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RECONSTRUCTION OF COSTA RICA'S MARINE FISHERIES CATCHES, 1950-2008

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ABSTRACT

Total marine fisheries catches in Costa Rica's Exclusive Economic Zone (EEZ) were reconstructed for 1950-2008 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 bycatch, and unreported artisanal, recreational and subsistence catches. During the time period considered, total reconstructed catches were 2.3 times higher than data supplied to FAO by Costa Rica. Of the previously unaccounted catch, 87% was shrimp trawl bycatch, 10% was misreported and unreported shark catches, and the rest was unmonitored subsistence fishing, and cockle and whelk harvest. According to data supplied to FAO, Costa Rican fisheries have extracted an average of 13,000 t·year^{-1} from their EEZ since 1950; our revised estimates suggest that total catches are closer to 30,000 t·year^{-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, 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.

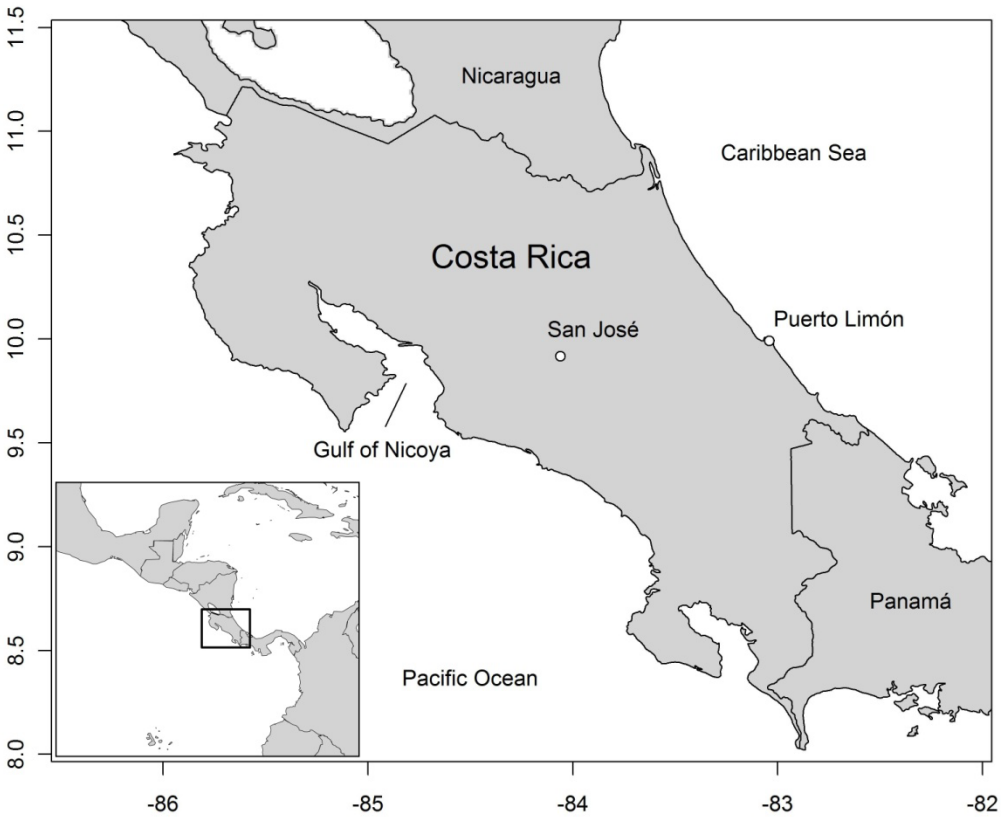

Figure 1. Map of Costa Rica showing its coastlines and main fishing areas.

Efforts to substitute seafood imports with local 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 gears 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 shrimp and dried fish. These exported products are destined mainly for the US, Asian and European markets and have an annual value of 92 million USD (Chaves *et al.*, 2009).

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 (UNCLOS) and FAO's Code of Conduct for Responsible Fisheries. In 1975, the declaration of the Exclusive Economic Zone (EEZ) granted Costa Rica a marine area more than 10 times the size of its land area (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 (572,000 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 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, 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, 1971).

