Fisheries Centre

The University of British Columbia

Working Paper Series

Working Paper #2015 - 96

Updated reconstruction of Bermuda's marine fisheries catches, 1950-2010

Esther Divovich, Lydia C.L. Teh, Kyrstn Zylich
and Dirk Zeller

Year: 2015

Email: e.divovich@fisheries.ubc.ca

UPDATED RECONSTRUCTION OF BERMUDA'S MARINE FISHERIES CATCHES, 1950-2010

Esther Divovich, Lydia C.L. Teh, Kyrstn Zylich and Dirk Zeller

Sea Around Us, Fisheries Centre, University of British Columbia,
2202 Main Mall, Vancouver,V6T 1Z4, Canada
e.divovich@fisheries.ubc.ca

ABSTRACT

We reconstruct marine fisheries catches for Bermuda from 1950-2010 to account for catches that are omitted from official statistics. Annual national landings statistics account for catches from Bermuda's small-scale commercial fisheries, whilst catches from recreational fishing, including fish taken for food (essentially subsistence catch), are not enumerated. This reconstruction thus focuses on quantifying catches that are taken domestically for subsistence and recreational purposes. Reconstructed total catch in Bermuda was 53,400 t from 1950-2010, suggesting that actual catches were nearly twice the 27,500 t of domestic catches reported in national landings statistics for the same time period. Although fisheries play a small part in Bermuda's economy, the magnitude of recreational and subsistence fishing belies its social and cultural significance. Steps should thus be taken to ensure the future sustainability of local fisheries, including comprehensive coverage of fisheries statistics that are essential for informed decision-making.

INTRODUCTION

Bermuda is an archipelago of seven main islands and numerous smaller islands located in the central North Atlantic Ocean (Figure 1). This British Overseas Territory has one of the world's highest per capita gross domestic product (GDP) and an economy that is centered on financial services and tourism. Fishing is a minor economic activity, accounting for <1% of total GDP in 2012 (Dept. of Statistics 2013). In comparison, international business activity contributed almost 25% to national GDP (Dept. of Statistics 2013). Reflecting this is the small number of full-time licensed fishers, which in 2010 included approximately 80 vessels and 115-120 individuals (Department of Environmental Protection, DEP), along with an additional 180 or so part-time fishers.[1] These numbers have remained remarkably consistent over time since the late 1940s (Mowbray 1949). However, local fish catch is not sufficient to support demand from both residents and tourists to the island, and Bermuda imports about two-thirds of its seafood (Dewailly *et al.* 2012).

Bermuda's fisheries are small-scale and multi-species in nature. Historically, fishers used pots to target groupers and other 'white meat' reef species. Up until the 1960s, the commercial fishery was relatively undeveloped and largely self-regulated (Barrett 1991). There was no formal market for fish - fishers sold their catch to customers at the landing site or directly to hotels and guest houses (Mowbray 1949). During the 1960s, the government increased efforts to modernize and expand the fishing sector, culminating in the fisheries Act of 1972 (Smith-Vaniz *et al.* 1999). The rise of the global economy and tourism created a market for local fish, which prompted the entry of bigger boats and increased catch, which ultimately contributed to the rapid decline of key reef species such as groupers during the late 1970s (Smith-Vaniz *et al.* 1999). In response to

[1] Government of Bermuda. A Strategy for the Sustainable Use of Bermuda's Living Marine Resources. Available at: http://www.caribbeanelections.com/eDocs/strategy/bm_strategy/bm_Fisheries_Strategy.pdf. [Accessed 20 September 2014].

this decline, the government implemented regulations that restricted the use of pots, and the number of fishing licenses was capped in 1982. However, even after fish pots were banned in 1990, some species of reef fish never recovered fully (Burnett-Herkes and Barnes 1996).

Prior to the 1970s, pelagic species were not commonly consumed due to local fears of scombroid poisoning (Joanna Pitt, pers. comm.). However, a shift in the marketing of pelagics came with the availability of bulk ice in the 1980s. Since fish pots were banned in 1990, pelagics have become more important in the commercial fishery and now comprise more than half of total landings, while reef fish landings have declined to about half their average levels of the mid-1970s and 1980s. Yellowfin tuna (*Thunnus albacares*) and wahoo (*Acanthocybium solandri*) make up approximately 83% of total pelagic landings. Following the 1990 ban on fish pots, a small, limited entry commercial fishery for spiny lobster (*Panulirus argus*) was re-established in 1996 and has since been relatively stable (Trott *et al.* 2002).

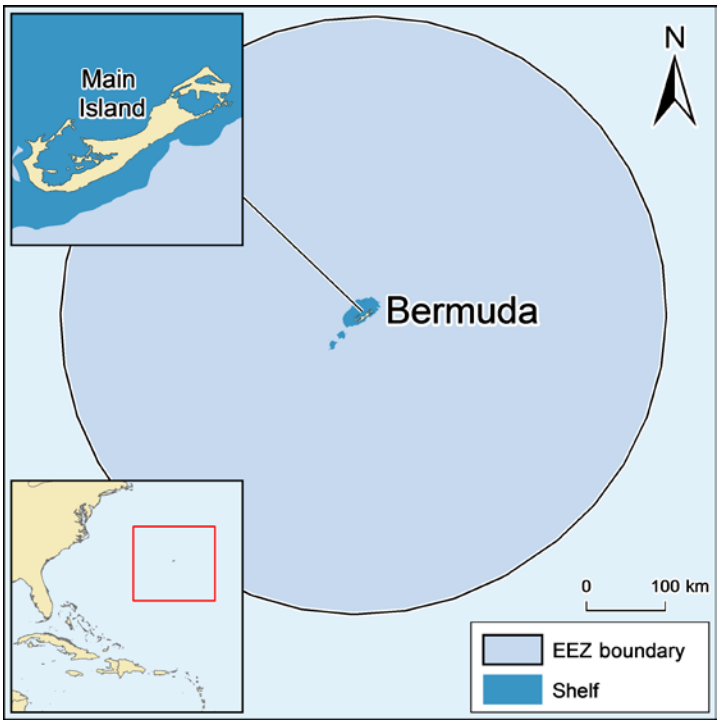

Figure 1. Exclusive Economic Zone (EEZ) and shelf area (to 200 m depth) for Bermuda.

In addition, recreational fishing is widespread in Bermuda as a leisure activity and also for supplementing local diets. Licenses are issued to recreational lobster divers, who are required to report their catches (Trott *et al.* 2002), and licensing has been required for recreational spear fishers since 2011. However, the quantity of fish taken by local recreational and subsistence fishers and the impact of this activity on domestic fish stocks is not fully known, despite initial steps to fill this knowledge gap having been taken (DEP 2011). Incomplete fisheries statistics hamper well-informed management of Bermuda's fisheries, particularly in the inshore environment where tourism and local fisheries can potentially overlap. The objective of this report is therefore to reconstruct Bermuda's fish catch from 1950-2010, with a focus on the undocumented subsistence and recreational sectors.

