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A 50-Year Reconstruction of Fisheries Catch in Puerto Rico

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A 61 year reconstruction of fisheries catch in Puerto Rico

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Abstract

To fully understand the nature and extent of fishing impacts on ecosystem processes and the economic status of coastal communities requires a clear baseline of the timing and magnitude of fishery extractions. We reconstructed a 61-year history (1950-2010) of fisheries catch in Puerto Rico that distinguishes between artisanal (commercial), recreational, subsistence and baitfish sectors. The by-catch for the artisanal fishery was also estimated. Few data were available before the 1970s for the commercial fishery, and before 2000 for the recreational fishery. The latter was reconstructed using anchor points and interpolations. For commercial data, estimates were obtained using linear interpolation between reported estimates. Results were compared to landings as reported by FAO on behalf of Puerto Rico. From 1950 to 1980, catch was dominated by the commercial fishery and increased to over 6,000 $t \cdot year^{-1}$. During this time, estimated catches were 2,000-3,000 $t \cdot year^{-1}$ higher than reported by FAO. After 1980, there was a marked decline in overall and in artisanal catches, but an increase in recreational catches, which reached a peak of almost 2,200 t (40% of total catch) in 2000. As a consequence, reported landings were still exceeded by around 30% through the mid 1990s, though marked improvements in reporting occurred subsequently. By 2010, total catch had dropped to 1,600 t or just 38% of the catch in 1950 and 24% of the peak catch.

Introduction

Puerto Rico is the eastern most island of the Great Antilles (18°15' N and 66°30' W), bounded by the Atlantic Ocean to the north and Caribbean Sea to the south. The island measures about 50 km in width and 180 km in length on its east/west axis. Puerto Rico includes the adjacent islands of Vieques and Culebra off the east coast, and Mona and Desecheo off the west coast (Figure 1). The coastline consists of a wide variety of marine habitats that include coral and rock reefs, sea grass beds, fringing mangroves and mangrove lagoons, sand and algal plains, soft bottom areas, and sandy beaches (Appeldoorn and Meyers 1993; Ballentine et al. 2008). These habitats are very patchily distributed.

The east coast has a wide shelf that extends to the Virgin Islands. Total shelf area (to 200 m depth; Figure 1) is 5,000 km^2 within an EEZ of over 177,000 km^2 (www.seaaroundus.org). The southeast coast has a narrow shelf (2 km wide), and 25 km to the southeast is Grappler Bank, a small seamount with its top at 58 m depth. The central south coast broadens to 15 km, and contains an expansive sea grass bed extending 9 km offshore to Caja de Muertos Island. Moving westward, the shelf narrows (2 km) and then at the southwest corner it extends to over 10 km. This area is characterized by hard or sand-algal bottoms with emergent coral reefs, sea grass beds and mangroves inshore, and submerged reefs offshore and along the shelf edge. This southwest corner is one of the principal fishing areas due to its broad shelf and good harbors. Compared to the other coasts of Puerto Rico, the north coast has a very narrow insular shelf (< 2 km wide) and is subject to sustained wave action due to the northeast trade winds and the seasonal North Atlantic storms that generate large (> 6m tall) swells. Few good bays are present, except for the San Juan Bay, which is the primary commercial harbor of the island. The coast is a mixture of extensive sandy beaches, rocky outcrops, coral and rock reefs. Along the northwest coast, the shelf continues being narrow, but the southwest platform broadens to a wide expanse, reaching 25 km from shore at its maximum.

