SCIENTIFIC COMMITTEE
THIRTEENTH REGULAR SESSION

Rarotonga, Cook Islands
9-17 August 2017

Summary of purse seine fishery bycatch at a regional scale, 2003-2016

WCPFC-SC13-2017/ST-WP-05

T. Peatman, V. Allain, S. Caillot, P. Williams, and N. Smith

Oceanic Fisheries Programme, FAME, Pacific Community (SPC)

Executive Summary

The Western and Central Pacific Fisheries Commission (WCPFC) has a responsibility to assess the impact of fishing on non-target species. In this report, we estimate the bycatch of the large-scale purse seine fishery operating primarily in tropical waters of the WCPFC Area east of 140°E. These large vessels, typically greater than 500 tonnes carrying capacity, have been responsible for approximately 83% of the purse seine catch of the main tuna target species, skipjack, yellowfin and bigeye tuna, in recent years, a catch which has varied between 1.5 and 2 million tonnes annually since 2010.

Data are collected from large-scale purse seine vessels through logsheets completed by vessel operators, in which catch, primarily of the target species, and other information are recorded for each purse seine set. Since the mid-1990s, some vessels have had observers on board to collect more detailed information on fishing operations, including the quantities of bycatch. Observer coverage of the purse seine fleet was modest (<10%) prior to 2010, after which a new rule that all purse seine vessels should carry observers was agreed by WCPFC and implemented by its members, most notably those coastal states who are members of the Parties to the Nauru Agreement (PNA). Therefore, from 2010, coverage of available observer data increased dramatically to around 60-80% per year. Note that smaller purse seine vessels operate in largely coastal waters of Indonesia, Philippines and Vietnam to the west, Japan to the north and New Zealand to the south. Observer data are not currently available for these fleets, which have made up approximately 17% of the WCPFC tuna purse seine catch in recent years. This report therefore focuses on estimating bycatch taken by the fleet of large purse seiners operating in tropical waters, using available observer data.

Species/species-group specific bycatch of large-scale purse seine fleets was estimated using the following approach:

1. Estimate bycatch rates by strata (year, quarter and association type) using available observer data.
2. Use observer data and aggregate catch/effort data to determine the number of unobserved sets by strata.
3. Apply observed strata-specific bycatch rates (bycatch per set) to the number of unobserved sets, to estimate strata-specific unobserved bycatch.
4. Aggregate observed bycatch data to obtain strata-specific observed bycatch.
5. Combine observed bycatch with estimates of unobserved bycatch to estimate total bycatch.

For a given species/species-group, estimates of bycatch rates for unobserved sets were based on the product of: the estimated proportion of sets where the bycatch species/species group was present; and, estimated bycatch levels for sets where the bycatch species/species group occurred. The presence/absence of bycatch was based on a binomial model for commonly encountered species/species groups, and a non-parametric bootstrap procedure for all other species/species groups. Estimates of bycatch levels when present were based on a non-parametric bootstrap procedure for all species/species groups. Bycatch rates were estimated in number of specimens per set for large pelagic species (i.e. sharks, billfishes, turtles, marine mammals) and in weight per set for small pelagic species (finfish).

Rainbow runner, silky shark, oceanic triggerfish, mackerel scad and mahi-mahi were the most frequently bycatch species recorded by observers. Other species were observed in less than 1 set out of 10. Bycatch was more frequently observed on sets on drifting FADs, anchored FADs and logs than for sets on unassociated schools, and schools associated with whales and whale sharks. Finfish species (rainbow runner, mackerel scad, mahi mahi, frigate and bullet tunas, oceanic triggerfish, wahoo) and silky sharks were most frequently observed on anchored FAD, drifting FAD and log sets. Silky shark, blue marlin and manta rays accounted for the majority of observations of bycatch on unassociated sets, and schools associated with whales and whale sharks. Diversity in catches were highest for log sets (generally with 10 or less species recorded), followed by anchored and drifting FAD sets (7 species or less), whale shark sets (5 species or less), whale sets (4 species or less), and unassociated sets (3 species or less). For the finfish bycatch composition, rainbow runner accounted for the largest proportion (~42%) of observed finfish bycatch, not including billfish, and mackerel scad, oceanic triggerfish, frigate and bullet tunas, and mahi mahi/dolphinfish each accounted for greater than 5 % of total finfish bycatch.

For most finfish bycatch species 50-80 % of observed bycatch was discarded, however retention rate was over 60 % for frigate and bullet tunas, albacore, kawakawa, wahoo, trevallies and batfishes. Blue marlin accounted for approximately half of the total observed billfish, with black marlin accounting for approximately a quarter. Approximately one half to two-thirds of billfish bycatch was discarded, with the exception of swordfish for which two-thirds of observed bycatch was retained. Silky shark accounted for approximately 85 % of total shark bycatch. Observed shark bycatch was generally discarded, but several species were discarded with fins retained (mako and blue sharks particularly). Marine mammals, whilst rarely caught, accounted for the majority of catch records for species of special interest (i.e. marine mammals, turtles and seabirds) in number of individuals. The vast majority of marine mammal and turtle bycatch was discarded.

In 2016, the median estimated bycatch for large-scale purse seine fleets were 5,600 tonnes of finfish, 5,900 specimens of billfish, 67,900 specimens of sharks, 330 specimens of marine mammals and 212 specimens of turtles. The increase in observer coverage from 2010 onwards resulted in strong reductions in uncertainty in bycatch estimates. Estimated total finfish bycatch for large-scale purse seine fleets peaked in 2004 at 10,000 tonnes, declining to approximately 5,000 tonnes from 2010 onwards. The main driver in this declining trend was the strong reduction in log sets over this period, which tend to have the highest probability of finfish bycatch presence. Rainbow runner accounted for 47 % of total finfish bycatch with mackerel scad, oceanic triggerfish, frigate & bullet tuna and mahi mahi together accounting for 42 % of total finfish bycatch.

Estimated total billfish bycatch for large-scale purse seine fleets peaked in 2012-2013 at 8,500 individuals, declining to approximately 6,000 individuals in 2016. The increase in billfish bycatch in 2012 and 2013 was mainly driven by the increase in sets on unassociated schools in these years, with more than 50 % of estimated billfish bycatch accounted for by unassociated sets from 2012 onwards. Blue marlin accounted for half of total estimated billfish bycatch with black marlin and striped marlin accounting for 26 % and 11 % respectively.

Estimated total sharks & rays bycatch for large-scale purse seine fleets were at a minimum in 2010 at 36,000 individuals, increasing to approximately 68,000 individuals in 2016. The low level of shark and ray bycatch in 2010 was a result of the reduced number of drifting FAD sets which have a relatively high chance of catching sharks. Silky shark accounted for 88 % of estimated shark bycatch, with mantas & mobulid rays, and oceanic whitetip shark accounting for 5 and 1.6 % respectively.

Estimated total turtle bycatch for large-scale purse seine fleets peaked in 2013 at 390 individuals, decreasing to approximately 240 individuals from 2014 onwards. Unassociated sets accounted for the highest proportion of turtle bycatch. Green turtle (24 %), olive ridley (23 %), loggerhead (20 %) and hawksbill turtles (16 %) accounted for the majority of turtle bycatch, noting that turtles started to be reported at the species level from 2006. Estimated total marine mammal bycatch for large-scale purse seine fleets was higher from 2003 to 2009 at ~ 1,200 individuals caught mainly on log sets, decreasing to 550 individuals on average from 2010 onwards caught mainly on drifting FAD sets.

A strong impact of the set type has been observed on the bycatch composition and, hence, any variation in the proportion of the various set types will have a strong impact on the annual catches of bycatch. This effect is observed for finfish in general and particularly for rainbow runner, with a strong reduction in estimated bycatch corresponding to the strong reduction in log sets observed from 2010 onwards. The set type effect is also noted in the third quarter of the year as a result of the FAD closure from 2010 onwards with decreased quantities of rainbow runner, mahi mahi and silky shark at this time of the year. There was also underlying inter-annual and intra-annual variations in bycatch that was not fully explained by the set type effect.

The report concludes with recommendations for consideration by the Scientific Committee, including recommendations for future work to improve the quality of purse seine bycatch data held by SPC.

1. Introduction

The convention on the conservation and management of highly migratory fish stocks in the western and central Pacific Ocean[1] clearly indicates that the WCPFC has responsibilities in not only managing tuna species, but also in assessing the impact of fishing and environmental factors on non-target species and species belonging to the same ecosystem or dependent upon or associated with the target stocks (article 5d), to minimize catch of non-target species (article 5e), to protect biodiversity (article 5f), to adopt, when necessary, CMM for non-target species to ensure the conservation of such species (article 6c).

Hence, since the establishment of the WCPFC a number of measures on non-target species have been implemented.

- The WCPFC is maintaining an open resource that focuses on bycatch mitigation and management in oceanic tuna and billfish fisheries: the Bycatch Management Information System (BMIS, https://www.bmis-bycatch.org/) (Fitzsimmons *et al.*, 2015).
- A resolution has been taken to encourage avoiding the capture of all non-target fish species and encourage prompt release to the water, unharmed (resolution 2005-03).
- Conservation and management measures (CMM) have been taken on billfishes (CMM 2006-04 for striped marlin in the southwest Pacific, CMM 2009-03 for swordfish, CMM 2010-01 for north Pacific striped marlin), and on species of special interest: sea turtles (CMM 2008-03), sharks (CMM 2010-07, CMM 2011-04 for oceanic whitetip shark, CMM 2012-04 for whale sharks, CMM 2013-08 for silky sharks, CMM 2014-05), cetaceans (CMM 2011-03) and seabirds (CMM 2015-03).

Most of those CMM encourage for a better reporting of the non-target species. However, even if reporting improves, data on non-target species are infrequently reported on logsheets provided by the fishing industry and the only reliable source of information on those species are observer data. The implementation of the 100% observer coverage on purse seiners since 1 January 2010 as stated in CMM 2008-01 (Western and Central Pacific Fisheries Commission, 2008), replaced by the currently in force CMM 2016-01, offers the possibility of providing reliable estimates of the quantities of the most frequent non-target species and data on non-target species composition for the most recent years for this fishery.

Since 2010 a number of studies estimating bycatches of the tuna fisheries have been produced:

- at the global level, the FAO produced three studies on bycatch of the small scale tuna fisheries (Gillett, 2011), of the tropical tuna purse seine fisheries (Hall and Roman, 2013) and of the tuna longline fisheries (Clarke *et al.*, 2014).
- at the regional level three studies have been conducted on edible bycatch species from the purse seine fishery (Pilling *et al.*, 2012, 2013, 2015), on key shark species (Lawson, 2011), and on non-target species interactions with the tuna fisheries (Oceanic Fisheries Programme of the Secretariat of the Pacific Community, 2010)
- at the national level two series of national reports were produced by the SPC oceanic fisheries programme on longline fisheries in 2012-2014 on “Bycatches of the longline tuna fisheries” and in 2017 on “Seasonality and value of target tuna and important bycatch species in the longline fishery” (confidential, available for authorized fisheries department staff on SPC country web pages for Cook Islands, Fiji, French Polynesia, Federated States of

[1] https://www.wcpfc.int/system/files/text.pdf

Micronesia, Marshall Islands, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, Vanuatu)

In this report observer data are used to estimate the catch of bycatch species and to provide details on the catch composition of the bycatch species of the purse seine fishery of the western and central Pacific Ocean at the regional level.

2. Definition of bycatch used in this report and other definitions

Bycatch

A consensus exists on the fact that it is difficult to define bycatch. In general this term refers to the incidental capture of non-target species; however it can be sometimes difficult to clearly identify the target species. There is no agreed definition and the significance of the term bycatch varies widely according to authors, fisheries, fate of the specimens (retained, discarded), size of the specimens… For example a different definition is used in the three global papers produced by FAO on bycatch of the tuna fisheries:

- in the context of small-scale tuna fisheries, Gillett (2011) defines bycatch as "non-tuna species" whether retained or discarded,
- in the context of the purse seine tuna fisheries, Hall and Roman (2013) define bycatch as dead discards regardless of species
- in the context of the longline tuna fisheries Clarke *et al.* (2014) define bycatch as non-tuna and non-tuna like species, that is, excluding the 51 species of the family Scombridae (mackerels, Spanish mackerels, bonitos and tunas), and the 13 species of the billfish and swordfish families Istiophoridae and Xiphiidae.

