Oceanic islands of Brazil: catch reconstruction from 1950 to 2010[1]

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Abstract

This catch reconstruction encompasses the waters within the 200 nautical mile Exclusive Economic Zones (EEZ) of three Brazilian oceanic island clusters: Fernando de Noronha (FN), Saint Peter and Saint Paul Archipelago (SPSPA), and Trindade Island and Martim Vaz Archipelago (TMV). Two industrial multi-gear fleets operate within the waters of these islands, one targeting yellowfin tuna, wahoo, and flying fish in the waters of SPSPA, and the other targeting various reef species in the waters of TMV. Artisanal and subsistence catches were also estimated within the waters of Fernando de Noronha, in addition to bait usage and discards at sea for all fleets. Reported data were only present for some years for SPSPA, where total estimated removals were twice as high as reported data from 1950 to 2010. Total removals from all islands increased from approximately 220 t·year^{-1} in the 1950s to a peak of over 770 t in 2004, before slightly declining by 2010. Only 40% of this catch was reported. Actual catches within their EEZs are even higher if one considers effort exerted by domestic and foreign pelagic longlining, which is not considered in the present reconstruction. Oceanic islands are especially vulnerable to overfishing, and this, paired with Brazil's inability to enforce the jurisdiction of these islands, have resulted in illegal fishing by foreign fleets, especially Asian fleets targeting pelagic species.

Introduction

The oceanic islands of Brazil consist of three major clusters remote from the Brazilian mainland, i.e., Fernando de Noronha Island (FN), Saint Peter and Saint Paul Archipelago (SPSPA), and Trindade Island and Martim Vaz Archipelago (TMV). Although each island cluster has a distinct history and is surrounded by its own Exclusive Economic Zone (see Figure 1), the common factors that link them are a fragile ecosystem paired with their importance to various species which rely on these islands as sanctuary, feeding, and spawning ground (Viana *et al*. 2010). While the Brazilian large-marine ecosystem is considered to have a low productivity, areas with seamounts, including all three oceanic islands covered here, are considered 'hot spots' of biodiversity (Campos *et al*. 2006). Yet due to their isolation, any type of exploitation or alteration can easily lead to extinction and threaten insular reef fish, especially as is being done by targeting top predators, which has a "*cascade effect on other species, including endemic species*" (Pinheiro *et al*. 2010). In such fisheries, commercial exploitation can drive the fishery to extinction in just five to ten years (Pinheiro *et al*. 2010).

Given this vulnerability, it is extremely important to obtain and study accurate catch statistics and monitor the biological status of species on the islands. Currently, commercial catches are not reported to FAO with the level of detail necessary to evaluate the total withdrawals from these waters. In this reconstruction, we estimated domestic commercial and artisanal catch, including bait usage and discards at sea using the same methodology as the catch reconstruction for the Brazilian mainland (Freire *et al*. 2014). Additionally, for the island of Fernando de Noronha, which unlike the other two islands has a small population of permanent residents, subsistence catches were calculated.

Fernando de Noronha (FN), Arquipélago de Fernando de Noronha

The Fernando de Noronha complex (03°50'S and 32°25'W) is composed of six islands, with the main island being Fernando de Noronha proper, comprising 91% of the archipelago, along with 14 remote islets (Castro 2010; Dominguez *et al*. 2013). It is located in the South Atlantic ocean, 350 km from Natal, Rio Grande do Norte (Castro 2010), and due to its closer proximity to the Brazilian mainland than the other oceanic islands, its history has been more intertwined with human development.

Discovered in the early 1500s by navigator Amerigo Vespucci, FN was originally a trading post, later a prison, although its beauty and wildlife often attracted many naturalist and researchers, including Charles Darwin in the 19th century (Castro 2010). According to historian Marietta Borges, in the time of the prison, fishing activity was performed by prisoners who had the duty to return from the sea with fish, otherwise they would be punished (IOPE 2010). The prison was disbanded after World War II, when the island served as a strategic military outpost (Anon 1978), and shortly thereafter a population of approximately 1,000 established itself, subsisting on agriculture and fishing.

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In 1988, the archipelago was declared a National Park (Parnamar – FN), which consequently restricted fishing activities, which to this day can only engage in more offshore waters at depths beyond 50 m (Silva Jr 2003). This, along with its transition to a civil government, was the impetus for a dramatic increase in tourism (Souza and Vieira Filho 2011). Currently, Fernando de Noronha has a substantial community of residents and a constant presence of tourists, whereby tourism is the main economic activity, which has generated multiple transformations of island life, including changes to preexisting economic activities such as agriculture, livestock and fisheries (Souza and Vieira Filho 2011).

Saint Peter and Saint Paul Archipelago (SPSPA), Arquipélago de São Pedro e São Paulo

Saint Peter and Saint Paul Archipelago is composed of six major islands, four smaller ones, and various rockheads located close to the equator at 00°55'N, 29°20'W, 533 nautical miles from Natal – RN and 985 miles from Guinea-Bissau, Africa (Viana *et al.* 2010). Due to its strategic location in the middle of the Atlantic Ocean, it is a key component in the life cycle of various migratory species (fish, crustaceans, and birds) that use this region as a sanctuary for food, spawning grounds, and shelter (Viana *et al.* 2010). Of the 123 known taxa of fish, 70 are pelagic fish (the other 52 are reef fishes) – this abundance of predators such as tunas, billfish, and sharks is explained by the aggregations of flying fish who are the main prey for species like yellowfin tuna and wahoo (Viana *et al.* 2010). Indeed, the CPUE of yellowfin tuna was cited in the 1980s to be four times higher than that of adjacent ocean areas (Hazin 1993).

Such factors undoubtedly attracted fishing, starting in the late 1950s by leased Japanese boats operating from the port of Recife, PE and once again briefly in the mid-1960s (Hazin *et al.* 1998). However, only in 1988 was more significant fishing effort exerted by national fishing boats based out of Natal, Rio Grande do Norte, mainly targeting species are yellowfin tuna (*Thunnus albacares*), wahoo (*Acanthocybium solandrii*) and flying fish (*Cypselurus cyanopterus*) (Viana *et al.* 2010). This fleet employed numerous gears, including handline, longline, dipnets, and trolling where flying fish is commonly used as bait (Vaske Jr. *et al.* 2006). In 1998, the 'Research Station of the Archipelago' (ECASPSP) was established, which has since supported a small staff of fisheries researchers and other biologists (Vaske Jr. *et al.* 2006).

Trindade Island and Martim Vaz Archipelago (TMV), Arquipélago de Trindade e Martim Vaz

The Island of Trindade (20°30'S and 29°20'W) and the Arquipélago Martim Vaz (20°28'S and 28°50'W) are the only emerged portions of extinct underwater volcanoes formed over three million years ago (Pinheiro *et al.* 2010; Serafini *et al.* 2010). Discovered in 1502 by Vasco de Gama, the islands were claimed by Portugal; however, with the independence of Brazil, they were transferred to Brazilian control. Approximately 1,160 km from the Brazilian state of Espírito Santo, the islands have their own distinct Exclusive Economic Zone (EEZ) of 200 miles, enforced mostly by a small but permanent Brazilian Navy base established in 1957.

Besides the 32 military personnel stationed there, the islands remain isolated and uninhabited (Pinheiro *et al.* 2010). Nonetheless, the islands are fished from the mainland, and perhaps even overfished as evidenced by the relatively low density of large carnivorous fishes (Pereira-Filho *et al.* 2011).

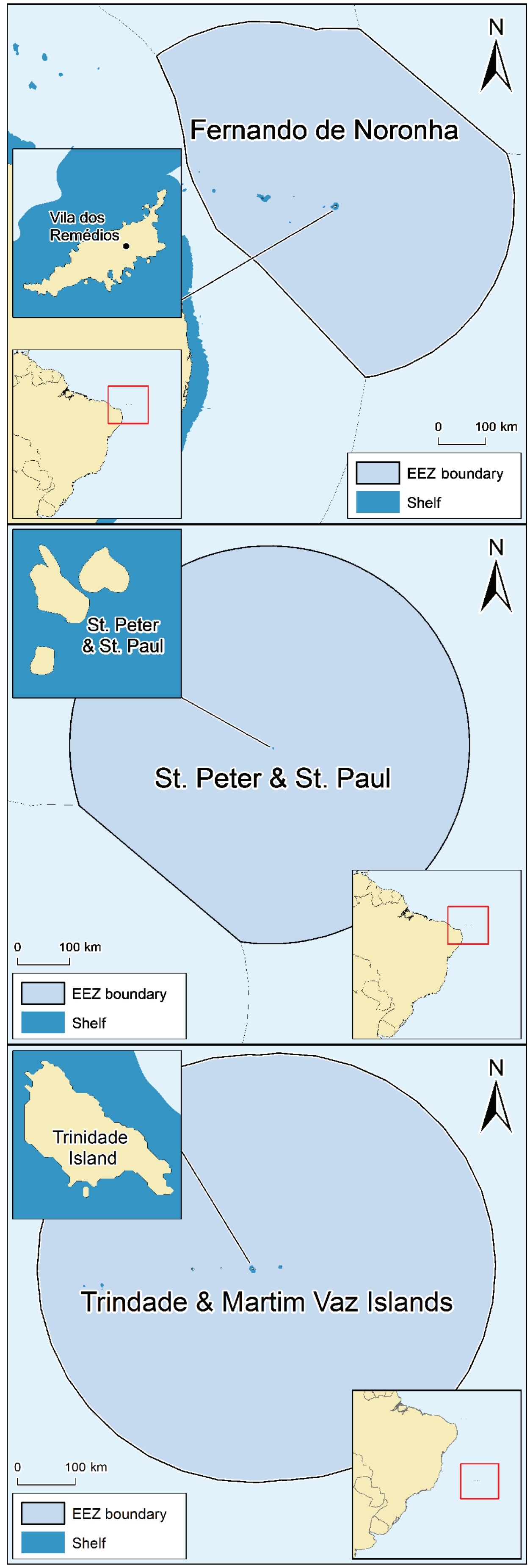

Figure 1. Oceanic islands of Brazil with their respective Exclusive Economic Zones (EEZs).