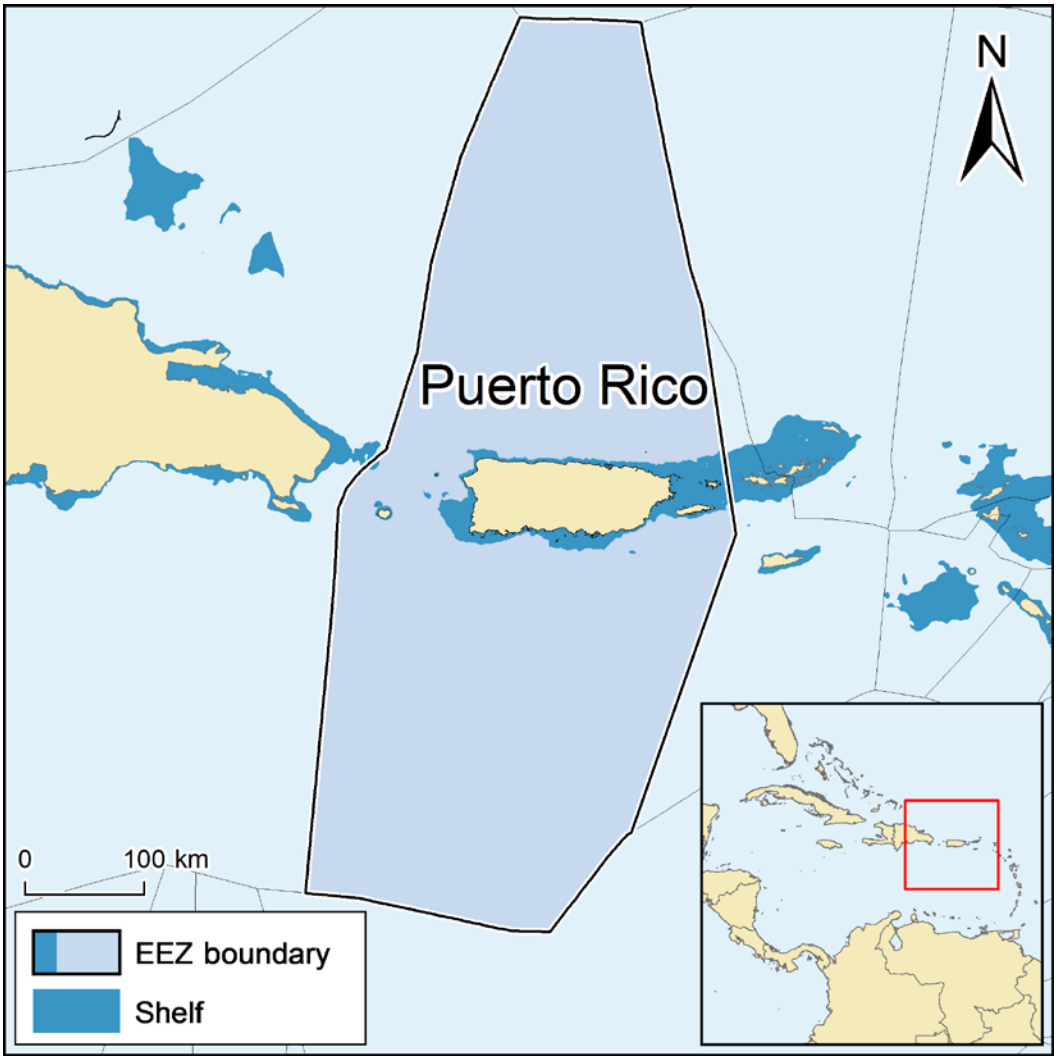

Figure 1. Map of Puerto Rico and its Exclusive Economic Zone (EEZ).

Extending west from the insular platform is the Mona Passage. The islands of Mona and Monito lie 45 km to the west, and rise from depths of 400 m. In between Mona and Puerto Rico is a unique, highly rugose and extensive area that ranges in depth from 300 m to 1000 m, with even greater depths to the north and south as the bottom falls into the Puerto Rico Trench and Caribbean Basin, respectively. To the north of Mona is a seamount (Pichincho) that rises to depths of only 50 m and represents the western edge of a deeper ridge that extends toward the island of Desecheo. Bajo de Sico and Bajo de Espongas are other seamounts located just off the western Puerto Rico platform, the former rising to approximately 20 m. These areas are important commercially as they support an active fishery for deep-water snappers, with Pichincho also noted as an important recreational site for highly migratory pelagic fishes.

A recent summary of Puerto Rico fisheries is given by Valle-Esquivel et al. (2011). The commercial fishery is small-scale, hence artisanal in nature and operates from a wide variety of locations. The principle gears used are fish traps, lobster traps, gillnets and trammel nets, beach seines, cast nets, spears, hand lines, long lines (both surface and benthic), trolling and hand collection, with many variations in both design and use. Historically, traps have dominated the catch, but their use has declined over time resulting in a more balanced fishery using lines, nets, traps, and spears. Over 155 species of finfish are exploited, plus an additional 10 species of shellfish. The shelf fishery targets snappers (Lutjanidae), groupers (Serranidae) and jacks (Carangidae), but also grunts (Haemulidae), parrotfishes (Scaridae) and trunkfishes (Ostraciidae). The deep-water fishery primarily targets snappers and groupers along the insular slope and in the Mona Passage. The pelagic fishery historically was small and targeted tunas and billfish, but more recently it has moved away from these species and expanded to target dolphinfish (*Coryphaena hippurus*). The recreational fishery expanded from the 1950s to become a significant component of the fishery. Historically, this component consisted of a large shore-based component, which probably included a high degree of subsistence fishing, and boat-based fishery targeting the shelf, and a specialized tournament fishery targeting large oceanic tunas and billfishes, especially blue marlin (*Makaira nigricans*). More recently, both the boat-based and tournament fisheries have increasingly targeted dolphinfish, while the billfish fishery has largely shifted to catch and release.