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, 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 large 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, while the bulk of catches come 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 t·year^{-1} to 34,000 t·year^{-1} (www.fao.org), while the ratio of coastal to pelagic landings changed from 3:2 to 1:4 (Mug-Villanueva, 2002). This fishing dynamic has masked overall declines in coastal landings.

Pelagic fisheries

Small pelagic species 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*). Overfishing due to national demand led to a decline in sardine catches in the late 1980s, and a moratorium was 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 families such as the 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 bycatch, 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*). Along 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 (*Peneaus occidentalis*, *P. stylirostris*, *P. vannamei*), conchudo (*Trachypenaeus byrdii*) and tití shrimp (*Xiphopeneaus riveti*), and in deeper waters (35 to 120 m) pink (*P. brevirostris*) and brown shrimp (*P. 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 (Alvarez and Ross, 2010). Shrimp landings from nearshore 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 bycatch of any of the Costa Rican fisheries sectors (Gutierrez, 1990; Kelleher, 2005). Given the fact that bycatch in deep-water shrimp trawlers is entirely discarded, a particularly worrisome statistic is the amount of bycatch relative to shrimp. In 2008 for example, yearly catch for this fishery consisted of about 5% target shrimps (almost exclusively *S. agassizii*), 55% stomatopods and 40% fish (Wehrtmann and Nielsen-Muñoz, 2009), the latter two discarded.

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 (INCOPESCA, 2006). Sea turtle catches are not considered in the present catch reconstruction and hence have been excluded from the data.

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 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 has contributed to this fishery being underrepresented 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 to waters beyond its 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 data on the operation of these fleets, so that some tuna and shark landings may have been 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., Inter-American-Tropical-Tuna-Commission).

In order to manage fisheries at a more sustainable level, we need a better understanding of actual total 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.* (2006; 2007). This improved assessment of Costa Rica's fishing past will help to better understand its current status and plan for future management.

METHODS

National landings data were compiled and compared to the landings submitted to FAO on behalf of Costa Rica. We then estimated discards and unreported catches by the shrimp fishery and the herring fishery, subsistence catches from the small-scale sector, underreported catches by the artisanal and recreational sector, and post-release mortality.

Shrimp fishery bycatch

Shrimp fishery bycatch was estimated using officially reported shrimp landings from 1950-2008. A sampling survey conducted by the regional office of Puntarena in 1987 determined that the total bycatch/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, 1990). Later reports suggest that declining shrimp catches during the 1980s-1990s led to an increase in bycatch retention, while overfishing resulted in a decrease in bycatch (Alvarez and Ross, 2010; Kelleher, 2005). Therefore, we used the lower estimate of bycatch/shrimp ratio (7.7:1) and the upper estimate of bycatch retention (14%; Gutierrez, 1990) to estimate total bycatch and discards per year, and gradually decrease the ratio of bycatch to shrimp landings from 1995-2008. To avoid overemphasizing outlier data points, we applied a 5-year moving average smoothing function to the estimated bycatch.

Subsistence fishery

Fishers, particularly in the artisanal sector, often keep fish for themselves and their families to eat (take home catch), a form of subsistence catch. Subsistence catch estimates were derived from a study conducted for the Atlantic coast of Guatemala that estimated 70 $kg \cdot fisher^{-1} \cdot year^{-1}$ were retained for home consumption (FAO, 1970). To estimate total fishers per year, we used a linear interpolation between

anchor points in 1985 and 2002 using the ratio of fishers (Salas *et al.*, 2007) to the total population (UN database), from 1950-2008 (Figure 2).