Background

Bermuda lies on top of a seamount and has a total coral reef area of about 1,000 km^2 (Burnett-Herkes and Barnes 1996). Most fishing occurs in the relatively shallow waters around the island and two outlying banks, and commercial fishing is artisanal (i.e. small-scale) in nature. In the past, fishing effort was directed mainly at reef species, although pelagic species now comprise more than half of commercial landings. There is a significant non-commercial, recreational fishery that is not monitored. Recreational fishers fish mainly with handlines, although trolling rods, spears, lobster noose, and cast nets are also used. Frequently caught species include Lane snappers (*Lutjanus synagris*), carangids, and hogfish (*Lachnolaimus maximus*), and total catch by recreational fishers is estimated to be close to two-thirds of total commercial landings by weight (DEP 2011).

Fisheries management

Management of Bermuda's marine resources and fisheries falls under the responsibility of the Marine Resources and Fisheries Enforcement Sections of the Department of Environmental Protection. These sections conduct fisheries monitoring and research and enforce fisheries regulations respectively. Bermuda has a long history of fisheries management dating back to the 1600s, which included gear, species, temporal, and spatial restrictions (Luckhurst *et al.* 2003). In 1972, parliament passed the Fisheries Act which made provisions for controlling foreign fishing and protecting selected species within Bermuda's exclusive fishing zone (Burnett-Herkes and Barnes 1996). This series of regulations included a requirement for all commercial fishers to be licensed and to submit statistics on fish landings, fishing effort, and fishing location. During this period, entry to the pot fishery was restricted to licensed commercial fishers only (Barrett 1991). Further regulations to control entry and effort in the pot fishery ensued in the 1980s as fishing reached unsustainable levels, culminating in the 1990 ban on fish pots. An unintended side effect of these policies was the creation of conflict between full-time and part-time fishers, as well as between fishers and the government. Past fisheries interventions have thus tended to be reactionary rather than precautionary in nature.

However, some important precautionary management measures include areas closed to fishing either on a permanent basis or on a seasonal basis to protect spawning aggregations, and size and bag limits for certain species. Some fisheries management measures also address recreational fishing, including licensing of lobster divers and spear fishers (plus two per species per day bag limits), and a recreational bag limit of 30 fish per day for Lane snapper.

The commercial fishing sector is presently separated into two categories, full-time and part-time fishers, where full-time status is defined as being a minimum of 800 hours at sea per year. Only full-time fishers are eligible for concessions (subsidies) such as tax rebates on fuel and imported fishing gear. Participation in specialized fisheries is also restricted to full-time fishers only. These specialized fisheries include the spiny lobster (*P. argus*) and Guinea chick lobster (*Panulirus guttatus*) trap fisheries, as well as offshore, and deep-water fisheries, which are managed on a limited entry basis. Scientific knowledge about the status of fish stocks in Bermuda is still limited; however, improving management of key fish stocks, along with that of commercial and non-commercial fisheries, including the collection of catch, effort, and biological data, is a key target in Bermuda's roadmap for marine resource management in the next decade.[1]

Recreational fishing

Bermuda has a long history of recreational fishing which dates back to the 1930s (Smith 1989). Nowadays, recreational fishing remains a popular social activity and also a source of supplemental food for local residents (in essence a modern form of 'subsistence' fishing). Recreational fish catch is not reported in national fisheries statistics and the characteristics of this sector and its impact on the marine environment are still unclear. In 2011, an island-wide survey was undertaken by Bermuda's Department of Environmental Protection's marine resource section to collect data on recreational catch composition and quantity, gear use, fishing platform, and location (DEP 2011). A prior survey conducted in 2008 (Sarkis et al. 2010) estimated that approximately 16,000 local residents of Bermuda participated in recreational fishing, with the majority (70%) fishing from the shoreline while the rest fished from boats. Total annual landings from the recreational sector were estimated at 287 t (DEP 2011), or around 70% of reported commercial landings in the late 2000s.

Recreational fishers are motivated by several factors, including relaxation, spending time with family, as well as the tradition, sport, and subsistence aspects of fishing (DEP 2011). According to the survey, fishing for food was cited as a motivation by 52% of respondents (DEP 2011). We identified this subset of fishers who fish for food as 'subsistence' fishers, which we define as those who fish for personal or family consumption as the primary driver. As such, their catch is allocated to the subsistence sector in this reconstruction. Most recreational fishers fished using hook and line, and targeted fish such as snappers, jacks, wahoo and tunas. The survey specifically omitted recreational fishing from charter fishing boats since they are managed as part of Bermuda's commercial sector, hence their catches are reported as part of commercial landings (Barrett 1991; DEP 2011).

Charter fishing

Bermuda's sport fishing sector is a major attraction for international fishing enthusiasts, and thus provides high economic benefits. The peak fishing season is usually from May to October, but sport fishing trips occur throughout the year. There are three major billfish tournaments, plus two smaller events that focus on other species.[2] There are also other tournaments that are only open to locals and do not include billfish (Joanna Pitt, pers. comm.). One tournament season was able to generate an estimated USD 3 million in revenue from visiting participants.[3] The Bermuda Fishing Guide's charter directory listed 25 companies that offered charter fishing trips to various locations. The majority of charter fishing trips take place at offshore locations and target blue marlin (*Makaira nigricans*), tunas, wahoo, and dolphinfish (*Coryphaena hippurus*). Three charter fishing companies offered fishing closer to the island, targeting bonefish (*Albula vulpes*), hogfish (*Lachnolaimus maximus*), and other inshore species. Catch and release is practiced during fishing tournaments, and one charter fishing company specified support for tag and release fishing.

Local charter boats have been considered part of the 'commercial' fleet since 1975 because the retained catch is sold in order to keep the charter fee competitive given the high cost of fuel in Bermuda and because many charter vessels fish commercially when they don't have charter bookings (Joanna Pitt, pers. comm.). Prior to 1975, charter fishing was more recreational in nature as the pelagic fish that were caught were not usually sold.

[2] Sport Fishing in Bermuda. Available at: http://www.gotobermuda.com/sportfishing/ [Accessed 17 February 2015].
[3] The Billfish Foundation. Potential Impacts of Bermuda's Marine Reserve on Sportfishing Tourism. Available at: www.billfish.org [Accessed 24 September 2014].

METHODS

Reported landings

Bermuda's national fisheries statistical program has been in operation since 1975 and relies on commercial fishers to self-reported catch and effort data (Luckhurst and Ward 1996). The reported landings are commercial in nature, including charter fishing operations since 1975, and hence have been appropriately labelled under the 'artisanal' sector in the present reconstruction.