Considering the lack of consensus on the significance of the term, it appears necessary to clearly define what is considered as bycatch in this report. For this report on tuna purse seine fisheries in the western and central Pacific ocean bycatch are defined as non- skipjack, non-yellowfin and non-bigeye tuna species. Discarded skipjack, yellowfin and bigeye will not be considered in this report. All other species, including albacore tuna will be considered as a bycatch whether they are retained or discarded.

School association / set type

The purse seine fisheries target schools of fish. Schools can be associated to objects or animals, or unassociated. The set types used in the analysis were sets on: anchored fish aggregating devices (aFAD); drifting fish aggregating devices (dFAD); drifting logs, debris or dead animals (log); unassociated schools (free schools - FS); live whales (whale); and, live whale sharks (whale.shk).

Skunk set

The purse seine operation comprises the visual spotting of a fish school at the surface and the setting of the net around this school. Often, during the setting operation and before the net is closed, the school of fish dive in an attempt to escape. It is only once the net has been closed and partially taken back onboard that we know if the school has managed to escape or if it is in the net. Sets from which the fish have escaped are called skunk sets. Skunk sets should be recorded in observer and vessel logbooks, even if there was no catch. In the present study skunk sets are considered as applied effort.

Observer coverage

Throughout the report, we use 'observer coverage' to refer to the proportion of total reported sets accounted for by trips for which SPC holds observer data.

Large-scale purse seine fleets
SPC holds observer data for large-scale purse seiners operating in equatorial and tropical waters. However there are a number of fleets operating in the WCFPC-CA with no corresponding observer data available in SPC's master observer, specifically: Indonesian and Vietnamese purse seiners, that operate west of 140°E; domestic Philippines purse seiners, that operate within the Philippines EEZ; and, purse seine fleets operating in temperate areas, *i.e.* New Zealand flagged vessels south of 25°S, and Japanese vessels north of 20°N. The available observer data held by SPC should not be considered representative of these fleets, due to large differences in the operational characteristics of the vessels, and the areas of operation. For example, the Indonesian, Vietnamese, and domestic Philippines purse seine vessels are smaller than those operating in the large-scale purse seine fleets, with smaller and shallower purse seine gear which have far lower catch rates. As such, in this report we look only at bycatch of large-scale purse seine fleets operating in equatorial and tropical waters, which we refer to throughout as 'large-scale purse seine fleets'. These large-scale purse seine fleets accounted for 83% of total reported purse seine catches of skipjack, yellowfin and bigeye tuna from 2003 to 2016. We do not attempt to estimate bycatch for the comparatively small-scale Indonesian, Vietnamese and domestic Philippines vessels, and purse seiners operating in temperate waters, which together accounted for 17% of total reported purse seine catch from 2003 to 2016. It should be noted that SPC has recently been provided observer data collected on domestic Philippines purse seiners. However these data had not been incorporated in to SPC's master observer database at the time of writing, and as such it was not possible to incorporate these data in to the analyses.

3. Data and methods

3.1. Area

For this regional summary the whole WCPFC-CA has been taken into consideration. However, we restricted the analysis to large-scale purse seine fleets operating in equatorial and tropical waters (), due to the lack of available observer data for smaller scale purse seine fleets, and purse seine fleets operating in temperate waters (see Section 2).

3.2. Time period

This report covers 2003 to 2016. The reliability of the purse seine observer data is considered to be lower pre-2003. The observer coverage rate has greatly improved since 2010 with the implementation of the CMM 2008-01 (Western and Central Pacific Fisheries Commission, 2008).

3.3. Species

Based on reporting rate in the observer data, we are considering in this report 28 species or groups of finfish, 10 species or groups of sharks and rays, 6 species or groups of turtles and 1 group gathering all marine mammals (Annex 1). We do not report on seabirds due to very low observation rate: less than 10 specimens of seabirds have been reported in the purse seine observer data since 2003. We do not report on "Unidentified Tuna" which are likely to be skipjack, yellowfin or bigeye tuna (see our definition of bycatch in section 2) and we do not report on "Porbeable shark" for which only one specimen was recorded (over a total of 265,735 sets).

A number of species for which identification is considered problematic were grouped together (Annex 1); they mostly belong to the same family within each group (e.g. triggerfish, frigate and bullet tuna). For sharks and finfish, the species with the lowest occurrences were grouped together in the Elasmobranchs nei and the Marine fishes nei groups respectively. For marine mammals all species have been grouped considering difficulties in identification and low occurrence. This approach allows estimation of total finfish, billfish, shark, marine mammal and turtle bycatch, whilst focussing species (or species group) specific bycatch estimates for those that are most frequently caught.

We note that the development of observer training and the distribution of identification booklets improved the species identification of the bycatch. However recent genetic testing indicated some misidentification between blue and black marlin in some instances and it can be difficult to identify rare species that are not necessarily recorded in the identification books. Moreover we also noted some data entry errors in the species codes.

3.4. Observer data

The only reliable source of information on bycatch is the observer data as bycatch are poorly reported by fishermen on the logsheets. All available WCPFC convention area observer data held by SPC have been considered for this study (this includes ROP data and national level data from the US, NZ, and AU for which SPC has authorisation to use the data).

3.5. Aggregate catch and effort data

SPC's Catch and Effort Query system was used to extract purse seine catch and effort by year, month, flag, fleet, set type and 1 degree square for 2003 to 2016. This dataset is referred to throughout the report as aggregate catch and effort data, and was used to raise bycatch rate estimates to total bycatch estimates.

3.6. Catch unit and catch data

In this study we report catch estimates in number of specimens for large or rare species (sharks, billfishes and species of special interest such as turtles and marine mammals) as their number is usually small and as such more likely to be correctly estimated than large weights. Weights will be used for all other finfish as observers generally do not record estimates of finfish bycatch in numbers, and weights are likely to be better estimated than numbers for large quantities of smaller fish.

In the field, observers record number of specimens of each species or total weight of each species or both data. When data reported by observers are incomplete, i.e. when only one value is reported by the observers (number or weight), the other value is then estimated within SPC's master observer database using internal algorithms (Annex 2). However a number of issues on the quality of the data have been reported (Annex 2) and for the present study we will only consider the data directly provided by the observers.

Whilst reviewing the observer data, it was clear that there were a small proportion of bycatch records with unrealistically high values. Excluding the top 0.2 % of records for each species resulted in observed bycatch distributions that were more plausible, noting that targeted examination of some of the most extreme values indicated that data-entry errors had occurred (e.g. bycatch numbers entered in the metric tonnes field). Consequently, the top 0.2 % of positive-bycatch records were excluded when drawing bootstrap samples of non-zero bycatch (see section 3.8). This should prevent upwards bias in bycatch estimates due to erroneous bycatch records, but could introduce downwards bias in bycatch estimates if real (but rare) high bycatch events have been excluded. It should be noted that these records were still considered as positive bycatch sets when drawing bootstrap samples of presence/absence (see section 3.8). Issues on data quality on bycatch weights and numbers reported by observers are detailed and discussed in Annex 2.

3.7. Effort unit

The effort unit used to estimate bycatch rates and raise bycatch rates to total bycatch estimates was the number of sets. Skunk sets (*i.e.* unsuccessful sets, see detailed definition in section 2) were included in the analysed observer data when estimating bycatch rates, as skunk sets should also be reported and included in the aggregate effort data.

The ratio of bycatch to target catch (or landings) has been used to estimate total bycatch in other purse seine fisheries (Amandè *et al.*, 2012). However, preliminary models of bycatch presence/absence indicated weak non-linear relationships between bycatch presence and target catch, with lower presence of bycatch for unsuccessful sets or low volume sets and no apparent relationship for sets with moderate to high catches (i.e. > 10 tonnes). Furthermore, when modelling bycatch at a set level (see below), there is a mismatch between the explanatory variable in the model, i.e. target catch for the set, and the information available in aggregate data used for raising to total bycatch estimates, i.e. the total catch for all sets for a specific combination of year, month, association type and 1 degree square. As such, we did not consider the ratio of bycatch to target catch to be an appropriate unit for estimating total bycatch of large-scale purse seine fleets operating in the WCPFC-CA.

3.8. Catch estimates and CPUE estimates

As described above, we used catch unit per set to estimate bycatch rates and raise bycatch rates to total bycatch estimates. We used the statistical software R for bycatch estimation (R Development Core team, 2015). Bycatch composition and quantities in WCPFC purse seine fisheries display strong variation between different set types (Pilling *et al.*, 2015). As such, we stratified available observer data and aggregate catch effort data by set type, as well as year and quarter to account for annual and seasonal variation in bycatch rates. We did not include spatial stratification. This would have only been possible at wide spatial scales, in order to have observed effort in all strata pre-2010. Furthermore, exploratory data analysis did not suggest strong systematic spatial variation in bycatch rates.

The general approach for a given species or species group was:

6. Estimate bycatch rates by strata (year, quarter and association type) using available observer data (see below for details on the calculation).
7. Use observer data and aggregate catch/effort data to determine the number of unobserved sets by strata.
8. Apply observed strata-specific bycatch rates (bycatch per set, step 1 above) to the number of unobserved sets, to estimate strata-specific unobserved bycatch.
9. Aggregate observed bycatch data to obtain strata-specific observed bycatch.
10. Combine observed bycatch (step 4) with estimates of unobserved bycatch (step 3) to estimate total bycatch.

Details on the estimate of bycatch rate (step 1 of the general approach).
For most species/species group there are records in the observer dataset of presence of bycatch, where the observer recorded the bycatch in a catch unit inconsistent with the catch units used in this analysis, *i.e.* tonnes for billfish, sharks and other species of special interest, or numbers for other finfish. If we simply disregard the records for which the data is not recorded in the unit used in the present study, we would introduce downwards bias in bycatch rate estimates. To prevent this issue we therefore estimated bycatch rates in a two-stage process. First we estimated the proportion of sets where bycatch was present and then we estimated the amount of bycatch when present.
We used 2 approaches to estimate the proportion of sets where bycatch were present: statistical models for the most frequently caught species, and a non-parametric bootstrapping procedure for

the other species with smaller amount of data. To estimate the amount of bycatch when present we use non-parametric bootstrap procedure for all species/species groups.

Estimate of presence/absence by statistical models

For frequently recorded bycatch species, statistical models were fitted to observer data to allow prediction of bycatch presence/absence, with uncertainty incorporated by taking 10,000 draws from the predicted mean probability of bycatch presence (and its associated standard error). Models of presence/absence were fitted for the following frequent species/species groups: rainbow runner (RRU); silky shark (FAL); oceanic triggerfish (TRI); mackerel scad (MSD); mahi-mahi (DOL); wahoo (WAH); blue marlin (BUM); frigate and bullet tunas (FRZ); manta and mobulid rays (MAN); barracudas (BAR); black marlin (BLM); and, oceanic whitetip shark (OCS). Explanatory variables used in the model were the year, the quarter, the set type and the sea surface temperature (SST). Association or set type was included to account for variation in bycatch presence/absence between set types (Pilling *et al.*, 2015). Sea surface temperature (Reynolds *et al.*, 2002) was included as a proxy for thermal habitat preference, noting however that there is little variation in sea surface temperature in the equatorial purse seine fishery (*e.g.* mean SST = 29.7 °C, sd = 0.6 for observed sets). Year and quarter were included to account for temporal trends and seasonal trends in bycatch rates. The specification of the statistical models of bycatch presence/absence is provided in Annex 3.

For the predictions of presence/absence, considering the low variation in sea surface temperature in the equatorial purse seine fishery, sea surface temperature was fixed at the strata-specific effort-weighted mean when predicting.

Estimate of presence/absence by bootstrapping procedure

For less frequent species, we used a non-parametric bootstrap sampling procedure (Efron and Tibshirani, 1994) to generate 10,000 bootstrap samples[2] of the proportion of sets where bycatch was present, using all records from the observer data.

This allows uncertainty in bycatch rate estimates to be reflected in uncertainty in predicted bycatch for unobserved sets (step 3 above), expressed as the lower and upper 95 % percentiles. With this approach, the uncertainty in bycatch rates for a given strata and species/species group increases as observer coverage decreases, and increases as variation in observed bycatch rates increases.