Like many other islands, the ecosystem is fragile due to few shallow areas and small reef area. Recent research found about 100 fish species in the reefs of Trindade, which is low compared to the Islands of Guarapari (the south coast of Espírito Santo), which has over 300 species. This is common for isolated tropical islands of the Atlantic Ocean (Gusmão *et al.* 2005) as are the high occurrence of endemic species; in this case there are six.

Methods

1. Industrial fisheries

In the two (mostly) uninhabited islands of TMV and SPSPA, there are Brazilian fleets that travel from the mainland to fish. The main fleet fishing in the waters of SPSPA is the multi-gear fleet based in Natal, state of Rio Grande do Norte, which is considered an industrial fleet. The waters of TMV are fished by an 'artisanal' fleet, based out of Vitoria, state of Espírito Santo, mainly targeting reef species. Although this fleet is considered artisanal by Brazil, the *Sea Around Us* considers this industrial, as artisanal catches are only those that are less than 50 km from inhabited shore or 200 m in depth. Since the islands are uninhabited, any fishing by non-inhabitants was considered industrial.

1.1 TMV – Multi-gear line fleet (handline, bottom longline, and trolling) targeting reef species

The use of hook and line is one of the few gears that allows fishers to access areas of rugged oceanic topography such as coral reefs and rocky bottoms where fish can hide (Martins *et al.* 2005).Targeting reef fish was practiced by the Espírito Santo fleet for many decades, but did not extend to the waters of TMV until there was a decline in catch rates of large reef fish in the coastal water of Espírito Santo in the 1980s (Martins *et al.* 2005). During the 1980s, the Vitória fleet (ES) began to search for more abundant fishing grounds, and in "*large movements*" established the Trindade and Martim Vaz seamounts as their destination (Pinheiro *et al.* 2010). Thus, this is a clear sign of spatial expansion of fishing fleets driven by unsustainable fishing effort (Swartz *et al.* 2010).

To estimate catch for the Vitória fleet in Trindade and Martin Vaz, we used the CPUE and effort data in (Martins *et al.* 2005) and made some adjustments to account for the specific CPUE, effort, and species distribution of Trindade and Martin Vaz in (Pinheiro *et al.* 2010). To calculate effort, which from here on will be represented as the number of trips per year, we obtained three anchor points from different periods of time from 1950 to 2010 and interpolated between them. From 1950 to 1980, we assumed that effort was zero, as the catch rates near to the coastal areas of Espírito Santo were still high and there were no cases of fishing cited within the waters of TMV by this fleet.

From 1990 to 1997, the fleet had established its fishing destinations around the islands and there was an effort of 3.9 trips per year, calculated from Martins *et al.* (2005) by using the effort of the entire bottom longline and handline Vitória fleet targeting reef species in 1997 as the baseline. That year, there were 84 boats and an effort of 434 trips taken. Furthermore, the spatial location of these trips was mapped and only three trips out of the 336 trips sampled, were within the EEZ of Trindade and Martin Vaz. This corresponds to 0.9% of all trips by the Vitória fleet, and by extending this sample proportion to the entire fleet, we can deduce that in 1997 there were approximately 3.9 trips per year into the EEZ.

After 1997, there is evidence of a dramatic increase in effort by the Vitória fleet due to the collapse of the coastal shrimp and Peroá (*Balistes capriscus*) populations, whereby these fishers shifted their efforts to target reef species. According to (Martins *et al.* 2005), between the late 1990s to 2002, the effort of the Vitória fleet as a whole increased by 50%. There is evidence, however, that effort within the waters of Trindade and Martim Vaz increased nearly fivefold.

During a 2007 scientific expedition, (Pinheiro *et al.* 2010) reported that around Trindade, there was a "*constant presence of fishing boats from Vitória*". The 1997 level of effort hardly fits this description, as four trips a year, at 20 days each means that there was a presence of one vessel only 22% of the year, rather than several vessels the entire year as described. For there to be a "*constant presence*" within the two month period of the expedition, there must be at least six trips within this time frame, which means that the entire 60 days there were about two boats present. Extending this to the entire year would yield 36 trips annually. In order to remain conservative and include the possibility that the two months of the survey were busier than most, we assumed that half of this amount, i.e., 18 trips were made in 2007. We also assumed that this effort stayed constant from 2007 to 2010. Since the effort for the entire Vitória fleet grew by at least 50% as stated, 18 trips a year is still quite small, amounting to less than 4% of all trips made by the Vitória fleets.

We interpolated between zero effort from 1950 – 1980 to an effort of 3.9 trips per year from 1990 – 1997, the transition period representing when the Vitória fleet was steadily exploring new fishing areas. Thereafter we interpolate to 18 trips in 2007 – 2010.

The CPUE of TMV was calculated by using the effort of the Vitória fleet targeting reef fish as a baseline, at 2.65 t per trip. However, the CPUE was undoubtedly higher, as fishers were leaving the Vitória coastal areas to find spots with higher catch rates. Specifically, a vessel bound for the Martim Vaz Islands Trinidad from Vitória had to travel five days at sea to arrive and five days to return, while trips lasted a maximum of 20 days at sea (Fundação Promar 2005). Using simple economics, in order for fishers to double their effort, losing 50% of the time on commuting, the CPUE for TMV must have been at least twice as high to offset their losses. Since the average CPUE for the Vitória fleet in 1997 was 2.65 t per trip, we assumed that the CPUE for the TMV islands was twice as high at 5.3 t per trip from 1950 to 2003. This is conservative, as it does not account for fuel cost.

There is evidence that this CPUE has declined since then, but this has varied by species. Caribbean reef shark (*Carcharhinus perzii*) and yellowfin grouper (*Mycteroperca venenosa*) have been exploited for a number of years by bottom longline fleet in shallow waters around TMV; captains and crews confirmed that population of these species declined over time (Pinheiro *et al.* 2010). According to one of the boat captains who has been fishing there for 12 years, yellowfin grouper visibly declined: from 1997 to 2003 they caught on average 600 kg per trip, whereas in 2007, they only caught one to three specimens per trip. Taking this statement at face value, this implies that the CPUE decreased from 600 kg to 4 kg per trip in just four years, the latter of which was calculated by estimating the average weight of yellowfin grouper using the length-weight function in Fishbase (www.fishbase.org) and multiplying this by the average of two specimens per trip.

We compared the 1997 CPUE of yellowfin grouper in at 0.6 t per trip to the overall CPUE of 5.3 t per trip, which yielded 11.3% contribution to the entire catch. We used this estimate as a baseline to estimate the contribution of other species, as no exact disaggregation was available, only a list of common species caught. Yellowfin grouper is caught using the handline hear, which is used both day and night when longlines soaking. This gear targets other serranids like misty grouper (*Epinephelus mystacinus*) and rock hind (*Ephinephelus adscensionis*), each of which were also assigned a contribution of 11.3% by weight. Likewise, the gear targets large carangids like black jack (*Caranx lugubris*), horse-eye jack (*Caranx latus*), rainbow runner (*Elagatis bipinnulata*) and various *Seriola* species (Pinheiro *et al.* 2010). The sum contribution of the serranids, 34%, was also applied to large carangids, split equally between the four species.

Bottom longline is also a common gear, at least two of which are deployed at the end of the afternoon in the shallow reef habitats of the islands a few meters from shoreline and retrieved the following morning. The bottom longline targets reef sharks, specifically Caribbean reef shark and nurse shark (*Ginglymostoma cirratum*), which were each assumed to contribute 11.3% to catch. The remaining 9% of catch was evenly distributed among the three remaining taxonomic groups caught occasionally with hand line: bigeyes or catalufas (Priacanthidae), snake mackerels (Gempylidae) and moray eels (Muraenidae).

To calculate CPUE for 2007, we assumed the same CPUE for all species as from 1950 – 2003, except for yellowfin grouper, as mentioned previously, and the Caribbean reef shark. The latter was reported to be overexploited, as the TMV insular complex is a nursery for Caribbean reef sharks and catches of juvenile species were common (Pinheiro *et al.* 2010). Therefore, we assumed that the CPUE of Caribbean reef shark decreased by 25% between 2003 and 2007, from a CPUE of 0.6 t per trip to 0.45 t per trip.

The total CPUEs of all species was added in 2007, assuming that all species except yellowfin grouper and Caribbean reef shark had constant CPUEs over time, resulting in a total CPUE of 4.6 t per trip in 2007. We assumed that the CPUE declined linearly between 5.3 in 2003 to 4.6 in 2007, and then remained constant thereafter. Please refer to Table 1 for a summary of the CPUE values and species disaggregation.