Prior to this, the FAO had reported annual marine fisheries landings from 1950-1974 on behalf of Bermuda. These landing were inconsistent with local records, an issue addressed Luckhurst *et al.* (2003), who reconstructed early FAO landings to provide a more accurate representation of total catch. Here, we also use national data to adjust and disaggregate FAO data from 1950 – 1974.

FAO landings for Bermuda were reported in only two groups, 'marine fishes nei' and 'Caribbean spiny lobster', with the majority of landed catch being in the former group. In the absence of any formal data collection during these years, it must be assumed that landings were initially estimated based on economic data, and later (in the 1960s) were also informed by the number of registered vessels and the effort data that was recorded.

We assumed the magnitude of catch in the FAO data labelled 'marine fishes nei,' was representative of catch from 1950-1974 and used the 1975 species composition (excluding Caribbean spiny lobster) from national data to disaggregate the catch taxonomically. For the Caribbean spiny lobster, local sources indicate a different magnitude of catch than commercial landings, so we have used local sources as a baseline for reported catch. Specifically, a local colonial report from 1946 reports a catch of 27,900 spiny lobsters (Joanna Pitt, pers. comm.), while the national data for 1975 reports 29,408. Assuming a constant per unit weight, this would yield a catch of approximately 36 t of lobster in 1946. We interpolated between this value to 38 t in 1975, which yielded estimates of artisanal catch of spiny lobster from 1950-1974.

Unreported catch

Fishers' intentional or unintentional misreporting of statistics and the lack of a validation process to monitor self-reporting can distort national fisheries statistics. This can be seen in the recreational fishery of Bermuda, where local catches generally go unreported. Recreational fishing in Bermuda has a strong subsistence component, therefore in this reconstruction we consider recreational fishing to have two subcomponents - 'leisure' and 'subsistence', whereby 'leisure' fishers are those that fish for relaxation, sport, or other social reasons, and 'subsistence' fishers are those that fish primarily to supplement their diet. In the following sections, we estimated catch from both the unreported subsistence sector and unreported recreational 'leisure' catch from 1950-2010.

Subsistence catch

Up until the late 1960s, the market for fish was weak given low wages and limited job opportunities (Barrett 1991). People thus worked a variety of jobs to earn a livelihood and fished on a part-time subsistence basis when they required fish to eat. We assumed that from 1950-1970, subsistence fishing in Bermuda was primarily carried out by the low income sectors of the population.

In calculating a per capita rate of consumption, we had to consider the fact that not all fish consumed was local. In the post-war era, imported canned fish and even imported fresh fish also featured in Bermudian diets, as evidenced by the import taxes on these items reported in the 1948 Blue Book of Colonial Government statistics. Based on conversations with older Bermudians, canned tuna and salmon were affordable on a weekly and fortnightly basis, respectively, for those in lower income brackets, although fresh imported fish would obviously be a luxury item and was only imported in small quantities (Joanna Pitt, pers. comm.). Furthermore, it is reasonable to believe that one weekly serving of fish in Bermuda would likely have come from imported dried salted cod, a cultural staple since the 1600s and still relatively inexpensive at the time (Joanna Pitt, pers. comm.).

The rate of fish consumption is high in the Caribbean, with rates up to 77 $kg \cdot person^{-1} \cdot year^{-1}$ in places like Antigua and Barbuda, [4] while the Caribbean wide consumption rate is 30 $kg \cdot person^{-1} \cdot year^{-1}$. In order to account for the consumption of canned and salted fish products in the present analysis, we estimated that 26 $kg \cdot person^{-1} \cdot year^{-1}$ was a representative consumption rate for most of the time period from 1960 – 2010. Since the consumption of fish was likely higher in the past (Joanna Pitt, pers. comm.), we assumed that typical consumption of local fish was 30 kg per person per year in 1950, interpolated to 26 kg per person per year in 1960, thereafter remaining at 26 kg from 1961 – 2010.

To calculate the low income population from 1950 – 1970, we used data on employment in Bermuda for 1950, 1960 and 1970 (Bermuda Government 1973b). Of the five employment categories cited, the top three categories are described as "white collar" while the bottom two could be considered as low income, with the roughly 100-132 self-described full-time fishers that appear in the censuses being included in one of these low income categories. To estimate the low income population (that could be presumed to be active subsistence fishers) we obtained the number of people holding jobs in the lowest two categories, subtracted those who declared themselves as full-time fishers, added those reportedly seeking work, and assigned the population of children aged 3-14, non-working women, and men who declared themselves out of the workforce (disabled, retired, or not needing to work) proportionally between low and high income job holders. Using this approach, low wage earners and their dependents numbered 16,947 in 1950, 16,366 in 1960 and 16,572 in 1970, which equates to 45%, 38% and 32% of the total population, respectively. Despite the overall increase in population, these numbers are affected by increases in the availability of higher income jobs, women moving into the workforce and therefore not being counted as dependents, and changing birth rates, which are somewhat counterbalanced by fewer 14 and 15 year olds working as time goes on. These estimates of the low income population in 1950, 1960 and 1970 were used as anchor points, and data gaps between these points were filled by linear interpolation. Total subsistence catch from 1950 to 1970 was then calculated as the low income population multiplied by the annual *per capita* subsistence fish consumption rate. From 1971 to 2010, a portion of total 'recreational' catch (which includes both leisure and subsistence components) was allocated to the subsistence sector, as is described in the section on recreational catch concerning leisure catch of the local population.

[4] Caribbean 360. Caribbean per capita fish consumption results in high imports. Available at: http://www.caribbean360.com/news/caribbean-per-capita-fish-consumption-results-in-high-imports [Accessed 24 September 2014].

Recreational catch

Unreported recreational catch in Bermuda is composed of several different subsets of the population and aspects in the fishery, notably, (i) charter catch from 1950 – 1974 (as well as sports catch by locals and military personnel for the same time period), (ii) leisure catch by the local population from 1971-2010, and (iii) catch by foreign visitors who bring their own private vessels to fish in billfish tournaments.

(i) Charter boat catch, 1950-1974

Charter boats, as part of the commercial fleet, have reported their catch along with commercial fishing landings since 1975. However, sport fishing has existed in Bermuda since before WWII (Smith 1989), so there is value in accounting for the charter sector prior to 1975, which we have done here.

From 1950 to 1970, we considered estimated local 'recreational' catch to come mostly from subsistence fishing (Figure 2). Nonetheless, some fish were caught recreationally by locals and also by personnel stationed at the military bases in the form of sports fishing. It is reasonable to assume that the fishing patterns for this group mirror those for the charter sector of the era (Joanna Pitt, pers. comm.), and hence we have estimated this catch alongside charter catch, from 1950-1974.

