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Pablo Trujillo, Andrés M. Cisneros-Montemayor, Sarah Harper, Kyrstn Zylich and Dirk Zeller

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Email: p.trujillo@fisheries.ubc.ca

RECONSTRUCTION OF COSTA RICA'S MARINE FISHERIES CATCHES, 1950-2010

Pablo Trujillo[a], Andrés M. Cisneros-Montemayor[b], Sarah Harper[a], Kyrstn Zylich[a] and Dirk Zeller[a]

[a]*Sea Around Us, Fisheries Centre, University of British Columbia*
2202 Main Mall, Vancouver, V6T 1Z4, Canada
[b]*Fisheries Economics Research Unit, Fisheries Centre, University of British Columbia*
2202 Main Mall, Vancouver, V6T 1Z4, Canada

p.trujillo@fisheries.ubc.ca; a.cisneros@fisheries.ubc.ca; s.harper@fisheries.ubc.ca;
k.zylich@fisheries.ubc.ca; d.zeller@fisheries.ubc.ca

ABSTRACT

Total marine fisheries catches in Costa Rica's Exclusive Economic Zone (EEZ) were reconstructed for 1950-2010 and compared to officially reported data as supplied to FAO by the government of Costa Rica. The reconstruction consists of improving FAO fisheries statistics with unreported data including discarded by-catch, artisanal, recreational and subsistence catches. During the time period considered, total reconstructed catches were 2.6 times the data supplied to FAO by Costa Rica. Of the previously unaccounted-for catch volume, 89% was unreported landed by-catch and discards from shrimp trawls, 8% from misreported and unreported shark catches (discards), and the rest from unmonitored subsistence fishing, and cockle and whelk harvest. According to statistics supplied to FAO, Costa Rican fisheries have extracted an average of almost 13,500 $t \cdot yr^{-1}$ from their EEZ since 1950; our revised estimates suggest that total catches are over 35,000 $t \cdot yr^{-1}$. This discrepancy has major implications for fisheries management and sustainability actions in this country, whose economy hinges heavily on the conservation of the terrestrial and marine ecosystem for ecotourism.

INTRODUCTION

With coastlines on both the Pacific Ocean and the Caribbean Sea, the Republic of Costa Rica has traditionally used the marine ecosystem for sustenance, although large-scale fishing operations began relatively recently. During the first half of the 20th century, the Costa Rican economy focused on agricultural exports, such as coffee beans and bananas, and relied on imports to supplement its dietary needs, including fisheries products (Gutierrez-Rodriguez 1990). The Costa Rican fisheries sector of this period was comprised of small-scale artisanal fishing fleets with little or no preserving (freezing) capacity. Fishing occurred mainly in the Gulf of Nicoya (Figure 1), though some subsistence fisheries targeted lobsters and whelks along the Caribbean coast. In 1949, Costa Rica issued Decree No. 190 "Ley de Pesca y Caza Maritima" (Fishing and Marine Hunting Law), with the purpose of regulating and stimulating its fisheries.

Efforts to substitute seafood imports with locally based catch began during the early 1950s and intensified in the 1970s with financial aid from the Inter-American Bank for Development (Breton 1991). Increased regional market integration, due in part to the construction of the Pan-American Highway, and Food and Agriculture Organization (FAO) subsidies (Tilic and Artavia 1971), led to the adoption of more modern fishing gear and the industrialization of the seafood processing sector. This in turn created a cultural change in Costa Rican seafood perception and consumption, increasing internal demand for seafood. Coupled with the rising demand of the North American seafood market, this sparked the expansion of Costa Rican fishing activities on both coasts. Fresh and frozen finfish are currently the main export product of Costa Rica, followed by shrimps and dried fish. These exported products are destined mainly to the US, Asian and European markets and have an annual value of 92 million USD (Chaves *et al.* 2010).

Costa Rica was a founding member of the Inter-American Tropical Tuna Commission (IATTC) in 1949, and has ratified numerous international agreements, such as the United Nations Convention on the Law of the Sea and FAO's Code of Conduct for Responsible Fisheries. In 1972, the international recognition of the Exclusive Economic Zone (EEZ) granted Costa Rica a marine area more than 10 times the size of its land area, that was officially claimed by the Costa Rican government in 1975 (Cajiao *et al.* 2003). Over 20 years later, in 1994, the Costa Rican Fisheries and Aquaculture Institute (INCOPESCA) was created with the goal of promoting sustainability and economic development, and became responsible for the implementation of all policies concerning marine fisheries management and aquaculture (www.incopesca.go.cr).

Starting in the early 1980s, Costa Rica invested heavily in the conservation of both its marine and terrestrial ecosystems. A major component of these efforts has been a focus towards ecotourism as an economic enterprise. As a direct result of this strategy, more than 25% of the country's land area (51,000 km^2) is protected in some way by national parks, biological reserves and refuges (Alpízar 2006). Approximately 20% of the Pacific coast and nearly 50% of the Caribbean coast also lie within the boundaries of state protected areas which are managed by the Ministry of the Environment and Telecommunications (MINAET, www.minae.go.cr; (Mack *et al.* 1992). In the remaining areas open to exploitation, recreational fishing has steadily increased, surpassing commercial fishing as an industry in economic terms. The momentum gained in the shift away from traditional commercial exploitation has led to Costa Rica's emergence as a regional spearhead for conservation efforts, as well as a hotspot for diving, recreational fishing and other forms of ecotourism that currently generate around 50 million USD in yearly expenditures (Cisneros-Montemayor and Sumaila 2010).

Costa Rican fisheries

The Pacific coast of Costa Rica is characterized by numerous bays, three large gulfs and a large EEZ (572 thousand km^2). Small scale fishing developed since the 1920s in the Gulf of Nicoya (Campos 1986), from where the majority of the country's fish catches are reported. Another important feature of Costa Rica's EEZ is "The Dome", a permanent and shallow thermocline off the Pacific coast (Brandhorst 1958) characterized by a high abundance of zooplankton and pelagic fish.

The Atlantic coast of Costa Rica has traditionally been far less important for fisheries, with only about 10% of registered fishing vessels (Alpízar 2006) and representing approximately 2-3% of reported landings (Gutierrez-Rodriguez 1990; Guzmán-Mora 2009). Appraisal studies carried out by the FAO in the late 1960s determined that it would be difficult to increase fisheries production in Caribbean waters, mostly because of low availability of resources due to oceanographic conditions (FAO 1970).

In the 1980s, before the establishment and growth of national fisheries, substantial quantities of seafood were imported from Peru, Ecuador, Nicaragua and Panama to supply the thriving Costa Rican canning industries, which catered to foreign markets (Gutierrez-Rodriguez 1990). By the early 2000s, the national fishing fleet had rapidly grown and separated into two distinct sectors, a large artisanal fleet (~75% of the fleet) operating in coastal waters, and a smaller industrial fleet expanding into offshore waters and targeting larger pelagic fishes. With a large portion of fishing effort concentrated along a relatively small coastline (90% in the Pacific), many poor fishers are now competing for dwindling coastal resources, with the bulk of catches coming from the offshore fleet (Alpízar 2006).

