benefit from the economic activity generated (Barnett et al. 2016). In Puerto San Jose in Guatemala, there is little opportunity besides the direct employment at the lodges. There are virtually no restaurants or shopping opportunities nearby, and clients are strongly discouraged from leaving the lodge premises due to safety concerns. Moreover, the costs of discarding all sailfish to artisanal longline fishers is unquantified. There are no reliable estimates of the portion of their income that was accounted for by the sale of sailfish.

Historically, fisheries management has neglected to conserve billfish, allowing the continued depletion of stocks through both targeted and non-targeted mortality. While some commercial fisheries target sailfish or marlin, the majority of mortality is through the bycatch of fisheries targeting tuna (www.iattc.org/CatchReportsDataENG.htm). International agencies that manage highly migratory fish like billfish and tuna have primarily focused efforts on maximizing the yield from tuna stocks, with lesser concern for bycatch species. In Guatemala and neighboring countries, highly migratory species like tuna and billfish are assessed and managed by the Inter-American Tropical Tuna Commission (IATTC). IATTC manages tuna and tuna-like species that are known to cross multi-national boundaries. Although they regularly collect and publish catch statistics of billfish, this commission has little effective management of sailfish or marlin. Billfish, sea turtles and other bycatch species are mandated to be released by Resolution C-04-05, which encourages fishermen to innovate and develop techniques to facilitate release, however it is virtually ineffective. Non air-breathing animals are almost entirely dead after by the time purse seine catches are released into the ship (IATTC 2016).

In the absence of strong international management, countries sharing Pacific billfish stocks must manage fishing operations that catch billfish within their own territorial waters. This approach means potentially limiting fishing mortality by limiting the amount of fishing effort. Traditionally, management organizations have sought to limit fishing effort to attain population levels that support Maximum Sustainable Yield (MSY), however many scientists now argue that effort should be further limited to reach Maximum Economic Yield (MEY) (Gordon, 1954; Hilborn 2007; Grafton et al. 2008). The Magnuson-Stevens Act, which governs fisheries in the USA, now explicitly addresses social and economic benefits as a key objective. Australia has adopted similar policy, however the IATTC and Guatemala have not officially recognized social or economic priorities. If fishery management continues to develop toward economic optimization of the stocks, the billfish resources within a country's EEZ should be allocated to the activity (effort) which brings the most economic and social value to the country. For billfish, research has shown that much of their value is lost in harvest fisheries (Edwards, 1990).

Formal environmental valuation has the ability to shed light on the economic value of non-traditional uses of billfish or other marine species, like catch-and-release sport fishing.

Environmental valuation provides guidance to optimize resource allocation or, conversely, provide estimates of the human costs of environmental degradation. McConnel (1979) defines efficient allocation as: "the allocation which maximizes the present discounted value of recreational benefits plus commercial benefits, subject to a constraint on the biological growth of the fish stock." Present discounted value represents the amount one is willing to pay in the present for a stream of expected future income. Thus, resource regulation policies can be evaluated in terms of expected economic value gained or foregone (Vassilopoulos and Koundouri, 2017). For billfish species, there is a need to estimate how the value of recreational fisheries changes in response to fluctuating fish densities.

Fisheries policies are often evaluated in terms of biological sustainability, i.e. potential changes to the biomass or mortality of a stock. Conversely, economic targets like B_{mey} (Biomass at maximum economic yield) and F_{mey} (Fishing mortality at maximum economic yield) explicitly optimize the annual economic return gained by using fish resources. Goods such as seafood, which are directly bought and sold as commodities, allow researchers to use market-based techniques. Some fisheries, however, provide multiple uses, and the economic value of activities other than the harvest and sale of seafood are often ignored. The activity most relevant to billfish species is recreational fishing. In these circumstances, alternative valuation techniques must be used to determine the economic consequences of a fisheries policy.

For the many of the societal benefits provided by the ocean, ecosystem services are not necessarily traded in formal markets, and the value of these services must be elucidated, often using stated preference methods. A stated preference method is based on utility theory and it assigns a value based on a respondent's choice in hypothetical scenarios (Adamowicz and Williams, 1994). Contingent valuation has been a popular stated preference method (Ditton 1998) used to value recreational fisheries, which directly asks anglers their willingness-to-pay (WTP) for given scenarios under hypothetical conditions. Similar methods may employ ranking of hypothetical fishing scenarios. However, the hypothetical nature of contingent valuation contributes several biases to the results. The lack of true budget constraint tends to inflate anglers' WTP estimates. Furthermore, there is the risk that a researcher's explanation of the hypothetical scenario may fall short of conveying all the necessary information for a truly educated choice (Ajzen et al. 1996).

Alternatively, revealed preference approaches such as Travel Cost and Hedonic modeling use actual market information to reveal the value for services. For instance, the experience of catching and releasing a billfish is not directly sold, but indirectly contributes to measurable changes in a consumer's WTP for an activity. These methods use observed data, and thus rectify the concerns of hypothetical bias. Revealed preference methods like hedonic price models can be applied to recreational fishing to estimate the demand, or WTP for marginal changes of a feature of the fishing experience.

Hedonic price models

Hedonic price modeling is a widely used method for estimating the monetary tradeoffs for quality changes of environmental resources (Palmquist and Smith, 2002). This method reduces an entire, multifaceted market item to its constituent features, or attributes. Next, the influence of each attribute on the overall price of the market item is estimated through regression. This approach represents the estimated value of that attribute. One drawback to hedonic price modeling is that it can only evaluate circumstances that are within the range of scenarios already experienced by users in real markets. Changes to the attribute that are outside of this range must be inferred.

While there is a large literature on stated preference modeling of recreational fishing trip attributes, hedonic method literature, which is considered a revealed preference model, is sparse. Hedonic models for recreational fishing are unusual because recreational fishing attributes tend to be purchased piece-meal. In other words, bait, fuel, gear, lodging etc. are all purchased separately by the angler. However, fishing packages are an exception. For the purposes of evaluating the demand for recreational fishing services, we consider billfish charter fishing packages a *differentiated good* insofar that they contain multiple attributes, each with a range of different levels. The differentiation of the good is necessary for the hedonic price model. A single, for-hire charter fishing package can be distinguished from others by its multiple attributes such as the length of trip, target species, size of boat, etc. Although anglers can choose their preference of attribute combinations, they are all close enough in the consumer's mind to be considered a single market item, and there is only one monetary transaction.

Hedonic price modeling can be used to study the value of an environmental condition that is being considered for management. In one study focusing on fishing in Ontario, Canada, researchers use the hedonic method to study the value of remoteness to anglers (Hunt, Boxall et al. 2005a). Fishing packages here have varying degrees of accessibility (remoteness) and are sold in an open market with many operators. Fly-in sites were, on average, more expensive than boat/train accessible sites, and followed by car accessible sites. Several factors, such as the presence of logging activities, were used to approximate remoteness (or lack thereof), and these had the expected results on price. The authors present a hypothetical scenario in which the remoteness of many fishing sites is lost, and they use their model parameter estimates to re-calculate the loss in revenue for fishing tourism operators in Ontario. The "degraded sites" on average declined in price 34% to 52% depending on the original condition. The same authors published a similar study that same year which incorporated spatial autocorrelation into the model. This analysis revealed, in addition to the remoteness of tourism sites, spatial lagged dependencies exist, where operators base their prices on those of their neighbors, to an extent (Hunt, Boxall et al. 2005b).

Hedonic price modeling is also useful for separating the values of multiple important features, which cannot be separated in real markets. Another study in 2010 used a similar approach to estimate the value of fishing trip features, focusing on the *expected* catch rates, instead of simply the presence/absence of certain species (Carter and Liese 2012). Anglers in the Gulf of Mexico are assumed to have access to information about recent catch rates via the internet or other avenues, and make their decisions according to their utility-maximizing preference. In this case, operators were aggregated into ports, a decision based on the lack of angler's ability to acquire catch rates information to any finer detail, such as the individual charter vessel/crew. These authors found that, on average, anglers were willing to pay around $9.00-$13.00 to fish on charters in locations where one could reasonably expect an additional fish kept per angler per trip, based on historical catch rates for the port location (Carter and Liese 2012).

Billfish Recreational Fishing in Guatemala

Guatemala's Pacific coast offers some of the highest seasonal densities of sailfish anywhere in the world (Chapter 3), due to its highly productive upwelling system, which is typical of waters on the western boundary of continents. The upwelling phenomenon brings cold, oxygen-poor waters very close to the surface during November through March. The habitat compression responsible for the sailfish density is highly seasonal (Chapter 2), and most anglers wish to fish during the winter months when the catch rates are the highest.

Similar to the anglers buying fishing packages for the Gulf of Mexico, billfish anglers who travel internationally are well-educated about expected catch rates in various times or locations (Chapter 3). Many anglers assume that the sailfish population is healthy due to the high catch rates compared to other popular billfish locations, for example, the eastern United States of America. In fact, research suggests that some sailfish and marlin populations are in decline (Kapur et al. 2017, Punt et al. 2015). The high catch rates experienced by some anglers only occur in isolated regions when environmental forcing is greatest.

Many countries, including Guatemala, are beginning to recognize the value of recreational fisheries as ecotourism, and the governments are considering policies that conserve billfish stocks. Elsewhere in the Eastern Pacific Ocean, Costa Rica has banned tuna purse seining within 60 miles of its coastline for the expressed purpose of conserving tuna for local longline fleets and billfish stocks for recreational fishing. This policy does not address the bycatch of billfish from longline fisheries operating in the Costa Rican Exclusive Economic Zone, which is typically an order of magnitude higher annually (INCOPESCA unpublished data) than purse seine bycatch in the same area (Chapter 1). Fisheries policies like this example should be evaluated systematically, and not implemented ad hoc. Economic valuation is one component to the efficient management of marine resources such as billfish.