Bait usage in TMV

The use of live bait was common in the fisheries of all three islands. We estimated the bait usage per trip for the fleet fishing in the waters of TMV at approximately 429 $kg \cdot boat^{-1} \cdot trip^{-1}$, which was an average of the bait usage of the two most common gears used, bottom longline and hand line as sampled by (Martins *et al.* 2005) for the Vitoria fleet. Trolling was used to catch bait-like small scombrids (Scombridae) and other local reef fish such as coney (*Cephalopholis fulva*), squirrelfish (*Holocentrus adscensionis*), glasseye (*Heteropriacanthus cruentatus*) and spotted moray (*Gymnothorax moringa*) (Pinheiro *et al.* 2010). We multiplied the rate of bait catch per trip by the effort already calculated and assigned 20% of the catch to each of the five taxa.

1.2 SPSPA – Multi-gear fleet targeting tunas and wahoo

The present-day fishing operations off the waters of Saint Peter and Saint Paul Archipelago began in 1988 with vessels based Rio Grande do Norte (Hazin *et al.* 1998), and due to the high productivity of the island, a constant presence of boats has been there ever since. The catch is mostly comprised of yellowfin tuna, wahoo, and flying fish targeted with various gears such as handline, trolling, pelagic longline, dip net, and traps (Vaske Jr. *et al.* 2006; Viana *et al.* 2008; Viana *et al.* 2010). According to (Vaske Jr. *et al.* 2006), fishing near the islands is carried out year-round with at least one and at most four vessels operating on site.

Except for the pelagic longline fleet, which is not considered in the present analysis, no literature is available on a domestic multi-gear fishery prior to 1988. However, personal communication with José Airton Vasconcelos, a member of IBAMA previously involved in the experimental fishery on the DIADOROM from 1977 to 1981, suggests otherwise. While the experimental fishery J.A. Vasconcelos was involved in was located mostly off the oceanic banks of Ceará and Rio Grande do Norte, the captain Manel Murrão of the Pernambuco-based vessel RIO NEGRO would regularly communicate with their team via radio about their trips to SPSPA. The reported fishing effort was one trip per month and the fishing methods were the same as is common in the present time period (J.A. Vasconcelos, pers. comm.). Furthermore, José Airton Vasconcelos provided catch data reported to the Brazilian state of Rio Grande do Norte from 1995 to 2010 (Appendix Table A1). This implies that any catches prior to 1995 were unreported.

Thus, to reconstruct catches, we generated a time series of CPUE and effort data using representative anchor points and multiplied these values for reconstructed catch. We then compared the reported data with reconstructed catch and made appropriate adjustments.

CPUE (Catch Per Unit of Effort)

Our CPUE for the earlier time period was obtained from the research vessel DIADORIM in 1977 and 1978 which spent some time near the islands of Saint Peter and Saint Paul Archipelago. The CPUE calculated for SPSPA was 60 kg·hour^{-1} by trolling, employed on average 6 hours per day, 74.1 kg·hour^{-1} for dipnet, employed on average 2.2 hours per day during the survey, and 74.8 kg·hour^{-1} by handline, with on average 2.9 hours fished per day for the survey (Oliveira *et al.* 1997). Cumulatively, the CPUE was 0.74 t·fishing day^{-1}.

Table 1. CPUE and relative proportion of catch by taxon for the Vitória multi-gear fleet.

Species name	Common name	Gear	Species group	Years 1950–2003		Years 2007–2010	
				CPUE (t/trip)	(%)	CPUE (t/trip)	(%)
Carcharhinus perzii	Caribbean reef shark	Bottom longline	Reef shark	0.60	11	0.450	10
Ginglymostoma cirratum	Nurse shark	Bottom longline	Reef shark	0.60	11	0.600	13
Caranx lugubris	Black jack	Handline	Large carangid	0.45	8	0.450	10
Caranx Latus	Horse-eye jack	Handline	Large carangid	0.45	8	0.450	10
Elagatis bipinnulata	Rainbow runner	Handline	Large carangid	0.45	8	0.450	10
Seriola	Amberjacks	Handline	Large carangid	0.45	8	0.450	10
Epinephelus mystacinus	Misty grouper	Handline	Serranid	0.60	11	0.600	13
Mycteroperca venenosa	Yellowfin grouper	Handline	Serranid	0.60	11	0.004	0.1
Epinephelus adscensionis	Rock hind	Handline	Serranid	0.60	11	0.600	12.9
Priacanthidae	Bigeyes or catalufas	Handline	-	0.17	3	0.170	4
Gempylidae	Snake mackerels	Handline	-	0.17	3	0.170	4
Muraenidae	Moray eels	Handline	-	0.17	3	0.170	4
Total	-	-	-	5.30	100.0	4.560	100.0

For the later time period, we used the sample data from (Viana *et al.* 2010) where a total of 2171 t of fish were caught, 20% wahoo, 12% flying fish, 60% tunas, 4% sharks, and 4% other species. Furthermore, it was stated that the CPUE for wahoo was 115 kg·fishing day^{-1} and for yellowfin tuna it was 450 kg·fishing day^{-1} (Viana *et al.* 2010). We determined the sample effort in fishing days using catch and CPUE estimates for both wahoo and albacore tuna, which was 3,775 fishing days and 2894 fishing days, respectively. We averaged the two to obtain an estimate of 3335 fishing days for the entire time period, and divided the total sample catch by effort exerted to obtain a CPUE of 0.65 t·fishing day^{-1}.

We assumed that from 1950 to 1977, the CPUE was 0.74 t·boat^{-1}·fishing day^{-1}, interpolated to 0.65 t·boat^{-1}·fishing day^{-1} in 1998, and then remained constant at this level until 2010.

Effort

As stated previously, the reported fishing effort for fishery in the 1970s was one trip per month, which needed to be converted to days at sea to apply the appropriate CPUE. Due to the similarity in fishing methods during the earlier and later time periods (J.A. Vasconcelos, pers. comm.), we converted the number of trips to the equivalent number of days at sea using a representative value of 11 days at sea per trip. This was calculated by comparing two independent measures of CPUE for yellowfin tuna, each with varying units of effort. The first measurement was official catch reported to Rio Grande do Norte from 2006 to 2010, divided by the number of trips taken annually (Appendix 1). The second measurement was the CPUE in (Viana *et al.* 2010) for yellowfin tuna for the equivalent years, which was in terms of kg·boat^{-1}·fishing day^{-1}. We assumed these two measurements were equal and consequently obtained that one trip is, on average, equivalent to 11 days at sea.

Thus, effort from 1977 to 1981 was 12 trips annually, or 132 days at sea. There is no clear way of knowing when the fishery truly began or ended, but in order to stay conservative we assumed these years are the peak years of the fishery. To account for the realistic scenario that fishing had gradually increased to this level (and conversely, waned after the peak of the fishery), we assumed half this effort for the years 1976 and 1982.

Next, we estimated the effort for the present fishery as described by (Vaske Jr. *et al.* 2006), who reported that fishing was carried out year-round with at least one and at most four vessels operating on site (Vaske Jr. *et al.* 2006), or an annual average of 2.5 boats operational for 912.5 fishing days cumulative, assuming each boat operated year-round as was stated. To be conservative, we estimated effort as the midpoint between this average, and the minimum fishing effort of one boat operating there annually, or 365 fishing days. In summary, our estimate of fishing effort during the later time period (starting with 1998) was 639 fishing days. For the years prior, effort was interpolated from 0 in 1987 to 639 fishing days in 1998.

Reconstructed catch

Effort and CPUE were multiplied to obtain an estimated reconstructed catch. Since the CPUE and effort values were constant from 1998 to 2010 (due to the aggregation of CPUE and catch data over the sample years), the catch for the later time period was constant. We compared this to the reported data from 1995 – 2010 (Appendix Table A1), which was more variable, and hence felt it was appropriate to follow the trend line of the reported data. Total reconstructed catch estimated at 416 t·year^{-1} from 1998 to 2010, while reported landings in this same time period averaged 261 t·year^{-1}. The unreported component for this time period was approximately 60% of reported landings. We applied this percentage to all reported landings from 1995 to 2010 assuming the same species composition as the reported portion.

Prior to this, we utilized the product of CPUE and effort data for the years 1976 to 1982, and then interpolated between zero catch in 1987, to the catch estimated in 1995 at 175 t. We utilized the species composition from the last two years of reported data for any catches from 1950 to 1994, i.e., we averaged the species compositions from 1995 and 1996.

The only taxon that we did not include in the species distribution was the brown spiny lobster (*Panulirus echinatus*), which has a small contribution by weight to overall catch, yet is a very economically important species. Thus, we modeled the catch separately for this species.

Brown spiny lobster

Spiny lobsters, which are one of the most highly valued resources in northeastern Brazil, have been heavily targeted and thus resulting in dramatic depletion due to illegal and predatory activities (Pinheiro *et al.* 2003). While most species of spiny lobster are well-studied and regulated by fisheries legislation, brown spiny lobster is the only species not considered in such management regulation, likely due to the fact that it prefers offshore rocky regions like Saint Peter and Saint Paul Archipelago, and thus has not been heavily targeted until the other lobster species closer to the mainland were depleted. While traps were originally used to target this species in the 1980s, by the 2000s this method was replaced by diving, which had significantly higher yields.

According to a sample of 15 research expeditions where traps were placed around SPSPA, 1494 lobsters were caught and sampled, each weighting an average of 200 g. We assumed that one research expedition was equivalent to two fishing days, or at least 1 day to set up traps and the following day to analyze and record findings. This results in a CPUE for traps of approximately 10 kg per fishing day. Since trap gear was known for yielding small catches, we assumed that CPUE for diving was twice as high, at 20 kg per fishing day. We modelled that traps were used until 1990, at which point the diving linearly replaced traps until 2003, when the only gear employed was diving. We also assumed that only 50% of the fishers, and thus 50% of the effort was directed at brown spiny lobster, especially since diving is a rather skilled endeavor.