Reported landings are quite telling of this expansion trend; from 1990 to 2000, landings almost doubled from around 18,000 to 34,500 $t \cdot year^{-1}$ (www.fao.org), while the ratio of coastal (fishes and crustaceans) to pelagic (tunas and billfishes) landings changed from 3:2 to 1:4 (Mug-Villanueva 2002). This fishing dynamic has masked declines in coastal landings.

Pelagic fisheries

Small pelagics are fished at an industrial scale and consist of sardines (mainly *Ophistonema medirastre, O. bulleri* and *O. libertate*) and anchovies (Engraulidae). Prior to the 1950s, the Pacific anchoveta (*Cetengraulis mysticelus*) was an important bait fish for tuna until its abrupt decline in 1953. Secondary bait species were taken, such as thread herring (*O. libertate*) and smaller anchovies (e.g, *Anchovia macrolepidota*). During this time period, U.S. tuna vessels were also collecting baitfish in these regional

waters, contributing to the decline of the stocks. Overfishing due to national demand led to a decline in sardine catches in the late 1980s and moratoriums were put in place to safeguard the endangered stocks, that now make up around 7% of total landings (Vega-Corrales 2010).

Catches of large pelagics have increased during the last decade, now making up around 50% of reported landings. These are dominated by a few families such as Carangidae, including jacks (*Caranx* spp.), moonfish (*Selene* spp.) and amberjacks (*Seriola* spp.); Scombridae, including bonitos (*Sarda* spp.) and skipjack tuna (*Katsuwonus pelamis*); Coryphaenidae (dolphinfish, *Coryphaena hippurus*); and Sphyraenidae (barracudas, *Sphyraena* spp.). In addition to commercial fishing, all of these species are actively targeted by recreational fisheries. Pelagic sharks are also an important target group for this sector, contributing around 15% of reported landings. The principal taxa caught are requiem sharks (Carcharhinidae), mainly silky shark (*Carcharhinus falciformis*) and hammerheads (Sphyrnidae).

Demersal fisheries

Demersal species found in Costa Rica are diverse, as is typically seen in many tropical ecosystems. In a Pacific shrimp trawl survey performed in 1984, 221 fish species were caught as by-catch, only a few of which were of perceived commercial value (Campos 1986). Important taxa for the commercial fishery include drums and croakers (Sciaenidae, particularly *Micropogon altipinnis* and *Cynoscion* spp.), snappers (Lutjanidae), groupers (*Epinephelus* spp.) and grunts (Haemulidae). Elasmobranch catch includes various rays (Rajidae and Torpedinidae, particularly *Raja equatorialis* and *Torpedo tremens*), as well as small demersal sharks (e.g., *Alopias superciliosus*). In the southern Pacific coast, artisanal catches are heavily dominated by snappers (*Lutjanus* spp.) (Guzmán-Mora 2009).

Shrimp fishery

Around 41 shrimp vessels were in operation along the Pacific coast of Costa Rica during the 2000s (Álvarez and Ross 2010). Target species in shallow coastal waters (5 to 40 m depth) include white shrimp (*Litopenaeus occidentalis, L. stylirostris, L. vannamei*), conchudo (*Rimapenaeus byrdi*) and tití shrimp (*Xiphopeneaus kroyeri*), and in deeper waters (35 to 120 m) pink (*Farfantepenaeus brevirostris*) and brown shrimp (*F. californiensis*). Deepwater shrimp fisheries (120-1000 m depth) focus mainly on three species, *Heterocarpus affinis, H. vicarius* (camello), and *Solenocera agassizii* (fidel).

Shrimp fisheries in Costa Rica have been characterized by a progressive move to deeper waters as stocks become overexploited and depleted (Álvarez and Ross 2010). Shrimp landings from near-shore waters have significantly declined, such that only tití shrimp are still commercially viable. In the case of deep-water shrimp, landings of around 220 $t \cdot year^{-1}$ of each of the three species were recorded in the mid-2000s. Since then, *H. affinis* catch has dropped dramatically, such that there are no landings on record since 2006. On the other hand, landings of *H. vicarius* and *S. agassizii* are relatively stable or slightly increasing (Wehrtmann and Nielsen-Muñoz 2009).

Shrimp trawl fisheries have the most by-catch of any of the Costa Rican fisheries sectors (Gutierrez-Rodriguez 1990; Kelleher 2005). Given the fact that by-catch in deep-water shrimp trawlers is entirely discarded, a particularly worrisome statistic is the amount of by-catch relative to shrimp. In 2008, for example, yearly catch for this fishery was of about 5% target shrimps (almost exclusively *S. agassizii*), 55% stomatopods and 40% fish (Wehrtmann and Nielsen-Muñoz 2009).

Other invertebrates

The only major commercial fishery resource on Costa Rica's Caribbean (Atlantic) coast is spiny lobster (*Panulirus argus*), targeted by artisanal boats and sold to hotels or exporters. From the 1950s until 1998, lobster accounted for almost 60% of reported landings in this region, with sea turtles and fish accounting for 25% and 17%, respectively. Since the onset of turtle protection efforts, reported landings are 75% lobster, 15% fish and 10% shrimps (Anon. 2006).

On the Caribbean coast, a species of whelk (*Cittarium pica*) is hand collected either by walking along the beach at low tide, or with snorkelling gear. It is done on a very small scale, mainly for subsistence or sale within the community (Schmidt *et al.* 2002). Because of its small scale, it is not monitored by INCOPESCA, and catches are therefore not reflected in official landings statistics.

The 'piangua' (*Anadara tuberculosa*) is an ark clam (cockle) that inhabits muddy substrates in and around mangrove forests. It is a targeted fishery undertaken by dedicated 'piangüeros', who often do not identify themselves as being fishers, even if they occasionally fish (Andrés M. Cisneros-Montemayor, pers. obs.). This perception perhaps has contributed to this fishery being under-represented in fishery statistics and research, despite the clear social and economic significance of the resource to small coastal communities in Costa Rica and most of tropical Latin America (MacKenzie 2001).

Foreign fisheries
Costa Rica's access beyond the EEZ remains limited due to a lack of high seas fishing boats, particularly tuna boats; however, the country sells fishing rights to foreign vessels in order to keep tuna canneries functioning (Mug-Villanueva 2002). These foreign fleets are responsible for virtually all tuna catch and a significant amount of shark catches in Costa Rica's EEZ. However, there is little available date on the operation of these fleets, so that some tuna and shark landings may have be caught outside of the EEZ, or conversely, catches within the EEZ may be landed in other countries. This study does not attempt to tackle this issue, but the potential problems associated with this type of unregulated and unreported fishing should be addressed by the Costa Rican government and relevant Regional Fisheries Management Organizations (i.e., the Inter-America Tropical Tuna Commission).