The fisheries resources of Puerto Rico have been exploited since pre-Colombian times, clearly targeting a variety of species, including manatees, turtles, fishes and conch. The fisheries expanded under Spanish colonial rule, but a lack of preservation techniques and high imports of salted cod kept overall demand low. During the 1940s and 1950s, the Puerto Rico government instituted programs specifically designed to expand fisheries production, an effort that continued through the 1980s (Valdez-Pizinni 2007). However, sustained efforts to estimate catch only started in the late 1960s and targeted only the commercial fishery. Recreational catches have been routinely monitored only since 2000. Yet, over the last 60 years there have been marked changes in the fishery, both in the technology and gears used, the areas of exploitation and the species targeted. The latter has resulted from both the decline of previously important species (Appeldoorn 2011), as well as the expansion of the fishery to include new resources. The purpose of this paper is to reconstruct the Puerto Rico fisheries catch back to 1950 following the method described in Zeller et al. (2007), including the commercial, recreational and subsistence components. Fishing is one of the most severe anthropogenic impacts on marine ecosystems (Jackson et al. 2001). Having a clear baseline of the extent of fishery extractions is prerequisite

for understanding the nature and extent of the impact these activities have had on an ecosystem and economic basis.

Methods

Commercial catch

Commercial fisheries landings data have been collected by the Puerto Rico Fisheries Research Laboratory since 1968. However, it is widely recognized that data from the first years of that effort were highly unreliable (Suárez-Caabro 1970). We accepted 1971 as a reasonable starting date for reliability of these data, based on the re-evaluation in SEDAR (2009), which corrected past landings records from 1971-2005 for under-reporting and misreporting. Similarly corrected data for 2006-2010 were obtained from Matos (2008, 2012).

Only scattered reports of estimated landings are available during the 1960s. Historically, these were discounted based on the original estimates of landings during the 1970s. However, in light of the revised estimates from SEDAR (2009), which more than doubled the uncorrected data, and because the few reported values are consistent with each other, we accepted these earlier estimates at face value. The first reported estimate for the total commercial catch (1959-1960) was 5,770,000 lbs (2,617 t) (Anonymous 1960). No earlier reports for total catch were found, but the subtotal for the spiny lobster catch was consistent with the value reported by Feliciano (1958) considering the large increase in effort that occurred in the 1950s. Iñigo (1963) reported commercial landings to be 11 million lbs (4,990 t), a value repeated for 1965 by Iñigo and Juhl (1968). Holmsen (1967) made an independent estimate of between 9 to 10 million lbs for 1965, for which we used the midpoint, or 4,309 t. Landings for years between the above values were estimated through linear interpolation. In order to reconstruct the catch prior to 1963, the ratio of the reconstructed artisanal landings to the FAO data for 1963 was maintained going back to 1950.

Discards/by-catch

Generally, by-catch is defined as all non-target catch which is caught along with the target. Discards are defined here as the weight of fish and shellfish estimated to have been caught and discarded dead or dying . However, given the predominance of equating by-catch with discards in US terminology, we treat all sources referring to ‘by-catch’ below as meaning ‘discard’. Only two studies of discards were available. Matos (2007) conducted a detailed study of discards for traps, trammel-nets, hand lines and beach seines. For each gear, he reported the mean length for each species caught with more than 10 individuals. We used published length-weight conversions (Bohnsack and Harper 1988, www.fishbase.org) to convert mean length to weight and then assumed that the mean of these weights applied to the entire catch to estimate the total discard for each gear. Except for lines, the total catch-per-unit-effort for the gears was reported and this was used to estimate total catch per gear based on the information given. For trammel nets, we used the midpoint (400 fathoms) of the range given as the mean net length and 12 hours as the soak time to estimate discard at 1.97%. For traps, we used the midpoint (45) of the range given for hauls/trip and assumed a mean soak time of 5 days (from Rosario and Sadovy 1996) to estimate discards at 4.87%. For beach seines, we used the midpoint (125 fathoms) of the range given as the mean net length and 2 hours as the time fished. Thirty percent of the unreported

catch was reported to be released alive, which resulted in a discard estimate of 23.2%. Insufficient information was available to calculate total catch for hand lines, but discard weight fell between that of traps and trammel nets, so we interpolated a value between the two, yielding a discard estimate of 3.14%.

In an earlier study on traps, Rosarios-Jiménez and Sadovy (1996) estimated trap discard for a range of mesh sizes. We took the average of four mesh sizes from 1.25 inch-hex to 2x2 inch square (those used historically), which equaled 29.75%. Of this Rosario and Sadovy (1996) reported that an unknown amount was released alive, while the rest was cut to rebait the trap or retained for personal consumption. We arbitrarily reduced the above value of trap discards to 20% as we assumed that trap discards were greatly reduced since the time of that study, which is consistent with Matos (2007).

To estimate overall discards from the artisanal fishery, we used the above estimates by gear and multiplied them by the reported catch caught by each gear; we combined trammel nets and gillnets for the latter. For traps, discards from 2004 on was taken from Matos (2007), while from 1994 and before, we used the value from Rosario and Sadovy (1996). For the intervening years, discards were estimated using linear interpolation between these two values. The sum of the discard values for the four gears was then used to calculate a total percent discard for each year of data. The discard rate varied markedly (Table 1) over the time period, primarily driven by the large decline in the use of traps from 1974 on. For the 1960s, the 1980s - early 1990s and the last four years, no data were available for catch by gear. For the latter period, total discard rate was estimated by linear regression. For the last four years, this regression was based on the years 1999-2006 ($r^2 = 0.984$), while for the 1980s - early 1990s the regression was based on values from 1974 – 1997 ($r^2 = 0.986$). The value for 1998 was taken as the average of 1997 and 1999. Total discard rate peaked in 1974 at 14.9%. Although no estimates of catch by gear are available prior to 1971, Holmsen (1967) estimated that about 70% of the catch was from traps. Given the variability inherent in this estimate and that trap catch rose steadily from 41% in 1971 to 67% in 1974, we assumed that although trap catch was high in the 1960s, the percentage catch was probably lower than estimated and more on par with that observed in the early 1970s. We thus chose a constant overall discard rate of 12% for the 1950-1960 time period.