Bait usage in SPSPA

Since the gears that used live bait for fishing in SPSPA were pelagic longline, hand line, and trolling, we took the average of the bait usage for these three gears in (Martins *et al.* 2005) and arrived at 293 kg ·boat^{-1}·trip^{-1}. Since the effort for SPSPA was represented in terms of days at sea, we adjusted the bait catch by dividing the estimate by 11, which was the average number of days at sea per trip as calculated previously. Thus, the bait usage was estimated at approximately 15 kg·boat^{-1}·fishing day^{-1}. This was multiplied by the effort previously calculated. In SPSPSA, dipnets were used to capture flying fish, which are used as live bait (Vaske Jr. *et al.* 2006). Sometimes shark skin was cut in the shape of a fish for bait, but most accounts focus on flying fish as the most common bait used (Vaske Jr. *et al.* 2006).

2. Artisanal fisheries

2.1 Fernando de Noronha artisanal fishery

The only artisanal fishery present is located on the island of Fernando de Noronha, which has a small-scale fishery active since 1950, where effort is exerted by artisanal fishers living on the island (Barros 1963; Lessa *et al.* 1998; Dominguez *et al.* 2013). In the early years of the fishery, after World War II, there was no strict control or oversight, so fishers freely brought fish to the beaches, often leading to the food poisoning of residents. This encouraged stricter measures, including beheading and gutting at sea along with storing fish in crushed ice (Barros 1963). By the mid-1950s and early 1960s, fishing took place along the entire coastline during the entire year by a solid base of artisanal fishers, working on four motorized boats (two with steel hulls and two with wood), ranging from 8 to 11.5 meters in length (Barros 1963). These fishers employed mostly hook and line gear, the most common of which were trolling and 'deep line' with line lengths between 5 to 100 fathoms and up to four hooks per line (Barros 1963; de Moura and Paiva 1965). On average, fishing took place eight to ten hours a day, starting in the early morning, employing between four to ten men on board, depending on the size of the boat (Barros 1963).

While the artisanal fleet continued using the same fishing gear and navigation techniques from 1950 to 2010, effort exerted changed significantly over time. Although the population did not grow significantly prior to the establishment of the island as a National Park in 1988, the number of fishing boats, and thus fishing effort increased substantially. After 1988, however, fishing effort declined as the tourist industry expanded. While the number of boats remained high, fishers "*were attracted by the income and began to work full or part-time in tourism, which gradually absorbed much of the labor force*" (IOPE 2010). Thus, during this later period of time, fishing effort declined.

Throughout the entire time period, fishing generally took place within a radius not exceeding 5 nautical miles from shore (Lessa *et al.* 1998), and congregating near the '*parede*', or 'wall' where the depth dramatically drops off to 800

– 1200 meters and creates an upwelling leading to nutrient enrichment (Dominguez *et al.* 2013). After 1988, when the PNM was established, fishing was no longer allowed within 50 m of shore, although on occasion the PNM allows fishing inside its limits for species "*of passage*", especially barracuda (Lessa *et al.* 1998).

In order to estimate catches by this fleet, we took the product of CPUE and fishing effort from 1950 to 2010. Annual effort was represented as the sum of the efforts of all boats, with the effort of a boat equal to the number of fishing trips (Lessa *et al.* 1998). One trip was equivalent to one day of fishing averaging eight to ten hours at sea (Lessa *et al.* 1998; Dominguez *et al.* 2013), and the CPUE was denoted in kg of catch per trip per year.

According to (Barros 1963), in the mid-1950s up until 1963 commercial catch was estimated between 150 to 200 t, derived from the fact that when the four boats of the fleet are in operation, they export to Recife about 3 to 4 tonnes weekly, for approximately 50 weeks per year. Additionally, Barros (1963) cites that on average, the CPUE was 700 kg·boat^{-1}·day^{-1}, i.e., 700 kg·boat^{-1}·trip^{-1}. We conservatively used the lower bound of 150 tonnes annually as our baseline and using the CPUE derived an average of 214 trips annually.

For the years 1989 and 1990, Lessa *et al.* (1998) estimated a significantly lower CPUE at 62 kg per trip and 52.5 kg per trip, respectively, but also a significantly higher effort with 1281 and 859 trips taken in the respective years. Additionally, Lessa *et al.* (1998) stated that the CPUE in 1995 recorded by IBAMA was on average 55.5 kg per trip and the effort in the mid-1990s was shared between nine boats each taking an average of 5.5 trips monthly. Thus, we estimated an effort of 594 trips in 1995.

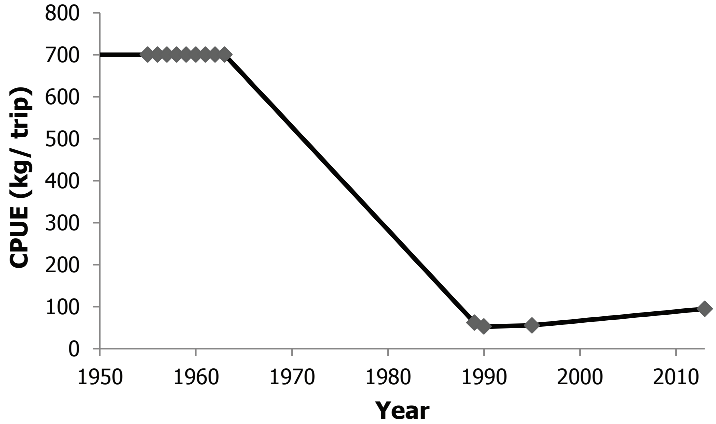

Figure 2. CPUE in kg per trip of the artisanal fishery in Fernando de Noronha.

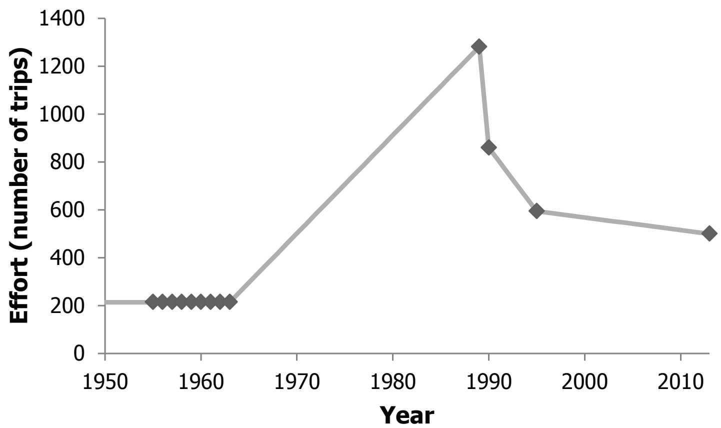

Figure 3. Effort in number of trips of the artisanal fishery in Fernando de Noronha.

Finally, during a six-month trip from April to September in 2013, Dominguez (2013) sampled 23.75 t of landings obtained by an effort of 250 trips, thus resulting in a CPUE of 95 kg per trip and an annual effort of 500 trips. We compiled all estimates of CPUE (Figure 2) and effort (Figure 3) and multiplied the quantities to obtain total catch. As a quick verification, we compared our results to some "*scarce records*" (Lessa *et al.* 1998) that were compiled from non-systematic catch statistics. The general trend marked that of the one calculated here, with catches peaking in the mid-1970s and declining thereafter. The only data point available in the 1970s was in 1974 where the catch was reported at 280 t. Our estimate resulted in a total of 286 t of catch in that year, which is remarkably similarly given an independent methodology.

In order to disaggregate the catch by species, we used the composition of catch from each of the three studies and interpolated the proportions over time (see Table 2). From 1950 to 1963, we used the description from (Barros 1963) to assign species composition. Although (Lessa *et al.* 1998) for the years 1988 to 1990 had more specific data about species composition than (Barros 1963), we hesitated to use it for the earlier time period later studies took place after the establishment of the Arquipélago as a National Park, which in consequence restricted the fishing activity until this day to outside 50m from the coast (Silva Jr 2003; IOPE 2010). Indeed, of the thirteen major commercially significant species or species groups listed in (Barros 1963), four were not included in (Lessa *et al.* 1998) at all. Furthermore, of the ones included in (Lessa *et al.* 1998), approximately half had a minuscule contribution to overall catch.

It was stated in (Barros 1963) that during a sample taken over seven days, the top catches were predominantly of red porgy pargo (*Pagrus pagrus*), barracudas (Sphyraenidae), and the group of species of tuna known by the Portuguese common name of 'albacora'. For these three species or taxonomic groups, we estimated a contribution of 20% each to catch by weight. In order to be consistent with the species classifications for later time periods in (Lessa *et al.* 1998) and (Dominguez *et al.* 2013), we assumed that the main barracuda species referred to was the great barracuda (*Sphyraena barracuda*), and that the species referred to as 'albacoras' were the yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), blackfin tuna (*Thunnus atlanticus*), and albacore (*Thunnus alalunga*), each of which contributed 5% by weight to catch. (Barros 1963) also mentioned 11 other species that were significant to the fishery, each of which we assumed contributed equally to the remaining 40% of catch, or 3.6% each. The species classification of jacks and groupers were further divided into more specific species so to have a comparable level of detail with (Lessa *et al.* 1998) and (Dominguez *et al.* 2013).