Since most, albeit not all, charters catered to foreign visitors, we generated a representative time series of charter boat passengers from 1950 to 1974 using data on visitors to Bermuda. In 1950, there were 60,000 'transient visitors' in Bermuda (Mowbray 1949) but, by the late-1970s (and early 1980s), between 330,000 and 430,000 visitors arrived annually by air alone (Bermuda Government 1973a). In recent years, an estimated 10,000 US visitors, roughly 4% of total tourist arrivals, participated in fishing during their stay in Bermuda (Cox 2013), and US visitors made up about 72% of total tourist arrivals to Bermuda in 2010 (Dept. of Statistics 2013). Indeed, based on surveys done in 2008, 4-5% of tourists reported fishing during their visit (Sarkis *et al.* 2010). This relatively high proportion of tourists who report engaging in fishing can be linked to the cost of visiting Bermuda in recent years, with the market therefore being skewed towards those who can afford expensive activities such as charter fishing (Joanna Pitt, pers. comm.). Although vacationing in Bermuda was more economically accessible during the tourist boom of the 1980s, Bermuda was considered more of an elite destination from 1950 through 1970 and so a similar rate of 5% of tourists engaging in fishing could be considered representative of this time period as well (Joanna Pitt, pers. comm.).

To model the time series of total tourists visiting Bermuda, we used the anchor points of 60,000 visitors in 1950 and 380,000 visitors in 1980, and for the years in between assumed a growth trend similar to that presented in (Luckhurst *et al.* 2003). Specifically, we assumed a slight growth in tourism from 1950 to 1960 (interpolated from 60,000 visitors to 90,000 visitors) and then a steep rise from 1960 onward to the estimated 380,000 visitors in 1980. Furthermore, to obtain a time series of the number of visitors engaged in fishing, we applied a variable rate of engagement in fishing to the population of total visitors, interpolated between 4% of visitors engaging in fishing in 1950 to 1% in 1980. We also added several boats of local fishers and military personnel to represent sports fishing from 1950 – 1974. For 1950, we assumed this equated to 100 fishers, increased incrementally to 1960 and 1970 based on the percentage growth of the top two 'white collar' occupations with respect to the total population, i.e., to an effort equivalent of approximately 135 fishers in 1960 and 154 in 1970, thereafter remaining constant at 154 until 1974.

Based on photos, which show a typical catch of about a dozen fish, the catch at that time focused on wahoo, yellowfin tuna and blackfin tuna, plus marlin to a rather lesser degree than today, as well as amberjack, Almaco jack, and barracuda (Joanna Pitt, pers. comm.). Virtually all of the fish caught would have been retained during this early time period; however, the catches on typical charters are likely slightly lower than those reported in Barrett (1991) because the boats were generally smaller (80% of registered fishing vessels in 1963 were under 30' in length) and did not go out as far. In addition, the limited consumption of pelagic fish in those days provided less incentive to catch and retain as many fish as is presently the norm (Joanna Pitt, pers. comm.).
Although Barrett (1991) described average charter vessels catches comprising between 8 - 10 tuna and 8 - 15 wahoo, we used these historical photographs as guidance to estimate catch per fisher during the 1950s and 1960. For this early time period, given that smaller boats would have taken fewer passengers, we assumed each passenger would catch 2 kg of jacks (Carangidae), 7 kg of tunas (Scombridae) and 7 kg of wahoo (i.e., one quarter of a 'typical' charter boat catch). In addition, perhaps 40 small sharks (at 20 kg each) and 15 marlin (at 200 kg each – anything larger would likely have been released because it would be too hard to get into the boat) might be caught across the whole charter fleet. This resulted in an individual annual catch rate of 17.6 $kg \cdot person^{-1}$. To obtain estimates of charter catch from 1950 – 1974, we multiplied the catch rates for jacks, tunas, and wahoo by the number of fishers (both charter and local/military), plus total catch of sharks and marlin.

(ii) Leisure catch by the local population, 1971-2010
From 1971 onwards, we estimated local leisure catch and local subsistence catch as a whole and then divided catch by sector. Furthermore, we assumed that economic development reduced people's dependence on subsistence fishing and the proportion of people pursuing the 'leisure' aspect of recreational fishing started to increase. Current levels of fishing for subsistence are at 52% (DEP 2011), and we assumed this rate back to 1980 when there was full employment in Bermuda due to the booming tourist trade (Joanna Pitt, pers. comm.). We thus divided total estimates proportionally, assuming the subsistence component decreased from 100% in 1970 to 52% by 1980, thereafter remaining constant until 2010, with the difference being allocated to the 'leisure' (i.e., true recreational fishing) component, yet excluding other recreational activities such as charter operations.

Total recreational catch (including leisure and subsistence) from 1971 onwards was based on the proportion of Bermuda's population that fished for recreation and an annual catch rate. In 2011, approximately 16,000 people, or about 25% of Bermuda's resident population, participated in recreational fishing (both leisure and subsistence). We applied this proportion (25%) to calculate the number of recreational fishers in 2010, and kept this proportion constant all the way back to 1971. Population statistics for Bermuda were obtained for the years 1970, 1980, 1990, 2000 and 2010 (Dept. of Statistics 2013). Gap years were filled by linearly interpolating between anchor points, then annual population was multiplied by the proportion of recreational fishers (25%) to obtain a time series of recreational fishers in Bermuda from 1971-2010.

Recreational fishers were further broken down as either shoreline fishers or boat fishers (Figure 2). During the early time period of this study (1950 – 1970), it would appear that all fishing was done from shore due to a lack of resources for the low income population, however fishing from small sailboats or even rowboats was relatively common, and many people were involved in the boat building trade and capable of building their own small vessel (Joanna Pitt, pers. comm.). Hence, we assumed for the year 1970, 25% of the population fished from boats while the remaining 75% fished from shore. Thereafter, we linearly declined the proportion of people fishing from shore from 75% to 70% by 2010.

Average annual catch of shore fishers was 16.5 kg·person^{-1}·year^{-1} in 2011, while that of boat fishers was 23 kg·person^{-1}·year^{-1}. While this is representative for the year 2010, it is probable that these figures underestimate the true level of fishing in the earlier time period given that fishing for food was likely still a comparatively stronger motivation and exploitation of marine resources in the past was lower, which corresponds to a higher CPUE (catch per unit effort) in the past. Hence, we used our estimate of total subsistence catch from 1970 (389 t) as a baseline, and using the formula below (where the rates of shore and boat fishing in proportion to one another were held constant) were able to estimate the catch rates for each fishing platform in 1970:

$$Population_{boat} * B + Population_{shore} * S = Total\ subsistence\ catch$$

$$Population_{boat} * (\frac{23}{16.5}S) + Population_{shore} * S = 431$$

where $Population_{boat}$ is the number of fishers in 1970 estimated to fish from boats (as stated above, assuming 25% of the population recreationally fished and of that an additional 25% fished from boats) , $Population_{shore}$ is the number of fishers in 1970 estimated to fish from shore, B is the catch rate of boat fishers in 1970, and S is the catch rate of shore fishers for the same year. By solving the above equations for S and B, we obtained catch rates in 1970 approximately 80% greater than in 2010, with average annual catch in 1970 of shore fishers estimated at 29.6 kg·person^{-1}·year^{-1}, while that of boat fishers at 41.3 kg·person^{-1}·year^{-1}. We linearly interpolated catch rates for shore fishers from 29.6 kg·person^{-1}·year^{-1} in 1970 to 16.5 kg·person^{-1}·year^{-1} in 2010 and for boat fishers from 23.0 kg·person^{-1}·year^{-1} in 1970 to 41.3 kg·person^{-1}·year^{-1} by 2010. Total recreational catch was then calculated as the number of shore- and boat-based fishers multiplied by annual shore and boat catch rates. Finally, total recreational catch was allocated to each of the subsistence and leisure subcomponents.