Estimate of amount of bycatch when present by bootstrapping procedure

We attempted to fit statistical models to allow prediction of the amount of bycatch when present. However, all attempts to fit robust models were unsuccessful. This was not unexpected, as Peatman and Pilling (2016) encountered a similar problem when modelling silky shark and oceanic whitetip bycatch rates for a subset of WCPFC observer data. See Annex 3 for more information.
To estimate the amount of bycatch when present we applied the bootstrap sampling procedure to generate bootstrap samples of the amount of bycatch when present, using only records with the 'correct' catch unit for the species/species group in question.

---

[2] By way of example, let us suppose that there were 750 anchored FAD sets in the first quarter of 2003, with observer data available for 75 of these sets. We draw 75 samples with replacement (each set can appear more than once in the 75 sets drawn) from the 75 observed data points 10,000 times, and calculate the average bycatch rate per set for each bootstrap sample. This gives 10,000 estimates of bycatch rate for anchored FAD sets in the first quarter of 2003, which we apply to the 675 unobserved sets to give 10,000 estimates of unobserved bycatch. The estimates of unobserved bycatch, combined with the total observed bycatch, give 10,000 estimates of total bycatch for anchored FAD sets in the first quarter of 2003. The distribution of these 10,000 estimates then provides information on the average total bycatch for the strata (the median), with 95 % confidence intervals taken as the lower and upper 95 % percentiles.

Additionally, when attempting to fit models to bycatch when present, we struggled to detect clear annual and seasonal patterns. As a result, when bootstrap sampling estimates of bycatch when present, we sampled from all positive bycatch records for the association type, rather than all positive bycatch records for the strata (association type, year and quarter) [3]. This was done to prevent strong inter-annual and seasonal variation in bycatch estimates as a result of random noise in observations, which could have been problematic in years when observer coverage was limited, or for species/species group which are less frequently caught.

Strata with more observed sets than reported sets

For some strata, there were more observed sets than reported sets. This was particularly prevalent for whale shark and whale sets (> 90 % of the total strata for these set types). In these instances we assumed that the reported number of sets in the strata was accurate, and resampled from observed bycatch rates to generate 10,000 estimates of observed bycatch. For example, suppose there were 100 sets recorded as whale shark sets by observers in the first quarter of 2004, with 10 whale shark sets reported in the aggregate data. We would take 10 samples without replacement from the 100 observations, and do this 10,000 times.

Estimate of total bycatch

We combined the estimates of presence/absence and the estimate of amount of bycatch when present in a stratified calculation. For each strata, we then have 10,000 estimates of the proportion of sets with bycatch, and 10,000 estimates of the amount of bycatch per set (for sets where bycatch was present). The product of these gives 10,000 estimates of overall bycatch rate per set to be applied to the unobserved sets (step 3 above).

4. Observer coverage

With the implementation of the 100% observer coverage on purse seiners since 1 January 2010 as stated in the CMM 2008-01 (Western and Central Pacific Fisheries Commission, 2008), we observe an important increase in coverage of available observer data in 2010 (Figure 1). However this coverage rate is not distributed evenly among the fisheries and in the WCPFC-CA (Figure 2 and Figure 3). Lower observer coverage rates are noticeable in the enclosed high seas pockets and reflects the observer coverage pre-2010 as those pockets were closed from 1 January 2010 (Western and Central Pacific Fisheries Commission, 2008) and re-opened with a limited number of fishing days from 2013 (Western and Central Pacific Fisheries Commission, 2012, 2016).

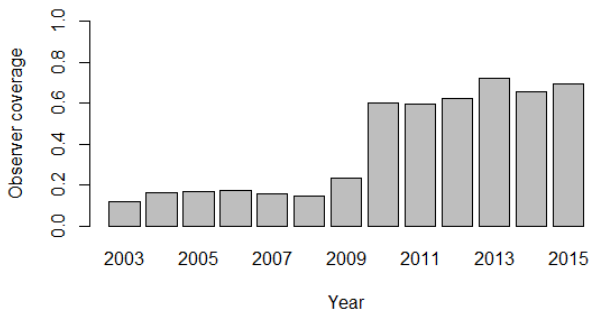


Figure 1 Annual observer coverage (proportion of sets) of large-scale purse seine fleets in the WCPFC-CA.

[3] To return to the hypothetical example presented in the previous footnote on bootstrapping, suppose that there were a total of 500 anchored FAD sets with positive bycatch from 2003 to 2016 for the species/species group in question. When generating bootstrap samples of bycatch when present, we would draw 75 samples from the 500 positive records, and do this 10,000 times.

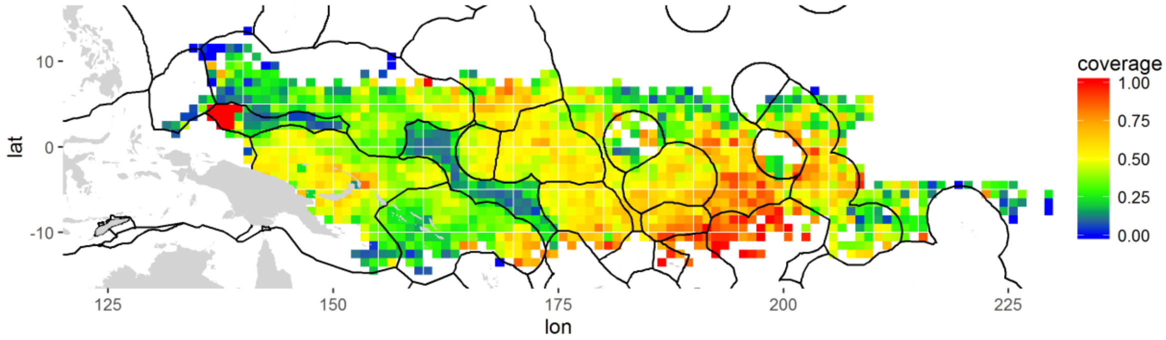
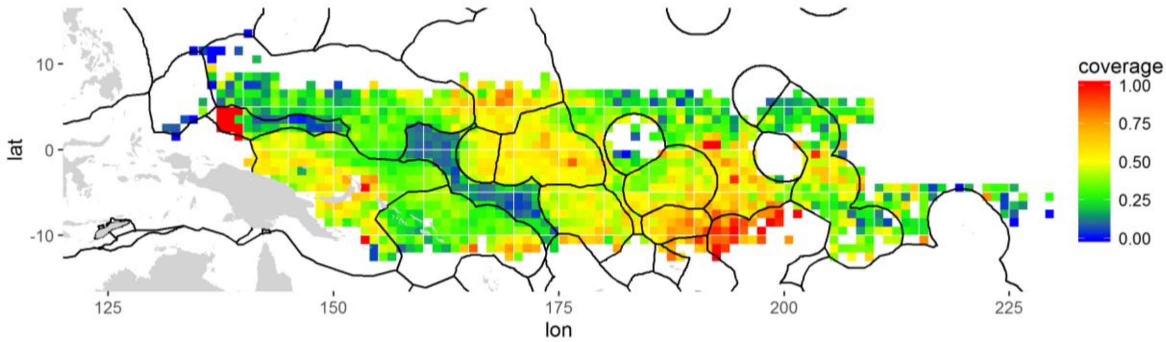


Figure 2 Observer coverage (proportion of sets) of large-scale purse seine fleets in the WCPFC-CA from 2003 to 2015, for all set types.

a) Associated sets



b) Free school sets

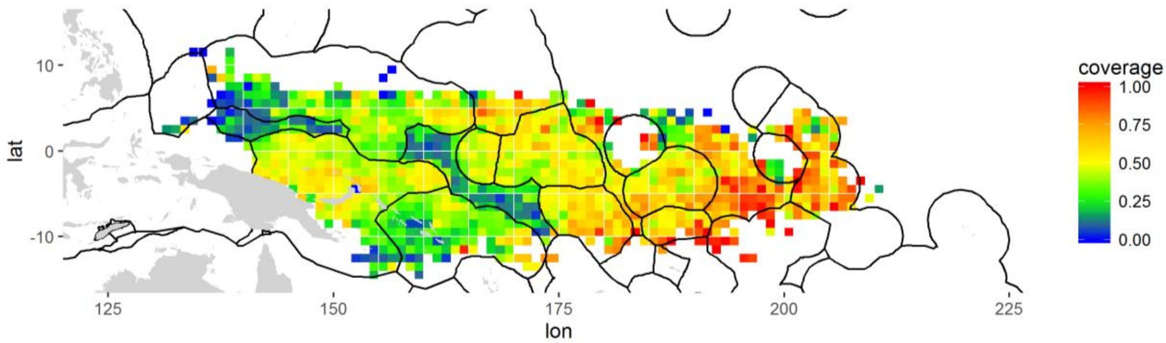
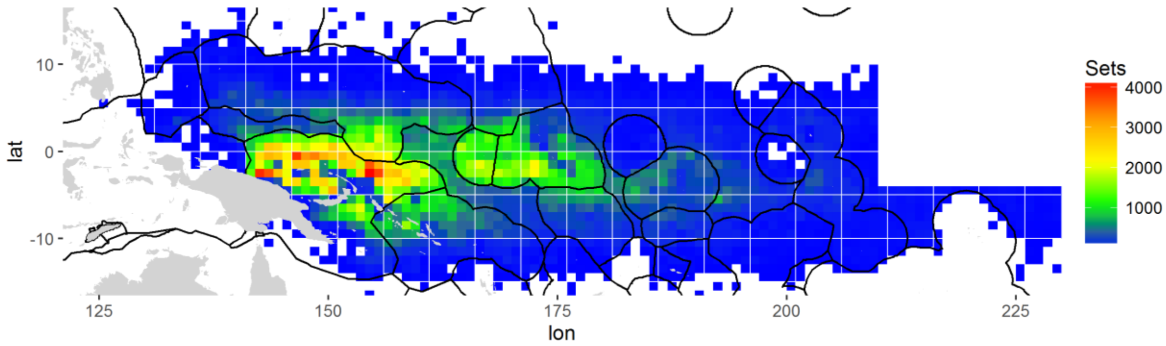


Figure 3 Observer coverage (proportion of sets) of large-scale purse seine fleets in the WCPFC-CA from 2003 to 2015, for associated (top) and unassociated (bottom) sets.

a) Effort (number of sets)



b) Catch (tonnes)

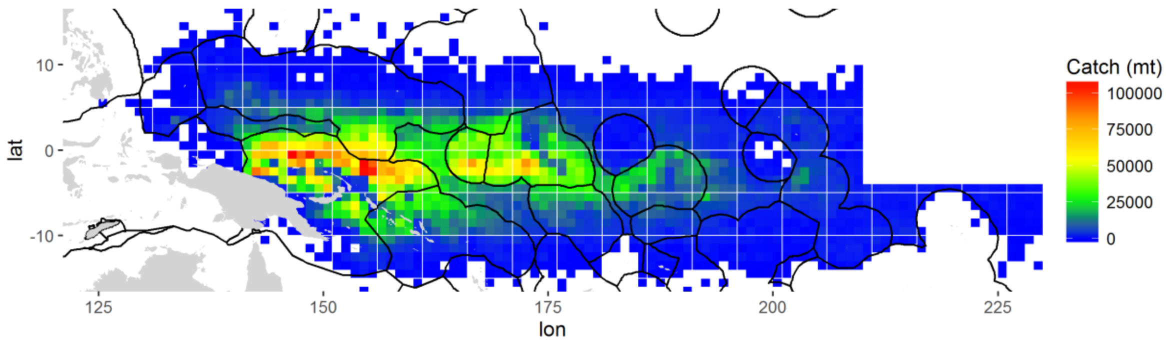


Figure 4 Total reported effort in number of sets (a-top) and catch (skipjack + yellowfin + bigeye + others as reported on fishing logbooks) in tonnes (b-bottom) for large scale purse seiners during the 2003-2015 time period in the WCPFC-CA.

Table 1 Total reported sets by year and association type for large scale purse seine fleets operating in the WCPFC-CA, from 2003 to 2016. Cell colours: red = highest number of sets, green = lowest number of sets, for all years and set types combined within a table.