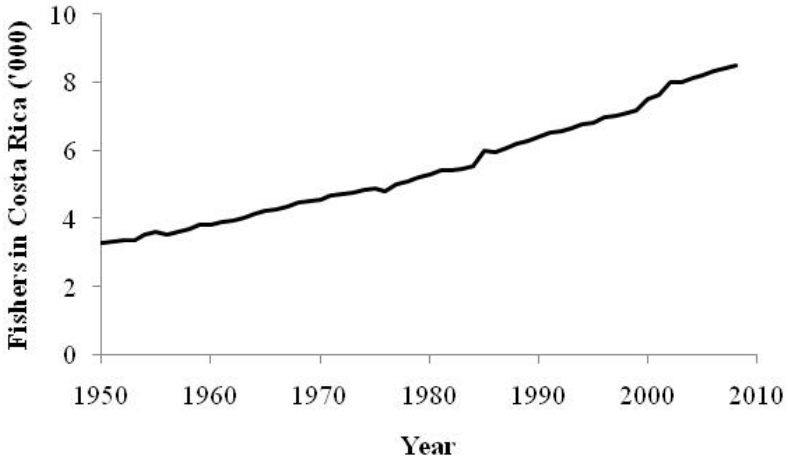

Figure 2. Costa Rica's artisanal fisher population numbers (including piangüeros) based on estimates from Salas *et al.* (2007).

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, reported shark catches 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 (INCOPESCA, 2003; La Asamblea Legislativa de la República de Costa Rica, 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 (Anonymous, pers. comm.)[1]. We therefore assumed that catches after 2003 were equal to the previous 5-year average.

[1] The source, known to the senior author, wishes to remain anonymous.

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 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 billfishing began around 1980. Catch per angler (~7 fish) was estimated based on 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 (Cramer, 2004; Pine *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).

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 the catch-per-fisher ratios have remained constant.

RESULTS

Shrimp trawl bycatch

The total amount of finfish, sharks and rays caught as bycatch in the Costa Rican shrimp fisheries between 1950 and 2008 was estimated to be 871,000 t (Figure 3). Almost 50% of these catches, approximately 420,000 t, were discarded. Bycatch 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 bycatch increased along with shrimp landings, from 650 t·year^{-1} in 1950 to a peak of 43,000 t·year^{-1} in 1986-87, before declining sharply to around 3,500 t·year^{-1} in 2008, as shrimp fisheries collapsed (Figure 3).

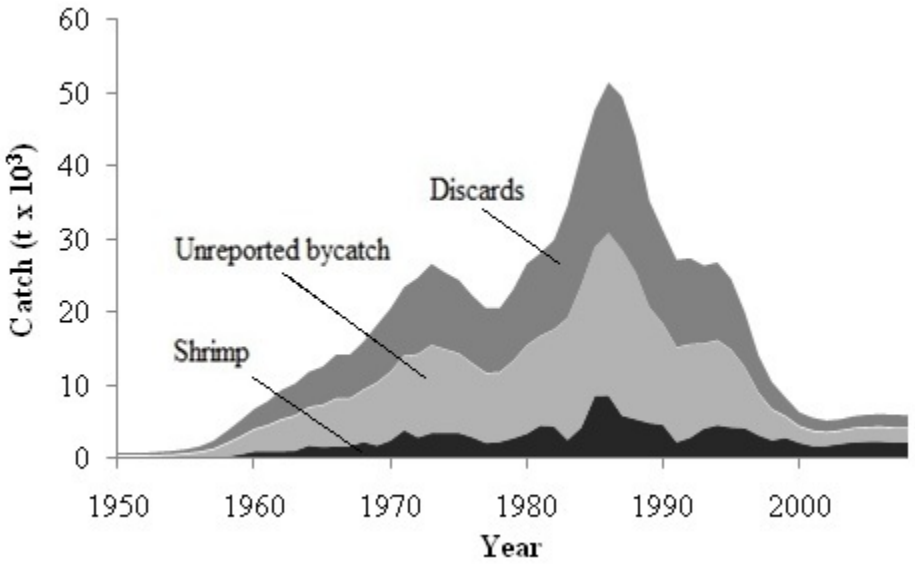

Figure 3. Total reconstructed catch of the shrimp fisheries of Costa Rica, including unreported bycatch landings and discards.

Shark fishery

Using conversion rates reported by Vannuccini (1999), and assuming that actual catches remained relatively constant after 2004 when reported landings decreased due to a formal ban on finning, we estimate that total shark catches in Costa Rican waters from 1950-2008 are 70% higher than FAO statistics suggest (Figure 4).