In order to manage fisheries at an optimal and sustainable level, we need a solid understanding of extractions from the marine ecosystem. The aim of this study was to gather all available information on fisheries catches and fishing practices to reconstruct Costa Rica's total marine fisheries catches from 1950 to 2008. The catch reconstruction approach used here is based on the methodology developed by (Zeller *et al.* 2007). This improved assessment of Costa Rica's fishing past will help to better understand its current status and plan for future management.

METHODS

Costa Rica's total fisheries catches for the years 1950-2010 were reconstructed using the approach developed by Zeller *et al.* (2006, 2007). National landings data sets were compiled and compared to the landings submitted to FAO[1] on behalf of Costa Rica. We then estimated by-catch, discards and unreported catches by the Pacific shrimp fishery, subsistence catches from the small-scale sector, under-reported catches by the artisanal sector and recreational catch and post-release mortality.

Shrimp fishery by-catch
Shrimp fishery by-catch was estimated using officially reported shrimp landings in the Pacific from 1950-2010. A sampling survey on board shrimp trawlers conducted by the regional office of Puntarena in 1987 determined that the total by-catch/shrimp ratio was between 7.7-9.1:1, of which an average of 7% was retained for commercial use in the late 1980s (Gutierrez-Rodriguez 1990). Later reports suggest that declining shrimp catches during the 1980s-1990s led to an increase in by-catch retention, while overfishing resulted in a decrease in by-catch (Kelleher 2005; Álvarez and Ross 2010). Therefore, we used the lower estimate of by-catch/shrimp ratio (7.7:1) and the upper estimate of by-catch retention (14%; Gutierrez-Rodriguez 1990) to estimate total by-catch and discards per year, and gradually decrease the ratio of by-catch to shrimp landings and increased the ratio of by-catch retention from 1995-2010.

Subsistence fishery
Fishers, particularly in the artisanal sector, often keep fish for themselves and their families to eat, a form of subsistence catch. Subsistence catch estimates were derived from a study conducted for the Atlantic coast of Guatemala, that estimated 70 kg per fisher per year were retained for home consumption (FAO 1970). To estimate total fishers per year, we used a linear interpolation between anchor points (at 1985 and 2002) using the ratio of fishers (Salas *et al.* 2007) to the total population (UN database), from 1950-2010 (Figure 2). In order to estimate how much subsistence catch to attribute to each coast we used the fact that 10% of registered vessels and 2-3% of reported landings belong to the Caribbean and therefore assumed that 5% of the subsistence catch is taken from the Caribbean and 95% from the Pacific.

[1] Data for 1950-2010 from the 2011 FAO dataset were used (March 2013 version).

Shark fishery

As Costa Rica's fisheries have expanded to offshore waters, sharks have been one of the major components of increasing pelagic landings, though there may be some confusion regarding catches made by foreign and domestic fleets. Communication with authorities within INCOPESCA provided us with additional data sets for various commercial species such as sharks. Although information on the type and scale of targeted and incidental shark fisheries catches were sparse, we were able to ascertain that many, if not all, shark reporting referred to eviscerated and headless sharks. Conversion factors (Vannuccini 1999) were therefore used to obtain whole weight estimates from reported landings. Furthermore, landings reported to FAO show a sharp (60%) decline occurring in the space of one fishing season, from 2003 to 2004, corresponding with the prohibition of shark finning and the landing of finned sharks in Costa Rica (Anon. 2003; Jiménez 2005). A likely result of the lack of enforcement of fleets targeting sharks and the newly established laws is that sharks caught in Costa Rica's EEZ are now being landed elsewhere (personal communication with anonymous sources). We therefore assumed that catches after 2003 were equal to the previous 5-year average.

A potential misreporting problem must be mentioned here, as INCOPESCA shark landings statistics for the last decade are significantly lower (~60%) than those reported by the FAO. We used FAO data for our estimation, but this discrepancy is an urgent issue to be addressed and clarified.

Recreational fishery

Recreational fishing is a rapidly growing sector in Costa Rica, mainly targeting billfish on the Pacific coast. The main species caught are sailfish (*Istiophorus platypterus*), followed by marlins (*Makaira* spp. and *Istiompax indica*) and swordfish (*Xiphias gladius*). Recreational billfish catches were estimated using tourism data and a conservative rate of recreational fishing participation as a percentage of tourist arrivals (~2%; Cisneros-Montemayor and Sumaila 2010; Matarrita-Cascante 2010), and assuming that recreational fishing began around 1980. Catch per angler (~7 fish) was estimated based on a sport fishing catch, catch-release rate (>95%) and catch composition reported for Costa Rica by Ditton and Grimes (1995), and a conservative billfish release mortality rate of 0.25 (based on Cramer 2004; Pine III *et al.* 2008). Catches including post-release mortality were estimated in tonnes using length-weight conversion parameters for each species (www.fishbase.org). As with other locations, it has been reported that billfish catches in Costa Rica are directly impacted by commercial targeting of billfish (Ehrhardt and Fitchett 2008), so we used commercial billfish catch trends to reflect this observation (i.e., recreational CPUE used in our estimation is directly and inversely correlated with commercial billfish landings as reported by the FAO).

Whelks and pianguas

Whelk collecting, usually for local sale, takes place on the Caribbean coast during low tides. Based on Schmidt *et al.* (2002), landings may be in the order of 330-4,600 whelks per fisher, plus about 100 whelks per household per year. In order to provide a conservative estimate, yearly whelk catches were estimated using the lower estimate together with the number of fishers and fishing households in the region (IBERINSA 2007; Salas *et al.* 2007). These catches are considered as additional subsistence catch.

Pianguas are collected in and around mangrove forests on both coasts (primarily the Pacific, although perhaps due to a larger population there), but there is very limited data on the scale of collecting operations. MacKenzie's (2001) review of cockle fisheries in Latin America estimates that around 500 piangüeros live in Costa Rica, with an average per-day catch of 145-500 pianguas. We estimated total landings assuming about 210 effective work days per year (harvesting in mangrove forests is subject to tides and rainy seasons), along with reported average piangua size (Stern-Pirlot and Wolff 2006) and their length-weight relationship (Guilbert 2007). A portion of the daily catch (~12%; MacKenzie 2001) is kept by piangüeros for their own consumption, so this was handled separately from commercial pianguas, and added to subsistence catch. Annual catches over the whole time period were calculated assuming that catch-per-fisher ratios have remained constant. In order to account for a small amount of pianguas collection on the Caribbean coast, we allocated 5% of the subsistence pianguas to the Caribbean. All other catches were assigned to the Pacific.