4.2 Problem Identification, Purpose, and Objectives

The economic value of Guatemala's recreational billfish fishery is unknown. There is a need to assess the value of the resource as it is used in catch-and-release fisheries, which brings monetary input and employment to the coastal community via tourism. This information is critical for managers considering sustainable alternative uses of marine resources in their regulatory decisions.

Purpose

The purpose of this study is to estimate the present value of the recreational billfish fishery in Guatemala, which is currently sustained by seasonally high sailfish density.

Objectives

1. Define seasonal fish density (catch or raise) expectations for anglers fishing for billfish in Guatemala
2. Compile a database of individuals who paid to fish for billfish in Guatemala, and the corresponding characteristics of their trip.

3. Produce a model that separates the influence of trip characteristics, including catch expectations, on the price paid by the client.
4. Produce a separate model that separates the influence of trip characteristics, including raise expectations, on the price paid by the client.
5. Extrapolate results to approximate the value of the billfish fishing portion of tourism to Guatemala
6. Compare results to other valuation or impact assessments of recreational billfish fishing

4.3 Methods

Generalized Model

Charter fishing trips contain attributes, or characteristics, that vary. Boat size, for instance, is well known to affect the price paid by clients for recreational fishing services. Clients are willing to pay more for trips that offer characteristics at levels that are more desirable. In this case, larger boats typically command a higher price, all else being equal. In a competitive market, producers maximize their profits (Equation 1), and clients maximize their utility at the equilibrium hedonic price function:

$$p = g(z; \gamma), \qquad \textbf{Equation 4.1}$$

where p is the trip price, z is a vector of trip attributes and γ is a vector of parameters describing the shape of the hedonic price function.

The derivative of the hedonic function with respect to a single attribute gives the implicit price of that attribute. We assume the linear specification of the regression of price and trip attributes. Although the fishing success expectations based on time of year are theoretically continuous and the rate is changing at different times, we have simplified this variable to an average for each month of the year. Therefore, the non-linear nature of fishing seasonality has been encompassed prior to regression in the estimation of the expected catches and expected raises variables. As in previous studies, in our version of the hedonic price model, we link marginal changes in charter fishing trip attributes to marginal changes to price. We also examine marginal changes to other factors as well, to determine their relative importance to the price.

In Guatemala, packages are typically sold to groups of several people, fishing for several days. However, all the people included in a single invoice do not necessarily experience the same fishing conditions. Most often, groups of three or more are split between several boats. Thus, clients experience different boat sizes and crowding conditions with fellow anglers. Sometimes, not every client fishes all days. To account for these differences, we used information provided by the lodges to divide the total price paid to represent USD/person/day, and every individual who fished represented one sample unit.

Assumptions

- We assume that fish density expectations are temporally variable. The majority of recreational fishing for billfish in Guatemala occurs between January through April, when catch rates are the highest.

- We assume clients are fully educated about the daily catch rate expectations for various times of year (months). Anglers have several sources of information regarding the seasonal catch rate expectations (magazines, fishing forums, online reports, staff personal communications, past experience, etc.). We define catch rate expectations as the historical averages for that month across 8 years.
- We assume that charter company operators are likewise fully educated about catch or raise rate expectations, and therefore the price charged is at equilibrium. In other words, consumers and producers are both basing their prices on the same definition of expected catch rates, which ignores the current year's catches, because packages are sold before these can be taken into consideration.
- We assume that anglers are familiar with the terms "raise" or "raising" a billfish, which refers to the act of luring a billfish to the surface, but not necessarily catching it. The number of billfish raises is a better estimate of density, as it removes the variability of crew/angler skill to successfully catch a fish (Chapter 3).
- We assume that charter companies are operational year round, and clients have free choice of booking date.
- We assume that there is a limit to the number of boats available for charter fishing on any given day.

Daily catch rate expectations

Two major billfish lodges operate out of the Marina Pez Vela in Guatemala, although several much smaller ones also exist. Casa Vieja and Pacific Fins have made extensive, detailed fishing reports available to the public via their websites. We used all available reports (2010-2017) from these two lodges to calculate monthly average daily CPUEs (billfish/boat/day). Reports became more numerous in recent years. We believe that although all trips were not reported until approximately 2014, the earlier data still reflects average fishing days, and not cherry-picked excellent fishing days for marketing purposes. Student's t-tests comparing January 2011 and January 2017 means show that the earlier year actually has lower monthly average ($p = 4.602E-09$), and the same is true for February 2011 and 2017 ($p = 6.261E-07$). Additionally, due to low demand for fishing, there are also very few trips reported for the summer months. In the eight years of reporting, July, August, and September only have a combined number of 23 total daily CPUEs available. Daily catch and raise expectations, calculated using historic averages, were assigned to every client in the sample based on the month of their fishing date. Under this assumption, anglers fishing in January, for example, could expect the highest catches and raises per day, 14.75 and 29.96 respectively.

Fishing Trip Data

Documents issued by the lodges relating to the sale transaction of charter packages, or invoices, were obtained via personal communications with the manager at Pacific Fins lodge, in Guatemala. Three complete years of invoices were provided by Pacific Fins (2014, 2015, 2016). Most of the clients fished and payed as part of a larger group, for several days. We divided each group, and the corresponding price paid, into individual samples, each representing a single client, and the average price that client paid, per day. We obtained a total of 712 complete sample units from the provided documents. All identifying personal information was discarded and kept confidential. We then matched these sample units to a lodge calendar, indicating the date of the client's fishing trip, the number of days fished, the size of the boat, and the number of people on each boat. The client's room type accommodations were also included in the documents. We used the month that the fishing trip took place to assign the fish density expectations (catches or raises) to each sample.

Price Models

The two variables relating to expected billfish density, C/B/D (historic catch per boat per day) and R/B/D (historic raise per boat per day) are highly correlated (Figure 4.3), for the obvious reason that an angler cannot catch a fish that has not first been raised. Including both in a single regression confounded the conceptual model and resulted in unrealistic estimates of parameters. However, there is utility in comparing the estimates resulting from the two available figures, raises or catches. Therefore, we modeled the two separately.

Hedonic Price Models:

$$p_C = \beta_0 + \beta_1 C_m + \beta_2 B + \beta_3 P + \beta_4 F + \beta_5 T + \beta_6 N + \varepsilon \qquad \textbf{Equation 4.2}$$

And

$$p_R = \beta_0 + \beta_1 R_m + \beta_2 B + \beta_3 P + \beta_4 F + \beta_5 T + \beta_6 N + \varepsilon \qquad \textbf{Equation 4.3}$$

where p_C and p_R are the model predicted prices paid per person per day (Equation 2 and 3, respectively), B is the boat size (feet), P is the number of anglers on the boat, F is the number of fishing days, T is the room type (on or off premises), N is the total number of people in the party, C is the historic average catch for month m, and R is the historic average raises for month m. β terms are to be estimated in the model, and ε is the independent normally distributed error.

We standardized all continuous independent variables to the mean (*B, F, N, C*, and *R*). Price was not standardized. Room type is a two level dummy variable. Clients stayed in either suites or villas (on premises), or they did not stay at the lodge (off premises). Model parameters were estimated using the ordinary least squares method, using R statistical software.

4.4 Results

We documented a strong seasonality of recreational fishing success using historic records from two fishing lodges in Guatemala, as defined by raises or catches. Figure 4.1 shows the monthly means, and 95% confidence intervals, as well as the number of monthly CPUEs available to the public at the time of analysis. Figure 4.2 Shows similar statistics for the number of fish raised by a boat in one day of fishing. Raises and catches are highly correlated (Figure 4.3) and were therefore used in separate price regressions.

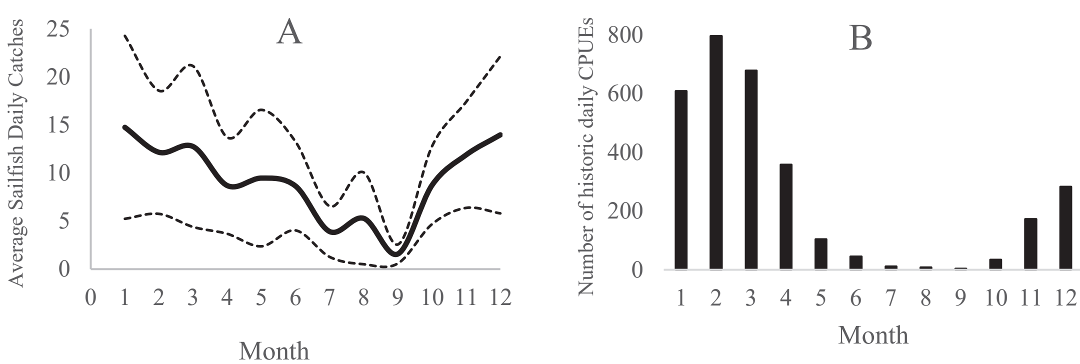

Figure 4.1 A: Black line represents the smoothed average catch of sailfish for each month. Dotted lines are 95% confidence intervals. B: The number of daily CPUE records available to the public from 2010-2017 by month.