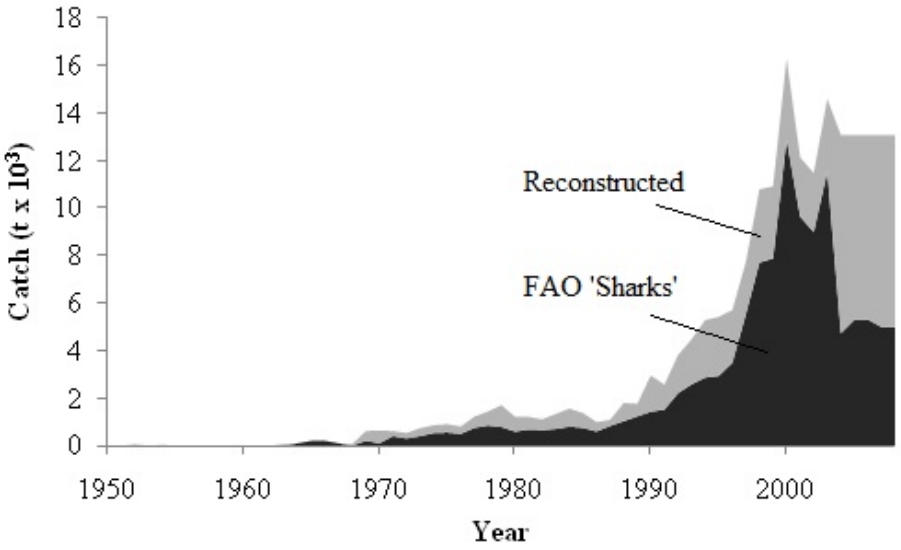

Figure 4. Reconstructed total catches of sharks compared to shark landings as reported by FAO on behalf of Costa Rica.

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 due to their fundamental food security importance. Using available data, we estimate that around 210,000 whelks, or 2 t, are currently harvested each year, with total catches of 80 t from 1950-2008. Subsistence fish catch estimates (catch retained for the fishers personal consumption) totalled over 24,000 t from 1950-2008, and approximately 620 t·year^{-1} in 2008. For pianguas, we estimated that a total of around 275 t·year^{-1} are currently taken, with 242 t of pianguas landed for sale in 2008 and the rest kept for own consumption. Over the entire study period, we estimate that approximately 10,400 t of pianguas have been collected (Figure 5).

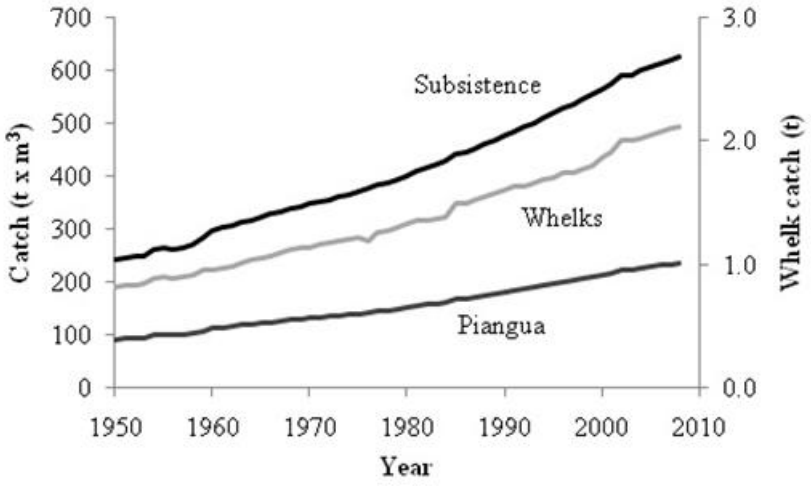

Figure 5. Subsistence catches (including fish and pianguas), piangua (for sale) and whelk landings.