RESULTS

Shrimp trawl
Shrimp catch from trawling in the Pacific increased from 100 t in 1950 to a peak of 8,700 t in 1986 and then declined to 1,700 t in 2010. The total amount of finfish, sharks and rays caught as by-catch in the Pacific Costa Rican shrimp fishery between 1950 and 2010 was estimated to be 55% of the reconstructed total catch. Almost 85% of these catches were discarded. By-catch that is not discarded is normally retained for sale by the vessel crew, but is not reported as landings and therefore does not appear in fishery statistics. Discards and retained by-catch increased along with shrimp landings, from 770 t in 1950 to a peak of 67,000 t in 1986, before declining sharply to around 6,500 t in 2010 as shrimp fisheries collapsed (Figure 3).

Shark fishery
Using conversion rates reported by Vannuccini (1999), and assuming that catches remained relatively constant after 2004 when reported landings decreased due to a ban on finning, we estimate that total shark catches in Costa Rican waters from 1950-2010 are 83% higher than FAO statistics suggest (Figure 4).

Subsistence catches and piangua and whelk collecting
Subsistence catches and piangua and whelk collecting appear to be small sectors compared with other fisheries, but should nevertheless be quantified. Using available data, we estimate that an average of around 210,000 whelks, or 1.4 t, are currently harvested each year, increasing gradually from 0.8 t in 1950 to 2.2 t in 2010. Subsistence catch estimates (catch retained for the fishers personal consumption) including both fish and pianguas increased from 200 t in 1950 to almost 600 t in 2010 (Figure 5). Approximately 1,300 t of this was pianguas catch. We estimated that the pianguas fishery (from both the artisanal and subsistence sectors) equates to a total of around 175 $t \cdot yr^{-1}$, with 220 t of pianguas landed for sale in 2010 and the rest kept for own consumption. Over the entire study period, we estimate that approximately 10,700 t of pianguas have been collected (Figure 5).

Recreational fisheries
Recreational fishing is an economically important and growing industry in Costa Rica; we focused our efforts on billfishing, the largest sector (Soto-Jiménez *et al.* 2010). Assuming significant operations began in 1980, we estimate that over 12,500 tonnes of billfish (~85% sailfish) were killed by recreational fishers in Costa Rica from 1980-2010, with an average of almost 750 $t \cdot yr^{-1}$ during the last ten years (Figure 6). Almost 94% of this estimate was a result of post-release mortality, highlighting the need to take this factor into account in addition to encouraging catch-and-release.

Total reconstructed catch
Following the methods described above, our reconstructed catch estimates suggest that, between 1950 and 2010, total fisheries catch in Costa Rica was 2.6 times the total reported to FAO for the same period (Figure 7a). The catch increased from 1,600 t in 1950 to a peak of 90,700 t in 1986, before declining to an average of 38,000 t from 2008-2010. The majority of this non-quantified catch, in order from largest to smallest, was discards in shrimp trawls (75%), by-catch in shrimp trawls (13%), under-reported shark landings (8%), subsistence (2%), recreational (1%) , and artisanal piangua catches (0.1%). In the more recent period (2000s), we estimate an 83% under-reporting rate relative to FAO statistics. The contribution by sector of the total reconstructed catch is 80.2% industrial, 18.0% artisanal, 1.2% subsistence, and 0.6% recreational (Figure 7a). Taxonomically, the total reconstructed catch was dominated by crustaceans with 33% of the catch (Figure 7b). Of the crustaceans, 19.3% (of the crustacean total) was from the family Squillidae, Galatheidae was another 17.2%, 15.7% was from Penaeidae and 14% was Panadalidae. Other taxonomically important groups were sharks (10.8%, this includes groups which may contain rays and chimaeras), and the families Synodontidae (7.7%), Paralichthyidae (5.7%), and Ophidiidae (4.4%; Figure 7b).

Catches from the Pacific represented 99.76% of the total reconstructed catch. In the Pacific 81.0% is from the industrial sector, 17.3% from artisanal, 1.2% subsistence and 0.6% recreation. The overall species breakdown is representative of the catch in the Pacific. In contrast, in the Atlantic, 94% of the catch is

artisanal and 6% subsistence. The catch is dominated by spiny lobster (Palinuridae) with 43.2% of the total catch. Sharks, rays and chimaeras make up another 15.1% of the catch with Penaeidae (8.7%) and Lutjanidae (6.4%) also contributing signification portions of the catch.

DISCUSSION

As is the case in many countries, a substantial portion of fisheries catches in Costa Rica are not reported, and are therefore ignored. The majority of this unreported catch comes in the form of by-catch, small artisanal fisheries, subsistence fisheries and recreational fisheries. An additional source of unreported catches, which was not addressed in this study, stems from potential misreported and illegal catch occurring in Costa Rica's EEZ, both by domestic and foreign fleets. In this study we estimate only domestic catches taken within Costa Rica's EEZ. For the period 1950-2010, total reconstructed catches were estimated to be 2.16 million t, which is 2.6 times the total landings data as supplied to the FAO. The difference between total reconstructed catch and reported landings was greatest from the 1970s to the 1990s due to large amounts of by-catch in shrimp trawl fisheries. However, under-reporting continues to be a problem in the more recent time period, with fisheries catches estimated to be 82% higher than reported landings in the 2000s.

By-catch and discarding in industrial-scale shrimp trawl fisheries have resulted in large-scale depletion of Costa Rican fish populations, and a waste of potential economic benefits (Álvarez and Ross 2010). The amount of by-catch has decreased by 87% in 2010 relative to 1986, the peak of shrimp landings. This is a classic sign of overexploitation and subsequent depletion of non-target species, particularly as no by-catch reducing devices are currently used by the trawling fleet. Greater retention of commercially valuable by-catch also has the effect of reducing discards and may make up for some of the economic impacts of lower shrimp catches. However, this does little to offset the much larger economic losses that have come with overfishing of shrimp resources, and serve as a subsidy to maintain trawling effort.

Our estimates suggest that shrimp trawling has been the most significant source of fishing mortality in Costa Rica's marine ecosystem. Moreover, the reported trend of coastal to deep-water expansion, with no visible recoveries in shrimp stocks, implies that there is nowhere new to go. Shrimp trawling in Costa Rica is extremely unpopular with artisanal fishers (Mug-Villanueva 2002), does not employ a substantial amount of people, has had significant environmental impacts on marine populations and habitat (Álvarez and Ross 2010), and has depleted shrimp populations to the point that their commercial importance is compromised (Tabash 2007). It therefore seems clear that this is a fishery in urgent need of reform and substantial effort reduction.

Sea turtles are another ecologically important by-catch species, and in Costa Rica include leatherback (*Dermochelys coriacea*), olive ridley (*Lepidochelys olivacea*) and hawksbill (*Eretmochelys imbricata*) turtles. Though we do not address this issue in this study, it is important to mention that, following large-scale exploitation for meat and eggs, significant positive advances in turtle conservation have been made in Costa Rica, including the use of turtle exclusion devices and protected marine areas and nesting beaches (www.pretoma.org).