For the time period 1988 – 1990, studied by (Lessa *et al.* 1998), the taxonomic composition by weight was based on the family of fish, with further clues in the text as to the particular contribution of each species. When there was no particular description in the text, all species for that family received an equal contribution to the percentage assigned for that taxonomic family. The majority of catch in (Lessa *et al.* 1998) was attributed to great barracuda (*Sphyraena barracuda*), yellowfin tuna (*Thunnus albacares*), blackfin tuna (*Thunnus atlanticus*), albacore (*Thunnus alalunga*), and black jack (*Caranx lugubris*). (Dominguez *et al.* 2013) also reported on the species composition of sampled catch by percentage and all but two of the 14 species listed were also in (Lessa *et al.* 1998). In order to have a comparable level of detail to that of (Lessa *et al.* 1998), we split the more general designation of *Caranx* species into horse-eye jack (*Caranx latus*) and blue runner (*Caranx crysos*). Further details can be seen in Table 2.

Table 2. -Species composition of catch by the artisanal fleet in FN, by time period.

Species name	English common name	Portuguese c. name	1950–1963 (%; Barros 1963)	1988–1990 (%; Lessa et al 1998)	2013 (%: Dominguez 2013)
Thunnus albacares	Yellowfin tuna	Albacora-laje	5.0	10.0	30.1
Thunnus obesus	Bigeye tuna	Albacora-bandolim	5.0	5.8	-
Thunnus alalunga	Albacore	Albacora-branca	5.0	10.0	-
Thunnus atlanticus	Blackfin tuna	Albacorinha	5.0	10.0	-
Acanthocybium solandri	Wahoo	Cavala-aipim, cavala	3.6	6.8	7.6
Katsuwonus pelamis	Skipjack tuna	Bonito-rei	3.6	0.5	-
Sphyraena barracuda	Great barracuda	Barracuda, bicuda	20.0	40.0	6.6
Sphyraena picudilla	Southern sennet	Barracuda-corona	-	2.0	-
Caranx lugubris	Black jack	Xaréu-preto	1.8	5.0	16.1
Caranx hippos	Crevalle jack	Xaréu-branco	1.8	0.2	0.3
Caranx crysos	Blue runner	Xaralete	-	0.2	2.2
Caranx latus	Horse-eye jack	Xixarro-preto	-	0.2	2.2
Decapterus spp.	Scads	Xixarro-branco	-	0.2	-
Elagatis bipinnulata	Rainbow runner	Peixe-rei	-	0.2	24.5
Seriola dumerili	Greater amberjack	Arabaiana	-	0.2	1.3
Selene vomer	Lookdown	Galo-de-penacho	-	0.2	-
Alectis ciliaris	African pompano	Galo-de-alto	-	0.2	-
Trachinotus ovatus	Pompano	Pampo-garabebel	-	0.2	-
Coryphaena hippurus	Common dolphinfish	Dourado	-	0.6	3.4
Istiophorus albicans	Atlantic sailfish	Agulhão-Vela	-	0.6	-
Xiphias gladius	Swordfish	Agulhão-roliço	-	0.6	-
Lutjanus jocu	Dog snapper	Dentão	-	0.6	2.0
Lutjanus purpureus	Southern red snapper	Pargo	20.0	0.6	-
Lutjanus analis	Mutton snapper	Cioba	3.6	0.6	-
Hyporthodus niveatus	Snowy grouper	Serigado-cherne	1.8	0.0	-
Mycteroperca bonaci	Black grouper	Serigado-badejo	1.8	0.0	-
Anisotremus surinamensis	Black margate	Pirambu	-	0.0	-
Epinephelus morio	Red grouper	Garoupa	3.6	0.6	-
Cephalopholis fulva	Coney	Piraúna	-	0.6	0.1
Melichthys niger	Black triggerfish	Cangulo-bandeira	-	0.6	2.2
Balistes vetula	Queen triggerfish	Cangulo-listrado	-	0.6	-
Holocentrus adscensionis	Squirrelfish	Mariquita	-	0.6	-
Lactophrys spp.	Cowfishes	Baiacu-caixão	-	0.6	-
Carcharhinus spp.	Sharks	Tubarão-sucuri, cacão	3.6	0.6	-
Carangoides bartholomaei	Yellow jack	Guarajuba	3.6	-	0.5
Makaira nigricans	Blue marlin	Marlin azul	-	-	0.7
Epinephelus itajara	Goliath grouper	Mero	3.6	-	-
Pomatomus saltatrix	Bluefish	Enchova	3.6	-	-
Clupeidae	Herrings and shads and sardines and menhadens	Sardinha	3.6	-	-

Octopus (Octopus vulgaris) fishery

Up until 1988, we believe, octopus fishing was purely subsistence in nature, carried out by residents, as there was no mention of this fishery prior to the 2000s. With increased tourist activity after 1988, there was an intensified exploration of activities related with the marine environment such as recreational diving and boating, as well as the gradual migration and adaption of fishing vessels towards the tourist industry (Lessa *et al.* 1998; Leite *et al.* 2008; IOPE 2010). Since octopus was caught via diving and a majority of octopus fishers were also involved in the tourist industry, it follows that octopus fishing grew proportionally with the tourist industry.

However, the base of octopus fishers themselves changed little, as more than 80% of the octopus fishers interviewed in 2003 to 2005 learned to fish with their parents and have been involved with octopus fishing since childhood or adolescence (Leite *et al.* 2008), implying that it was a tradition carried down in the family. In 2004, an average octopus fisher has been fishing for 14 years, which is further evidence that these fishers had been fishing prior to the explosion of tourism.

Between 2003 to 2005 (Leite *et al.* 2008) stated that there were 45 octopus fishers, mostly operating part-time, and that 80% of them, or 36, were the stable base of octopus 'traditional' fishers from 1988 to 2010. We assumed that the other 20% of fishers began fishing as a result of the increase in tourism, so that these 'non-traditional' fishers numbered 0 in 1987 and increased linearly to 9 in 2004 when the study was done and continued to increase following the same trend to 12 in 2010.

From 2003 to 2005 an average fisher consumed 1.35 kg and sold 6.55 kg of octopus on a weekly basis (Leite *et al.* 2008). For subsistence activity, we will assume they are active all 52 weeks of the year, while for commercial activity it was stated in (Leite *et al.* 2008) that fishers were most active 32 weeks of the year. Subsistence was thus a product of the weekly consumption by 52 weeks by the total number of fishers from 1988 to 2010, both traditional and nontraditional.

As for the 6.55 kg sold to restaurants, hotels, and local residents, we separated out the amount sold to local residents, as this was related with subsistence, while the amount sold to restaurants and hotels was related to the growth in tourism. This was done by first calculating the total amount sold in 2003 to 2005, using 2004 as a base year, which we estimated at 9.4 t annually (a product of 6.55 kg weekly by 45 fishermen for 32 weeks in a year). According to (Leite *et al.* 2008) the amount provided to hotels and restaurants from the small-scale local fishery was 11% of their yearly consumption, or 0.9 t, which was subtracted from the total of 9.4 t. Thus, in 2004, 8.5 t of octopus went to local residents for consumption.

We varied these estimates over time from 1988 to 2010 by assuming that the total amount sold to restaurants and hotels increased linearly from 0 in 1987 to 0.9 t in 2004, and then we extrapolated the linear trend to 1.3 t in 2010. We inferred the amount sold to local residents as a proportion of the growth in resident population (see section on Consumption for resident population methodology). This was equivalent to 3.3 t in 1987, increasing linearly to the aforementioned 8.5 t in 2004, and culminating at 8.7 t in 2010.

We believe these estimates are conservative, because even though the number of fishers is small, the total number of people involved in recreational fishing for octopus is high, as seen by the interviews conducted with non-fisher residents, 41.3% already fished octopus sometime in their life.

Bait usage in FN

In 1978, one of the locals exclaimed, "*throw a net, and come dragging 300, 400, 500 sardines!*" (Anon 1978). Residents and fishers alike used 'tarrafas', a conical- shaped net cast out by hand, to target the abundant schools of sardines on beaches and in shallow waters. Sardines were the most common live bait used by fishers to target commercial species from 1950 to 2010 (Lessa *et al.* 1998; Dominguez *et al.* 2013).

In order to calculate the number of sardines used as bait, we adjusted estimates of bait usage in (Martins *et al.* 2005) for various gears of the Espírito Santo (ES) fleet, to represent the bait usage for the Fernando de Noronha fleet. Since trolling and pargueira, or 'deep line,' were the predominant gears of the Fernando de Noronha fleet, (Lessa *et al.* 1998), we averaged the bait usage per trip for these gears as presented in (Martins *et al.* 2005) at 215 $kg\cdot boat^{-1}\cdot trip^{-1}$. In (Martins *et al.* 2005), the maximum days at sea per trip was 20, while for Fernando de Noronha the duration of one trip was equivalent to one day. Thus, we divided the estimated by 20, to obtain 11 $kg\cdot boat^{-1}\cdot trip^{-1}$, which was multiplied by the total effort previously calculated.

Lastly, we considered that from 1950 to 1990, it was reported that 100% of the hooks used sardines as live bait (Barros 1963; Lessa *et al.* 1998), while a report in 2013 by (Dominguez *et al.* 2013) stated that live sardine was most commonly used while artificial bait was used for 7.2% of landings. Thus we adjusted the amount calculated accordingly, assumed that sardines were used 100% of the time from 1950–2000, and for the years after the proportion of bait used linearly decreased to 92.8% in 2013.

3. Discards

Discards were applied to industrial and artisanal landings, except for the species of octopus and brown spiny lobster, as these species were generally caught by diving or traps, and thus would have little to no discards associated with them. For discard rates, we referred to the same proportions as those assumed by Freire *et al.* (2014), i.e., 5.3% of catch for the 'line' gear, which includes hand-line, vertical longline, and bottom longline gears, and 14.8% for pelagic longline gears. The discard rates and species proportions for each island follow.