In order to allocate the catch to likely species caught, we estimated catch in these recreational and subsistence fisheries (as well as subsistence catch from 1950-1970) by the likely species of which the catch was composed. In a survey of recreational fishers in 2011, fishes that were most commonly targeted and caught included grey snappers (*Lutjanus griseus*), lane snappers (*Lutjanus synagris*), longfin yellowtail (*Seriola rivoliana*), yellowtail snapper (*Ocyurus chrysurus*), little tunny (*Euthynnus alletteratus*), hogfish (*Lachnolaimus maximus*), grunts (Haemulidae), porgies (Sparidae), triggerfishes (Balistidae), coney (*Cephalopholis fulva*), yellowfin tuna, wahoo, and Creole-fish (*Paranthias furcifer*) (DEP 2011). From 1975 to 2010, the percentage contribution of these species to total recreational catch was matched to Bermuda's national landings statistics, i.e., the artisanal sector, including adjustments for over and under-reporting. Table 1 indicates the recreational taxa and their associated artisanal taxa equivalent.

A small recreational lobster diving fishery has also been active since the 1960s, which was likely composed of about 100 divers each catching about 20 lobsters annually (equivalent to about 3 t·year^{-1}), as opposed to the current time period where approximately 500 divers catch 5 lobsters per diver, or approximately 3.5 t annually (Joanna Pitt, pers. comm.). Thus, we estimated catch of Caribbean spiny lobster increased from 0 t in 1960 to 3 t in 1965, and then to 3.5 t by 1985. Since then, lobster catch has more or less remained constant except for the early 1990s (1991-1995) when the commercial spiny lobster fishery was suspended and recreational lobster catch increased dramatically to between 5 to 7 t annually, most of which was likely subsistence in nature due to the lack of available lobster on the market (Joanna Pitt, pers. comm.). Hence, we assumed that from 1991-1995, an additional 2.5 t of lobster was caught annually for subsistence purposes. For all other years we used the equivalent proportions of recreational to subsistence catch as for the other species calculated above.

(iii) Visiting foreign sports fishing boats

Foreign vessels are not permitted to charter in Bermuda waters. However, a number of elite private vessels visit Bermuda to fish in the three billfish tournaments, and catch from these fishers is not captured by the present reporting system. This is a fairly recent phenomenon, beginning approximately 15 years ago, and numbers have increased to a high of about 25 vessels in the last few years, from about 2 or 3 in the late 1990s (Joanna Pitt, pers. comm.). The start of the Big Game Classic in 2001 and the Billfish Blast in 2005 made it worthwhile for these elite vessels to make the trip from the US east coast, while prior to this there was only one billfish tournament.

Although data on the catch of these vessels is not available, a personal communication with Joanna Pitt, estimates the maximum catch from 22 vessels in 2010 (as there were 22 visiting sport fishing vessels in 2011) at 45 kg of tuna and 40 kg of wahoo per boat per day, with a conservative estimated fishing time of five days per visit / year (outside of tournament fishing). This corresponds to 5 tonnes of tunas and 4.4 tonnes of wahoo landed annually. In order to be more conservative, we applied a 75% retention rate to these catches, indicating a tuna catch of 3.7125 t in 2010 and 3.3 t of wahoo. We interpolated between 2 boats in 1997 to 22 boats in 2010, and applied the constant catch rate to this time series.

RESULTS

Bermuda's reconstructed domestic catch totalled 53,400 t from 1950-2010, which was nearly twice (1.94 times) the landings reported in national landings data for the same period. Unreported catches were from the subsistence and recreational sectors, which totalled 18,100 t (33.9% of total catch) and 7,830 t (14.6% of total catch), respectively, from 1950-2010, while the remaining 51.5% of catch was reported small-scale commercial catch, i.e., artisanal catch (Figure 3a). Reconstructed total catches averaged 830 t·year^{-1} in the 1950s, peaked at 1,350 t in 1972, declined almost 40% in the late 1970s and early 1980s, rebounded to 1160 t·year^{-1} in the late 1980s, and since then have declined to about 710 t·year^{-1} in the 2000s. The taxonomic composition of reconstructed catches shifted from primarily high trophic level reef fishes such as groupers and snappers in the 1950s to being dominated by pelagics in the 1980s (Figure 3b).

DISCUSSION

This reconstruction provides a preliminary estimate of Bermuda's total domestic marine fisheries catches. Tuna catches totalling 48,190 t from 1971-1983 that were caught outside of Bermuda's EEZ were not considered in this reconstruction. From 1950 to 2010, Bermuda's total estimated fish catch of 53,400 t was approximately twice the data reported in national landings statistics.

Bermuda's fisheries have shifted from being dominated by valuable demersal reef species such as groupers and snappers to a more variable mix consisting mainly of pelagics. During the late 1970s and 1980s, uncontrolled fishing pressure driven by local and tourist demand contributed to the rapid decline of groupers in less than 10 years. Fisheries landings statistics reported by the FAO for the period 1950 to 1975 only reported two categories of catch, 'marine fishes nei' and 'spiny lobster', which is not helpful for alerting managers to dynamics at the species level. These early landings were reconstructed to provide an estimate of species composition (Luckhurst *et al.* 2003), which showed the clear trend that later alerted managers to the decline in reef species catches. Although fishing effort restrictions were put in place in response to this situation, they were not enough to help grouper stocks recover. The responsibility is with the government reporting agency in Bermuda (likely the Marine Resources Section of the Department of Environmental Protection) to request from FAO and ensure that all FAO data are

retroactively corrected for the uninformative taxonomic pooling, especially in the earlier years. Bermuda could also request the inclusion of all recreational and subsistence catches in the data they report to FAO, since recreational as well as subsistence catches are included in data reported to FAO by other countries (Zeller *et al.* 2011; Zeller *et al.* 2014), a reasonable and necessary step given increasing predominance of ecosystem-based considerations in fisheries and fisheries management (Pikitch *et al.* 2004). FAO's data mandate explicitly permits countries to retroactively request such data corrections.