Baitfish catch

Baitfish catch was studied by Kimmel (1987), who compared his estimates to those of reported landings from the previous three years. His study only surveyed and compared two months of the year; we multiplied his result by six to obtain yearly estimates. Kimmel (1987) found in his study that the mean reported baitfish landings over the three years were only 14.4%. Since baitfish are used for both commercial and recreational fishing, we indexed the reported and observed baitfish catch to the sum of the commercial and recreational catches (Table 1) for the years of the study, which indicated that unreported baitfish represented 5.65% of the combined catch. This estimate was used as a correction factor for the entire catch history.

Recreational catch

The recreational fishery in Puerto Rico consists of boat-based fishing, shore fishing, charter boat fishing and tournament fishing, the latter specifically targeting highly migratory and coastal pelagic fishes such as blue marlin (*Makaira nigricans*) and dolphinfish. Recreational finfish catch has been routinely monitored since 2000 through the US Marine Recreational Fisheries Statistics Survey (MRFSS) (www.st.nmfs.noaa.gov/recreational-fisheries/index), which can be partitioned into the above groups. These data only include finfish, so they were adjusted upward by the percent weight of shellfish recorded in the recreational survey by Appeldoorn and Valdez-Pizzini (1996), see below. Before 2000, there is limited information on recreational fishing outside the small tournament fishery. Appeldoorn and Valdez-Pizzini (1996) conducted a three-month survey of the boat-based fishery through interviews conducted at boat ramps. Over 300 boats were surveyed, of which 13.4% had been engaged in fishing activities. The catch of these were measured, and converted to weight using published length-weight conversions (Bohnsack and Harper1988; www.fishbase.org). Average catch per boat fishing was 4.221 kg, with 3.96% being shellfish, and participants indicated that they made an average of 40 trips per year. Using these data and the reported number of boats in 1996 (37,351), an overall estimate of the boat-based catch of 1,858,809 lbs (or 843 t) was derived. Valdez-Pizzini (1987) reported on a small survey of recreational fishing boats, which indicated that the average number of trips per year was 72. Using these data jointly with those from Appeldoorn and Valdez-Pizzini (1996) and reported number of boats for 1987 (22,699) resulted in an estimated catch of 2,033,395 lbs, i.e., 922 t.

One study of the shore line fishery was available. For 1988, Berrios et al. (1989) estimated the catch from the shore fishery at six locations around Puerto Rico, representing 65% of the coast. Their resultant total catch was scaled up to the entire coast to yield 12,936 kg. We assumed a linear trend in the shore fishery from this point until 2000 and 2001, when the reported shore catch was 25,614 and 91,662 kg, respectively. We thus assumed a value for 1999 of 27,215 kg (60,000 lbs) and decreased the catch by 1,360 kg (3,000 lbs) each year back to 1989 and further assumed a shore catch of 13,607 kg (30,000 lbs) for 1986.

Based on studies by Valdez-Pizinni (1989), the charter boat fishery at that time was quite small. We chose a base for that year of 2,000 lbs (907 kg) and increased that amount by 1,360 kg each year until 1995, after which it was increased by 1,360 kg annually until 1999. For 1987 to 1999, total recreational catch was estimated as the sum of the boat-based, shore line and charter boat catch estimates. The above calculations for the boat-based, shoreline and charter boat recreational catches were summed for the years in which at least some data were available for the boat-based fishery (1986 and 1989), since that represented the vast majority of the catch.

Two other estimates of total recreational catch were available for years prior to 1986. Suárez Caabro (1979) reported that total recreational catch was 1 million lbs (453.6 t) for 1971 with a fleet of 2,500 boats. Schmeid and Burgess (1987) reported that for 1979, the total recreational catch was 1,910,065 lbs of which 58% was landed. We assumed no discard mortality, and thus the catch was 1,107,838 lbs (502.5 t).