Saint Peter and Saint Paul Archipelago

Since fishermen in SPSPA employ mostly handline and pelagic longline gears, we averaged the two discard rates for line gear, 5.3%, and pelagic longline, 14.8%, and obtained a rate of 10.1% of catch, or 11.2% of landings. This fishery mostly targets tuna, a highly prized fish, and there is evidence that almost all catches of tuna were juvenile (Vaske Jr. *et al.* 2006). Thus, we believe very little tuna was discarded. We also assumed there were no discards of spiny lobster. The remaining 23 species were assigned a contribution of discards proportional to landings.

Fernando de Noronha

While describing the artisanal fishery, (Barros 1963) mentioned that small juvenile species, or '*peixes miúdos*,' were "*constantly hooked*" on various hooks. Since it was implied that these fish were not commercially desirable, we assumed they were discarded. We assumed a discard rate of 5.3% of catch, or 5.6% of landings. The Portuguese common names of ten species were given, however only eight of them were identifiable: coney (*Cephalopholis fulva*), grunts (*Haemulon*), spotted goatfish (*Pseudupeneus maculatus*), squirrelfish (*Holocentrus adscensionis*), doctorfish (*Acanthurus chirurgus*), greater soapfish (*Rypticus saponaceus*), parrotfishes (*Scaridae*), and a species in the family of jacks and pompanos (*Carangidae*). The two unidentifiable species had the common names of '*manteguinha*' and '*lingua de negro'*. We equally distributed the discards amongst these eight identifiable species.

Trindade Island and Martim Vaz Archipelago

For this fishery, there is the least amount of certainty regarding discards, which are not mentioned. Also, the species composition was derived from interviews with fishers, who, likely mentioned only commercially desirable fish. Nonetheless, we assumed the discard rate for the line fishery, 5.6% of landings, and applied this rate to all landings. Since there was uncertainty as to the species composition, we assumed the same proportion of contribution to discards for all the species, including bait fish that must be alive, and thus any dead fish were likely discarded.

<u>Subsistence fisheries</u>

Although there are several dozen military personel residing in TMV and researchers in SPSPA, catches from their consumption are likely not important enough to warrant study. FN on the other hand has had a population ranging from approximately 800 residents 1950 to 2,600 in 2010, and thus we have estimated consumption for this fishery.

According to (Barros 1963), any estimations for catch were incomplete, as fishing was also done almost daily by inhabitants for personal consumption without ever reporting catch. Species specifically mentioned by (Barros 1963) that were fished for by inhabitants were '*agulhões*,'or needle fishes (Beloniformes*)*, lobster (Decapoda), crab (Portunidae). It was also stated that octopus and squid (*Loligo*) were very common in the waters of Noronha, although he did not mention any fishing for them (Barros 1963). Additionally, an account by a tourist visiting Fernando de Noronha in 1978 mentions several cases of consumption and fishing by islanders, notably, sardines (Clupeidae), yellow jack (*Carangoides bartholomaei*), jacks and pompanos (Carangidae), octopus, and the aforementioned needle fishes and lobster (Barros 1963).

To calculate subsistence fishing, we assumed that as a minimum, each person consumed one serving daily. A three ounce cooked serving of most fish or shellfish provides about one-third of the average daily recommended amount of protein (Seafood Health Facts 2012). The logical maximum bound to our estimates would be three portions of fish daily per person, but to make this leap we would have to assume that fish is the only source of protein. This is not unreasonable, as historically, the primary activites of the island were fishing and agriculture (IOPE 2010). However, since this cannot be verified, we will conservatively assume consumption of one serving a day per inhabitant.

A three ounce serving is equivalent to 85g of edible fish. We assigned an equal split, in edible weight, between the seven species mentioned: lobster, crab, needle fishes, sardines, yellow jack, jacks and pompanos, and octopus. In order to convert to whole weight, we used estimates of edible weight as a percentage of whole weight, i.e., 44% of lobster, 31.5% of crab (Waterman 2001), 56% of species in the Carangidae family, 65% of sardines and needlefishes (Barros 1963; FAO 1989), and 100% of octopus is edible, as it is commonly eaten whole. Overall, this was equivalent to 159 g per serving of whole fish, which resulted in an annual per capita consumption of 58 kg. This is reasonable for an island society during the 1950s and 1960s when store-bought food was not common.

For population figures from 1950 to 2010, we compiled several anchor points and interpolated linearly between them. According to (SAE 2014) in the 1960s the population was constant ranging from 1,200 to 1,300, in the 1970 census the population was 1244, and in the 1980 census it was 1,266. Population after this time period grew dramatically, from 1,342 in 1990 to 2,520 in 2003 (Leite *et al.* 2008). The final anchor point was a population of 2,605 in (Souza and Vieira Filho 2011), who states that this is the population during the time of writing (i.e., between 2009 – 2011). For the decade preceding 1960, we assumed that the population in 1945 was 625, as this was the year the prison was shut down and the island became a place hospitable for settlers. We assumed a linear growth from 625 residents in 1945 to 1250 residents in 1960.

As seen by the fairly constant population up until 1988 and the insular nature of island environments, we assumed that consumption patterns did not change until 1988 with the establishment of the national park. Thus, for these early years we used the constant per capita consumption by specie and multiplied it by the population from 1950 to 1987.

Once the National Park was established in 1988 and tourism exploded (Silva Jr 2003; Leite *et al.* 2008; Souza and Vieira Filho 2011), there were dramatic changes in fishing and consumption patterns. Firstly, the water 50 m around the entire island were considered restricted to fishing, meaning that inhabitants could not easily access these fishing waters to fish by themselves. Although subsistence consumption undoubtedly continued, we believe that nearly all the catch was absorbed into the catch already calculated for commercial fishing by the artisanal fishers. This is supported by a 2008 survey of fishers in Fernando de Noronha, which found that 52% of catch is sold directly to consumers (IOPE 2010). Thus, we assumed that after 1988, 52% of artisanal catches already calculated actually support the livelihoods of island residents and are therefore considered subsistence.

Results

Industrial fisheries (landings and bait)

Catches (discards not included here) for the industrial fleet operating in the waters of TMV began in 1981 with 2 t of catch and increased to 90 t by 2010, bait accounting for approximately 8.6% of this. Catches from within the waters of SPSPA began in 1976 with an average catch of 86 t·year^{-1} until 1983 when the catches dropped to zero until rebounding in 1988. Thereafter, removals increased to 432 t in 1997 before slightly declining and then peaking at 564 t in 2004, subsequently dropping to 351 t in 2010 (Figure 4). For SPSPSA, bait accounted for about 4% of catch.

Artisanal fisheries (landings and bait)

Artisanal catches (discards not included here; Figure 5) were constant in the 1950s and early 1960s at 152 t·year^{-1} of catch, but as effort climbed, catches increased to 294 t in 1975, at which point increasing effort was offset by a decreasing CPUE and catches decreased to 146 t in 1987, the year before the National Park was built. Thereafter, catches declined dramatically, averaging 26 t·year^{-1} in the 1990s and 2000s. On average, baitfish was 11% of the annual catch, which was mostly due to later years when effort was still relatively high but catch was low.

Discards

Discards for the artisanal fleet in Fernando de Noronha were stable at 9 t·year^{-1} from 1950 to the early 1960s, at which point they increased proportionally with catch to 16 t in 1975, and then declined to about 1.5 t·year^{-1} in the 1990s and 2000s (Figure 6). Industrial discards in the waters of TMV were low for the entire period, starting at 0.1 t in 1981 and increasing to about 5 t in 2010. Discards for the SPSPA fleet were the highest, averaging 10 t·year^{-1} from 1976 to 1982, zero for the years after until 1988 when discards climbed to 48 t in 1997 and thereafter oscillated around 49 t·year^{-1} in the 2000s.

Subsistence

Subsistence catches grew proportionally with population for the years prior to 1988, increasing from 48 t in 1950 to approximately 73 t·year^{-1} from 1960 to 1988 (Figure 7). With the creation of the National park, subsistence consumption was bought directly from fishers, and thus catches changed proportional to artisanal activity, dropping to 26 t in 1995, and then increasing to 37 t by 2010. Coinciding with this drop in fish consumption, was a drastic change in the distribution of species consumed as catches of lobster, crab, sardines, and needlefishes dropped to zero in 1988 when residents were no longer legally allowed to fish from shore.

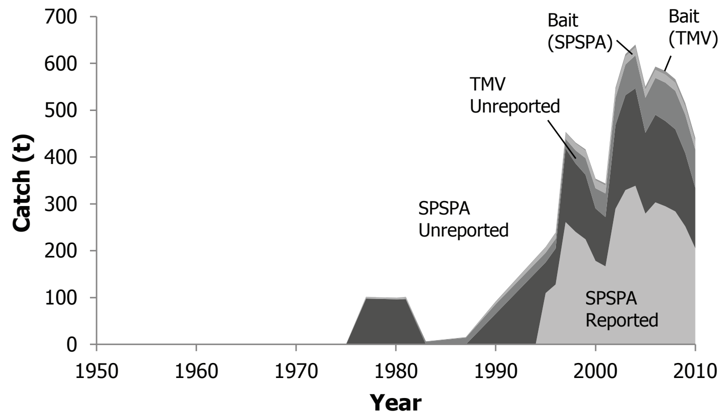

Figure 4. Industrial catch and baitfish for Saint Peter and Saint Paul Archipelago (SPSPA) and Trindade and Martim Vaz Archipelago (TMV).