Year	aFAD	dFAD	log	FS	whale	whale.shk	Total
2003	2,644	3,576	7,051	17,043	29	18	30,361
2004	2,899	4,776	13,289	11,162	33	2	32,161
2005	3,223	3,982	9,842	19,494	39	4	36,584
2006	2,067	4,931	11,118	15,309	28	9	33,462
2007	2,117	5,539	8,971	19,648	64	11	36,350
2008	3,084	10,423	4,887	22,718	70	10	41,192
2009	3,058	11,370	6,779	22,803	88	9	44,107
2010	2,353	6,847	3,798	38,185	260	18	51,461
2011	2,925	15,244	3,642	30,306	155	1	52,273
2012	2,765	13,405	4,438	36,611	136	9	57,364
2013	2,178	12,110	3,498	38,014	99	5	55,904
2014	1,700	13,733	2,772	38,454	81	4	56,744
2015	1,260	10,370	2,081	33,999	132	9	47,851
2016	1,146	11,266	2,157	32,471	112	11	47,163

5. Bycatch species frequency and diversity

Rainbow runner, silky shark, oceanic triggerfish, mackerel scad and mahi-mahi were the most frequently bycatch species recorded by observers, in descending order of prevalence (Figure 5). Other species and species groups were observed in less than 1 set out of 10.

Observed bycatch composition and quantities varied strongly between set types (Figure 6, Figure 7). Generally speaking, bycatch was more frequently observed on sets on drifting FADs, anchored FADs and logs for which the most frequent species was observed in six sets out of ten than for sets on unassociated schools, and schools associated with whales and whale sharks for which the most frequent species was observed in one to three sets out of ten. Finfish species and silky sharks were most frequently observed on anchored FAD, drifting FAD and log sets. Silky shark, blue marlin and manta rays accounted for the majority of observations of bycatch on unassociated sets, and schools associated with whales and whale sharks, noting that whale sharks were recorded as caught in approximately a third of whale shark associated sets.

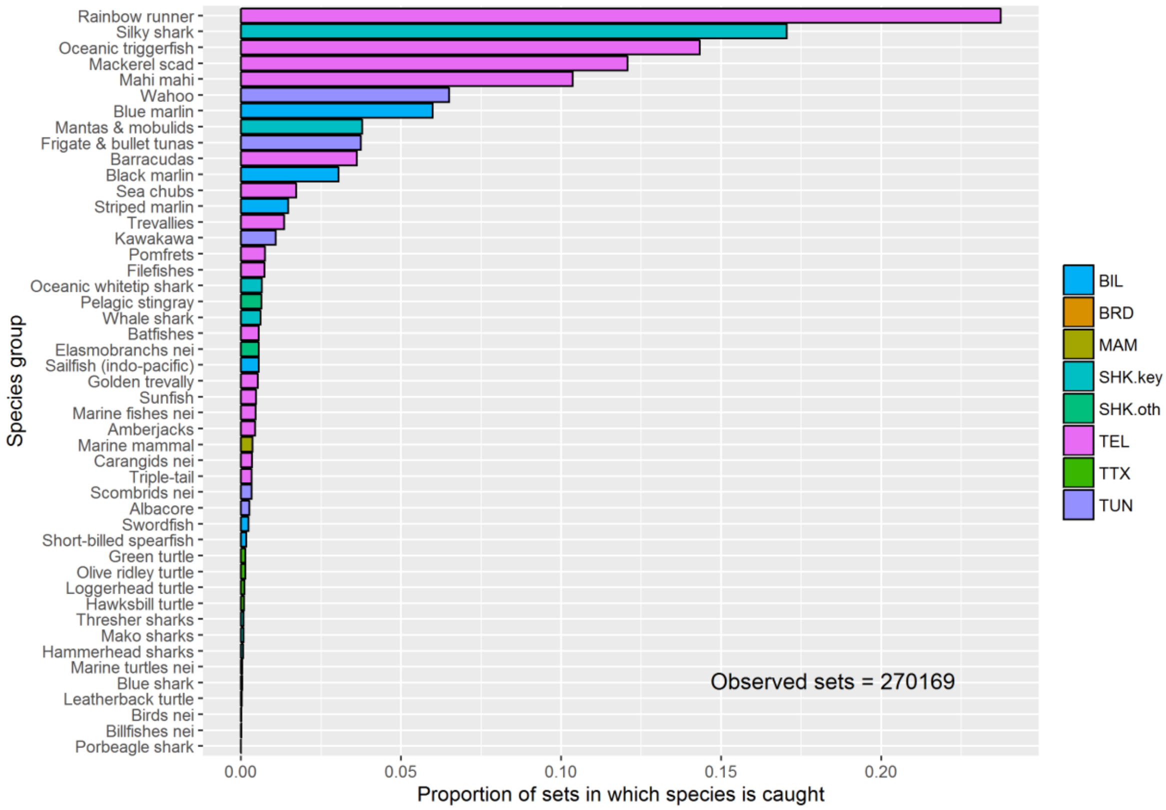


Figure 5 The proportion of purse seine sets with observed bycatch against species/species group. Bar colour denotes billfish (BIL), scombrids (TUN), other teleosts (TEL), WCPFC key shark species (SHK.key), other shark species (SHK.oth), marine mammals (MAM), turtles (TTX) and seabirds (BRD).

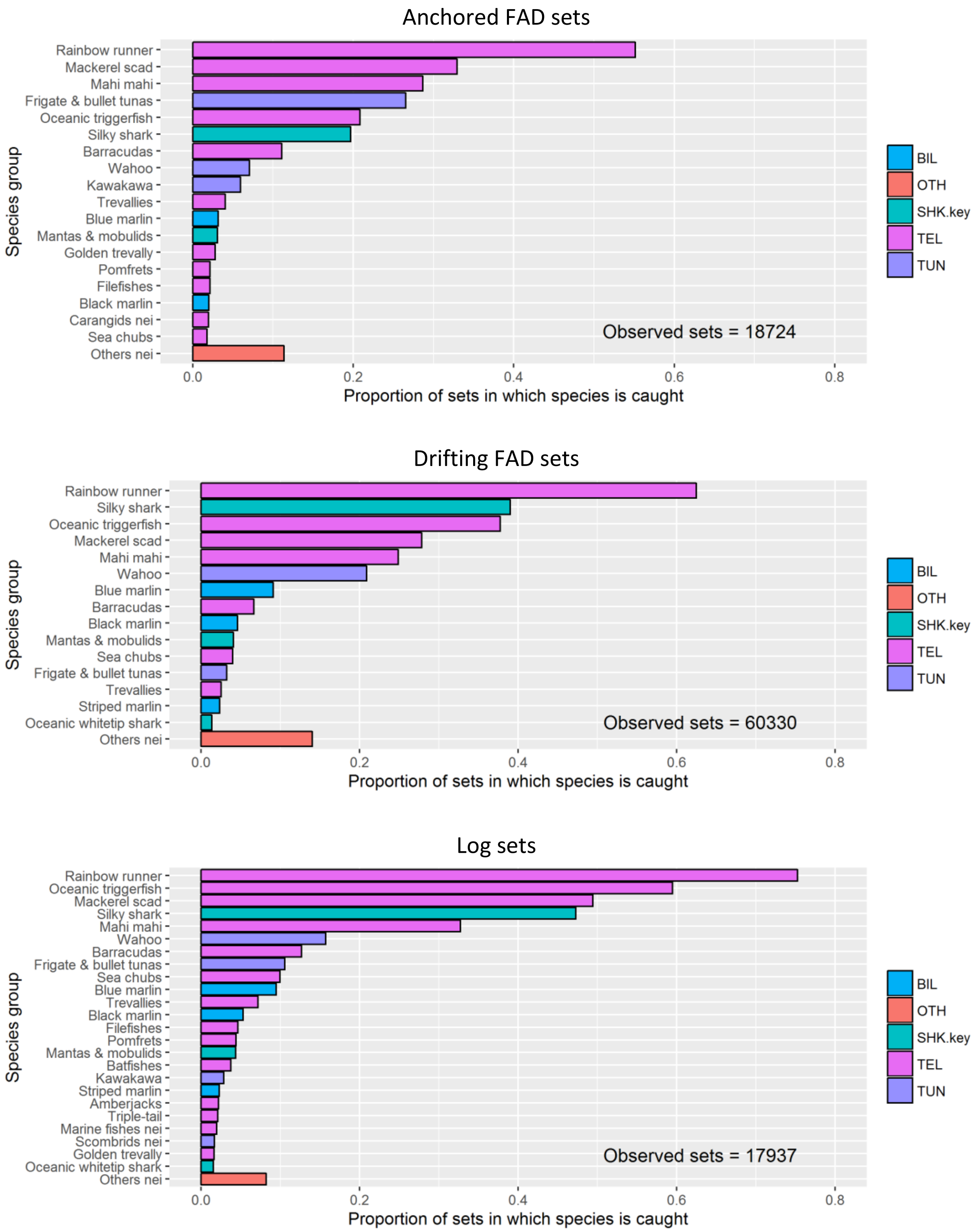


Figure 6 The proportion of purse seine anchored FAD (top), drifting FAD (middle) and log sets (bottom) with observed bycatch against species/species group. Rarely observed species have been grouped in to ‘others nei’. Note – x-axis scale is consistent with Figure 7 for direct comparison. Bar colours as in Figure 5.

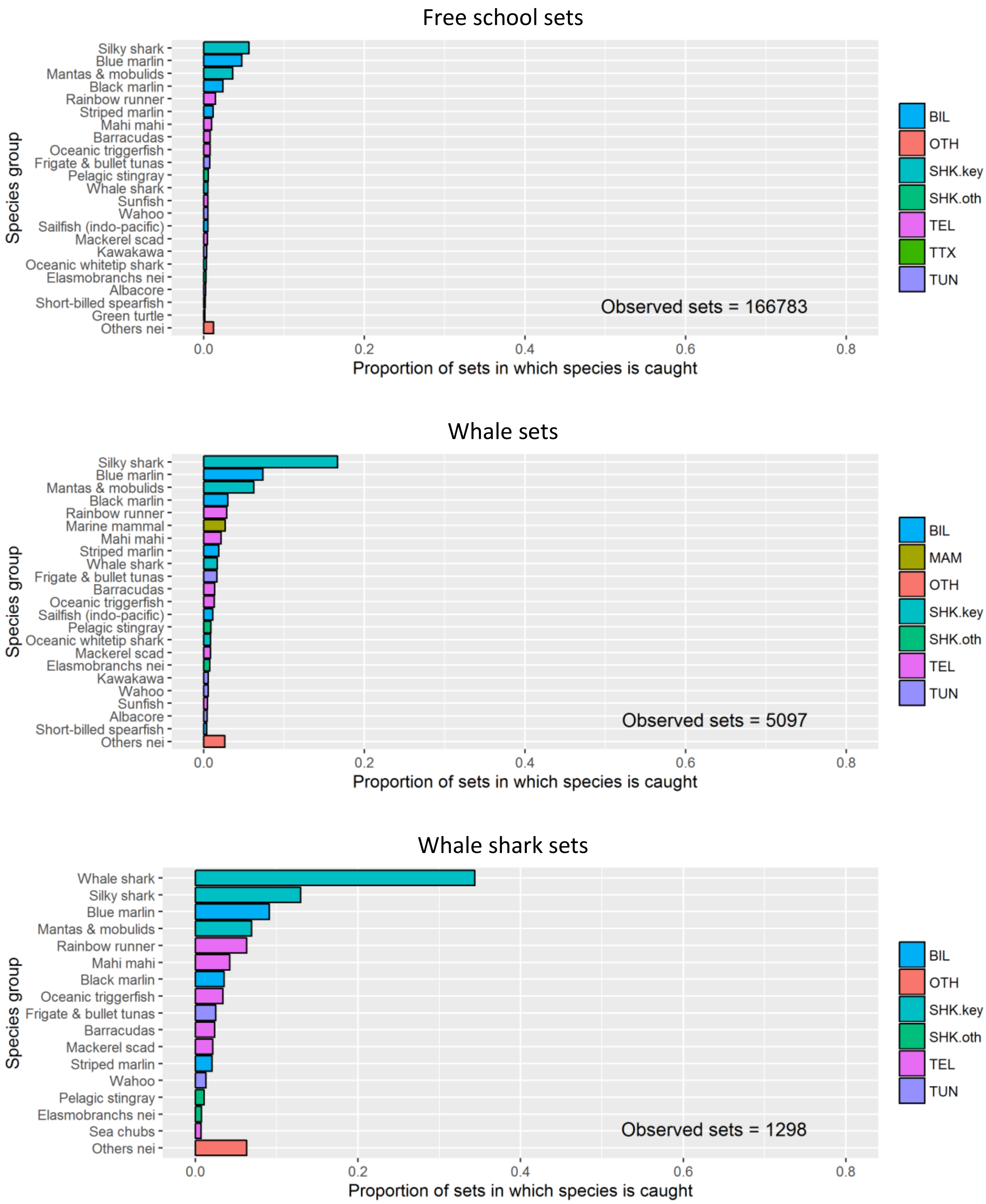


Figure 7 The proportion of purse seine free school (top), whale (middle) and whale shark sets (bottom) with observed bycatch against species/species group. Rarely observed species have been grouped in to 'others nei'. Note – x-axis scale is consistent with Figure 6 for direct comparison. Bar colours as in Figure 5.