Fisheries of large pelagics such as sharks and tunas are very difficult to monitor in Costa Rica. A significant source of uncertainty follows from the fact that large foreign fishing fleets operate in the region (Mug-Villanueva 2002), with foreign markets driving demand (Clarke *et al.* 2006). One particularly troublesome practice is that sharks are often dressed at sea, so that only trunks are recorded in catch statistics. A large part of the difference between data supplied to FAO and reconstructed shark catches are based on our assumption that recorded landings after the onset of laws prohibiting landings of shark trunks without fins or heads reflect a change in landing, but not fishing, practices. For example, a recent issue of debate has been the landing of shark fins in private docks, which are not subject to government inspection (A.M. Cisneros-Montemayor, pers. obs.).

Even if the decrease in shark landings reported to FAO is in fact a reflection of a decrease in catches, our estimate is still 77% higher due to the conversion to whole shark weight. This is yet another example highlighting the need for adequate monitoring of fishing regulations. For now, the steps taken to ban

finning and the landing of shark fins alone are valuable foundations for future improvements in Costa Rican shark fisheries, and indeed are an example for other countries struggling to ensure sustainable catches. However, as with many fishing regulations, this needs to be coupled with better enforcement to truly be effective.

Tuna fisheries are even more of a challenge for fisheries management as catches are often not landed in the EEZ where they were caught, opening up multiple loopholes to avoid regulations, preventing adequate monitoring necessary to sustainable fisheries. We unfortunately do not currently have enough data available to estimate tuna catches by foreign fleets in the Costa Rican EEZ, but we stress the importance of such an estimate, both from an ecosystem perspective and in managing foreign access fisheries.

The small-scale sector is commonly overlooked in fisheries management and policy. Our estimated subsistence and piangua catches, totalling to 25,600 t and 9,700 t, respectively, over the entire study period, hardly seem negligible. Please note that the pianguas estimate given here is only the artisanal estimate (i.e., for sale) and does not include 1,300 t of pianguas which are here counted in the subsistence estimate. Using the FAO classifications, our estimate of ark clam catch would make it the second-largest invertebrate fishery in Costa Rica (after shrimp), yet it is not specifically discussed in any official reports that we could find. FAO statistics for "Ark clams" begin in 2001 and have averaged 30 $t \cdot yr^{-1}$ since, with 20 t in 2010, 12.7 times less than our estimate for that year. The lack of documentation on subsistence and small-scale fisheries is the responsibility of government agencies charged with fisheries monitoring and management. While these sectors may be overshadowed by the large industrial fisheries, it is precisely the economic benefits and ecological sustainability of such localized fisheries that are vital to the welfare of coastal communities and should warrant better monitoring and reports.

Recreational fishing is another source of fishing mortality that is often overlooked, though there have been important efforts recently to combat this trend (e.g., Coleman *et al.* 2004). As in many localities around the world, recreational anglers in Costa Rica increasingly employ catch-and-release practices (Ditton and Grimes 1995). However, post-release mortality must also be included in estimates of total fishing mortality. Mortality rates can easily be improved through more careful handling and the use of circle hooks that reduce hooking damage (Prince *et al.* 2002), already gaining popularity with anglers. With the recreational fishing industry becoming an increasingly crucial source of economic benefits for Costa Rica (Soto-Jiménez *et al.* 2010), management and regulations are required to ensure these benefits are maintained, and to address increased conflict with commercial fisheries.

Illegal, unreported and unregulated catch is a major problem that affects fisheries around the world (Agnew *et al.* 2008). While many fisheries are difficult to monitor, and even more difficult to effectively manage, the first step towards sustainability is to account for all catches taken from a country's EEZ. We have attempted to do so for Costa Rica, under the premise that unknown catch does not mean zero catch. However, every effort was made to document our sources of data and information, and to err on the side of conservative estimates when faced with ranges of potential values for estimation. We must stress that this is not meant to be a final product, but rather a baseline and framework to be built and improved upon. Costa Rica claims to be a world leader in working towards conservation of the marine ecosystem and the sustainability of activities that depend on it; we hope the results of this work will facilitate this effort.

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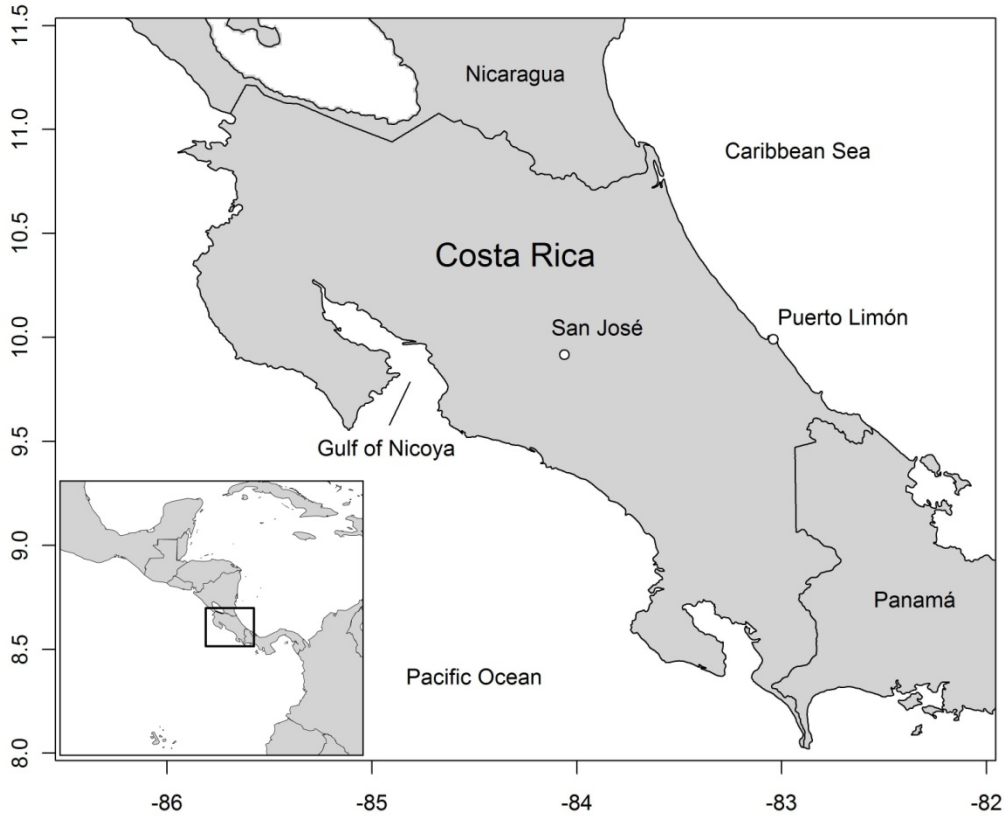

Figure 1. Map of Costa Rica showing its coastlines and main fishing areas.