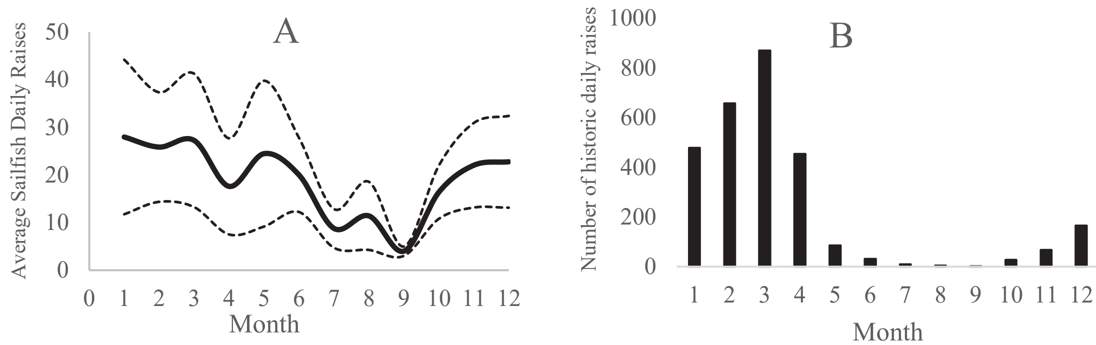

Figure 4.2 A: Black line represents the smoothed average raises of sailfish for each month. Dotted lines are 95% confidence intervals. B: The number of daily raise statistics available to the public from 2010-2017 by month. The number of raised fish is approximately twice the amount successfully caught.

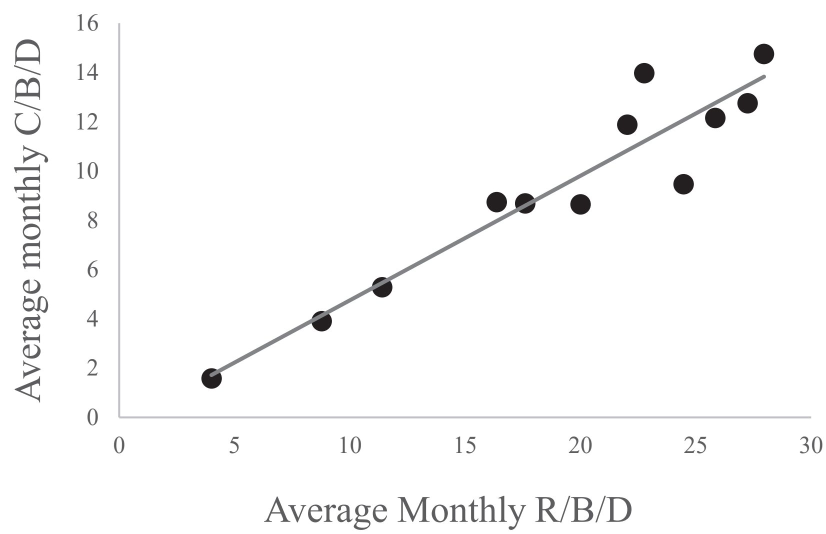

Figure 4.3 The two variables relating to fish density, Catch per Boat per Day (C/B/D) and Raise per Boat per Day (R/B/D) are highly correlated and thus modeled independently in equations 2 and 3.

In assigning fishing factors to individual client units, we found many groups of clients that were so large that two or more boats were used. We assigned the number of people to each respective boat using calendars and schedules provided by the lodges and reasonable assumptions, such as putting the extra, odd person on the larger boat. Boat size ranged between 31 and 39 feet. Most boats contained between 3-4 anglers. Within the database, only 6 anglers fished alone. Most anglers fished for 3 days.

Table 4.1 shows the means and standard deviations of numeric variables used for the hedonic regressions. On average, clients paid $1143 per person per day. Average historic monthly raises and catches are 24.83 and 12.20, respectively. The room type was categorized as either Villa/Suite (on premises) or off premises. Only 17 clients stayed in rooms or hotels off premises of the fishing lodge. When records failed to specify a variable of interest definitively, we dropped that variable from the sample unit (pair-wise deletion).

Following the regression procedures, we found that all variables significantly affected the price per person per day of the fishing packages, in both the catch and raise models. Furthermore, the variables influenced the price in the predicted direction. Results of the model estimations are shown in Table 4.2 and Table 4.3, corresponding to standardized equations 4.2 and 4.3 respectively.

Table 4.1 Summary statistics for unstandardized variables used in analysis

Factor	Mean	Stdev
Price per Person per Day	1143.75	391.98
Average Historic Monthly Catches	12.20	2.02
Average Historic Monthly Raises	24.83	3.87
Boat Size	33.38	2.01
# Anglers on the Boat	3.46	1.03
# Fishing Days	2.91	0.96
Number days Booked Ahead of Time	149.85	113.22

Table 4.2 Estimation results from Equation 2.

Variable	Parameter	Estimate	Pr(>|t|)
Constant	β_0	1160.966	< 2e-16 ***
Average Historic Monthly Catches	β_1	52.594	4.77e-05 ***
Boat Size	β_2	13.338	0.00246 **
# Anglers on the Boat	β_3	-159.516	< 2e-16 ***
# Fishing Days	β_4	-111.960	< 2e-16 ***
Room Type (off premises)	β_5	-473.832	3.60e-08 ***
# Anglers in Party	B_6	-55.315	9.15e-05 ***
Adjusted R^2		0.3147	

Table 4.3 Estimation results from Equation 3.

Variable	Parameter	Estimate	Pr(>|t|)
Constant	β_0	1161.295	< 2e-16 ***
Average Historic Monthly Raises	β_1	37.231	0.005363 **
Boat Size	β_2	13.302	0.002788 **
# Anglers on the Boat	β_3	-160.965	< 2e-16 ***
# Fishing Days	β_4	-113.521	< 2e-16 ***
Room Type (off premises)	β_5	-488.268	2.42e-08 ***
# Anglers in Party	B_6	-54.121	0.000186 ***
Adjusted R^2		0.3062	

Significance levels p < 0.05 *, p < 0.01 **, p < 0.001 ***.

The results of our models show that selecting a fishing date during a month corresponding to high expected catches and raises increases the average price paid by the clients. When including C/B/D as the fish density variable, anglers are willing to pay an additional $53 per person per day to fish during a month when they can expect to catch one additional fish per day. Similarly, when including R/B/D as the fish density variable, anglers are willing to pay an additional $37 per person per day to fish during a month when they can expect to raise one additional fish per day on their boat. On any given fishing trip, there are always more fish raises than successful catches. Therefore, the addition of one more standardized unit of expected fish raises will add relatively less to the increase marginal WTP than catches would, for the same client.

The other variables behave as expected, for both models. Increasing the boat size by one foot, on average, increases the price paid per person per day for the fishing package $13 in both models. Conversely, increasing the number of additional anglers on the boat reduces the average price paid for the fishing package by each individual on that boat. When the number of anglers on board is increased, anglers feel more "crowded," which is undesirable for most clients. Every additional angler reduces the price, on average, by $160 per person per day. Also as expected, fishing for more days reduces the average cost per person per day because a slight discount is offered to individuals booking long trips. A similar discount is offered to large groups, revealed in the negative value for the anglers in party variable. Lastly, when anglers are staying somewhere besides the lodge, their price per person per day is on average, between $474 - $488 cheaper.

We used our results to extrapolate a value for the billfish resources to the recreational fishing industry based on the most recent year, when all fishing days are accounted for from the two main lodges. In 2016, there were approximately 850 boat days recorded for the two major lodges operating in Guatemala, catching and releasing a total of 17,409 billfish. Since these two lodges provide the majority of billfish charters in Guatemala (personal communication from the lodge owners), this number is probably close to the total catch, but should be considered a minimum estimate.

Our catch model estimates an average increase of $53.00 per angler per day when anglers can expect to catch an average of one additional billfish per boat per day. Therefore, by multiplying this figure by the number of released fish, we estimate sailfish sport fishery in Guatemala is worth approximately of $920K per year, using the catch model. Alternatively, using the raise model, and a total of 33,970 raises in 2016, the value of the fishery is increased to $1.26 million per year. These value estimates can be considered a minimum, given that there are other, much smaller charter companies operating in addition to Casa Vieja and Pacific Fins, and these fishing trips are unaccounted for.

4.5 Discussion

Our hedonic price models demonstrated the value of high fish density in Guatemala's recreational billfish fishery. We found that, based on the average number of fish either raised or caught, this fishery is worth between $920K – $1.20 Million USD annually (in approximate 2016 dollars). This value does not include the hospitality component of fishing tourism (WTP for food, beverage, service, etc.), which has a value of its own, and would not exist without the fishery. The economic input generated from recreational fishing is substantial for this small developing community, where many people still live in semi-permanent huts, and cook food over burning plastic garbage. Approximately 100 locals have high-quality employment, either in the hotels/lodges or as captains/mates on the fishing vessels (personal communications with lodge managers).

Although it is the first for Guatemala, this is not the first study to estimate the value of a recreational billfish fishery. Our methodology and estimates for WTP per additional fish vary dramatically from similar estimated marginal values in previous studies (Gentner and Whitehead, 2018; Duffield et al. 2012; Whitehead et al. 2013), at different locations (mainland USA, Hawaii, and Caribbean). In these other locations, fishing circumstances may differ (ease of travel, local language, seasonality, regulations, etc.), however using the marginal value for catching (or raising) a single fish removes the WTP for these other factors. And, since the clients for these other locations are from the same pool (typically American or European males) of people who are willing to travel to catch billfish, we should expect marginal values for individual fish to be on the same approximate scale. There are several possible explanations for the inconsistency with other research, discussed below.