The number of species codes used by observers provides a proxy for the species diversity of catches, including bycatch. Observers used the fewest species codes on unassociated sets, with 95 % of these sets having three or fewer codes with about 43% of the sets with no bycatch (Figure 8). Whale associated sets were similar to unassociated sets, with 95 % of sets having four or fewer species codes. Sets on anchored FADs and drifting FADs generally had 4 - 7 and 3 - 7 distinct species codes respectively, with 95 % of these sets having 8 or fewer species. Sets on drifting logs had the highest number of species codes, with 95 % of sets having 10 or fewer species codes. Whale shark sets generally had more species than unassociated and whale associated sets, and fewer species than anchored FAD, drifting FAD and log sets, with 95 % of sets having 5 or fewer species codes.

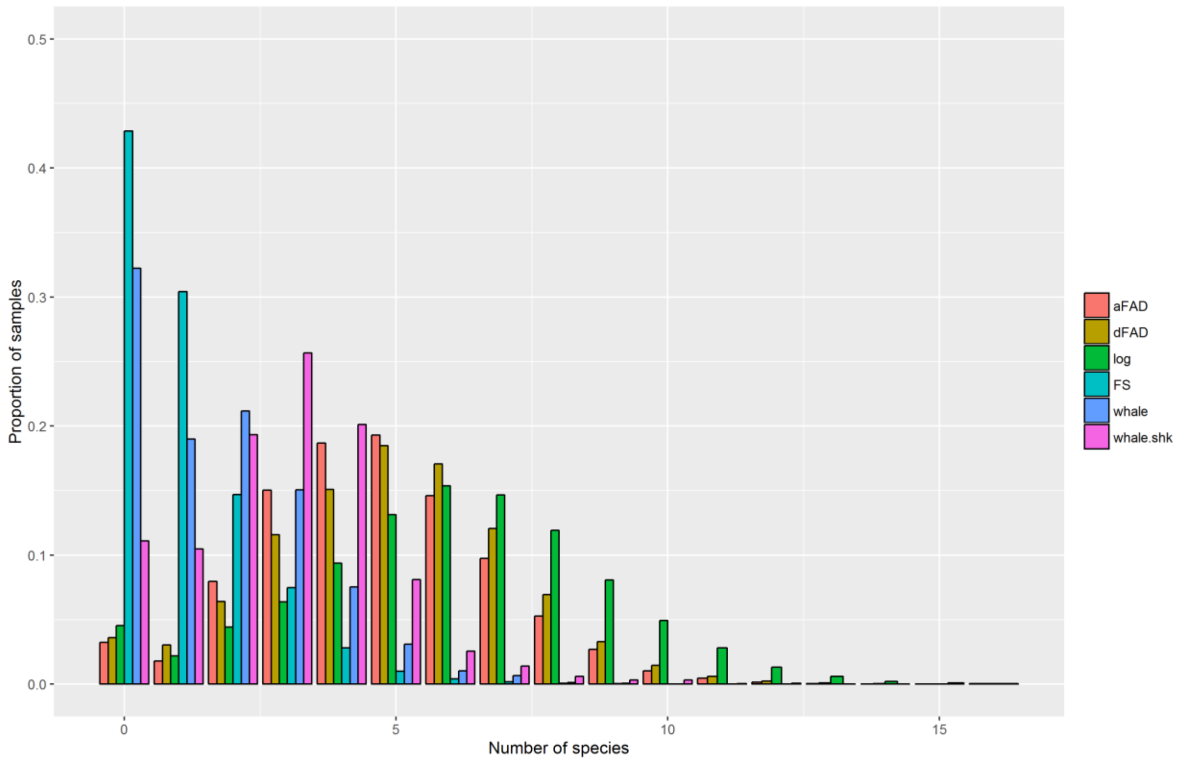


Figure 8 Number of distinct species codes used in observer catch estimates (per set) by set type in the purse seine fisheries.

6. Bycatch composition and fate

In the sub –sections below, we provide a summary of observed bycatch by species/species group, and the recorded fate of the bycatch, for finfish (excluding billfish), billfish, sharks, and other species of special scientific interest.

6.1.Finfish

Rainbow runner accounted for the largest proportion (~42%) of observed finfish bycatch, not including billfish, from 2003 to 2016 (Figure 9). Mackerel scad, oceanic triggerfish, frigate and bullet tunas, and mahi mahi/dolphinfish each accounted for greater than 5 % of total finfish bycatch over the same period. For most finfish bycatch species 50-80 % of observed bycatch was discarded (Figure 10). However for some species retention rate was higher: over 60 % of observed bycatch of frigate and bullet tunas, albacore, kawakawa, wahoo, trevallies and batfishes were retained from 2003 to 2016, though these species accounted for a small proportion of total finfish bycatch compared to rainbow runner, mackerel scad and oceanic triggerfish.

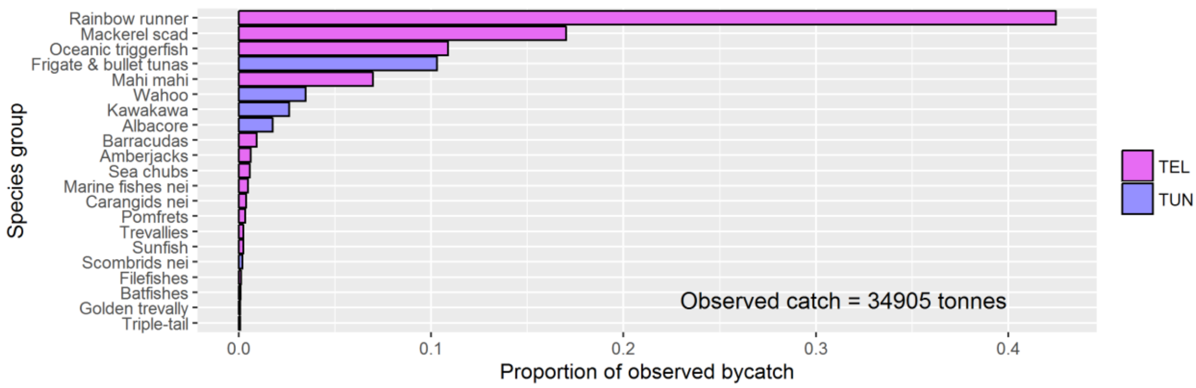


Figure 9 Proportion of observed finfish bycatch (metric tonnes) by species/species group in the purse seine fisheries. Bar colours as in Figure 5.

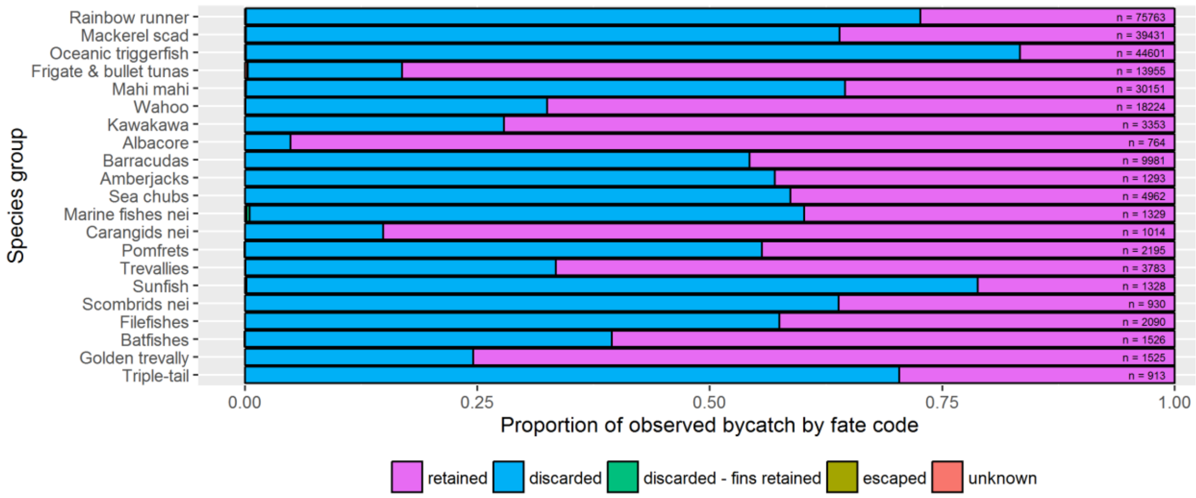


Figure 10 Recorded fate of observed finfish bycatch by species/species group, as a proportion of total observed bycatch (metric tonnes) for the species/species group in the purse seine fisheries. The number of records is provided (n = … for each species/group).

6.2. Billfish

Blue marlin accounted for approximately half of the total observed billfish bycatch between 2003 and 2016, with black marlin accounting for approximately a quarter (Figure 11). Approximately one half to two-thirds of billfish bycatch was discarded over the same period, depending on the species, with the exception of swordfish for which two-thirds of observed bycatch was retained (Figure 12).

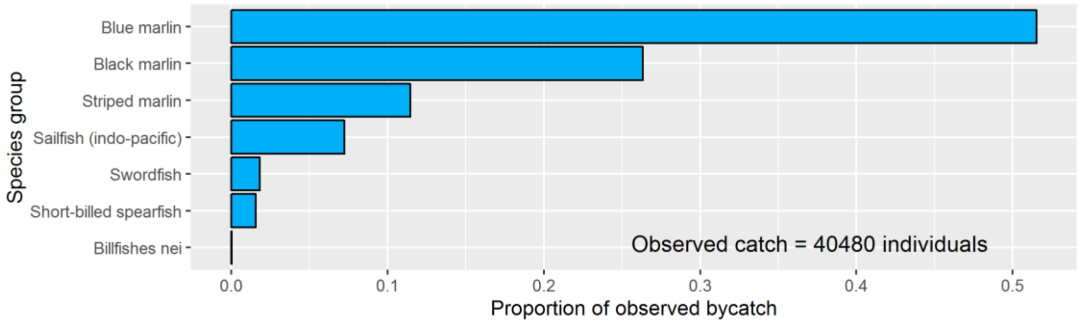


Figure 11 Proportion of observed billfish bycatch (individuals) by species/species group in the purse seine fisheries.

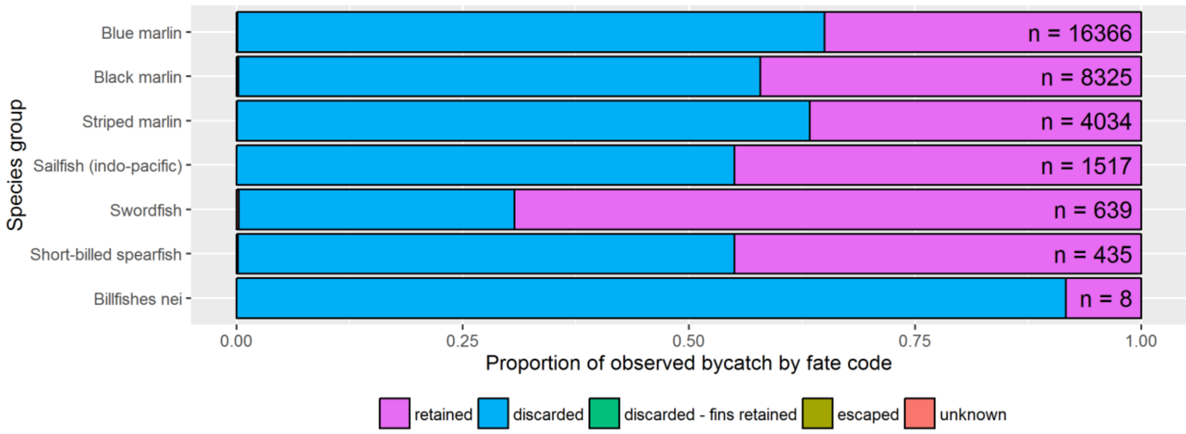


Figure 12 Recorded fate of observed billfish bycatch by species/species group, as a proportion of total observed bycatch (individuals) for the species/species group in the purse seine fisheries. The number of records is provided (n = …).