Recreational fisheries

Recreational fishing is an economically important and growing industry in Costa Rica; we focused our efforts on sportfishing for billfish, the largest sector (Soto-Jiménez *et al.*, 2010). Assuming significant operations began in 1980, we estimate that over 10,000 tonnes of billfish (~90% sailfish) were killed by recreational fishers in Costa Rica from 1980-2008, with an average of 600 t·year^{-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, even while encouraging catch-and-release.

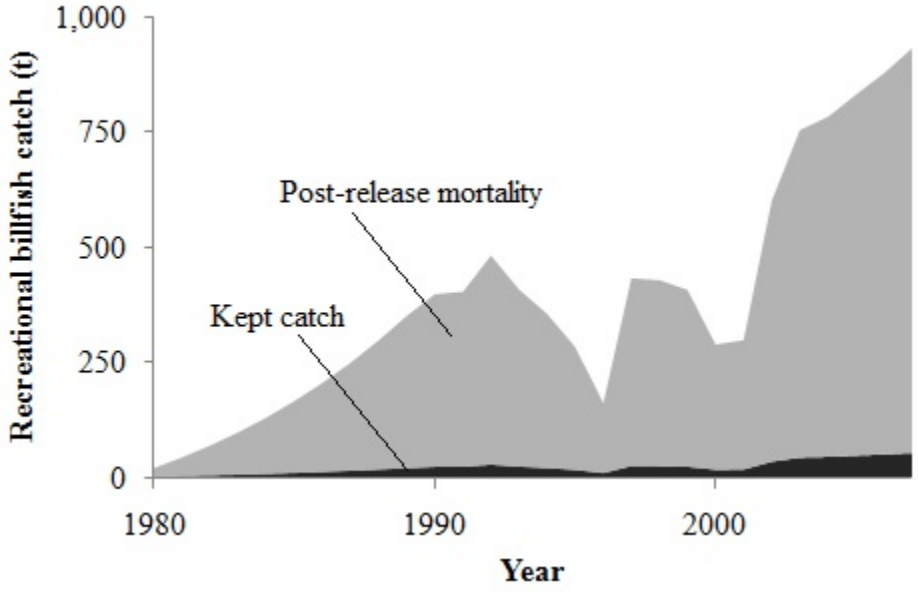

Figure 6. Recreational catch of billfish, including retained catch and post-release mortality, from 1980 to 2008.

Total reconstructed catch

Following the methods described above, our reconstructed catch estimates suggest that, between 1950 and 2008, total fisheries catch in Costa Rica was 1.8 million tonnes, 2.3 times the total landings reported to FAO for the same period (Figues 7). The majority of this unreported catch, in order from largest to smallest, was bycatch in shrimp trawls, underreported shark landings, and recreational, subsistence, piangua and whelk catches. In the more recent period (2000s), we estimate a 47% underreporting rate relative to data reported to FAO. Details on reconstructed catch estimates for these sectors are provided below.