One method of estimating of total recreational catch in other years is to relate catch to the number of recreational boats. Data on the number of boats was incomplete; however, from the available data, we only included data on powered vessels not counting personal water craft (e.g., jet skis). Garcia (2003) reported the number of recreational boats from 1986-2001, which showed a relatively linear increase. More recent data (2007-2009) were available from the Department of Natural and Environmental Resources, which showed that the number of vessels had leveled off from earlier years. Finally, there is also the above estimate for 1971 from Suárez Caabro (1979). The number of vessels for early years without data was estimated by modeling a four parameter S-shaped function to the data. This was based on the knowledge that recreational boats increased markedly after the mid-1980s due to the increase in US Federal funding for Puerto Rico, the number of boats would level off in later years, and that the number of predicted boats during the 1960s could not fall to zero. The number of boats from 1971 and 1986-2001 was used, which resulted in the following equation:

$$\text{Number of Boats} = 70871(1-e^{-0.638(0.0881(\text{Year} - 1944))})^{1/0.638} \quad (1)$$

Six values of recreational catch and number of boats were used to model the relationship between the two. These included the first two years of recreational catch available from the MRRFS database (2000-2001), which varied substantially, and the values as above for 1996, 1986, 1979 and 1971. The number of boats for 1979 was estimated from Equation (1). A plot of these data indicated a straight line relationship between the ln(recreational catch) and number of boats as follows (Figure 2):

$$\ln(\text{recreational catch}) = 5.986 + 0.0000305(\text{number of boats}) \qquad r^2 = 0.823 \quad (2)$$

Based on the estimation of the number of boats from Equation (1), the total recreational catch was estimated from Equation (2) for all remaining years back to 1950.

For the recreational catches, the above equations (1 and 2) were not applicable to reconstruct the catches until 1950, as the predicted numbers of boats and resultant catches were too high to be reasonable. Thus we accepted the catches of 1971, 1979, 1987 and 1996 at face value and assumed for 1950 a total recreational catch of 400 t. Interpolations were then performed between these anchor values to fill-in catches for the missing years. The values from 2000 onwards were adopted since from this time on there was routine monitoring of the recreational fishery.

Subsistence catch

For subsistence catches, we conservatively assumed a minimal value of 4% (Acosta and Valdés Pizzini 2005) of the commercial catches, which represents the fishers' take-home catch, for the whole time period of this reconstruction.

Taxonomic breakdown

The taxonomic breakdown of the artisanal landings and discards was derived by using the values presented by Valle-Esquivel et al. (2011) and Matos-Caraballo (2008) with the assumption that since 1995, the fraction of pelagic fish and invertebrates in the total catch increased. We assumed

that invertebrates made up 20% of the total catch in 1950-1990 and 30% from 2000 onwards. The composition of the invertebrates also changed during the period 1990-2000. Queen conch decreased from 36.5% to 27% and spiny lobster from 39.5% to 29.7% of the total invertebrates. The rest of this proportion was divided equally between the remaining invertebrate groups (Table 1). The pelagic fish were 7% and 12.2% of the total catch in 1950-1990 and 2000, respectively. The species breakdown of the pelagic fish portion was derived from Valle-Esquivel et al. (2011) and was kept constant from 1950 to 2010 (see Table 2). The proportion for the miscellaneous tuna group was equally divided into the 3 tuna species, i.e., yellowfin (*Thunnus albacares*), skipjack (*Katsuowonus pelamis*) and blackfin tuna (*T. atlanticus*; Matos-Carabello 2008).

For reef fish, a proportions of 73% and 57.8% of the total catch were assumed for the years 1950-1990 and 2000, respectively. Deep-water snappers were 0% of the reef fish catch in 1950. The value was steadily increased to 16.3% in 2000 and kept constant to 2010. Groupers, in 1950, were 22.9% of the reef fish catch and decreased to 5% in 2000. All the other reef fishes were kept constant from 1950 to 1990, then interpolated from 1991-99 and stayed constant again from 2000 to 2010. We assumed a constant contribution of 'miscellaneous marine fish' of 15% to the total catch throughout the years (Table 3).

For the recreational and subsistence catch a breakdown was derived from the artisanal composition but at the family level. For the recreational catches the invertebrates, parrotfishes (Scaridae) and boxfishes (Ostraciidae) were excluded. The percentages of the remaining taxa were renormalized.

For baitfish catches, we assumed that mostly Engraulidae were caught.

Table 1. Anchor points for the breakdown of artisanal landings and discards into functional groups. Percentages were interpolated for the years 1991-1999.

Taxonomic group	1950-1990 (%)	2000-2010
Invertebrates	20	30.0
Pelagic fishes	7	12.2
Reef fishes	73	57.8

Table 2. Taxonomic breakdown of the invertebrates in the artisanal catch. The years 1991-1999 were interpolated.

Taxa	1950-90 (%)	2000-10 (%)
Panulirus argus	39.5	29.7
Lobatus gigas	36.5	27.0
Brachyura	4.8	8.7
Bivalvia	4.8	8.7
Octopodidae	4.8	8.7
Misc. molluscs	4.8	8.7
Misc. invertebrates	4.8	8.7

Table 3. Taxonomic breakdown of the pelagics in the artisanal catch, 1950-2010.

Taxa	%
Scomberomorus cavalla	27.0
Coryphaena hippurus	24.6
Scomberomorus regalis	15.6
Katsuwonus pelamis	10.9
Thunnus albacares	10.9
Thunnus atlanticus	10.9

Table 4. Taxonomic breakdown for reef fishes. Deep water snappers and groupers were interpolated from 1951-1999, for the other reef fishes the 1950 anchor point was kept constant until 1990 and were then interpolated from 1991-1999.