6.3. Sharks and rays

Silky shark accounted for approximately 85 % of total observed shark bycatch between 2003 and 2016 (Figure 13). However it should be noted that we are comparing shark bycatch in terms of number of individuals, and silky shark may contribute a lower proportion of shark bycatch in terms of weight, given the relative sizes of the different species. Observed shark bycatch was generally discarded over the same time period, at least for species that were most frequently caught (Figure 14). During this time period several species were discarded but with fins retained, particularly for the mako and the blue sharks, but also for the silky, oceanic whitetip, thresher and hammerhead sharks.

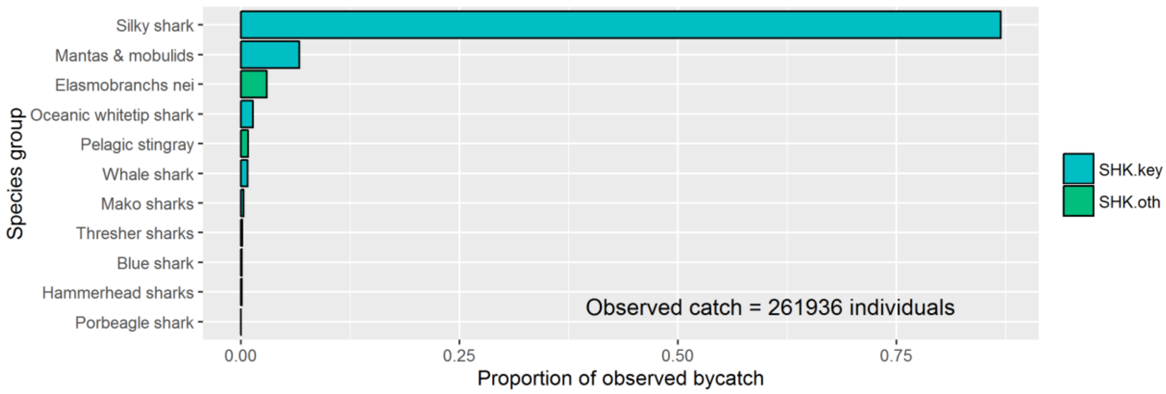


Figure 13 Proportion of observed shark bycatch (individuals) by species/species group in the purse seine fisheries. Bar colours as in Figure 5.

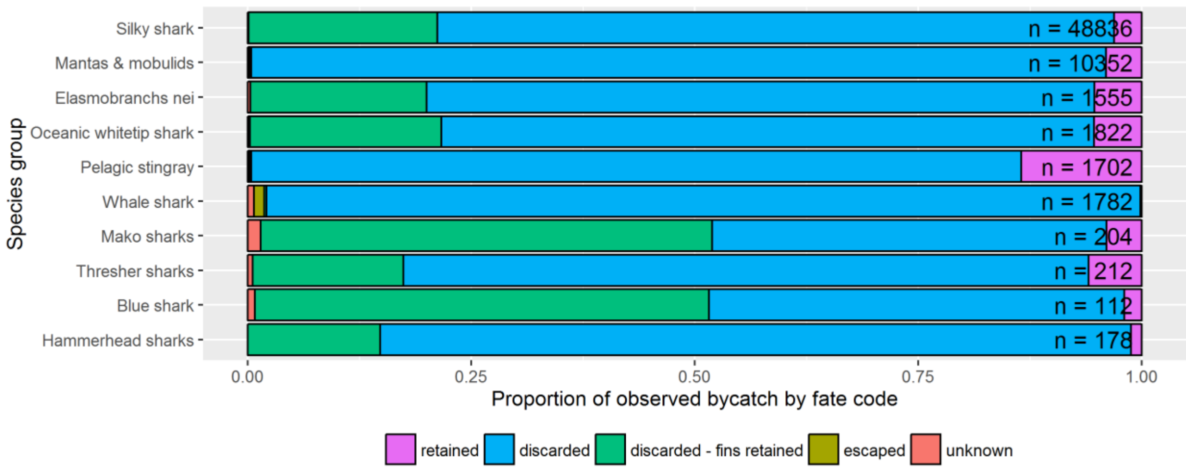


Figure 14 Recorded fate of observed sharks and rays bycatch (individuals) by species/species group, as a proportion of total observed bycatch for the species/species group in the purse seine fisheries. The number of records is provided (n = …).

6.4. Other species of special interest (marine mammals & turtles)

Marine mammals, whilst rarely caught in the large-scale purse seine fishery, accounted for the majority (> 70 %) of observer catch records for species of special interest (i.e. marine mammals, turtles and seabirds) in number of individuals (Figure 15). Observed catches of sea turtles were comparatively rare, accounting for approximately 30 % of the total number of individuals of marine mammals, sea turtles and seabirds. Green, olive ridley, loggerhead and hawksbill turtles were the most frequently observed sea turtle species. The vast majority of marine mammal and turtle bycatch was discarded (Figure 16).

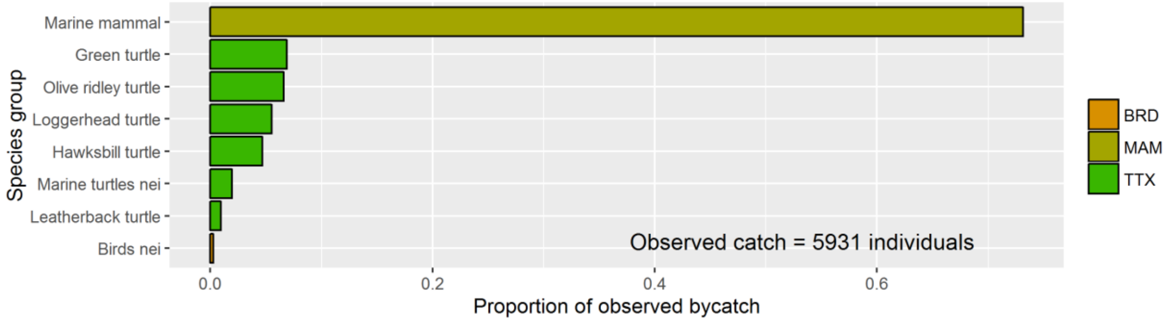


Figure 15 Proportion of observed turtle and marine mammal bycatch (individuals) by species/species group in the purse seine fisheries. Bar colours as in Figure 5.

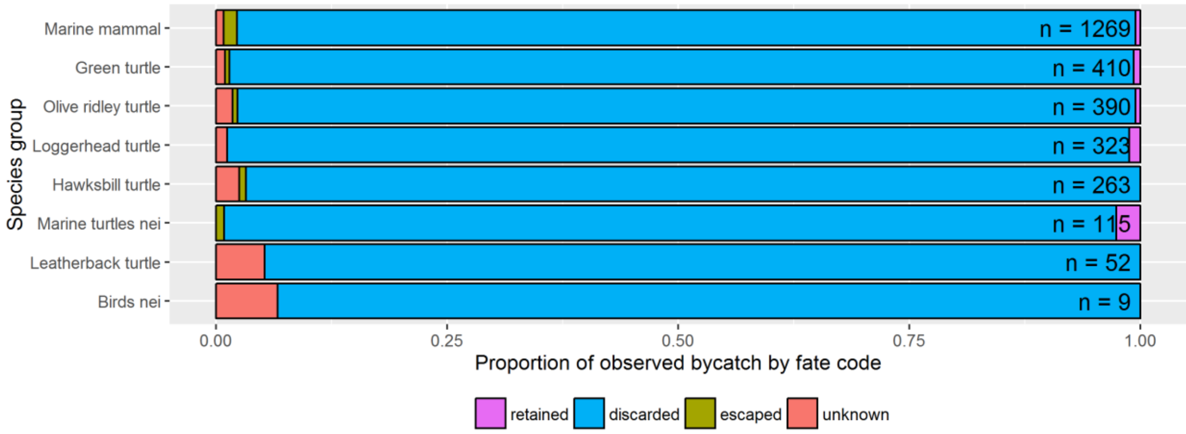


Figure 16 Recorded fate of observed turtle and marine mammal bycatch (individuals) by species/species group, as a proportion of total observed bycatch for the species/species group in the purse seine fisheries. The number of records is provided (n = …).

7. Bycatch estimates

Annual large-scale purse seine bycatch estimates for finfish (excluding billfish), billfish, sharks and rays, marine mammals and turtles are provided in Table 2. It is important to note that these bycatch estimates do not include bycatches of (smaller-scale) Indonesian, Vietnamese and domestic Philippines purse seiners, and Japanese and New Zealand purse seiners operating in temperate waters (see Section 2).

Estimated bycatch for rainbow runner, mahi mahi, blue marlin and silky shark are presented in the main body of the report. Equivalent information for other selected species/species groups are provided in Annex . Effect plots of the bycatch presence/absence models are provided in Annex .

Table 2 Estimated annual bycatch for large-scale purse seine fleets. Median bycatch (med), and lower (low) and upper (high) 95 % confidence intervals, are provided for finfish (excluding billfish) in metric tonnes (mt), and, billfish, sharks and rays, marine mammals and turtles in number of individuals (n).

	Finfish (mt)			Billfish (n)			Sharks (n)			Marine mammals (n)			Turtles (n)		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	5,166	5,543	5,961	6,121	6,539	7,010	55,447	59,109	63,062	419	832	1,556	229	340	471
2004	9,111	9,577	10,060	6,315	6,662	7,063	66,678	70,038	73,662	1,038	1,638	2,420	79	133	204
2005	7,484	7,900	8,354	6,136	6,484	6,894	58,695	61,482	64,390	443	795	1,404	135	201	282
2006	7,244	7,609	7,999	5,973	6,272	6,619	56,447	58,894	61,490	980	1,510	2,205	126	185	256
2007	6,876	7,331	7,819	6,444	6,742	7,073	53,337	56,145	59,233	647	1,172	2,046	210	298	412
2008	5,371	5,830	6,341	6,111	6,434	6,831	53,118	56,129	59,409	627	1,254	2,303	174	252	344
2009	5,996	6,330	6,711	6,494	6,766	7,069	45,084	46,989	48,978	1,114	1,649	2,419	216	292	382
2010	5,093	5,168	5,246	5,786	5,876	5,970	35,410	35,953	36,520	406	490	607	204	222	242
2011	4,520	4,601	4,687	6,467	6,570	6,677	56,168	57,057	57,940	531	620	729	406	432	461
2012	4,575	4,656	4,742	8,512	8,608	8,708	43,418	43,992	44,574	587	696	829	310	333	357
2013	4,760	4,840	4,923	8,359	8,432	8,509	46,588	47,083	47,600	792	872	970	371	390	411
2014	4,819	4,921	5,026	7,843	7,926	8,012	55,081	55,622	56,175	344	412	500	227	246	267
2015	4,529	4,589	4,652	7,447	7,509	7,573	46,201	46,597	47,015	412	469	548	233	247	262
2016	5,409	5,577	5,780	5,706	5,856	6,020	66,512	67,883	69,367	202	331	670	173	212	258

7.1.Finfish

Estimated total finfish bycatch for large-scale purse seine fleets peaked in 2004 at 10,000 tonnes, declining to approximately 5,000 tonnes from 2010 onwards (Table 3). Over the period 2003 to 2016, rainbow runner accounted for 47 % of total finfish bycatch. Mackerel scad, oceanic triggerfish, frigate & bullet tuna and mahi mahi together accounted for 42 % of total finfish bycatch. Log sets accounted for the highest proportion of finfish bycatch from 2003 to 2010, after which drifting FAD sets accounted for the majority of bycatch (

Table 4). The main driver in the declining trend in estimated finfish bycatch from 2003 to 2010 was the strong reduction in log sets over this period (Table 1), which tend to have the highest probability of finfish bycatch presence (Annex). Uncertainty in finfish bycatch estimates was highest pre-2010 when observer coverage was comparatively low, with 95 % confidence intervals of approximately ± 6 % (

Table **4**). The increase in observer coverage reduced uncertainty in bycatch estimates, with 95 % confidence intervals of approximately ± 2 %.