The Nature of recreational billfish fishing in Guatemala

The high average catch rates are the most likely explanation for the large disparity in previous estimates for WTP for one additional fish (in USA, Caribbean, and Hawaii) compared to our estimate. Guatemala is a unique location among billfish fishing destinations due to its seasonally high catch (or raise) rates. A major limitation in our study was the lack of a large range of expected catch rates available from this fishery. We obtained very few sample units that corresponded to a time when expected catches (or raises) were low. As previously noted, anglers fishing during the "high" season may expect to raise or release 30 or 15 fish, respectively, in a single day. Other locations may occasionally experience high fish density; however, the catches are never this consistently high.

As with most consumer products, the satisfaction derived from one additional unit is very high when the product is rare, and people are willing to pay a higher price. Fisheries with much lower catch rates belong in this category, at the upper end of the demand curve, and WTP for one additional catch is very high due to scarcity (Figure 5). The blue marlin fishery in Hawaii is a good example, as the expected catch rates used in the 2012 choice experiment are either zero or one (Duffield et al. 2012). At the other end of the demand curve, clients have already derived much satisfaction from the many units already consumed. Figure 4.4 represents the demand for catch rates in two different locations to illustrate this point. It is likely that Guatemalan clients reside at the lower end of the demand curve for billfish catches (or raises), and they are almost completely satisfied. Very little additional satisfaction will be obtained through catching (or raising) an additional billfish, and therefore the WTP estimate is much lower. This does not mean, however, that the fishery is less valuable. Indeed, when the Guatemalan values are summed over all of the catches for the recreational fishery, the total value approaches $1 million per year.

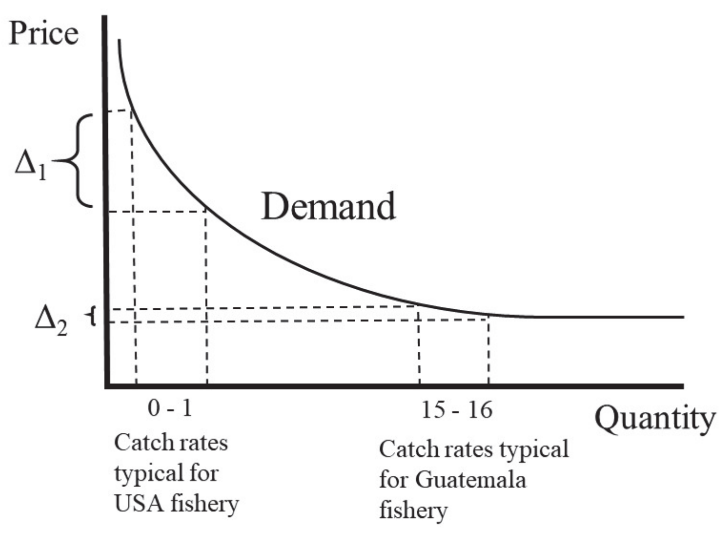

Figure 4.4 Demand curve representing the consumer's WTP for one additional billfish catch when catch rates are low (Δ_1) vs. when catch rates are high (Δ_2).

Our estimated marginal WTP for increasing catch and release rates of billfish are similar to the estimates provided by Cox (2012). Cox estimated an average of $89.41 per angler that fished in Isla Mujeres, Mexico. In that study, researchers used a discrete choice experiment involving 26 surveyed anglers instead of a hedonic price method. Despite the large variation in methodology and sample size, we obtained similar results. Arguably, Isla Mujeres and Guatemala have similar recreational billfish fisheries. Both rely mainly on high catch rates and foreign tourism.

In addition to the high catch rates, there are several other possible explanations for the large discrepancy of our marginal WTP estimate with previous attempts to value an additional billfish caught recreationally.

Hypothetical Bias

Studies which rely on hypothetical surveys have produced estimates of WTP for catching billfish which are an order of magnitude higher than ours. For example, Gentner and Whitehead (2018) estimated an average WTP of $761 for anglers to catch an additional billfish in the Caribbean. These authors used a choice experiment to survey anglers in the USA and Caribbean countries. In a similar choice experiment, Duffield and colleagues (2012) estimated a WTP value of between $276 and $521 to catch an additional blue marlin in Hawaii.

The hedonic price model has been rarely used to study recreational fishing, due to the lack of observable, single market exchanges. By using charter fishing packages, sold as complete units, we were able to use this revealed preference methodology. Our method is conceptually superior to stated preference methodologies because it does not rely on hypothetical scenarios, which have been shown to produce biased estimates (Murphy et al. 2005, List and Gallet, 2001). Economists have suggested that stated preference models, such as choice experiments (CE) and contingent valuation (CV) of environmental resources can provide biased results due to the hypothetical nature of the approach (Murphy and Stevens, 2004) and lack of a real budget of the client. The magnitude of hypothetical bias is debatable, but it most often produces inflated estimates of WTP. In 2005, Murphy and colleagues used a meta-analysis to estimate that results from contingent valuation studies are, on average, 1.35 times higher than revealed preference approaches such as our hedonic model (Murphy et al. 2005).

Disparity in defining catch rates.

Defining catch rates for billfish is problematic because fisheries in different locations vary in the degree to which fish are released. The billfish in Guatemala are universally released, due to the stakeholders' commitment to conservation, and the establishment of a national Sailfish Commission, which enforces the no sailfish harvest regulation in Guatemala. Therefore, we defined catch rates as catch-and-release.

A notable contrast to our definition of catch rates is the 2013 study pertaining to Atlantic billfish in the USA (Whitehead et al. 2013). These researchers used a variation of the travel cost method to estimate the average economic value to catch and *keep* an additional billfish when fishing on a charter boat in North Carolina. Anglers in the US fishery also practice nearly universal catch-and-release of billfish. From individual surveys, the researchers estimate an average catch and keep rate of only 0.02 billfish per person per fishing trip. The average catch-and-release rate is certain to be considerably higher (Figure 4.5), however the value of this activity is ignored by their model.

Many authors have documented the high rate of catch-and-release by American billfish anglers (Goodyear 2002). In fact, Nelson and Farber (1998) estimate between 376 – 843 total sailfish were caught and harvested on Florida's East coast in 1994. Fisher and Ditton (1992) estimate that 89% of billfish caught are released, and there is much evidence to suggest that number has increased significantly in the last 26 years. NOAA's recreational survey program estimates that in 2018, only 75 sailfish and 56 blue marlin were harvested in the Atlantic by the 3rd quarter of the year. There is also a gaining movement to leave the fish completely in water before releasing it, to improve chances of survival (Schlenker et al. 2016).

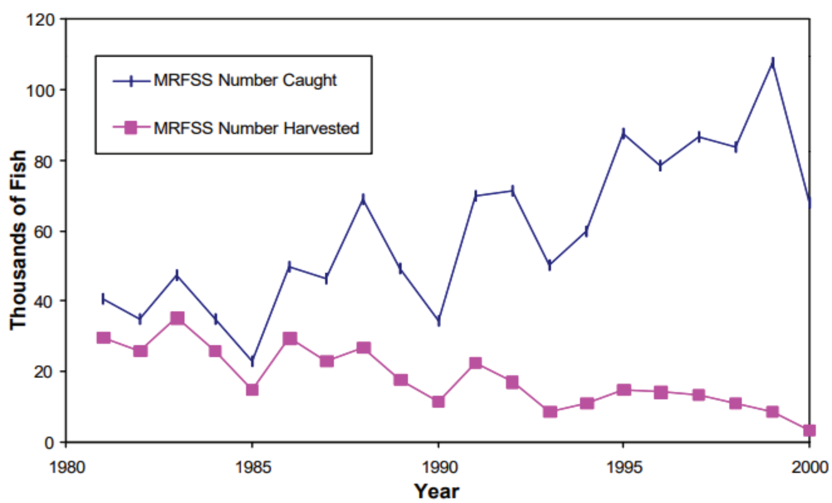

Figure 4.5 from (Goodyear, 2002) Estimated number of sailfish caught and harvested by non-tournament, USA recreational anglers. Results estimated from National Marine Recreational Fishery Statistics Survey.

Whitehead and colleagues (2013) estimate the average sum of the travel cost and charter fee (for primary purpose anglers) to be $630. When other factors are included, these authors estimate an increase of $2,243.89 WTP by an average angler when an additional billfish is expected to be caught and kept by that individual. In the year prior to this study, 2012, NOAA estimated that a mere 184 Atlantic sailfish were caught and harvested (non-tournament) in the USA. Assuming all billfish are equally as valuable as those caught in North Carolina, this brings the total value of the sailfish recreational fishery to $412,712 in 2013 dollars for the entire USA Atlantic region. When blue marlin and white marlin harvest are added (63 harvested and 30 harvested respectively), the total billfish fishery is $621,311 in 2013 dollars. These estimates are substantially less than the value of the Guatemalan fishery estimated by our model, despite the Guatemalan fishery having much fewer users. The estimate provided by Whitehead and colleagues neglects the large amount of utility of the catch-and-release method for recreational billfish anglers. Much of the disparity of their result of WTP per additional billfish with our estimates can be attributed to the different definitions of catch rates.

Additionally, most people fish as part of a group, and there is likely utility in being on board of a vessel while another angler catches the billfish. We account for this value by defining catch rates on a boat level, instead of the individual level, meaning that increased catches will contribute to the enjoyment of all individuals on board the boat. This value is also unaccounted for in the model by Whitehead and colleagues (2013). Our estimate, calculated at the boat level, will result in a lower WTP (per person per day) for each additional fish, but would still have substantial value when summed over the total fishery. The marketing of catch rates for billfish in Guatemala and elsewhere are most often reported per boat. Clients are more likely to be familiar with these statistics and base their WTP from these expected numbers. For these reasons, we believe our estimates are more appropriate for recreational fishing for billfish.