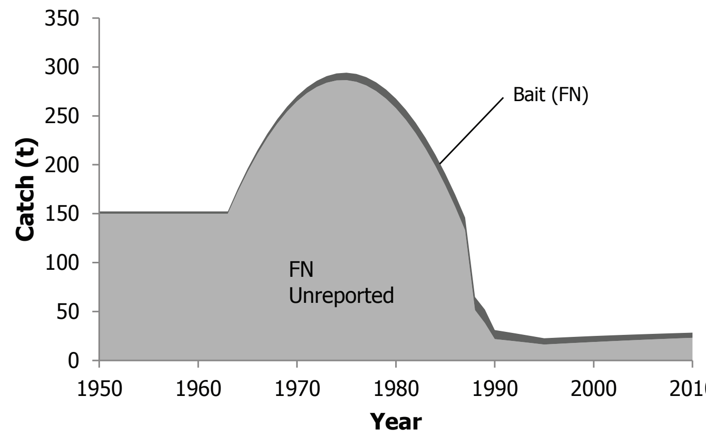

Figure 5. Artisanal catch and baitfish for Fernando de Noronha (FN).

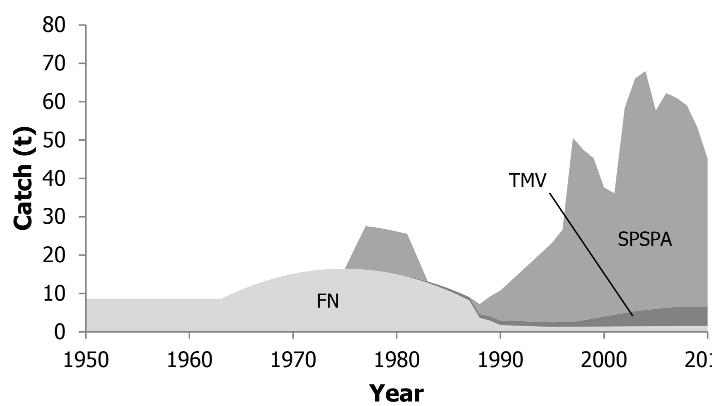

Figure 6. Discards for of industrial and artisanal catch for SPSPA, TMV, and FN.

Reconstructed total catch by sector

Altogether, removals increased from 209 t in 1950 to 492 t in 1977, declined to a minimum of 165 t in 1990, and then peaked twice in 1997 and 2004 with 555 t and 770 t of catch, respectively (Figure 8). Total removals decreased by 2010 to 550 t, most of which was caught in the waters of SPSPA.

Reconstructed total catch by species

Catch was composed of a total of 71 species, most of them varying from island to island due to their unique ecosystems. Barracuda, sardines, and tunas were common in the early years of the fisheries, which in the later years the most common species were flying fish, wahoo, and yellowfin tuna (Figure 9).

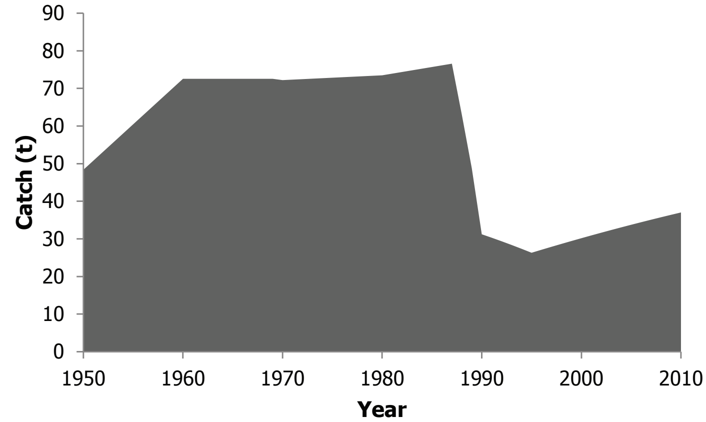

Figure 7. Subsistence catch for Fernando de Noronha (FN).

Discussion

Total catches for the industrial fleets operating in Trindade and Martim Vaz Archipelago and Saint Peter and Saint Paul Archipelago began in 1976 and by the 2000s, were averaging 580 t·year⁻¹. Currently there are no quotas for optimal catch or measurements for the health of fishery, although some inferences can be made. In the waters of TMV, five shark species are threatened, two of which, the blue shark and nurse shark are targeted by the Espírito Santo fleet in the TMV complex (Pinheiro *et al.* 2010). Likewise, in St Peter and St Paul Archipelago, historical records point that shark populations, notably the reef sharks are already extinct (Luiz and Edwards 2011). Indeed, due to SPSPA's important role in the lifecycle of many species, extra caution must be taken while fishing, especially for species of silky shark for whom the Archipelago is a place to give birth (Oliveira *et al.* 1997). The targeting of yellowfin tuna also must be careful, as this is the primary target of fishing activities in SPSPSA, yet nearly all catch in the archipelago was shown to be immature (Vaske Jr. *et al.* 2006). The 'cascade effect,' previously mentioned, forewarns that the extinction of predatory species can cascade onto other species of lower trophic levels. As seen by the rapid decline of the yellowfin grouper in TMV waters, extinction or overexploitation can be very swift in such remote island ecosystems. As stocks fail closer to the mainland, and effort is increasingly exerted on new unexploited grounds, fishing pressure is only expected to increase.

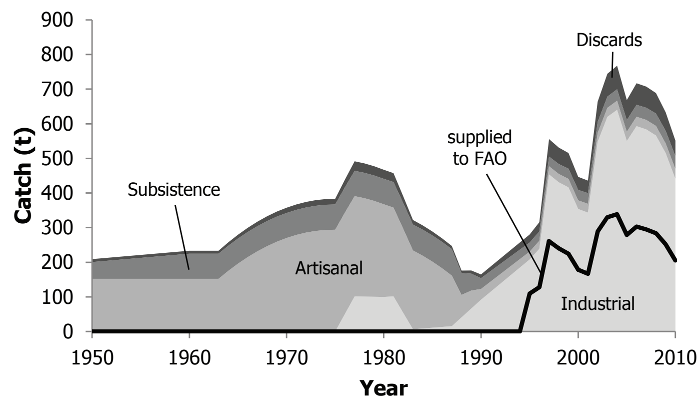

Figure 8. Catch by sector for SPSPA, TMV, and FN.

Fernando de Noronha is unique from the other islands in that fishing effort by the artisanal fleet has actually declined over time. Catches for Fernando de Noronha were 209 t in 1950, peaking in 1975 with 383 t, and stabilizing at 59 t·year⁻¹ as tourism expanded in the 1990s and 2000s. This is especially peculiar given that the resident population over doubled as catches declines, and this does not even consider the waves of tourists that stay on the island. The decline in catches was largely a result of the artisanal fisher labor force being absorbed by tourism. Additionally, as the number of tourists expanded and demand for fish increased, the seasonal variation in the domestic supply of fish "forced owners of restaurants and hotels to import fish from Recife and Natal" (IOPE 2010). A striking example of this is octopus, of which only 11% of what is served in local restaurants and hotels in in the mid-2000s was from the island itself (Leite *et al.* 2008), even though they are extremely abundant around the islands (Barros 1963). While tourism has been lucrative in some ways, it has also had several negative repercussions for the residents of the islands. One example is the establishment of National Park, which caused residents to be unable to fish from shore. Thus, along with the decline in artisanal fisheries, this caused the consumption of fish by local residents to decrease substantially, as seen by the fact that approximately 30% of the residents have developed a metabolic syndrome due to poor diet and lack of exercise (Marinho 2014). Thus, the result of modernization has had both pros and cons for the residents of Fernando de Noronha (Souza and Vieira Filho 2011).

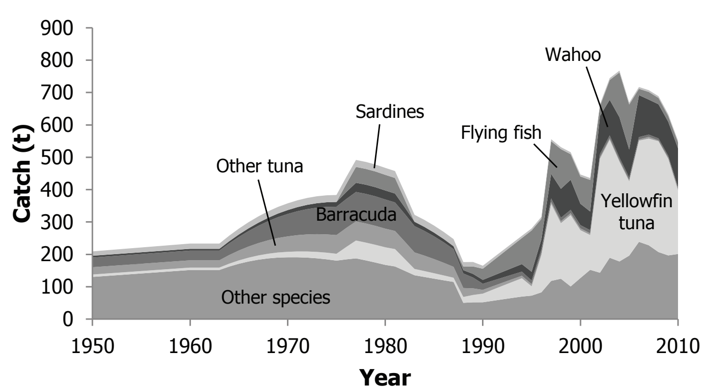

Figure 9. Catch by taxon for SPSPA, TMV, and FN.

The catches reconstructed in the present research are not all inclusive, as both national and foreign pelagic longline fleets operate in waters of all three islands, exerting substantial effort (Mazzoleni and Schwingel 2010). Furthermore, due to the limited to non-existent ability of Brazil to enforce its jurisdiction over its entire EEZ (Kalikoski and Vasconcellos 2006), particularly in SPSPA and TMV due to their distance from the mainland, illegal fishing activities are rampant, especially by foreign distant water fleets targeting pelagic species the 1990s; e.g., "vessels from Japan, Korea, Spain, and Taiwan frequently called Brazilian ports in the northeastern region for services and it is suspected that such vessels were targeting tuna in Brazilian waters (Weidner and Hall 1993). The same pattern is seen in TMV, where all domestic pelagic longline boat captains interviewed in (Pinheiro *et al.* 2010) "reported the presence of large Asian vessels operating clandestinely in Brazilian water".