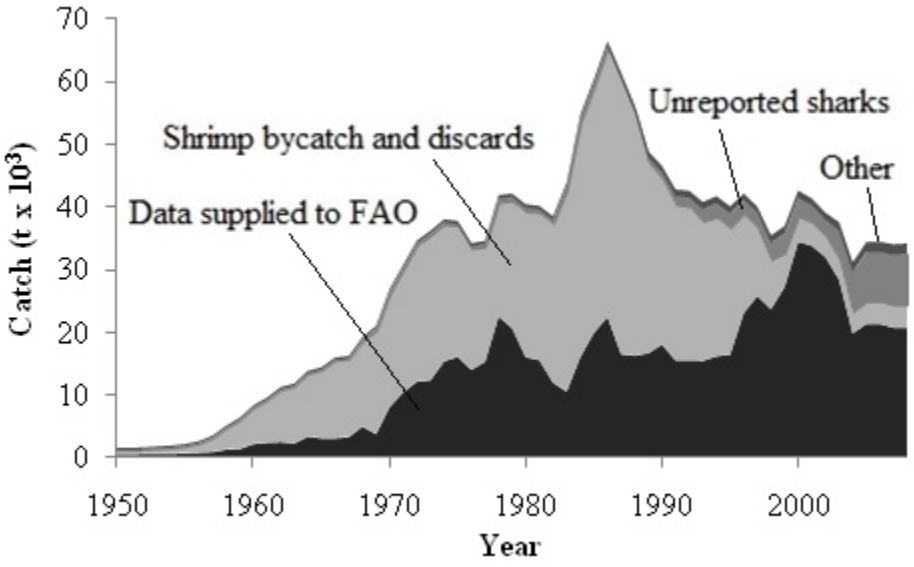

Figure 7. Total fisheries catches for Costa Rica from 1950-2008 compared to landings reported to FAO by Costa Rica. The 'Other' category represents the sum of unreported recreational, subsistence, piangua and whelk catches.

DISCUSSION

As is the case in many countries, a substantial portion of total fisheries catches in Costa Rica are not reported, and therefore ignored in management and policy decisions, especially at regional and global scales. The majority of this unreported catch comes in the form of bycatch, small-scale artisanal 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 1950-2008, total reconstructed catches were estimated to be 1.7 million t, which is 2.3 times larger than total landings as reported to the FAO by Costa Rica. The difference between total reconstructed catch and reported landings was greatest from the 1970s to the 1990s, due to large amounts of bycatch in shrimp trawl fisheries. However, underreporting continues to be a problem in more recent times, with total catches estimated to be 46% higher than reported landings in the 2000s.

Bycatch 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 (Alvarez and Ross, 2010). By 2008, the amount of bycatch has decreased by 90% 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 bycatch-reducing devices are currently used by the trawling fleet. Greater retention of

commercially valuable bycatch 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 thus simply serve as a minor subsidy to maintain excessive 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 trend of progressively moving from shallow coastal waters to deeper offshore waters, 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 habitats (Alvarez 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 bycatch 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 comes from the large foreign fishing fleets that operate in the region (Mug-Villanueva, 2002), with foreign markets driving demand (Clarke *et al.*, 2006). One particularly problematic 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 the 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 at private docks, which are not subject to government inspection (Andrés 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 40% 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 also a challenge for fisheries management, as catches are often not landed in the EEZ where they were caught, opening up numerous loopholes to avoid regulations, preventing adequate monitoring necessary to sustainable fisheries. Unfortunately, we do not have enough data available to estimate actual, total tuna catches by foreign fleets in the Costa Rican EEZ, although the responsible Regional Fisheries Management Organization IATTC should have detailed and complete data on such catches.

The small-scale sector is commonly overlooked in fisheries management and policy. Our estimated subsistence and piangua catches, totalling 24,000 t and 10,400 t, respectively, over the entire study period, hardly seem negligible. 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 $t \cdot year^{-1}$ since, with 20 $t \cdot year^{-1}$ in 2008, nine 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. The general disinterest in and lack of attention on such sectors by the responsible government agencies continues to be driven by a misguided and erroneous believe of these sectors' small size and limited socio-economic importance, which only further adds to the marginalization of small-scale fisheries (Pauly, 2006). While these sectors may be overshadowed by the large industrial fisheries, it is precisely the socio-economic benefits and ecological sustainability of such localized fisheries that are not only vital to the welfare of coastal communities but will increasingly be fundamental to national food security, 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 conflicts with commercial fisheries.

Illegal, unreported and unregulated catches are 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 the absence of formally recorded time series of catches does not imply 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 and encourage the Costa Rican government to ensure all fisheries are accounted for, and their catches estimated and reported to the global community via FAO.

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Appendix A. FAO reported landings and total reconstructed catch (t).