Disparity in defining value

This is not the first study to conduct a valuation for a billfish recreational fishery in Central America. Table 4.4 compares our estimated average daily expenditures for billfish anglers fishing in Guatemala with other estimates from previous studies in comparable locations. Jimenez and colleagues (2010) quantified all expenditures of USA and Canadian sport fishers in Costa Rica. The study extrapolated results from a survey which included travelers in two major Costa Rican airports who came to fish for any species. The study inferred that 283,790 anglers traveled to Costa Rica to fish and spent a total of $467 million US dollars on fishing or travel related expenses. They additionally estimated all expenses paid by all Costa Rican companies which have sport fishing clients, but the entirety of their business is not necessarily from sport fishing. The income/investment ratio of these companies was around 30%. Using their econometric model, they estimate a $599 million effect on Costa Rica's GDP, or economic impact, by sport fishers. Because many of these anglers reported that they expected to catch at least one billfish, this number has been cited as an appropriate proxy for the value of billfish angling in Costa Rica (Gentner, 2016).

Table 4.4 Our estimated daily expenditure per billfish angler per day and other valuation studies. Dollars are reported in USA dollars of the year of the study; they are not adjusted for inflation.

Location	Species	Daily expenditure per person	Study
Atlantic Coast, USA	Highly Migratory Species	$900	Hutt et al., 2014
Panama	All species	$217	Southwick et al., 2013
Costa Rica	All species	$549	Jimenez et al., 2010
Cabo San Lucas, Mexico	Mostly Billfish	$331	Southwick et al., 2010
Guatemala	Billfish	$1,144	Present study

Impact studies such as the one described above should not be confused as an approximation for a fishery's value. Impact analysis, which quantifies the economic activity generated under certain conditions, fails to evaluate the efficiency of a scenario, i.e. it adds all spending together, instead of recognizing that some spending is actually a cost to society. For example, a local government paying people to clean up trash on a beach would result in money spent, and impact an economy. However, leaving trash on a beach does not increase the beach's value, in fact it decreases the value. The money spent on cleanup crews could be spent elsewhere, on more productive activities, so it is actually a cost. Hedonic modeling focuses on separating the economic value of one attribute (catch rates, in our case) away from other confounding activities, instead of adding them all together. Although not the intention of the authors, economic impacts are often misrepresented or misinterpreted as societal benefits, and there is great potential for misleading stakeholders (Crompton 2006).

A useful next step to our valuation study would be to incorporate the results into an environmental cost-benefit analysis (Kuosmanen and Kortelainen, 2007). Cost benefit analysis determines the total social welfare effects. Only by considering the pros and cons of a decision can the maximum benefits from a resource be gained. Future research in Guatemala should quantify economic losses to the artisanal fishers, who are currently banned from harvesting sailfish, and local seafood markets.

Conservation implications

Much of recent marine conservation efforts have involved demonstrating the value of fish or other marine life being left in the sea. Accurate estimates of economic values for natural resources are often elusive due to the necessary assumptions of the estimation techniques, such as the hypothetical nature of contingent valuation. Our method relied on user expenditures from Guatemala's catch and release billfish fishery, providing tangible figures to use in policy evaluations.

Policies that impact billfish catch rates in Guatemala will alter the demand for recreational fishing services. Managers may want to consider the tourism supported by billfish fishing when deciding the level of harvest or protection imposed on the species. Currently, there is little commercial fishing of pelagic species in Guatemala compared to other countries in the region, such as Costa Rica. Sailfish and marlin stocks, however, are highly migratory, and their annual movements brings them across international boundaries (Pohlot 2019, in review), and consequently, different management regimes. Because the population may experience depletion elsewhere, billfish stocks should be managed cooperatively with other nations.

Chapter 5

Dissertation Key Findings, Conclusions, Future Research, and Management Implications

Costa Rica and Guatemala's recreational fisheries for billfish have served as an excellent testing ground to study the role of recreational fishing as a form of ecotourism. Lodge operators (Casa Vieja and Pacific Fins) in Guatemala have cooperated with our team to gather data that would otherwise be inaccessible to researchers. We were also able to obtain a large number of catch statistics from Guatemalan and Costa Rican billfish tournaments for our analysis. The main finding of this dissertation is the estimation of the economic value of the sailfish fishery, and identification of factors that support the demand for the tourism services offered. The knowledge acquired in these analyses may assist managers in Central America to efficiently regulate the multi-gear fisheries affecting multiple species in the EPO, as well as incentivize investments for further research of these under-studied species.

5.1 Catchability Regimes in Central America

In Chapter 2, we use catch rates from billfish tournament to examine the role of a seasonally dynamic ecosystem in forming the basis for successful recreational fishing and high catch rates, which subsequently support the demand (Chapter 3) for tourism services. Because of the localized nature of the CPUE relative to the much larger overall spatial and temporal distribution of the sailfish population in the EPO, we do not attempt to standardize sailfish CPUEs as indices of abundance for stock assessment purposes; however, the results from our study on the mechanisms affecting local catchability may inform such attempts in the future. Our analysis describes environmental conditions that are likely affecting the fish's depth distributions, horizontal movements, residency times, and ultimately the vulnerability to a given fishing gear. The EPO is a highly dynamic environment that has supported some of the world's most productive fisheries, including the growing sport fisheries. Western boundary currents and seasonal gap winds initiate upwelling near the continent that pushes the thermocline and minimum oxygen layer toward the surface. The effect is seasonal compression of habitat for marine species. The HMS species, such as tuna and billfish, have the ability to migrate elsewhere, but they do not, as evidenced by their high catch rates, meaning that the compressed habitat is still suitable or even preferable for their survival or reproduction needs. Our research suggests that the high catch rates (CPUE) for sailfish during the months of November through April correspond to increases in local density and/or local catchability and not changes in population abundance.

Our analysis focused on indicators of habitat compression: the two indices we created using mixed layer depth (MLD) and El Niño Southern Oscillation Index (ENSO). These were prioritized because habitat compression is directly linked (spatially and temporally) to the depth of the oxygen minimum layer, thought to be a limiting boundary for billfish. Seasonal upwelling draws oxygen-poor waters from the deepest parts of the ocean, creating this biological barrier. In accordance with previous researchers, we found evidence that the compression of oxygen habitat is a determinant of billfish behavior, in both their vertical and horizontal migrations in the water column (Prince and Goodyear, 2006). In Guatemala, which has fewer tournaments, the negative direct correlation between average MLD and catch rates was more apparent than in Costa Rica, after removing an outlier. Additionally, in Guatemala, this relationship was in the expected direction, with higher catch rates observed when the MLD was shallow. Conversely, catch rates improved when there was decreased horizontal compression toward the coast, measured by our Shoaling Index, suggesting that a more homogenous habitat is preferable. It should be noted that the 2014 outlier, which was the beginning of a persistent El Niño, greatly influenced the relationship of the compression indices with catch rates. This interaction should be investigated further in the Guatemalan coastal habitat

We also used the ENSO index as an indirect measurement of many ocean processes that affect not only the compression of habitat, but also other features like eddies and current strength/location, which might affect adult sailfish behavior. The ENSO index did show a degree correlation with catch rates in some of our analysis. However, the relationship is in the opposite direction of what we expected. We would expect a strong El Niño to suppress the upwelling (habitat compression) and reduce the catchability of sailfish. Our results show that catch rates in Costa Rica actually increased when the ENSO index is high. It is likely that the ENSO index is revealing mechanisms that affect the horizontal movement of adult sailfish. Water temperature, for example, is affected by the ENSO oscillations, and other researchers have suggested that this may be controlling the movement of billfish. Satellite tagging studies show that most billfish thrive in a narrow temperature range, approximately 22° – 24° C (Braun et al. 2015). Our exploration of the temperature habitat in Guatemala's fishing area shows that this range of temperature corresponds to approximately 30 meters below the surface (Figure 5.1), which is also the approximate depth of the majority of our MLD values from external sources.

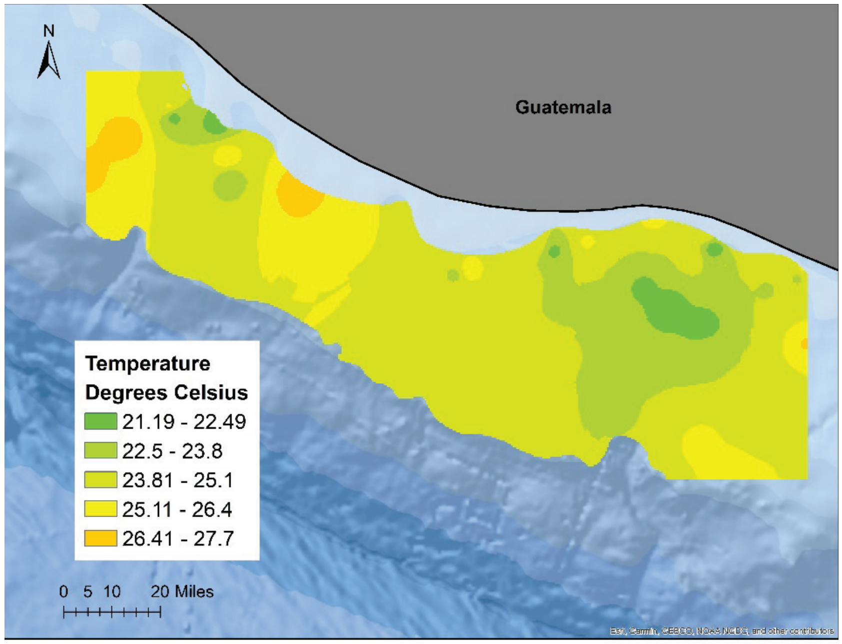

Figure 5.1. Temperature profile at 30 meters depth, measured in April 2018.