	Catch (%)	
Taxa	1950	2000
Etelis spp.	0.0	16.3
Serranidae	22.9	5.0
Ocyurus chrysurus	21.2	19.7
Lutjanus synagris	13.3	12.4
Haemulidae	9.1	8.5
Scaridae	7.4	6.9
Ostraciidae	5.7	5.3
Miscellaneous marine fish	20.5	26.0

Results

Total reconstructed catch for Puerto Rico from 1950 to 2010 was estimated to be almost 279,000 t, which is 1.9 times the data reported by FAO on behalf of Puerto Rico (Figure 3a, Appendix Table A1). . Catch trends can be divided into two periods. The first runs from 1950 to approximately 1980, when total catch grew and was dominated by the artisanal fishery. Total catch peaked at over 6,000 $t \cdot year^{-1}$ twice, once in the mid 1960s and again in the late 1970s. During this period, artisanal landings made up over 87% of the estimated total catch. Estimated catch was 2,000-3,000 $t \cdot year^{-1}$ greater than that reported by FAO. The second period is marked by a large decline in overall catch, driven by an absolute decline in the commercial catch. At the same time, there was an absolute rise in the recreational catch with a peak in 2000 (2,200 t, around 40% of the total catch). As a consequence the proportion of the total catch represented by the artisanal fishery dropped to as low as 48% in 2007. The discards are quite steadily decreasing from 1950 to 2010 and reach a low in 2007 with >1% of total catches.

As of 1994, catch as reported by FAO tracked the artisanal catch more closely, but due to the rise in recreational fishing total catch was still approximately 30% greater. However, by 1997 FAO records equaled 80% of the total catch and continued to improve, on three occasions actually over estimating total catch slightly (not including discards). By the end of the time periodtotal

catch had dropped to 1,600 t or just 38% of the catch in 1950 and 24% of the peak catch in 1977. The catch was dominated by 5 taxa, Ocyurus chrysurus (11.4%), Serranidae (10.3%), Lutjanus synagris (7.2%), Haemulidae (6.8%), and other Lutjanids. The rest of the catch was represented by 19 additional taxa (Figure 3b). In the years from 1950-79 total catches were dominated by of *Ocyurus chrysurus* (Yellowtail snapper) and Serranidae (Groupers), each with a yearly average of 13% of the total catch. From 1984 onwards catches were dominated by other unspecified snappers (Lutjanidae), with a peak contribution in 2007 (almost 29% of total catches).