It is possible that the oceanic islands of Brazil are out on a limb; on the edges of what is considered to be 'Brazil', they are isolated and lack the surveillance necessary to keep foreign presence at bay. This is compounded by the inherently fragile ecosystems of oceanic islands in the Atlantic, which puts them more at risk to overfishing than other regions of the world.

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Appendix Table A1. Total reported and reconstructed catch by sector for the oceanic islands of Brazil.

Year	Reported landings	Total reconstructed catch	Industrial	Artisanal	Subsistence	Discards
1950	-	209	-	152	48	9
1951	-	212	-	152	51	9
1952	-	214	-	152	53	9
1953	-	216	-	152	56	9
1954	-	219	-	152	58	9
1955	-	221	-	152	60	9
1956	-	224	-	152	63	9
1957	-	226	-	152	65	9
1958	-	229	-	152	68	9
1959	-	231	-	152	70	9
1960	-	233	-	152	73	9
1961	-	233	-	152	73	9
1962	-	233	-	152	73	9
1963	-	233	-	152	73	9
1964	-	258	-	175	73	10
1965	-	280	-	196	73	11
1966	-	300	-	215	73	12
1967	-	317	-	232	73	13
1968	-	333	-	247	73	14
1969	-	347	-	259	73	15
1970	-	358	-	270	72	15
1971	-	367	-	279	72	16
1972	-	374	-	286	72	16
1973	-	379	-	291	73	16
1974	-	383	-	293	73	16
1975	-	383	-	294	73	16
1976	-	439	51	293	73	22
1977	-	492	102	290	73	28
1978	-	486	101	284	73	27
1979	-	478	100	277	73	27
1980	-	467	100	268	73	26
1981	-	457	102	256	74	26
1982	-	391	54	243	74	19
1983	-	322	7	228	75	13
1984	-	307	9	210	75	12
1985	-	289	11	191	76	11
1986	-	269	13	169	76	10
1987	-	247	16	146	77	9
1988	-	176	41	65	63	7
1989	-	176	66	52	49	9
1990	-	165	92	31	31	11
1991	-	188	115	29	30	13
1992	-	211	138	28	29	16
1993	-	234	162	26	28	18
1994	-	257	185	24	27	21
1995	110	280	208	23	26	23
1996	128	316	239	23	27	27
1997	261	556	454	24	28	51
1998	240	531	431	24	29	47
1999	224	516	416	25	29	45
2000	178	447	354	25	30	38
2001	167	436	344	25	31	36
2002	290	664	548	26	32	58
2003	330	745	620	26	32	66
2004	339	768	640	26	33	68
2005	279	669	550	27	34	58
2006	303	717	593	27	34	62
2007	295	707	584	27	35	61
2008	284	689	566	28	36	59
2009	252	633	515	28	36	53
2010	205	551	441	28	37	45

Appendix Table A2. Data reported to the Brazilian state of Rio Grande do Norte for catches taken within the waters of Saint Peter and Saint Paul Archipelago (SPSPA).

Species name	*Thunnus albacares*	*Thunnus alalunga*	*Thunnus obesus*	*Istiophorus albicans*	*Tetrapturus albidus*	*Makaira nigricans*	*Xiphias gladius*	*Alopias superciliosus*	*Sphyrna lewini*	*Carcharhinus falciformis*	*Prionace glauca*
Portuguese c. name	**Albacora-laje**	**Albacora-branca**	**Albacora-bandolim**	**Agulhão-vela**	**Agulhão-branco**	**Agulhão-negro**	**Meka; Espadarte**	**Cação-raposa**	**Cação-panam**	**Cação-branco***	**Cação-azul**
Year											
1995	15.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	8.1	0.1
1996	69.2	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.1	4.1	0.0
1997	145.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0
1998	103.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0
1999	134.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0
2000	88.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2	0.0
2001	62.7	0.0	0.0	0.1	0.1	1.4	5.0	0.0	3.7	9.8	7.7
2002	215.7	0.1	0.0	0.2	0.0	0.6	3.8	0.1	0.9	5.0	0.9
2003	223.2	0.0	0.0	0.1	0.0	0.4	2.5	0.1	2.1	9.8	5.6
2004	187.5	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.7	4.2	0.7
2005	137.8	0.1	0.1	0.1	0.2	0.2	3.9	0.2	2.0	7.8	3.1
2006	189.7	0.0	0.0	0.2	0.0	0.6	4.5	0.3	1.0	9.1	2.9
2007	199.9	0.0	1.5	0.0	0.0	0.0	1.9	0.0	0.6	6.0	1.6
2008	207.6	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.8	1.8	1.2
2009	179.5	1.2	0.0	0.1	0.0	0.0	4.1	0.0	0.5	3.1	0.9
2010	115.3	1.2	1.0	0.0	0.0	0.1	0.2	0.0	1.1	1.2	0.6

* In original data source, stated that this refers to catch of 'cação tuninha' e 'cação lombo preto'. We assumed these catches mostly referred to the former (silky shark), a very common taxon in this region

Appendix Table A2 continued. Data reported to the Brazilian state of Rio Grande do Norte for catches taken within the waters of Saint Peter and Saint Paul Archipelago (SPSPA).

Species name	*Isurus oxyrinchus*	*Galeocerdo cuvier*	*Coryphaena hippurus*	*Acanthocybium solandri*	*Cheilopogon cyanopterus*	Marine fishes not identified	Number of trips
Portuguese c. name	**Cação-cavala**	**Cação-jaguara**	**Dourado**	**Cavala**	**Voador**	**Outros**	
Year							
1995	0.1	0.0	0.2	13.5	64.5	7.4	
1996	0.0	0.0	0.2	13.7	25.8	14.6	
1997	0.0	0.0	1.8	36.3	43.7	19.5	
1998	0.0	0.0	2.0	45.2	56.3	26.8	
1999	0.0	0.0	0.5	43.9	30.7	9.3	
2000	0.0	0.0	1.0	32.1	34.2	7.7	
2001	0.7	0.0	0.4	29.0	42.3	3.9	
2002	0.1	0.0	0.3	49.7	5.5	6.7	
2003	0.4	0.1	1.1	49.4	20.4	14.2	
2004	0.7	0.0	0.4	60.6	60.4	22.8	
2005	0.4	0.1	2.1	42.3	62.3	16.6	
2006	0.2	0.0	3.4	60.5	1.2	29.6	37
2007	0.3	0.0	3.5	48.2	3.1	28.5	36
2008	0.3	0.0	1.6	44.7	1.1	22.7	38
2009	0.3	0.0	2.0	45.0	0.5	14.7	35
2010	0.3	0.0	4.0	57.3	0.7	22.5	32

* In original data source, stated that this refers to catch of 'cação tuninha' e 'cação lombo preto'. We assumed these catches mostly referred to the former (silky shark), a very common taxon in this region

Appendix Table A3. Total reconstructed catch by taxon for the oceanic islands of Brazil.

Year	*Thunnus albacares*	Other tunas	Barracuda	*Acanthocybium solandri*	*Cheilopogon cyanopterus*	Clupeidae	Other species
1950	8	23	30	5	0	13	130
1951	8	23	30	5	0	14	132
1952	8	23	30	5	0	14	135
1953	8	23	30	5	0	14	137
1954	8	23	30	5	0	15	139
1955	8	23	30	5	0	15	141
1956	8	23	30	5	0	15	143
1957	8	23	30	5	0	15	145
1958	8	23	30	5	0	16	147
1959	8	23	30	5	0	16	150
1960	8	23	30	5	0	16	152
1961	8	23	30	5	0	16	152
1962	8	23	30	5	0	16	152
1963	8	23	30	5	0	16	152
1964	9	27	36	6	0	17	162
1965	10	31	42	7	0	18	171
1966	12	34	48	8	0	19	178
1967	13	38	54	9	0	20	184
1968	15	42	59	10	0	20	187
1969	16	45	64	11	0	21	190
1970	17	48	69	12	0	21	191
1971	18	50	74	13	0	21	191
1972	19	53	78	13	0	21	190
1973	20	55	82	14	0	21	188
1974	21	56	85	14	0	22	185
1975	21	58	88	15	0	22	181
1976	38	59	90	22	25	22	184
1977	55	59	91	28	49	22	188
1978	55	59	91	28	49	22	181
1979	55	59	91	28	49	22	175
1980	54	58	90	28	48	21	168
1981	54	56	88	27	48	21	163
1982	37	54	85	20	24	21	149
1983	19	51	81	13	0	22	135
1984	18	48	76	12	0	22	130
1985	17	44	70	11	0	22	125
1986	15	39	63	10	0	22	120
1987	13	34	55	9	0	22	115
1988	18	28	45	10	11	13	50
1989	23	20	33	11	23	14	52
1990	27	12	19	12	34	9	52
1991	34	11	17	15	46	9	56
1992	42	10	16	18	57	8	61
1993	49	9	14	20	69	8	65
1994	57	8	13	23	80	7	70
1995	29	7	11	27	128	6	72
1996	116	7	11	30	64	6	83
1997	238	6	11	75	101	6	118
1998	172	6	11	89	123	6	125
1999	221	6	10	93	79	6	101
2000	148	5	10	66	84	6	127
2001	108	5	10	58	97	6	152
2002	352	5	9	118	30	6	143
2003	365	5	9	110	61	6	189
2004	308	4	8	125	138	6	178
2005	230	4	8	86	139	6	196
2006	313	3	7	130	19	6	239
2007	330	5	7	108	24	6	228
2008	343	2	6	105	20	5	207
2009	298	4	6	105	18	5	197
2010	197	5	5	120	18	5	201