Bermuda keeps landing statistics of commercially valuable fish, but overlooks fish that are taken for food and recreation. We estimated that in the 2000s, around 170 t of subsistence catch is taken annually to supplement local diets, which at 24% of total reconstructed catch for the same time period is a significant amount of unreported catch. In addition, recreational catch is up to 160 $t \cdot year^{-1}$ in the 2000s, equivalent to 22% of reconstructed total catch for this decade (Appendix 1). Bermuda has been a destination for sport fishers since the first half of the 20th century (Mowbray 1949; Smith 1989) and continues to attract tourists who generate large financial benefits for the local economy.

As this reconstruction focuses on documenting catches in domestic waters taken by domestic fishers, we omitted foreign fishing (authorized or unauthorized) within Bermudan waters. However, it should be noted that foreign industrial longline vessels that were capable of holding 80 to 120 t of frozen fish and that were fishing under Japanese, Korean, and Taiwanese flags, fished for albacore tuna in Bermuda's offshore waters from the 1960s through the 1980s.[5] This activity was uncontrolled until 1977 when Bermuda declared its 200 mile Exclusive Fishing Zone, after which licensing conditions for foreign vessels were set. In the early 1980s, there were up to 68 registered foreign vessels, which besides tunas, were also very likely taking substantial by-catch of sharks. Foreign longlining in Bermudan waters ended when the government stopped issuing licenses to any foreign vessels in 1994.

CONCLUSION

Fisheries play a small role in Bermuda's economy but have high social and cultural value. As much as 75% of Bermuda's food is imported; therefore, artisanal, subsistence and recreational fisheries are particularly important for supporting local food security and consumption habits. Sustainable fisheries management should therefore be a priority for the government so that society can continue to benefit from this valuable marine resource which also acts as a major attractor for tourism (Sarkis *et al.* 2010). The government's long-term outlook includes introducing small-scale longlining and aquaculture to increase fish production, as well as improved research and monitoring programmes for commercial and non-commercial (i.e., recreational) sectors. As the Bermuda government moves towards these targets, it should also address social dynamics within the fisheries so as to avoid further breakdown in fisher relationships that led to the decline of Bermuda's once valuable reef fisheries.

ACKNOWLEDGEMENTS

We would like to thank Dr. Joanna Pitt and Dr. Tammy Trott for their significant contribution to the present report. Without their wealth of data and expert knowledge, this reconstruction would not have fully grasped the multi-faceted dynamics of Bermuda's fisheries. Also, we thank the *Sea Around Us*, a scientific collaboration supported by The Pew Charitable Trusts and the Paul G. Allen Family Foundation.

[5] Marine Resources Section, Department of Environmental Protection. Pelagic Longline Fishing in Bermuda's Exclusive Economic Zone. Unpublished report.

REFERENCES

Barrett G (1991) The fish pot ban: artisanal overfishing and state management in Bermuda. Paper presented at Conf. Int. Ass. Study of Common Property, Winnipeg, 26-29 September 1991.

Bermuda Government (1973a) Digest of Statistics. Government of Bermuda, Hamilton, Bermuda. 1-82 p. Available at: http://www.govsubportal.com/social-statistics/ad-hoc-surveys [Accessed: March 2015].

Bermuda Government (1973b) Report of the Population Census 1970. Government of Bermuda, Hamilton, Bermuda. . 1-265 p. Available at: http://subportal.gov.bm/census/1970-census [Accessed: March 2015].

Burnett-Herkes J and Barnes J (1996) Banning the use of pots and other management introduced in Bermuda to protect declining reef fish stocks. Proceedings of the Gulf and Caribbean Fisheries Institute 44: 239-256.

Cox A (2013) Bad Plan for Bermuda: A no-take zone is not the way to go. Marlin 32(8): 24.

DEP (2011) Report on the 2011 Survey of Recreational Fishing Activity in Bermuda. Government of Bermuda.

Dept. of Statistics (2013) Bermuda Digest of Statistics 2013. Government of Bermuda, Hamilton, Bermuda.

Dewailly E, Rouja P, Forde M, Peek-Ball C, Cote S, Smith E, Drescher O and Robertson L (2012) Evaluation of a public health intervention to lower mercury exposure from fish consumption in Bermuda. PLOS one. DOI:10.1371/journal.pone.0047388.

Luckhurst B, Booth S and Zeller D (2003) Brief history of Bermudian fisheris, and catch comparison between national sources and FAO records. Fisheries Centre Research Reports 11(6): 163-169.

Luckhurst B and Ward J (1996) Analysis of trends in Bermuda's fishery statistical database from 1975 to 1990, with reference to fishery management measures implemented during this period. . *In* Proceedings of the Gulf and Caribbean Fisheries Institute, 44:306-324.

Mowbray L (1949) The commercial and game fishing industries of Bermuda. Bermuda Mid-Ocean News, 19pp.

Pikitch EK, Santora C, Babcock EA, Bakun A, Bonfil R, Conover DO, Dayton P, Doukakis P, Fluharty DL, Heneman B, Houde ED, Link J, Livingston PA, Mangel M, McAllister MK, Pope J and Sainsbury KJ (2004) Ecosystem-based Fishery Management. Science 305: 346-347.

Sarkis S, Van Beukering PJ, McKenzie E, Hess S, Brander L, Roelfsema M, Looijenstijn-van der Putten L and Bervoets T (2010) Total economic value of Bermuda's coral reefs: valuation of ecosystem services. Technical Report, Department of Conservation Services, Bermuda Government, Bermuda. 199 p.

Smith-Vaniz WF, Collette BB and Luckhurst BE (1999) Fishes of Bermuda: History, Zoogeography, Annotated Checklist, and Identification Keys. Allen Press. 424 p.

Smith T (1989) A short history of recreational fishing and its association with tourism in Bermuda: 1930-1986. *In* Waugh G and Goodwin M (eds.), Proceedings of the 39th Annual Gulf and Caribbean fisheries Institute, Hamilton, Bermuda, November 1986. GCFI, USA.

Trott T, Luckhurst B and Medley P (2002) Report on the spiny lobster fishery of Bermuda. *In* Report of the Second Workshop on the Managmement of Caribbean Spiny Lobster Fisheries in the WECAFC Area, Havana, Cuba, 30 Septmeber - 4 October 2002. FAO Fisheries Report No. 715.

Zeller D, Harper S, Zylich K and Pauly D (2014) Synthesis of under-reported small-scale fisheries catch in Pacific-island waters. Coral Reefs DOI: 10.1007/s00338-014-1219-1.

Zeller D, Rossing P, Harper S, Persson L, Booth S and Pauly D (2011) The Baltic Sea: estimates of total fisheries removals 1950-2007. Fisheries Research 108: 356-363.

Table 1. Common species in local recreational and subsistence catch paired with associated taxa names in artisanal landings statistics.