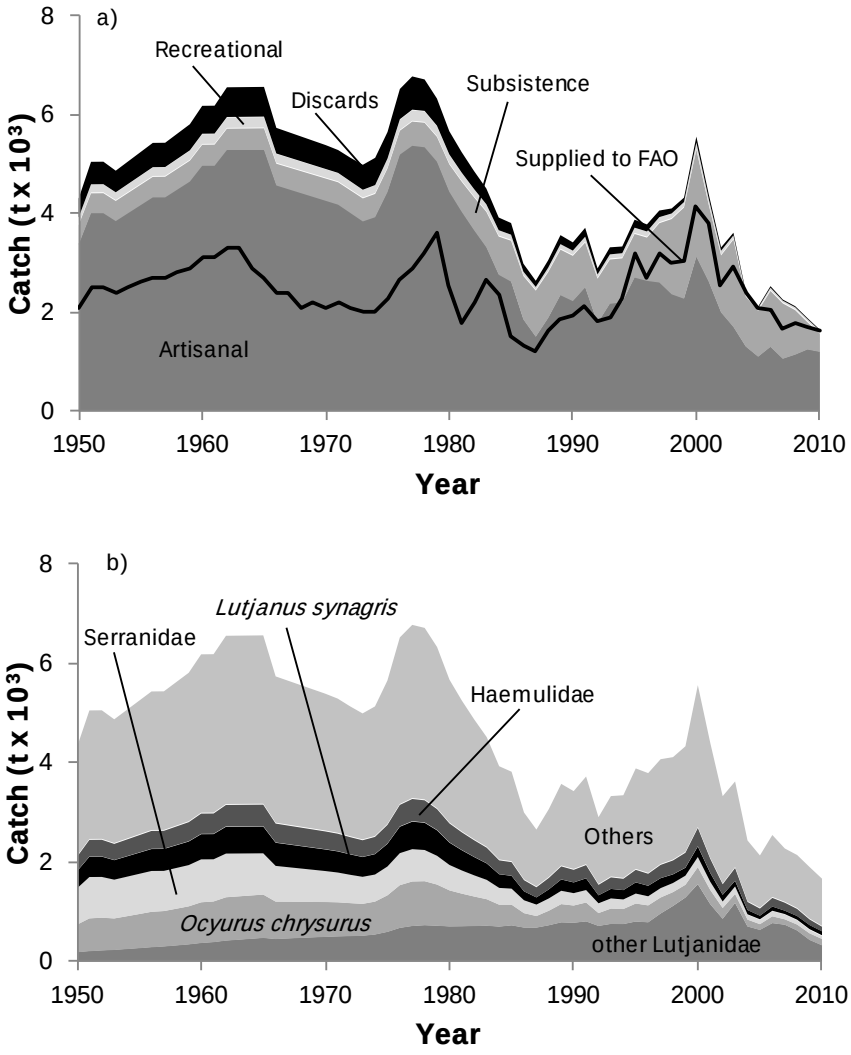

Figure 3. Estimated total fisheries catch for Puerto Rico, 1950-2010, a) by sector along with landings as reported by FAO (black line); and b) by major taxonomic group. 'Others' represents 19 additional minor taxonomic categories.

Discussion

Our goal in estimating total historical catch was to develop a more realistic picture of the extent of fisheries extraction during the period when the fishery and underlying ecosystem were undergoing large-scale changes (Valle-Esquivel et al. 2011, Appeldoorn et al. 2009). As a consequence, we did not include certain sectors of the fishery that were considered to be of

marginal importance relative to overall catch. Not included was the catch from the tournament fishery prior to 2000, when recreational landings began to be systematically collected. While this fishery is both economically and socially important, overall catch was always less than 1% of total estimated catch (Rodriguez-Ferrer et al. 2007). For similar reasons, and because the *Sea Around Us* excludes it from consideration, the impact of Puerto Rico's ornamental fishery (Ojeda et al. 2001) was also not included. Conversely, it is widely understood that during the first half of the 1980s, the catch data also include landings from fishing activities elsewhere in the Caribbean, such as Saba Bank and the Turks and Caicos Islands, by a small group of vessels operating out of the west coast port of Puerto Real (Valdez-Pizinni 2007). We were not able to model a correction for these landings, but we note that this occurred after the peak landings were recorded in the late 1970s. Thus, we think that failing to incorporate these data did not affect the overall trends.

The greatest deviation between reported landings and estimated total catch occurred prior to 1982, and is primarily due to greatly underestimating the artisanal catch. From 1971, this results from the correction of landings data for under and misreporting conducted by SEDAR (2009), which resulted in an increase of 77% over previous estimates and suggested that artisanal landings peaked at over 5,000 t in 1977. This revision is critical, because it fundamentally changes our perception of reported landings in the 1960s. Previously, the validity of those high estimates of catch were discounted in light of later estimates based on a standardized data collection system and because full descriptions of how those estimates were obtained were not available. We now feel that these estimates are realistic because (1) the magnitude of the catch is on par with that reported through the SEDAR correction, (2) there were at least two independent estimates indicating high catch levels, and (3) the increase in catch that these estimates represent since 1960 were considered at that time to be a reliable reflection of the aggressive plan to stimulate fishing activity during this period. Nevertheless, it is assumed that there is substantial variability in those estimates, so while the magnitude of the catch may be accuratly reflected, the overall catch trends may not reflect actual changes, e.g., the peak shown for 1963-65 may not really indicate when catch peaked exactly during the 1960s.

From 1982 to 1994, the recreational catch was the largest source of discrepancy between estimated catch and reporting landings. After this time, reported landings, while still underestimating total catch, seem to track total estimated catch fairly well. By 2001 both data sets were in general agreement as recreational catch statistics became readily available. The growth and magnitude of the recreational fishery during the late 1980s through the 1990s represents a fundamental change in the fishery in terms of total impact, species composition, data collection and assessment, and potential management options. This increase was modeled to follow the large increase in recreational boats. Interestingly, our best fit to the data indicated that recreational catch/boat actually increased across the time series. This could be explained by increases in both the size (range) and gear sophistication of recreational vessels and the disproportional expansion of the fishery (relative to the commercial fishery) into pelagic fisheries.

The magnitude of the overall catch as estimated by this study suggest that fishery policy be re-evaluated, and that potential significant cascading impacts of fishing on the ecosystem, especially within coral reefs environments be considered when setting current management goals and corresponding catch limits.

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Appendix Table A1. Reconstructed fisheries catch (mt) for Puerto Rico by sector, 1950-2010, with adjusted FAO landings.