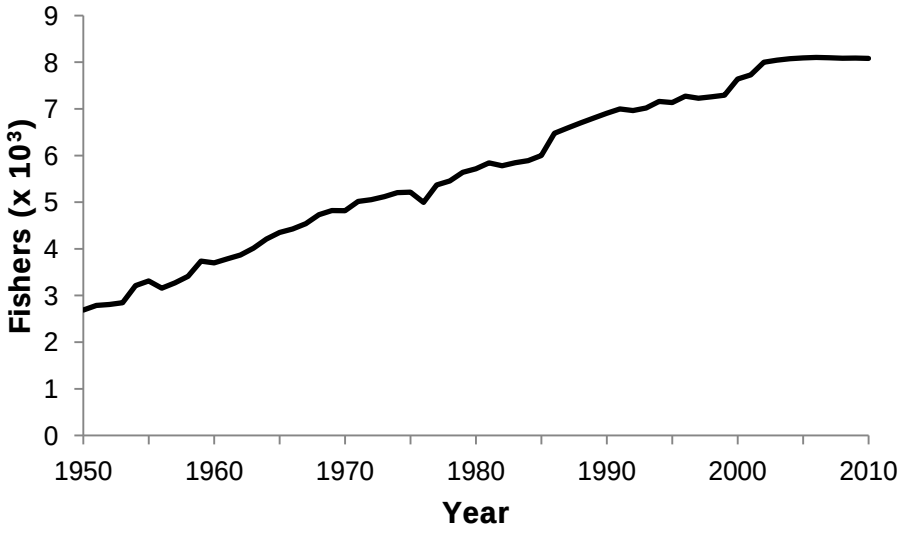

Figure 2. Costa Rica's artisanal fisher population numbers (including piangüeros) based on estimates from Salas et al. (2007).

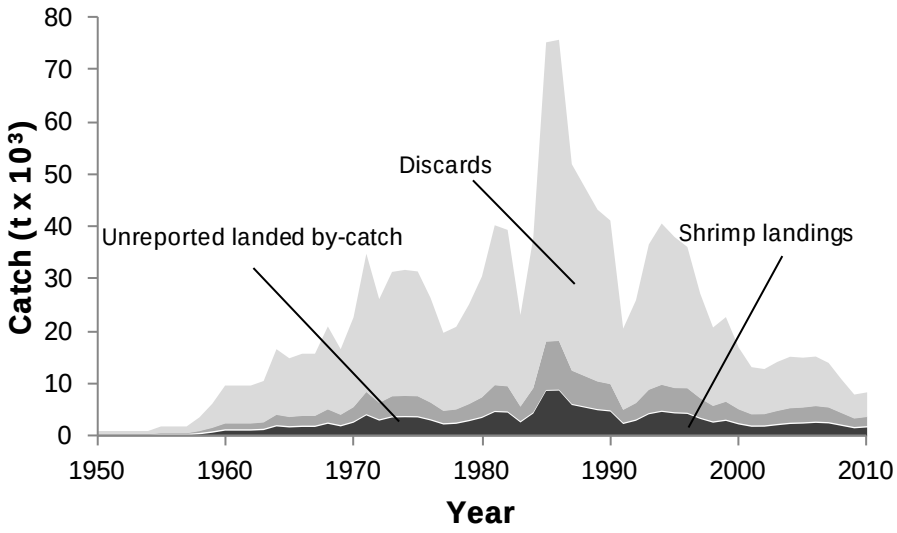

Figure 3. Total reconstructed catch of the shrimp fisheries of Costa Rica, including reported landings, unreported landed by-catch, and discards.

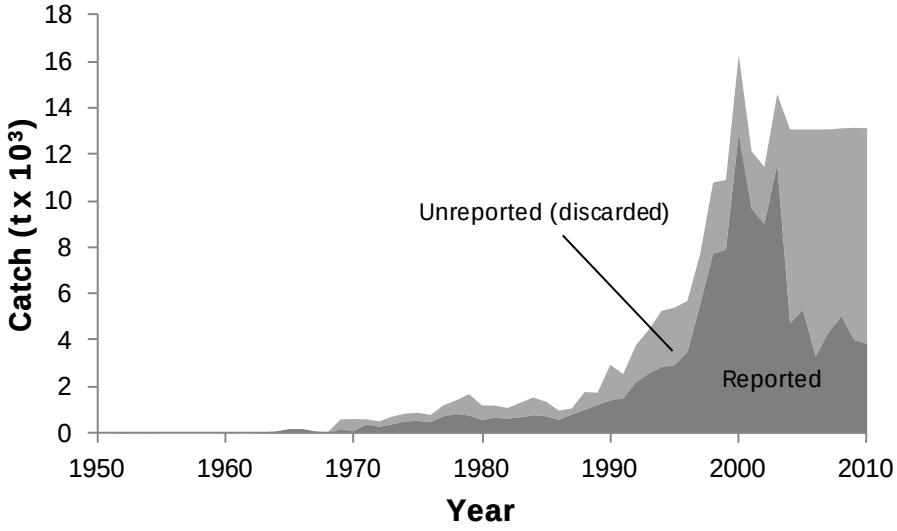

Figure 4. Reconstructed total shark catches shown by data as reported by FAO on behalf of Costa Rica and reconstructed unreported catches.

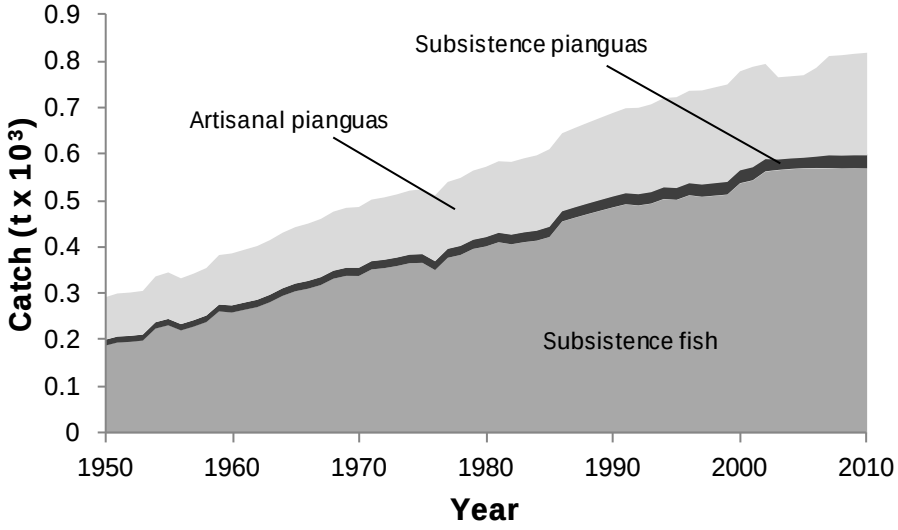

Figure 5. Subsistence catches (fish and pianguas shown separately) and artisanal pianguas (for sale), 1950-2010. Whelk landings are too small to be shown.