Recreational taxa name	Common name*	Local name(s) if different from common name	Associated taxa in landings data
Acanthocybium solandri	Acanthocybium solandri		*Acanthocybium solandri*
Balistidae	Triggerfishes		Marine fishes not identified
Seriola rivoliana	Longfin yellowtail	Almaco jack, bonito	*Seriola rivoliana*
Euthynnus alletteratus	Little tunny		Scombridae
Haemulidae	Haemulidae		Haemulidae
Lachnolaimus maximus	Lachnolaimus maximus		*Lachnolaimus maximus*
Lutjanus griseus	Lutjanus griseus		*Lutjanus griseus*
Ocyurus chrysurus	Ocyurus chrysurus		*Ocyurus chrysurus*
Lutjanus synagris	Lane snapper		*Lutjanus*
Paranthias furcifer	Paranthias furcifer	Barber	*Paranthias furcifer*
Cephalopholis fulva	Cephalopholis fulva		*Cephalopholis fulva*
Sparidae	Sparidae		Sparidae
Thunnus albacares	Thunnus albacares		*Thunnus albacares*

**According to FishBase (fishbase.org)*

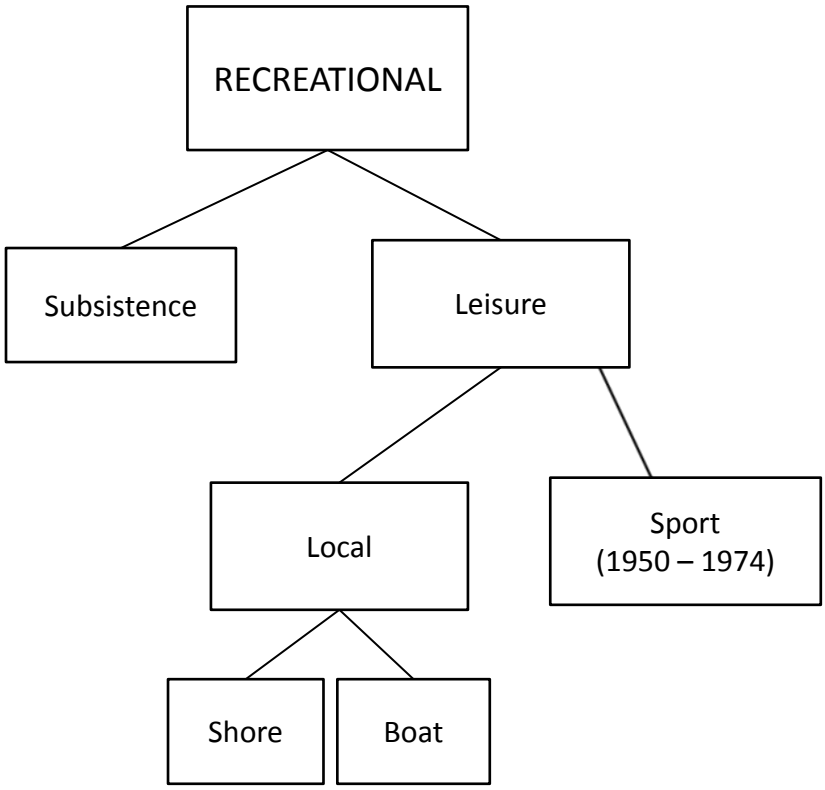

Figure 2. Subcomponents of recreational fishing as defined in this reconstruction. Subsistence catches are allocated to the subsistence sector while catches from all other subcomponents are treated as recreational catch.

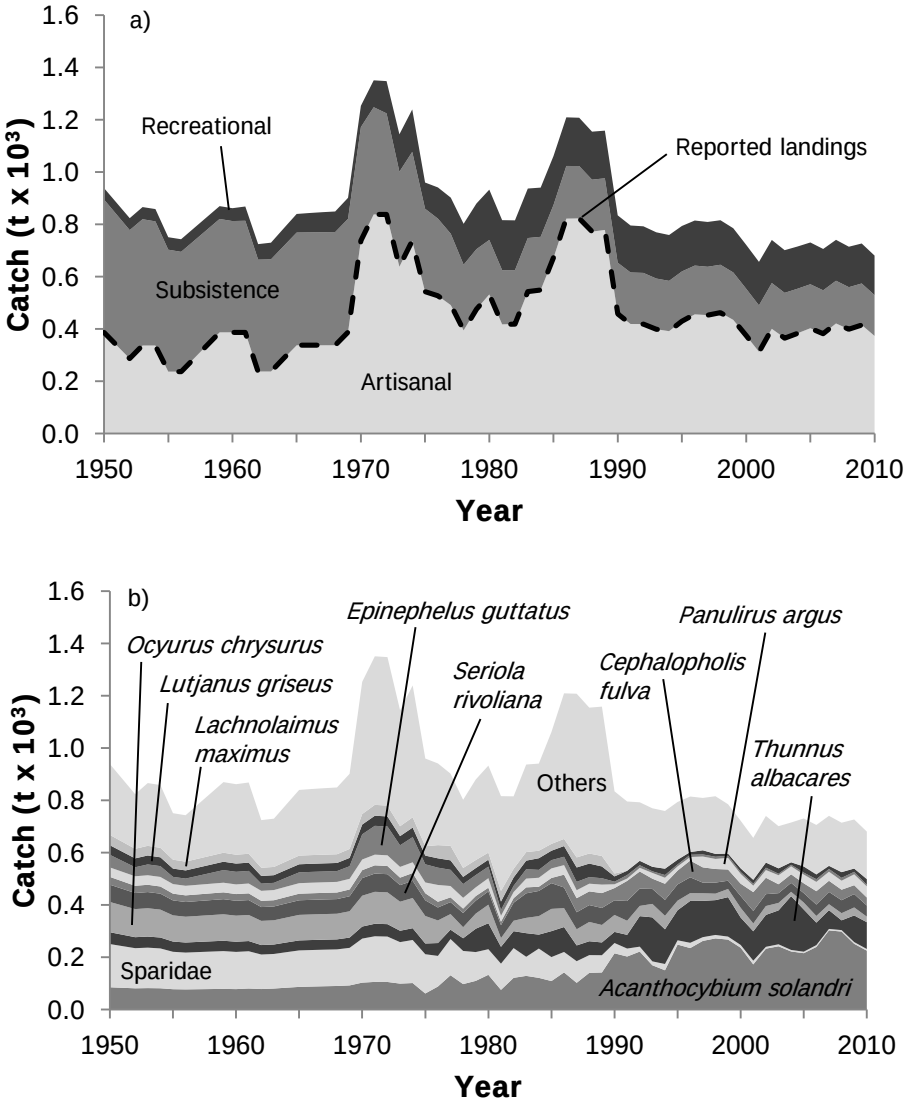

Figure 3. Bermuda's reconstructed total catches from 1950-2010 by a) sector, with dotted overlaid line representing national reported landings, and b) major taxonomic groupings, with 'Others' consisting of 61 other taxa.