In this analysis, we were also able to confirm previous research (Fitchett 2015) that shows a link between the major EPO currents and sailfish populations in the coastal regions. When the strength of the NEC prevailed over the ECC at the time of recruitment, recreational fisheries approximately 5 years from then experienced higher catch rates. The NEC and the ECC may play a role in the successful recruitment of sailfish to the adult population, and they should be investigated further.

Scientists predict the climate will change in the next century, and this will be a driving force regulating distribution, abundance, and behavior of pelagic fish populations (Dell'Apa et al. 2018). Climate change will undoubtedly change the distribution of fish species (Rijnsdorp et al. 2009), as it disrupts and changes the frequency and intensity of climate phenomenon like El Niño (Cai et al. 2014). Our study highlights the uncertain nature the environment's effect on fishing success. We found that the ENSO index and El Niño events cannot be reduced to simple cause and effect mechanisms, like compression of vertical habitat, that affect billfish behavior predictably. It is likely that several, connected mechanisms will be altered under future conditions, and we can speculate some potential outcomes related to climate change. For example, as a result of their literature synthesis, Dell'Apa and colleagues predict that increased water temperature and spreading hypoxic zones (both vertically and horizontally) may further reduce the acceptable habitat for species like sailfish, marlin, and their prey, increasing their vulnerability to fishing gear. Of particular importance to Central America's recreational fisheries, we predict that the potentially increased hypoxic zones may reduce billfish's ability to recover metabolically post-release, putting the sustainability of recreational fisheries at risk.

In our research, our lab has found enthusiastic assistance from the recreational fishing industries in Central America, whose business relies on stable populations of sailfish. These same individuals may, in the future, be able to provide higher resolution environmental data through direct measurements, as sensors become smaller and cheaper. Higher resolution data, on a fine spatial scale, may further illuminate sailfish and marlin habitat preferences. Our results, used in conjunction with direct observation studies like satellite tagging, may be used to sustainably manage and conserve billfish populations in the future by incorporating spatial considerations at a smaller scale than is currently regulated.

5.2 Angler Motivations and Satisfaction in Guatemala

To optimize human benefit of recreational fisheries, identification and protection of fishing aspects that motivate and satisfy recreational anglers is necessary to preserve the perceived value, defined as the financial benefits of a fishery to its users. Certain attributes may initially motivate anglers, and depending on the outcome of the fishing experience, satisfy the anglers, both contributing to the overall demand for fishery resources. In our second analysis (Chapter 3), we studied the backgrounds and opinions of anglers who traveled to Guatemala to fish, and explored the relationships between these factors.

Anglers catching billfish in Guatemala are prohibited from harvesting sailfish, and most have no desire to do so. Therefore, the purpose was to identify other attributes of the fishery that anglers are looking for. Our survey explored the motivations and other factors that influence satisfaction among this specialized subset of recreational fishers and collected demographics and fishing statistics from respondents.

With the cooperation of billfish fishing lodges operating out of Marina Pez Vela in Guatemala, we surveyed 75 anglers who fished in 2017. These anglers had, on average, 13 years of fishing experience and had a roughly 60% success rate, defined as the number of raised fish that were subsequently caught and released. Based on the responses from our survey, two groups became apparent: those who mentioned an aspect of quantity in catch rates, and those who did not. Anglers with the most experience (over 21 years) were much more likely to report quantity as their main motivation for choosing to travel to Guatemala than those with less experience. These anglers are likely very familiar with billfish fishing success in other locations, supporting our hypothesis that Guatemala may offer a perceived "unique" experience for those seeking high daily catch rates. None of the anglers reported that they were seeking a large billfish, or an International Game Fish Association Grand Slam (3 billfish species in one day.)

Clients were generally either satisfied or very satisfied, defined as the extent to which the trip met their expectations. Despite many over-estimating the relative abundance of billfish in Guatemala, only two survey respondents reported that the trip failed to meet their expectations, and these anglers were not outliers in any other regard. We predicted that angler motivation, avidity, experience, as well as expected fish abundance, observed abundance, and fishing success would influence the satisfaction of billfish anglers in Guatemala. We found evidence that the initial motivation (quantity or not) influenced the anglers' satisfaction more than any other variable. Those who were motivated by the high catch rates in Guatemala were on average more satisfied with their experience. Interestingly, the angler's "success" i.e. the number of raised fish that they were able to hook and release, did not influence their satisfaction.

In accordance with motivation theory, other researchers have suggested that when anglers become more "deprived" i.e. they are catching less fish, their motivations become more oriented toward catch factors, such as quantity or size (Finn and Loomis, 2001), than non-catch factors, like companionship. This has interesting implications for billfish anglers who travel internationally seeking billfish. Many of the world's sailfish and marlin stocks are continuing to decline (Ehrhardt and Fitchett 2016, 2006), although some are seeing signs of recovery (Sharma et al. 2018). These anglers may enter a state of deprivation when fishing in depleted locations. Thus, they may become more motivated to seek high catch rates. In fact, this state of deprivation likely already exists for many older anglers who can still remember higher catch rates in other places (e.g. the USA), and it has contributed to the growth of sport fisheries in Central American countries like Guatemala and Costa Rica, where catch rates are still relatively high. That being said, Guatemala's high catch rates may not sustain continued growth of this industry and the addition of substantially more fishing effort. Other researchers have warned against the over-investment of recreational effort in Guatemala's billfish fishery (Fitchett 2015), as catch rates may decline with vessel aggregation on "hotspots" and crowded conditions. It is clear that anglers traveling to Guatemala are expecting very high catch rates compared to other billfish fishing destinations. If the recreational industry is to continue thriving, these catch rates must be preserved. Further research may investigate the level of dissatisfaction, particularly pertaining to catch rates, where anglers no longer perceive the experience to be unique, and are subsequently unwilling to travel to fish in Guatemala.

Generally, recreational anglers show an affinity to involvement in management decisions (Young et al. 2016). A logical next step to this survey would be to collect opinions on regulations pertaining to Guatemala's fishery. Anecdotal evidence from captains and lodge operators suggests that anglers are happy with mandatory release of sailfish and would like to see more enforcement of this regulation in the country's artisanal longline fisheries. Others, though, argue that the use of billfish resources as a local food source should take priority over their use as a leisure sport or hobby for foreigners. Thus, Guatemala's recreational fishing industry needs to show that conservation of sailfish brings substantial benefits to the community. Support for this contention is addressed in Chapter 4, however calculating the total economic impact of the fishery is beyond the scope of this dissertation.

Guatemala's Sailfish Commission currently has limited resources to enforce these regulations. Anglers in Guatemala may be willing to contribute financially to research or enforcement of conservation regulations. They may even find additional regulations limiting their effort to be palatable if it further reduces fish post-release mortality. Regular consultation with these stakeholders may not only provide valuable information, but also change the participatory atmosphere of this fishery. Our research highlights the importance of high daily catch and release rates to the anglers who travel to Guatemala for billfish, who are an experienced and specialized group of anglers.

5.3 Value of Sailfish in Guatemala's Recreational Fishery

In our last analysis, we examined the economic demand for billfish resources in Guatemala, generated by tourists (self-reported) seeking very high catch rates (Chapter 3). Because the demand must be based on a predicted experience, we first gathered several years of historical catch rates from the two major fishing lodges to define client expectations for fish abundance depending on the month of fishing. Because every trip from the two major lodge operators was included, we consider this endeavor a census rather than survey. We documented a strong seasonality of recreational fishing raises and catches.

To estimate the economic value of catching a billfish here, we used a rarely employed technique for recreational fisheries. Hedonic price modeling reduces a multi-faceted market item to its constituent parts, and examines the contribution of each to the price paid by the consumer. It does not rely on hypothetical scenarios, as many recreational fishing studies do. We performed two separate hedonic price regression models: one that used the expected fish raises per day, and the other used the expected fish releases per day. These two variables are conceptually linked; one cannot release a fish that has not first been raised.

For every additional expected fish catch, anglers were willing to pay an additional $53.00 per person per day. For every additional raise, the value was $37.00. To extrapolate these values to the entire fishery, we multiplied these values to the estimated total raises and releases for the fishery in 2016. Using the raise model, the value is $1.26 million per year. Using the catch model, the figure is $920K per year.

Others have used different methodologies and different definitions of value and catch rates to assess other sport fisheries in the region, with varying results. Our analysis, which relies on real market data, provides a realistic snapshot of the demand for billfish resources in a small, semi-isolated fishery. We believe that our methodology could be replicated for other fisheries in the region, based on our experience of cooperation from stakeholders in Guatemala.

In the case of the Guatemalan fishery, the economic contribution of billfish resources may be thought of as more than the sum of its parts. The fish population, when either raised or released, contributed approximately $1 million to this tourism economy based on our hedonic model results. However, it provides the foundation for other services and items that were not accounted for in this analysis. All of the hospitality, accommodations, travel expenses, and goods purchased by fishing clients have additional value, and would not exist without the fishery. A full impact analysis would be an important next step in appreciating the economic contributions of sport fishing in Marina Pez Vela. However, the necessary input-output tables for these calculations are not readily available for Guatemala's industries, and quantifying the nature of relationships between sectors would require research investment beyond our current capabilities.