Year	FAO[1]	Artisanal	Recreational	Subsistence	Discards
1950	2,100	3,380	400	132	381
1951	2,500	4,020	403	157	454
1952	2,500	4,020	405	157	454
1953	2,400	3,860	408	151	435
1954	2,500	4,020	410	157	454
1955	2,600	4,180	413	164	472
1956	2,700	4,340	415	170	490
1957	2,700	4,340	418	170	490
1958	2,800	4,500	420	176	508
1959	2,900	4,660	423	183	526
1960	3,100	4,980	426	195	562
1961	3,100	4,980	428	195	562
1962	3,300	5,300	431	208	599
1963	3,300	5,300	433	208	599
1964	2,900	5,300	436	208	599
1965	2,700	5,300	438	208	599
1966	2,400	4,580	441	180	517
1967	2,400	4,500	443	176	508
1968	2,100	4,420	446	173	499
1969	2,200	4,340	448	170	491
1970	2,100	4,270	451	167	482
1971	2,200	4,190	454	164	461
1972	2,100	4,020	460	157	475
1973	2,000	3,850	466	151	503
1974	1,993	3,940	472	154	550
1975	2,264	4,450	478	174	534
1976	2,650	5,200	484	204	609
1977	2,881	5,380	490	211	670
1978	3,197	5,350	496	210	634
1979	3,597	5,060	503	198	547
1980	2,557	4,450	557	174	467
1981	1,784	4,050	611	158	412
1982	2,202	3,670	665	143	363
1983	2,655	3,320	719	130	318
1984	2,354	2,770	773	108	255
1985	1,496	2,630	828	102	234
1986	1,327	1,860	882	71	159
1987	1,191	1,510	936	58	124
1988	1,611	1,890	929	73	150
1989	1,867	2,360	923	91	181
1990	1,949	2,240	916	86	165
1991	2,115	2,510	910	97	179
1992	1,812	1,790	903	69	121
1993	1,877	2,180	896	84	142
1994	2,275	2,210	890	85	135
1995	3,173	2,710	883	105	161
1996	2,701	2,650	877	102	142
1997	3,187	2,610	1,200	100	133
1998	3,006	2,370	1,523	90	101
1999	3,020	2,290	1,847	86	90
2000	4,154	3,130	2,170	119	120
2001	3,794	2,630	1,557	100	92
2002	2,529	2,010	1,156	77	66
2003	2,919	1,710	1,771	64	53
2004	2,377	1,320	1,012	50	35
2005	2,083	1,110	930	42	27
2006	2,042	1,310	1,133	49	30
2007	1,675	1,070	1,120	40	22
2008	1,793	1,150	901	43	21
2009	1,703	1,260	550	48	20
2010	1,626	1,210	370	47	17

[1] FAO landings were negatively adjusted in 2004, 2005 and 2010 as there was a small amount of over-reporting.

Appendix Table A2. Reconstructed fisheries catch (mt) for Puerto Rico 1950-2010, with landings as reported to FAO.

Year	other Lutjanidae	*Ocyurus chrysurus*	Serranidae	*Lutjanus synagris*	Haemulidae	Others
1950	195	549	723	345	288	2,190
1951	215	654	829	411	335	2,590
1952	229	654	816	411	335	2,590
1953	240	628	776	394	324	2,490
1954	257	654	792	411	336	2,590
1955	275	680	807	427	348	2,690
1956	294	706	821	443	359	2,790
1957	308	706	808	443	360	2,790
1958	328	732	820	460	372	2,890
1959	350	758	832	476	384	2,990
1960	377	811	867	509	407	3,190
1961	394	811	852	509	408	3,190
1962	425	863	885	542	431	3,390
1963	443	863	869	542	431	3,390
1964	460	863	853	542	432	3,390
1965	478	863	837	542	432	3,390
1966	457	745	721	468	380	2,940
1967	468	733	697	460	374	2,900
1968	479	720	672	452	369	2,850
1969	489	707	649	444	363	2,800
1970	499	694	625	436	358	2,750
1971	508	680	601	427	352	2,700
1972	515	657	571	413	342	2,610
1973	521	637	544	400	334	2,530
1974	546	656	546	412	343	2,610
1975	598	728	584	457	376	2,890
1976	677	850	654	534	431	3,350
1977	715	886	661	556	448	3,490
1978	731	876	639	550	444	3,450
1979	720	820	588	515	420	3,240
1980	706	718	518	451	380	2,880
1981	710	650	470	408	355	2,630
1982	714	588	429	369	333	2,410
1983	720	529	390	332	313	2,210
1984	703	438	336	275	278	1,880
1985	728	414	320	260	273	1,800
1986	683	290	253	182	224	1,340
1987	683	233	223	146	204	1,140
1988	729	292	242	183	230	1,370
1989	788	365	266	229	262	1,640
1990	779	345	247	217	252	1,570
1991	807	377	249	237	265	1,760
1992	716	258	190	162	211	1,340
1993	756	307	200	193	231	1,620
1994	753	302	188	189	227	1,660
1995	804	360	198	226	252	2,020
1996	788	338	181	212	241	2,010
1997	963	321	189	201	266	2,110
1998	1,113	277	187	174	278	2,060
1999	1,281	254	189	160	299	2,120
2000	1,547	338	219	212	368	2,860
2001	1,149	284	168	179	283	2,310
2002	858	217	126	136	212	1,750
2003	1,174	180	153	113	257	1,720
2004	705	140	97	88	164	1,220
2005	637	117	86	74	145	1,050
2006	772	138	104	87	175	1,250
2007	740	111	96	70	161	1,070
2008	625	121	86	76	144	1,070
2009	438	135	68	85	115	1,040
2010	331	130	57	82	95	950