Table 3 Median finfish bycatch estimates (metric tonnes) by species/species group for large-scale purse seine fleets. Species/species group accounting for less than < 2% of total finfish bycatch have been grouped in to 'others'.

Year	Rainbow runner	Mackerel scad	Oceanic triggerfish	Frigate & bullet tunas	Mahi mahi	Wahoo	Kawakawa	Others	Total
2003	2,457	718	598	774	356	79	86	408	**5,543**
2004	4,559	1,210	1,338	815	622	168	152	661	**9,577**
2005	3,645	1,323	1,003	707	442	108	97	523	**7,900**
2006	3,792	1,204	1,021	406	525	96	69	449	**7,609**
2007	3,523	1,157	926	745	335	126	122	330	**7,331**
2008	2,897	740	586	578	419	175	92	253	**5,830**
2009	3,020	961	630	371	525	165	187	418	**6,330**
2010	2,576	819	710	187	356	102	62	349	**5,168**
2011	2,395	471	458	269	311	166	191	330	**4,601**
2012	2,098	629	434	348	361	166	174	439	**4,656**
2013	1,927	964	528	443	441	138	147	247	**4,840**
2014	1,849	921	380	867	350	170	177	200	**4,921**
2015	2,321	921	412	196	347	76	64	247	**4,589**
2016	2,950	1,252	642	95	173	69	93	277	**5,577**
Species totals	**40,008**	**13,290**	**9,667**	**6,801**	**5,564**	**1,803**	**1,712**	**5,131**	**84,473**

Table 4 (left) Total estimated finfish bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated finfish bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	5,166	5,543	5,961	0.183	5.57
2004	9,111	9,577	10,060	0.298	9.00
2005	7,484	7,900	8,354	0.216	6.62
2006	7,244	7,609	7,999	0.227	6.21
2007	6,876	7,331	7,819	0.202	5.40
2008	5,371	5,830	6,341	0.142	4.16
2009	5,996	6,330	6,711	0.144	4.14
2010	5,093	5,168	5,246	0.100	3.48
2011	4,520	4,601	4,687	0.088	3.26
2012	4,575	4,656	4,742	0.081	2.82
2013	4,760	4,840	4,923	0.087	3.06
2014	4,819	4,921	5,026	0.087	2.77
2015	4,529	4,589	4,652	0.096	2.89
2016	5,409	5,577	5,780	0.118	3.46

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	13.6%	14.7%	66.7%	5.0%	0.0%	0.0%
2004	8.4%	11.5%	78.0%	2.1%	0.0%	0.0%
2005	10.7%	14.4%	69.7%	5.2%	0.0%	0.0%
2006	5.6%	16.5%	74.5%	3.4%	0.0%	0.0%
2007	8.0%	19.3%	67.4%	5.4%	0.0%	0.0%
2008	14.0%	39.4%	42.0%	4.6%	0.0%	0.0%
2009	10.0%	37.4%	47.6%	4.9%	0.0%	0.0%
2010	8.9%	41.4%	42.0%	7.7%	0.0%	0.0%
2011	9.6%	56.1%	25.9%	8.4%	0.0%	0.0%
2012	12.0%	40.6%	37.0%	10.5%	0.0%	0.0%
2013	16.6%	39.3%	36.7%	7.4%	0.0%	0.0%
2014	24.5%	41.0%	26.4%	7.9%	0.0%	0.0%
2015	12.4%	50.9%	31.3%	5.4%	0.0%	0.0%
2016	5.3%	61.7%	26.0%	7.0%	0.0%	0.0%

7.1.1. Rainbow runner

Estimated bycatch of rainbow runner displays a similar trend to that of finfish as a whole with a large increase in bycatch from 2003 to 2004, followed by a general decline from 2004 to 2014 (Figure 17, Table 5). However rainbow runner bycatch estimates did increase more strongly between 2014 and 2016, compared to finfish bycatch as a whole. The main driver of the annual trends in rainbow runner is the number of sets by set type, both in a relative and absolute sense, as a result of the strong effect of set type on rainbow runner presence/absence (Figure 27, Annex). The declining trend in rainbow runner between 2004 and 2014 resulted from the reduction in log sets, which have a higher chance of rainbow runner bycatch compared with other set types (Figure 27, Annex). The increasing trend in rainbow runner bycatch from 2014 to 2016 was primarily driven by the increasing trend in the probability of catching rainbow runner in these years (Figure 27, Annex), along with an increase in the observed bycatch when present for these years. Log sets accounted for the majority of rainbow runner bycatch from 2003 to 2007; from 2008 onwards log sets and drifting FAD sets accounted for the majority of rainbow runner bycatch (Table 5). Rainbow runner bycatch in the third quarter was dramatically reduced from 2010 onwards, reflecting the reduction in fishing effort on FADs as a result of FAD closures (Western and Central Pacific Fisheries Commission, 2016 - WCPFC CMM 2016-02).

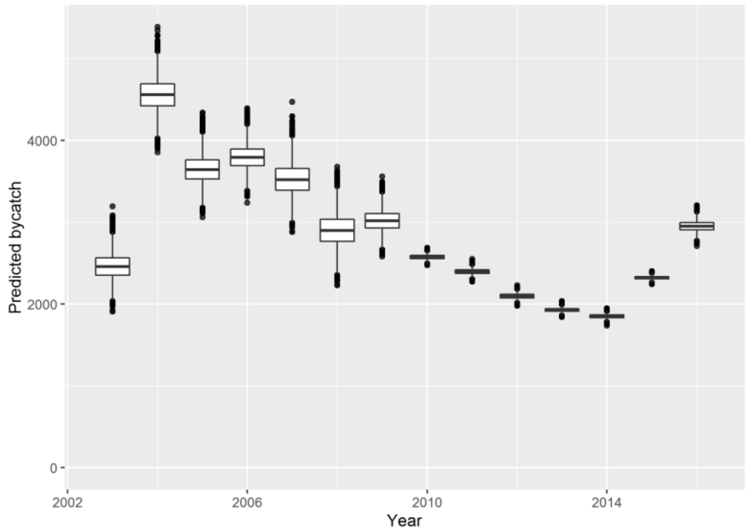


Figure 17 Predicted total annual rainbow runner bycatch (metric tonnes) by year for large-scale purse seine fleets.

Table 5 (left) Total estimated annual rainbow runner bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated rainbow runner bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	2,175	2,457	2,781	0.081	2.47
2004	4,185	4,559	4,954	0.142	4.28
2005	3,326	3,645	3,993	0.100	3.06
2006	3,507	3,792	4,101	0.113	3.09
2007	3,159	3,523	3,930	0.097	2.59
2008	2,534	2,897	3,313	0.070	2.07
2009	2,773	3,020	3,290	0.068	1.98
2010	2,519	2,576	2,635	0.050	1.73
2011	2,330	2,395	2,464	0.046	1.70
2012	2,038	2,098	2,161	0.037	1.27
2013	1,877	1,927	1,978	0.034	1.22
2014	1,801	1,849	1,901	0.033	1.04
2015	2,279	2,321	2,366	0.049	1.46
2016	2,828	2,950	3,093	0.063	1.83

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	9.6%	15.7%	72.7%	1.9%	0.0%	0.0%
2004	6.3%	12.1%	80.4%	1.2%	0.0%	0.0%
2005	7.8%	14.5%	75.3%	2.3%	0.1%	0.0%
2006	4.6%	17.2%	76.6%	1.6%	0.0%	0.0%
2007	5.0%	21.2%	71.4%	2.4%	0.0%	0.0%
2008	10.0%	41.8%	45.2%	2.9%	0.0%	0.0%
2009	6.4%	38.9%	51.7%	3.0%	0.0%	0.0%
2010	6.8%	44.3%	44.4%	4.5%	0.0%	0.0%
2011	7.9%	60.3%	27.8%	4.0%	0.0%	0.0%
2012	9.2%	46.1%	41.7%	3.0%	0.0%	0.0%
2013	7.2%	44.8%	44.7%	3.3%	0.0%	0.0%
2014	7.3%	53.2%	35.0%	4.4%	0.0%	0.0%
2015	10.3%	53.4%	33.1%	3.2%	0.0%	0.0%
2016	3.9%	63.4%	27.7%	5.0%	0.0%	0.0%

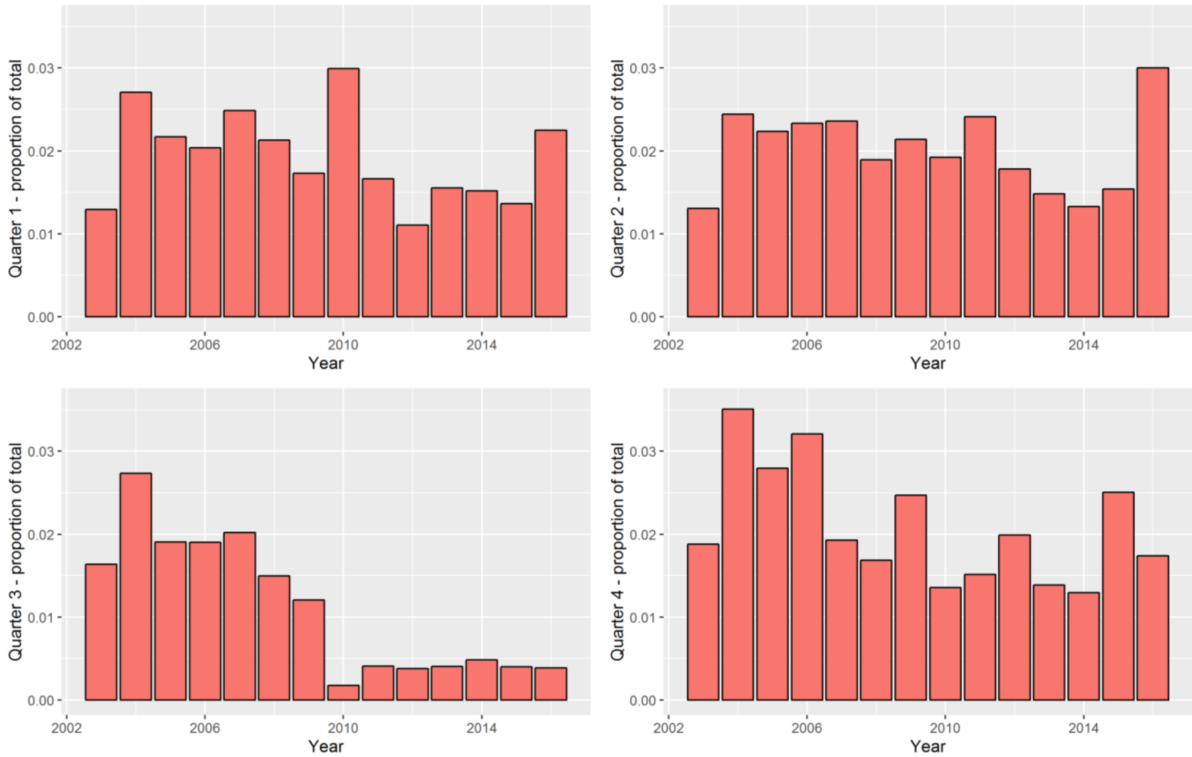


Figure 18 Quarterly rainbow runner purse seine bycatch (as a proportion of total rainbow runner bycatch from 2003 to 2016), by year for the first quarter (top left), second quarter (top right), third quarter (bottom left) and fourth quarter (bottom right).