Year	FAO	Reconstructed
1950	500	1,480
1951	500	1,502
1952	600	1,604
1953	600	1,746
1954	600	1,875
1955	700	2,110
1956	800	2,583
1957	900	3,465
1958	1,300	5,035
1959	1,400	6,321
1960	2,200	8,304
1961	2,400	9,545
1962	2,500	11,218
1963	2,300	11,799
1964	3,401	13,811
1965	3,101	14,401
1966	3,101	15,959
1967	3,301	16,187
1968	5,001	19,196
1969	3,801	21,023
1970	8,101	26,932
1971	10,462	30,787
1972	12,131	34,651
1973	12,361	36,232
1974	15,407	38,065
1975	16,096	37,796
1976	14,037	34,230
1977	15,310	34,615
1978	22,552	41,927
1979	20,671	42,173
1980	16,046	40,461
1981	15,580	40,205
1982	11,991	38,543
1983	10,568	43,891
1984	16,051	54,741
1985	19,924	60,453
1986	22,464	66,509
1987	16,521	61,459
1988	16,271	56,244
1989	16,681	48,926
1990	18,061	46,599
1991	15,518	42,834
1992	15,561	42,619
1993	15,462	40,828
1994	16,181	41,758
1995	16,440	40,115
1996	23,096	42,180
1997	25,824	40,073
1998	23,714	35,489
1999	27,279	37,000
2000	34,463	42,660
2001	33,817	41,388
2002	32,020	39,105
2003	28,398	37,606
2004	19,850	31,171
2005	21,341	34,422
2006	21,341	34,468
2007	20,736	34,050
2008	20,750	34,207

Appendix B. Breakdown of reconstructed catch (t).

Year	Total	Shrimp bycatch	Shark	Piangua	Subsistence	Recreational
1950	1,480	646	0	91	242	0
1951	1,502	646	17	93	246	0
1952	1,604	646	17	93	247	0
1953	1,746	775	27	94	249	0
1954	1,875	905	10	98	261	0
1955	2,110	1,034	10	100	265	0
1956	2,583	1,422	0	98	261	0
1957	3,465	2,197	0	100	266	0
1958	5,035	3,361	0	102	271	0
1959	6,321	4,524	7	107	283	0
1960	8,304	5,686	8	112	297	0
1961	9,545	6,720	8	114	302	0
1962	11,218	8,270	24	116	307	0
1963	11,799	9,046	22	118	312	0
1964	13,811	9,950	22	120	318	0
1965	14,401	10,855	0	122	323	0
1966	15,959	12,406	0	124	328	0
1967	16,187	12,406	21	125	333	0
1968	19,196	13,569	161	127	338	0
1969	21,023	16,412	337	129	343	0
1970	26,932	17,962	389	131	347	0
1971	30,787	19,513	326	133	352	0
1972	34,651	21,767	261	134	357	0
1973	36,232	23,072	300	136	361	0
1974	38,065	21,813	340	138	366	0
1975	37,796	20,857	332	140	371	0
1976	34,230	19,296	378	142	377	0
1977	34,615	18,319	458	144	383	0
1978	41,927	18,177	662	147	389	0
1979	42,173	20,245	712	149	395	0
1980	40,461	23,170	690	151	402	0
1981	40,205	23,504	536	154	409	21
1982	38,543	25,398	537	157	416	44
1983	43,891	32,053	616	159	423	69
1984	54,741	37,326	671	162	431	98
1985	60,453	39,194	592	167	444	130
1986	66,509	42,838	425	168	446	166
1987	61,459	43,634	472	171	454	206
1988	56,244	38,569	518	174	462	249
1989	48,926	30,358	942	177	469	298
1990	46,599	26,491	1,037	180	477	351
1991	42,834	24,857	1,392	183	486	398
1992	42,619	24,461	1,512	186	494	403
1993	40,828	22,222	1,970	189	502	482
1994	41,758	22,199	2,265	192	510	408
1995	40,115	20,232	2,371	196	519	355
1996	42,180	15,779	2,293	199	528	283
1997	40,073	10,857	2,490	203	537	162
1998	35,489	7,828	2,759	206	547	433
1999	37,000	5,367	3,157	210	557	429
2000	42,660	4,047	2,962	213	566	408
2001	41,388	3,711	2,778	216	575	289
2002	39,105	3,325	2,663	205	591	298
2003	37,606	3,220	4,617	177	592	601
2004	31,171	3,404	6,384	177	599	755
2005	34,422	3,551	7,961	178	607	783
2006	34,468	3,615	7,873	191	614	832
2007	34,050	3,621	7,979	214	620	878
2008	34,207	3,596	8,084	216	627	932