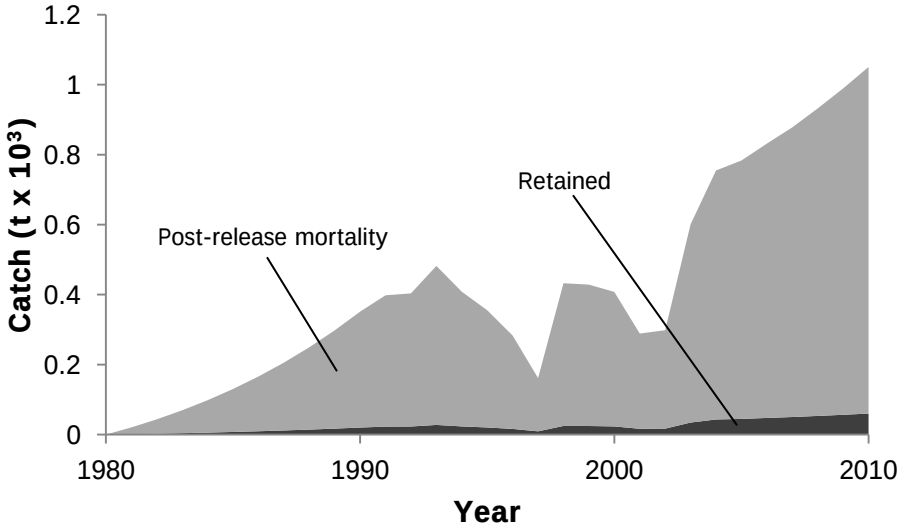

Figure 6. Recreational catch of billfish, including retained fish and post-release mortality, from 1981 to 2010. Please note 1980-2010 horizontal axis as opposed to standard 1950-2010 axis.

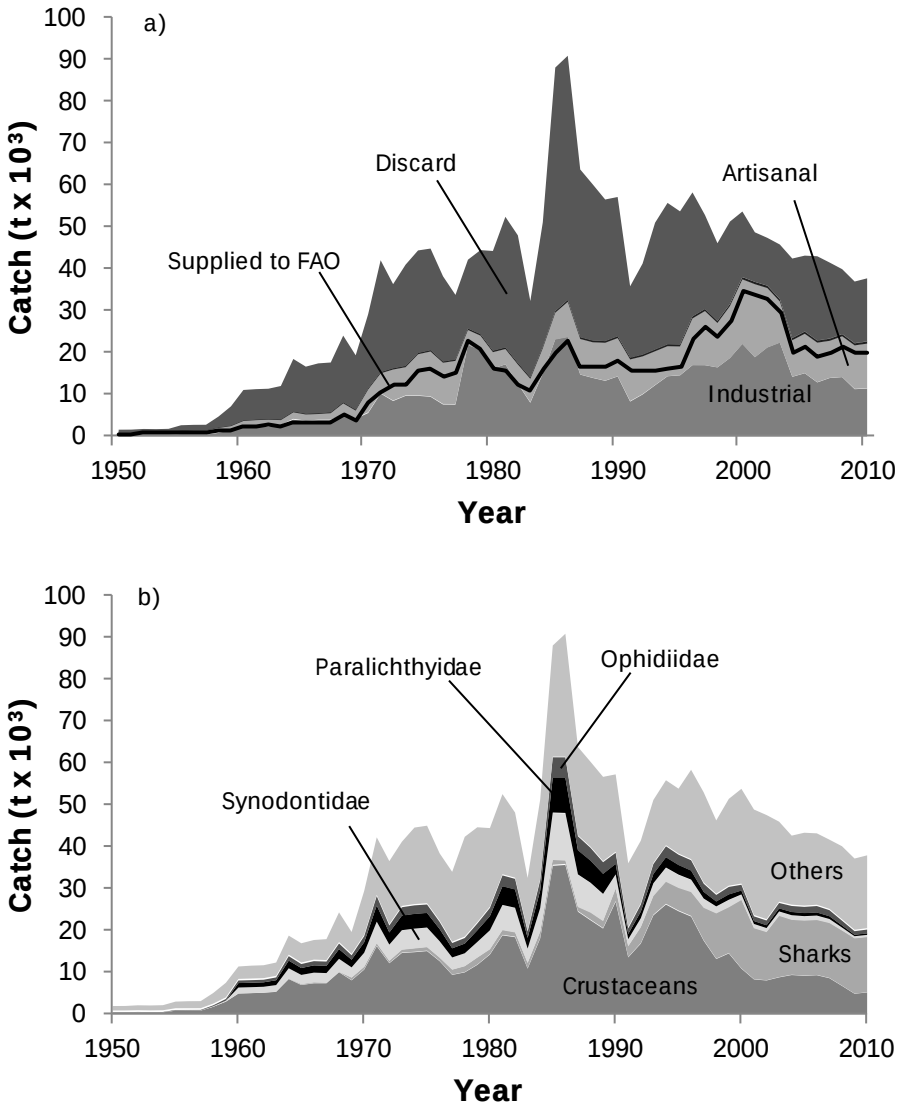

Figure 7. Costa Rica's total reconstructed catch a) by sector, with official reported data overlaid as a line graph. Note that subsistence and recreational catches are not visible on the graph; b) by major taxonomic groups. "Others" consists of 25 additional families and 4 higher taxonomic groupings.

Appendix Table A1. FAO landings vs. total reconstructed catch (in tonnes), and catch by sector, for Costa Rica, 1950-2010.