In Guatemala, there is an avenue for anglers to directly contribute to the management and enforcement of sailfish regulations, through the National Sailfish Protection Commission. There is a website (http://sailfishconservation.org/) where anglers or anyone can make donations to projects funding the enforcement or educational opportunities for locals. Donations are not mandatory, and although we demonstrate substantial value of this fishery, the website currently lists 0% of its fundraising goal achieved.

5.4 Management Implications

The research in this dissertation highlights the importance of valuable sport fisheries in Guatemala, which we consider a sustainable use of billfish resources. Sailfish are protected in Guatemala; however, due to the highly migratory nature of these fish, protection within a single country's EEZ is insufficient.

As the status of the sailfish stock is still uncertain, managers should use a precautionary approach when managing this and other bycatch species. Also, regulators should avoid non- practical, unenforceable regulations. For example, a 2008 Costa Rican law mandates that pelagic longline landings cannot include more than 15% sailfish, and all landings over that have to be donated to food assistance programs. Artisanal longline fishers in the EPO currently employ few methods/technologies to control what they catch, and additionally there is no dockside authority calculating landings percentages. The rule is entirely unenforced and there is yet to be a single donation of sailfish. Laws like this have more value as political posturing than conservation tools. At a minimum, there needs to be a systematic sampling of landings from artisanal fishers, which could come in the form of collaborations with national governments, Non-Governmental Organizations, or Universities. Future assessment attempts may benefit from insight and data provided by sport fisheries targeting sailfish and marlin. We caution against applying recreational CPUE statistics as indices of abundance for the stock(s), as the spatial sampling domain is not representative of the majority of the distribution of the stock, and the misinterpretation will have management consequences. The environmental factors affecting these fisheries are also uncertain for the future, providing further incentive for cooperative management between stakeholders and among countries/regions that exploit these resources.

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Appendices

Supplemental Information

Appendix A. Billfish length to weight conversions. Average length of harvested sailfish and marlin (entire ocean) are reported by the IATTC for each year, as well as the total number per 1X1 grid square. Average weight is calculated using published conversion factors a and b. We chose female blue marlins as a representative for all marlins to convert the lengths to weight. Total harvest is calculated by multiplying this by the number of sailfish and marlin (all species) removed from Costa Rica's EEZ, according to IATTC spatial data. The most recent 5 years are shown for demonstration. Blue Marlin Parameters are from Brodziak 2013, and sailfish parameters are estimated from our lab.

W = aL^b		**2012**	**2013**	**2014**	**2015**	**2016**
a	Sailfish 4.21E-05					
b	2.803376923					
	Average Length (cm)	160	156	153	166	173
	Average Weight (kg)	63.6	59.3	56.1	70.5	79.2
	Numbers in CR	130	207	71	100	523
	Total Weight (kg)	8270.2	12266.5	3984.4	7053.4	41417.5
	Total Weight (tons)	8.3	12.3	4	7.1	41.4
a	Blue Marlin (female) 0.00001844					
b	2.956					
	Average Length (cm)	206	202	204	203	202
	Average Weight (kg)	127.5	120.3	123.9	122.1	120.3
	Numbers in CR	57	224	40	61	40
	Total Weight (kg)	7268.2	26954.3	4955.5	7448.2	4813.3
	Total Weight (tons)	7.3	27	5	7.4	4.8
	Total billfish (tons) harvested in CR	15.5	39.2	8.9	14.5	46.2

Appendix B. Average MLD and Shoaling index for all Costa Rican Tournaments.

Date of 1st day	Tournament	Boats	Average MLD	Shoaling Index
6/27/2004	Presidential Challenge in Costa Rica	5	6.59	6.18
1/12/2005	Los Suenos Signature Series Leg I	33	14.65	4.80
3/11/2005	Los Suenos Signature Series Leg II	32	7.63	7.85
5/2/2005	Presidential Challenge in Costa Rica	9	8.11	2.82
1/19/2006	Los Suenos Signature Series Leg I	46	7.48	6.02
3/2/2006	Los Suenos Signature Series Leg II	49	15.11	4.42
4/21/2006	Presidential Challenge in Costa Rica	9	10.2	3.50
1/18/2007	Los Suenos Signature Series Leg I	54	16.56	14.26
3/15/2007	Los Suenos Signature Series Leg II	58	12.51	4.73
4/20/2007	Presidential Challenge in Costa Rica	12	8.4	2.06
1/9/2008	Los Suenos Signature Series Leg I	41	9	3.43
3/12/2008	Los Suenos Signature Series Leg II	42	15.41	6.10
4/12/2008	Presidential Challenge in Costa Rica	11	16.56	2.74
11/19/2008	2008 Marlin Invitational	15	8.09	5.95
1/21/2009	Los Suenos Signature Series Leg I	43	12.13	2.28
2/25/2009	Los Suenos Signature Series Leg II	44	13.3	8.69
3/21/2009	Presidential Challenge in Costa Rica	7	20.73	5.34
11/18/2009	2009 Marlin Invitational	13	8.39	13.04
1/13/2010	Los Suenos Signature Series Leg I	42	17.8	3.81
2/17/2010	Los Suenos Signature Series Leg II	43	16.56	5.18
3/5/2010	Presidential Challenge Costa Rica	12	23.93	4.42
12/1/2010	2010 Marlin Invitational	12	8.2	7.09
1/26/2011	Los Suenos Signature Series Leg I	41	7.78	5.41
3/2/2011	Los Suenos Signature Series Leg II	35	12.13	3.43
3/24/2011	Presidential Challenge Costa Rica	11	15.543	1.67
6/22/2011	Presidential Challenge Papaguayo	9	10.45	5.18
11/30/2011	2011 Marlin Invitational	16	7.93	9.91
1/25/2012	Los Suenos Signature Series Leg I	37	9.84	2.82
3/1/2012	Presidential Challenge in Costa Rica	12	21.54	8.85
3/21/2012	Los Suenos Signature Series Leg II	41	15.33	10.83
4/13/2012	Quepos Billfish Cup	13	7.86	15.64
6/6/2012	Presidential Challenge in Papaguayo	9	9.69	5.87
12/12/2012	2012 Marlin Invitational	11	7.17	13.27
1/16/2013	Los Suenos Signature Series Leg I	38	8.93	5.18
2/8/2013	Quepos Billfish Cup	12	10.6	7.09
3/1/2013	Presidential Challenge in Costa Rica	8	14.5	5.95

3/13/2013	Los Suenos Signature Series Leg II	39	10.68	5.18
4/14/2013	Costa Rica Offshore World Championship	67	6.64	4.95
5/16/2013	Presidential Challenge in Papaguayo	8	7.93	8.54
1/22/2014	Los Sueños Signature Triple Crown LEG 1	42	11.21	7.24
2/20/2014	Quepos Billfish Cup	11	14.57	8.54
2/26/2014	Los Sueños Signature Triple Crown LEG 2	39	16.1	4.88
3/12/2014	Los Sueños Signature Triple Crown LEG 3	37	13.27	3.96
3/17/2014	12th annual Osa Classic at Croc. Bay	9	9.61	10.75
4/6/2014	Offshore World Championship in Quepos	64	11.67	6.10
1/22/2015	Los suenos triple crown leg 1	39	18.2	9.38
2/7/2015	Quepos Billfish Cup	13	13.2	9.30
2/26/2015	Los Suenos Triple Crown leg 2	40	15.9	5.56
3/25/2015	Los Suenos Triple Crown leg 3	37	13.7	4.04
1/21/2016	Los Suenos triple crown leg 1	44	30.7	8.54
2/25/2016	Los Suenos triple crown leg 2	45	23.9	15.03
3/29/2016	Los Suenos triple crown leg 3	42	17.7	5.41
4/19/2016	Offshore World Championship in Quepos	60	13.35	5.11

Appendix C. Average daily CPUE and 5-year delayed average of winter NEC and ECC strengths.

Tournament	Sailfish CPUE	NEC Average	ECC Average
Presidential Challenge in Costa Rica	3.27	223.75	180.17
Los Suenos Signature Series Leg I	4.95	208.96	204.96
Los Suenos Signature Series Leg II	9.24	208.96	204.96
Presidential Challenge in Costa Rica	5.63	208.96	204.96
Los Suenos Signature Series Leg I	8.91	239.67	244.92
Los Suenos Signature Series Leg II	5.10	239.67	244.92
Presidential Challenge in Costa Rica	3.44	239.67	244.92
Los Suenos Signature Series Leg I	2.50	289.33	273.71
Los Suenos Signature Series Leg II	3.81	289.33	273.71
Presidential Challenge in Costa Rica	0.78	289.33	273.71
Los Suenos Signature Series Leg I	2.49	294.46	256.04
Los Suenos Signature Series Leg II	5.77	294.46	256.04
Presidential Challenge in Costa Rica	3.09	294.46	256.04
2008 Marlin Invitational	4.40	263.92	223.17
Los Suenos Signature Series Leg I	5.74	263.92	223.17
Los Suenos Signature Series Leg II	1.30	263.92	223.17
Presidential Challenge in Costa Rica	2.86	263.92	223.17
2009 Marlin Invitational	3.15	226.79	194.58
Los Suenos Signature Series Leg I	5.36	226.79	194.58
Los Suenos Signature Series Leg II	2.47	226.79	194.58
Presidential Challenge Costa Rica	1.58	226.79	194.58
2010 Marlin Invitational	0.94	215.75	181.38
Los Suenos Signature Series Leg I	0.89	215.75	181.38
Los Suenos Signature Series Leg II	9.84	215.75	181.38
Presidential Challenge Costa Rica	2.73	215.75	181.38
Presidential Challenge Papaguayo	5.04	215.75	181.38
2011 Marlin Invitational	3.15	204.96	168.83
LOS SUEÑOS SIGNATURE BILLFISH SERIES LEG 1	5.52	204.96	168.83
Presidential Challenge in Costa Rica	1.86	204.96	168.83
Los Suenos Signature Series Leg II	5.27	204.96	168.83
Quepos Billfish Cup	1.69	204.96	168.83
Presidential Challenge in Papaguayo	4.81	204.96	168.83
2012 Marlin Invitational	6.94	206.67	207.92
Los Suenos Signature Series Leg I	12.33	206.67	207.92