Appendix Table A1. Reported landings and reconstructed catches (t) for Bermuda, 1950-2010.

Year	Reported landings	Total reconstructed catch	Artisanal	Subsistence	Recreational
1950	386	938	386	508	44
1951	336	881	336	500	45
1952	286	824	286	491	46
1953	336	866	336	483	46
1954	337	858	337	475	47
1955	237	751	237	466	48
1956	237	743	237	458	48
1957	287	785	287	450	49
1958	337	827	337	442	49
1959	387	870	387	434	49
1960	387	862	387	426	49
1961	387	868	387	427	54
1962	237	724	237	428	59
1963	237	730	237	429	64
1964	287	785	287	430	68
1965	337	840	337	431	71
1966	337	843	337	432	74
1967	337	846	337	432	77
1968	338	849	338	433	79
1969	388	901	388	433	80
1970	738	1,250	738	434	81
1971	838	1,350	838	410	103
1972	838	1,350	838	387	123
1973	638	1,140	638	363	143
1974	737	1,240	737	340	162
1975	542	960	542	317	100
1976	527	941	527	295	119
1977	491	902	491	273	138
1978	394	802	394	251	156
1979	476	880	476	230	175
1980	532	933	532	208	192
1981	417	816	417	207	191
1982	419	815	419	206	190
1983	543	937	543	205	189
1984	548	940	548	204	188
1985	671	1,060	671	203	187
1986	822	1,210	822	201	186
1987	823	1,210	823	200	185
1988	772	1,150	772	199	184
1989	779	1,160	779	197	182
1990	457	834	457	196	181
1991	419	796	419	197	180
1992	419	792	419	196	178
1993	399	770	399	194	177
1994	391	759	391	192	175
1995	429	794	429	191	174
1996	456	815	456	187	172
1997	453	809	453	185	171
1998	462	816	462	183	170
1999	435	785	435	181	169
2000	374	722	374	180	168
2001	313	656	313	177	166
2002	400	740	400	175	165
2003	365	701	365	173	163
2004	383	715	383	170	161
2005	403	731	403	168	160
2006	382	706	382	166	158
2007	421	741	421	163	156
2008	399	714	399	161	155
2009	415	727	415	159	153
2010	373	680	373	156	151

Appendix Table A2. Bermuda reconstructed catches by major taxa, 1950-2010. 'Others' includes 61 other taxa.

Year	Serranidae	*Acanthocybium solandri*	*Cephalopholis fulva*	*Paranthias furcifer*	Lutjanidae	*Thunnus albacares*	*Seriola rivoliana*	Carangidae	*Panulirus argus*	Clupeidae	Others
1950	85	165	45	116	66	30	36	48	37	39	271
1951	83	159	44	112	64	29	36	41	35	38	240
1952	81	154	42	107	61	28	36	34	34	37	209
1953	82	155	42	108	62	28	36	41	34	37	240
1954	81	152	42	107	61	27	37	41	34	36	240
1955	78	143	39	100	57	26	37	28	32	34	178
1956	77	141	39	99	56	25	37	28	31	34	177
1957	78	142	39	99	57	26	37	34	31	34	208
1958	78	143	39	100	57	26	37	41	32	34	239
1959	79	145	40	101	58	26	37	48	32	34	270
1960	78	142	39	100	57	26	37	48	32	34	270
1961	80	142	39	100	57	26	38	48	32	34	273
1962	78	132	36	92	53	24	38	28	29	31	182
1963	80	132	36	93	53	24	39	28	29	32	185
1964	84	136	37	95	54	24	40	34	30	32	218
1965	87	140	38	98	56	25	40	41	31	33	251
1966	88	140	38	98	56	25	40	41	31	33	253
1967	89	140	38	98	56	25	40	41	31	33	254
1968	90	140	38	98	56	25	41	41	31	33	255
1969	92	144	39	101	57	26	41	48	32	34	287
1970	103	168	46	118	67	30	41	96	37	40	506
1971	106	175	48	122	70	31	41	110	39	42	568
1972	105	174	47	122	69	31	41	110	38	41	568
1973	99	159	43	111	63	29	41	83	35	38	443
1974	101	165	45	115	66	30	41	96	36	39	504
1975	61	150	41	105	60	27	41	69	33	36	335
1976	88	117	49	86	50	22	64	66	36	50	312
1977	131	139	36	60	46	18	43	62	36	56	276
1978	97	127	49	42	54	17	41	53	27	34	261
1979	110	110	89	58	50	18	33	47	27	31	308
1980	133	98	99	71	51	14	36	44	26	27	333
1981	75	100	64	33	49	13	22	22	32	41	362
1982	121	114	65	40	69	17	23	24	32	33	277
1983	129	73	90	59	94	23	33	36	33	33	335
1984	121	112	53	71	96	16	34	30	44	29	333
1985	109	92	99	85	98	20	37	32	36	26	428
1986	142	78	95	72	79	49	37	32	41	27	557
1987	102	83	60	62	65	54	31	32	55	38	626
1988	140	68	53	74	64	52	30	25	52	38	558
1989	142	66	49	67	65	57	33	24	45	40	571

Appendix Table A2. Bermuda reconstructed catches by major taxa, 1950-2010. 'Others' includes 61 other taxa.

Year	Serranidae	*Acanthocybium solandri*	*Cephalopholis fulva*	*Paranthias furcifer*	Lutjanidae	*Thunnus albacares*	*Seriola rivoliana*	Carangidae	*Panulirus argus*	Clupeidae	Others
1990	215	39	42	65	56	47	15	10	20	11	314
1991	203	30	52	54	76	77	9	13	16	1	264
1992	222	19	117	39	66	66	14	10	17	1	223
1993	169	15	168	52	57	39	22	6	17	0	223
1994	150	24	133	52	61	62	23	10	24	0	220
1995	248	16	115	37	62	53	16	7	18	0	221
1996	235	20	160	30	61	64	14	9	10	0	212
1997	262	14	139	29	40	58	42	8	16	0	200
1998	272	13	133	25	42	52	39	8	11	0	220
1999	267	11	151	31	32	43	45	8	9	0	188
2000	236	11	105	37	45	47	38	7	14	1	181
2001	173	14	112	30	48	72	25	8	15	0	160
2002	233	7	122	34	45	63	30	9	19	0	178
2003	242	8	130	29	37	34	35	6	21	0	161
2004	222	6	206	16	34	33	31	6	9	0	152
2005	215	6	162	26	36	37	34	7	23	1	183
2006	239	7	86	25	44	51	36	11	18	2	187
2007	303	6	72	23	47	43	35	11	12	1	190
2008	298	6	37	27	50	40	35	11	22	0	189
2009	251	7	102	31	51	34	42	10	13	0	187
2010	225	6	102	21	43	31	43	6	21	1	181