Year	FAO landings	Total reconstructed catch	Industrial	Artisanal	Subsistence	Recreational	Discard
1950	500	1,600	210	540	0	201	660
1951	500	1,600	210	550	0	209	660
1952	600	1,800	210	660	0	210	710
1953	600	1,800	210	670	0	213	660
1954	600	1,800	210	680	0	239	690
1955	700	2,700	420	690	0	246	1,320
1956	800	2,800	420	790	0	235	1,320
1957	900	2,800	420	800	0	244	1,330
1958	1,300	4,700	830	1,000	0	254	2,650
1959	1,400	7,200	1,450	810	0	277	4,640
1960	2,200	11,100	2,290	1,210	0	275	7,300
1961	2,400	11,300	2,290	1,410	0	281	7,290
1962	2,500	11,400	2,290	1,520	0	287	7,280
1963	2,300	12,000	2,490	1,220	0	298	8,010
1964	3,401	18,500	3,950	1,620	0	312	12,580
1965	3,101	16,600	3,530	1,520	0	322	11,260
1966	3,101	17,400	3,740	1,420	0	328	11,920
1967	3,301	17,600	3,740	1,630	0	336	11,920
1968	5,001	24,000	4,990	2,730	0	350	15,960
1969	3,801	19,300	4,150	1,830	0	356	13,000
1970	8,101	29,100	5,500	5,530	0	356	17,750
1971	10,462	42,000	10,070	4,830	0	370	26,710
1972	12,451	36,300	8,330	7,490	0	373	20,090
1973	12,361	40,900	9,540	6,840	0	378	24,170
1974	15,407	44,300	9,550	9,920	0	384	24,470
1975	16,096	44,800	9,330	10,800	0	385	24,260
1976	14,037	38,200	7,510	9,930	0	370	20,350
1977	15,310	33,700	7,490	10,400	0	397	15,440
1978	22,552	42,100	21,530	3,750	0	403	16,430
1979	20,671	44,400	20,430	3,500	0	416	20,040
1980	16,046	44,200	15,920	4,050	0	422	23,800
1981	15,580	52,300	16,990	3,730	1	431	31,180
1982	11,991	47,900	12,370	4,660	2	427	30,460
1983	10,568	32,300	7,920	5,670	4	432	18,240
1984	16,051	51,000	14,770	6,140	6	436	29,690
1985	19,924	87,900	22,900	6,510	7	444	58,030
1986	22,464	90,700	23,450	8,570	9	478	58,200
1987	16,521	63,600	14,560	8,570	12	486	39,990
1988	16,271	60,100	13,770	8,570	14	494	37,220
1989	16,681	56,500	13,090	9,130	17	502	33,720
1990	18,061	57,100	14,120	9,220	20	510	33,180
1991	15,518	35,800	8,200	10,040	23	517	17,000
1992	15,561	41,200	9,870	9,090	23	514	21,700
1993	15,462	50,900	12,030	8,150	28	519	30,190
1994	16,181	55,600	14,150	7,250	23	529	33,690
1995	16,440	53,600	14,370	6,970	20	528	31,740
1996	23,096	58,200	16,790	11,260	16	538	29,550
1997	25,824	52,800	16,770	13,040	9	535	22,400
1998	23,714	46,000	16,250	10,710	25	538	18,520
1999	27,279	51,200	18,460	12,530	24	541	19,640
2000	34,463	53,600	21,810	15,580	23	566	15,610
2001	33,817	48,600	18,650	17,590	17	572	11,810
2002	32,895	47,300	20,980	14,340	17	590	11,400
2003	29,407	45,700	22,120	9,990	34	589	13,000
2004	19,850	42,400	14,030	8,800	43	591	18,930
2005	21,340	43,100	14,870	9,510	45	593	18,070
2006	19,046	42,900	12,710	9,540	48	595	20,050
2007	19,651	41,400	13,740	8,950	50	598	18,090
2008	21,305	39,900	13,960	9,810	53	597	15,440
2009	19,714	36,900	11,120	10,480	57	598	14,660
2010	20,000	37,700	11,270	10,750	60	598	15,000

Appendix Table A2. Total reconstructed catch (in tonnes) for Costa Rica by major taxa, 1950-2010.

Year	Crustaceans	Sharks[1]	Synodontidae	Paralichthyidae	Ophidiidae	Others[2]
1950	457	0	36	2	55	1,060
1951	465	0	36	2	55	1,070
1952	472	51	36	2	55	1,170
1953	479	0	36	2	55	1,180
1954	486	30	36	2	55	1,210
1955	900	0	72	3	111	1,590
1956	908	0	72	3	111	1,670
1957	916	0	72	3	111	1,680
1958	1,831	0	144	7	222	2,540
1959	3,052	0	251	12	388	3,470
1960	4,981	20	1,422	1,066	622	2,970
1961	5,081	5	1,422	1,066	622	3,070
1962	5,181	0	1,422	1,066	622	3,080
1963	5,388	66	1,552	1,163	679	3,170
1964	8,440	100	2,457	1,841	1,075	4,550
1965	7,025	200	2,198	1,647	961	4,600
1966	7,433	200	2,327	1,744	1,018	4,690
1967	7,433	100	2,327	1,744	1,018	5,000
1968	10,077	64	3,103	2,325	1,357	7,100
1969	8,140	618	2,457	1,841	1,075	5,200
1970	10,692	631	3,362	2,519	1,470	10,470
1971	16,295	619	5,172	3,875	2,262	13,760
1972	12,221	529	3,879	2,906	1,697	15,060
1973	14,666	735	4,655	3,488	2,036	15,350
1974	14,856	862	4,711	3,530	2,061	18,300
1975	15,117	902	4,668	3,497	2,042	18,540
1976	12,716	809	3,912	2,932	1,711	16,080
1977	9,435	1,221	2,922	2,189	1,278	16,680
1978	10,039	1,437	3,093	2,317	1,353	23,870
1979	11,826	1,702	3,734	2,798	1,633	22,700
1980	14,291	1,216	4,525	3,391	1,979	18,790
1981	18,873	1,207	5,981	4,482	2,616	19,170
1982	18,440	1,109	5,849	4,383	2,558	15,570
1983	10,929	1,333	3,426	2,567	1,499	12,510
1984	18,141	1,559	5,629	4,218	2,462	19,020
1985	35,477	1,373	11,184	8,380	4,892	26,590
1986	35,695	989	11,256	8,434	4,924	29,410
1987	24,520	1,089	7,719	5,784	3,376	21,120
1988	22,483	1,793	7,072	5,299	3,093	20,330
1989	20,496	1,762	6,426	4,815	2,811	20,150
1990	26,882	3,074	3,369	2,524	2,699	18,500
1991	13,616	2,625	1,675	1,255	1,342	15,260
1992	16,904	3,881	2,121	1,589	1,699	15,000
1993	23,647	4,575	2,995	2,244	2,399	15,060
1994	26,231	5,399	3,322	2,489	2,661	15,540
1995	24,636	5,526	3,111	2,331	2,492	15,540
1996	23,364	5,813	2,912	2,182	2,504	21,370
1997	17,608	7,822	2,158	1,617	1,985	21,570
1998	13,227	10,863	1,617	1,212	1,588	17,530
1999	14,555	10,992	1,744	1,307	1,822	20,770
2000	10,942	16,344	1,274	954	1,412	22,670
2001	8,363	12,194	974	730	1,144	25,240
2002	8,108	11,523	930	697	1,155	24,910
2003	8,847	14,655	1,011	757	1,325	19,140
2004	9,405	13,146	1,062	796	1,467	16,510
2005	9,220	13,147	1,029	771	1,495	17,420
2006	9,359	13,150	1,022	766	1,562	17,080
2007	8,649	13,146	919	689	1,474	16,550
2008	6,814	13,180	695	521	1,169	17,480
2009	4,939	13,190	495	371	872	17,040
2010	5,250	13,176	508	381	937	17,420

[1] "Sharks" includes a miscellaneous category which may also contain rays and chimaeras.
[2] "Others" contains 25 additional families and 6 higher taxonomic groupings.