Quepos Billfish Cup	6.00	206.67	207.92
Presidential Challenge in Costa Rica	1.33	206.67	207.92
Los Suenos Signature Series Leg II	8.62	206.67	207.92
Costa Rica Offshore World Championship	3.03	206.67	207.92
Presidential Challenge in Papaguayo	4.13	206.67	207.92
Los Sueños Signature Triple Crown LEG 1	17.13	233.75	252.58
Quepos Billfish Cup	12.09	233.75	252.58
Los Sueños Signature Triple Crown LEG 2	9.02	233.75	252.58
Los Sueños Signature Triple Crown LEG 3	16.53	233.75	252.58
12th annual Osa Classic at Croc. Bay	2.44	233.75	252.58
Offshore World Championship in Quepos	10.65	233.75	252.58
Los suenos triple crown leg 1	18.21	231.92	207.25
Quepos Billfish Cup	9.56	231.92	207.25
Los Suenos Triple Crown leg 2	13.89	231.92	207.25
Los Suenos Triple Crown leg 3	16.86	231.92	207.25
Los Suenos triple crown leg 1	14.74	213.88	169.88
Los Suenos triple crown leg 2	20.39	213.88	169.88
Los Suenos triple crown leg 3	14.67	213.88	169.88

Appendix D. Date of first day of each Costa Rican Tournament and the 5-year delayed current ratio index.

Date of 1st day	Tournament	ECC/NEC
6/27/2004	Presidential Challenge in Costa Rica	0.80
1/12/2005	Los Suenos Signature Series Leg I	0.98
3/11/2005	Los Suenos Signature Series Leg II	0.98
5/2/2005	Presidential Challenge in Costa Rica	0.98
1/19/2006	Los Suenos Signature Series Leg I	1.02
3/2/2006	Los Suenos Signature Series Leg II	1.02
4/21/2006	Presidential Challenge in Costa Rica	1.02
1/18/2007	Los Suenos Signature Series Leg I	0.94
3/15/2007	Los Suenos Signature Series Leg II	0.94
4/20/2007	Presidential Challenge in Costa Rica	0.94
1/9/2008	Los Suenos Signature Series Leg I	0.86
3/12/2008	Los Suenos Signature Series Leg II	0.86
4/12/2008	Presidential Challenge in Costa Rica	0.86
11/19/2008	2008 Marlin Invitational	0.84
1/21/2009	Los Suenos Signature Series Leg I	0.84
2/25/2009	Los Suenos Signature Series Leg II	0.84
3/21/2009	Presidential Challenge in Costa Rica	0.84
11/18/2009	2009 Marlin Invitational	0.85
1/13/2010	Los Suenos Signature Series Leg I	0.85
2/17/2010	Los Suenos Signature Series Leg II	0.85
3/5/2010	Presidential Challenge Costa Rica	0.85
12/1/2010	2010 Marlin Invitational	0.84
1/26/2011	Los Suenos Signature Series Leg I	0.84

3/2/2011	Los Suenos Signature Series Leg II	0.84
3/24/2011	Presidential Challenge Costa Rica	0.84
6/22/2011	Presidential Challenge Papaguayo	0.84
11/30/2011	2011 Marlin Invitational	0.82
1/25/2012	Los Suenos Signature Series Leg I	0.82
3/1/2012	Presidential Challenge in Costa Rica	0.82
3/21/2012	Los Suenos Signature Series Leg II	0.82
4/13/2012	Quepos Billfish Cup	0.82
6/6/2012	Presidential Challenge in Papaguayo	0.82
12/12/2012	2012 Marlin Invitational	1.00
1/16/2013	Los Suenos Signature Series Leg I	1.00
2/8/2013	Quepos Billfish Cup	1.00
3/1/2013	Presidential Challenge in Costa Rica	1.00
3/13/2013	Los Suenos Signature Series Leg II	1.00
4/14/2013	Costa Rica Offshore World Championship	1.00
5/16/2013	Presidential Challenge in Papaguayo	1.00
1/22/2014	Los Sueños Signature Triple Crown LEG 1	1.08
2/20/2014	Quepos Billfish Cup	1.08
2/26/2014	Los Sueños Signature Triple Crown LEG 2	1.08
3/12/2014	Los Sueños Signature Triple Crown LEG 3	1.08
3/17/2014	12th annual Osa Classic at Croc. Bay	1.08
4/6/2014	Offshore World Championship in Quepos	1.08
1/22/2015	Los suenos triple crown leg 1	0.89
2/7/2015	Quepos Billfish Cup	0.89
2/26/2015	Los Suenos Triple Crown leg 2	0.89

3/25/2015	Los Suenos Triple Crown leg 3	0.89
1/21/2016	Los Suenos triple crown leg 1	0.79
2/25/2016	Los Suenos triple crown leg 2	0.79
3/29/2016	Los Suenos triple crown leg 3	0.79
4/19/2016	Offshore World Championship in Quepos	0.79

Appendix E. Rationale for objectively scoring angler responses.

Issues with interpretation of responses.

1. If respondent identified as a non-angler, relevant questions were not included for analysis. There was only 1.
2. Some results had to be interpreted. Handwriting an issue, or for instance, if "other activities" was left blank, but the next question they wrote "only fishing" then "no" was inferred.
3. Someone selected NO for "other activities", but then wrote that they had spent the previous week at Antigua, so the answer was changed to yes.
4. If someone wrote an answer that didn't make sense, I filled in their exact words, later scored as blank.
5. One angler wrote "OK this trip, but that's fishing for you." Satisfaction was interpreted to be "meet."
6. Some people seemed to not see the last page.
7. When people estimated "expected raises", if they indicated "at least..." or “more than…”, the lower number stated was used. The average was used for answers given in the form of a range.

Appendix F. Sample of Survey questionnaire given to anglers fishing in Guatemala in 2017 (reformatted for space.)

Thank you for participating in this scientific study from the University of Miami's Billfish Research Program. Your answers will provide valuable information about the sailfish and marlin fishery in Guatemala. Our scientists are working closely with Casa Vieja and Pacific Fins to support billfish conservation efforts in Central America. Please fill out the following 24 questions to the best of your knowledge. You do not have to answer the questions. Your decision to participate is voluntary, and will not affect the services you receive at Casa Vieja or Pacific Fins. The survey is anonymous; you will not be asked to provide any identifying information.

If you have any questions about the study, you may contact the investigator above. If you have any questions about your rights as a research participant, you may contact the University of Miami Human Subjects Research Office at:
305-243-3195 or hsro@med.miami.edu.

Angler Demographics and Travel Information

Date of your fishing trip:________________

1. How many years have you been fishing for Billfish?
   _______________ years

2. What country do you permanently reside in?

____

3. Are you traveling alone?
   - Yes
   - No

4. Are you traveling with non-anglers in your party?
   - Yes
   - No

5. Do you get information on billfish from any fishing magazines? (check all that apply)
   - Marlin Magazine
   - IGFA
   - Guy Harvey
   - Saltwater Sportsman
   - None
   - Other _____________________________________

6. Are you planning on participating in other recreational activities on your trip?
   - o Yes
   - o No

7. If yes, what do you plan on doing?

____
____
____

8. What is your main motivation for fishing in Guatemala instead of elsewhere?

____
____
____

9. Please identify yourself based on what type of gear you prefer to use to catch billfish in Guatemala:

- o I prefer to use a fly rod
- o I prefer to use conventional gear
- o I usually use conventional gear, but would like to try fly while I am in Guatemala
- o I usually use fly gear, but would like to try conventional while I am in Guatemala

10. Do you check current fishing reports before booking a destination fishing trip?

- o Yes, I check several of the most up-to-date fishing reports
- o Yes, I usually check only 1 fishing report
- o No, I book a trip regardless of what the most up-to-date catches are.

<u>Angler Opinions</u>

Please rate the following statements to the best of your knowledge. Use the following scale:

1: Agree Strongly **2**: Somewhat Agree **3**: No Opinion or Not Sure **4**: Somewhat Disagree **5**: Disagree Strongly

13. The number of sailfish in Guatemala is at a healthy level.	1	2	3	4	5
14. The number of Blue Marlin in Guatemala is at a healthy level.					
15. Commercial Fishing operations are harmful to Blue Marlin and Sailfish.					
16. Sport fishing activities, including catch and release, are harmful to Blue Marlin and Sailfish populations.					
17. Sailfish have very large migrations, they cross many international boundaries within a year.					
18. Blue Marlin have very large migrations, they cross many international boundaries within a year.					
19. I would be willing to pay more to fish with a lodge or charter company that has a strong commitment to science and conservation of Billfish.					

21. What do you look for most when booking a charter?

____

Do you prefer to fish alone, or with fellow anglers?

- o I prefer to fish alone
- o I prefer to fish with fellow anglers

If you prefer to fish with other anglers, why?

____

22. Approximately how many billfish (Sailfish and Marlin) did you expect your boat to **raise** per day in Guatemala?

____

23. If you have already fished, how many TOTAL fish did your boat raise on this trip? Catch?

____________________ Raised
____________________ Caught
____________________ Number of fishing days