7.1.2. Mahi mahi

Estimated bycatch of mahi mahi displays a generally decreasing trend from 2003 to 2016, though with substantial inter-annual variation (Figure 19, Table 6). The main driver of the annual trends in mahi mahi is the number of sets by set type, both in a relative and absolute sense, as a result of the strong effect of set type on mahi mahi presence/absence (Figure 31, Annex). The increases in mahi mahi bycatch in 2004 and 2006, and decreases in 2005 and 2007 were driven by the change in numbers of log sets. Log sets accounted for the majority of mahi mahi bycatch from 2003 to 2007; from 2008 onwards drifting FAD sets accounted for the highest proportion of mahi mahi bycatch (Table 6). Similarly to rainbow runner, mahi mahi bycatch in the third quarter was dramatically reduced from 2010 onwards, reflecting the reduction in fishing effort on FADs as a result of FAD closures (Western and Central Pacific Fisheries Commission, 2016 - WCPFC CMM 2016-02).

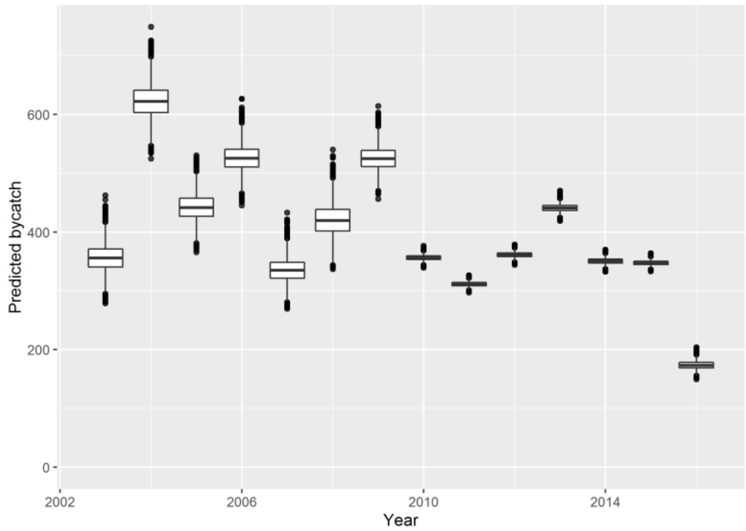


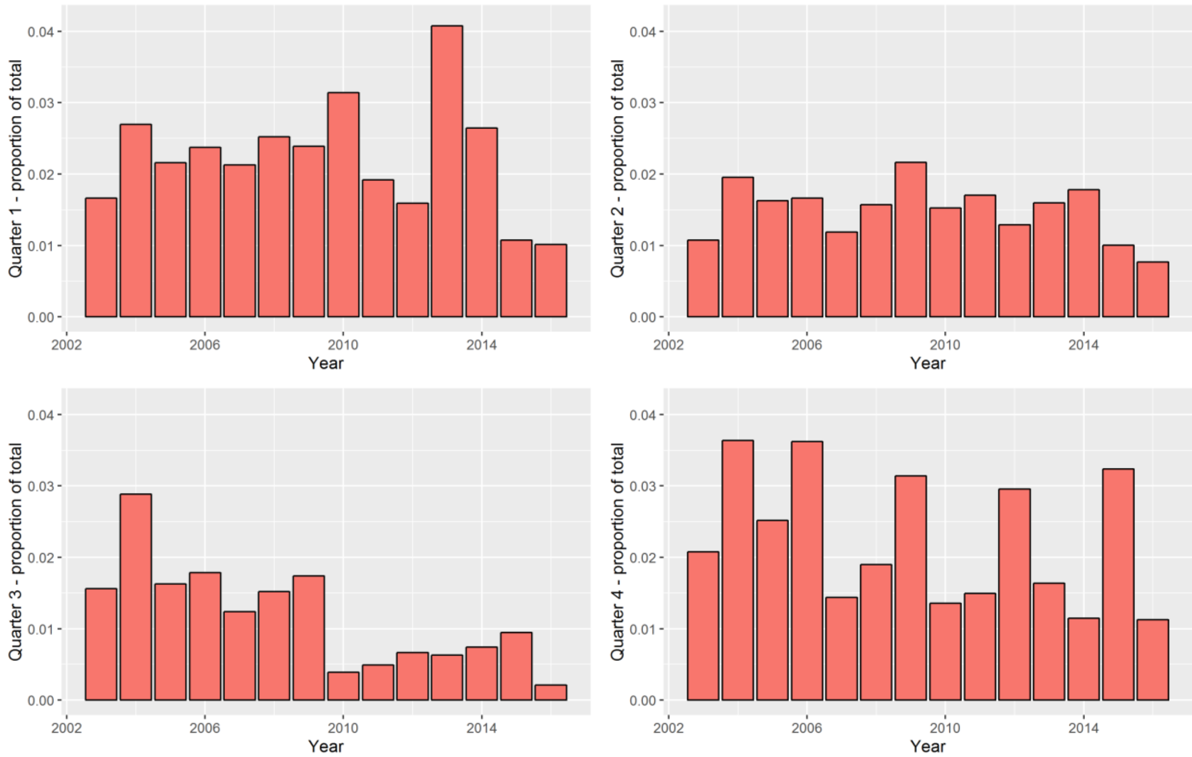
Figure 19 Predicted total annual mahi mahi bycatch (metric tonnes) by year for large-scale purse seine fleets.

Table 6 (left) Total estimated annual mahi mahi bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated mahi mahi bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	313	356	405	0.012	0.36
2004	570	622	680	0.019	0.58
2005	401	442	489	0.012	0.37
2006	484	525	572	0.016	0.43
2007	298	335	379	0.009	0.25
2008	373	419	477	0.010	0.30
2009	488	525	566	0.012	0.34
2010	347	356	365	0.007	0.24
2011	304	311	319	0.006	0.22
2012	352	361	370	0.006	0.22
2013	429	441	453	0.008	0.28
2014	341	350	361	0.006	0.20
2015	340	347	356	0.007	0.22
2016	161	173	188	0.004	0.11

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	14.1%	20.3%	61.0%	4.6%	0.0%	0.0%
2004	9.1%	14.8%	74.5%	1.6%	0.0%	0.0%
2005	12.5%	19.1%	65.0%	3.4%	0.0%	0.0%
2006	7.0%	21.5%	68.7%	2.9%	0.0%	0.0%
2007	8.5%	23.6%	64.4%	3.5%	0.0%	0.0%
2008	12.3%	49.4%	34.2%	4.1%	0.0%	0.0%
2009	10.5%	43.8%	40.3%	5.5%	0.0%	0.0%
2010	11.7%	47.9%	31.1%	9.2%	0.1%	0.0%
2011	13.1%	59.9%	21.1%	6.0%	0.0%	0.0%
2012	15.4%	47.5%	30.8%	6.2%	0.0%	0.0%
2013	10.5%	63.0%	21.8%	4.7%	0.0%	0.0%
2014	10.3%	60.4%	21.4%	7.9%	0.0%	0.0%
2015	19.9%	45.1%	30.0%	5.0%	0.0%	0.0%
2016	7.6%	66.6%	18.3%	7.5%	0.0%	0.0%

Figure 20 Quarterly mahi mahi purse seine bycatch (as a proportion of total mahi mahi bycatch from 2003 to 2016), by year for the first quarter (top left), second quarter (top right), third quarter (bottom left) and fourth quarter (bottom right).



7.2.Billfish

Estimated total billfish bycatch for large-scale purse seine fleets remained in the region of 6,500 individuals from 2003 to 2011. In 2012 billfish bycatch increased to 8,500 individuals, before decreasing from 8,500 individuals to 6,000 individuals from 2013 to 2016 (Table 7). Blue marlin accounted for half of total billfish bycatch over the period 2003 to 2016, with black marlin and striped marlin accounting for 26 % and 11 % respectively. (Note that recent as yet unreported genetic analyses suggest that historically billfish identified as black marlin by observers in some fisheries may generally actually be blue marlin. A caveat is that the sample sizes involved in the genetics work are small.)

Unassociated sets and sets on drifting FADs accounted for the highest proportion of billfish bycatch from 2008 onwards, with unassociated sets and log sets accounting for the highest proportion of billfish bycatch before 2008 (Table 8). The increase in billfish bycatch in 2012 and 2013 was mainly driven by the increase in sets on unassociated schools in these years (Table 1). Uncertainty in billfish bycatch estimates was highest pre-2010 when observer coverage was comparatively low, with 95 % confidence intervals of approximately ± 6 % (Table 8). The increase in observer coverage in 2010 reduced uncertainty in bycatch estimates, with 95 % confidence intervals of approximately ± 1.5 %.

Table 7 Median billfish bycatch estimates (individuals) by species/species group for large-scale purse seine fleets. Species/species group accounting for less than < 2% of total marlin bycatch have been grouped in to 'others'.

Year	Blue marlin	Black marlin	Striped marlin	Sailfish (indo-pacific)	Swordfish	Others	Total
2003	2,441	2,423	653	703	121	171	**6,539**
2004	2,894	2,255	562	674	137	123	**6,662**
2005	3,098	1,663	689	837	145	38	**6,484**
2006	3,001	1,702	631	616	229	82	**6,272**
2007	4,116	1,383	550	386	201	85	**6,742**
2008	3,629	1,639	471	490	128	57	**6,434**
2009	3,336	1,649	959	489	184	135	**6,766**
2010	2,701	1,589	769	530	133	151	**5,876**
2011	3,143	1,760	866	590	131	78	**6,570**
2012	4,416	2,261	1,142	443	172	172	**8,608**
2013	4,157	2,460	1,132	430	102	149	**8,432**
2014	4,481	1,804	980	446	97	117	**7,926**
2015	4,624	1,488	932	274	68	122	**7,509**
2016	3,521	1,240	599	307	107	74	**5,856**
Species totals	**49,559**	**25,317**	**10,934**	**7,213**	**1,955**	**1,553**	**96,675**

Table 8 (left) Total estimated billfish bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated billfish bycatch (individuals) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	6,121	6,539	7,010	0.215	6.57
2004	6,315	6,662	7,063	0.207	6.26
2005	6,136	6,484	6,894	0.177	5.43
2006	5,973	6,272	6,619	0.187	5.12
2007	6,444	6,742	7,073	0.185	4.97
2008	6,111	6,434	6,831	0.156	4.59
2009	6,494	6,766	7,069	0.153	4.43
2010	5,786	5,876	5,970	0.114	3.95
2011	6,467	6,570	6,677	0.126	4.66
2012	8,512	8,608	8,708	0.150	5.22
2013	8,359	8,432	8,509	0.151	5.32
2014	7,843	7,926	8,012	0.140	4.46
2015	7,447	7,509	7,573	0.157	4.72
2016	5,706	5,856	6,020	0.124	3.64

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	5.9%	15.1%	36.5%	42.3%	0.1%	0.1%
2004	4.9%	16.7%	56.5%	21.8%	0.1%	0.0%
2005	4.8%	13.7%	40.9%	40.5%	0.1%	0.0%
2006	4.0%	16.5%	48.0%	31.4%	0.0%	0.0%
2007	3.8%	21.2%	34.3%	40.5%	0.3%	0.0%
2008	5.0%	36.3%	18.1%	40.4%	0.2%	0.0%
2009	4.4%	36.5%	22.9%	35.9%	0.3%	0.0%
2010	3.8%	23.5%	14.8%	57.0%	0.9%	0.1%
2011	5.0%	41.4%	11.2%	42.1%	0.4%	0.0%
2012	3.3%	34.5%	11.6%	50.4%	0.2%	0.0%
2013	1.9%	35.3%	11.9%	50.7%	0.2%	0.0%
2014	1.1%	38.6%	7.6%	52.4%	0.2%	0.0%
2015	1.7%	30.2%	8.1%	59.6%	0.4%	0.0%
2016	2.6%	35.2%	10.1%	51.7%	0.3%	0.0%

7.2.1. Blue marlin

Estimated bycatch of blue marlin displays a complex temporal trend, with an increasing trend from 2003 to 2005, a declining trend from 2007 to 2010, an increasing trend from 2010 to 2015, and often large inter-annual changes (Figure 21). Again, the number of sets by set-type is the main driver in temporal trends in blue marlin bycatch, given the strong effect of set type on blue marlin presence/absence (Figure 34, Annex). For example, the large increases in bycatch in 2007 and 2012 were mainly driven by large increases in the number of sets on unassociated schools (Table 1). As for billfish in general, unassociated and log sets accounted for the highest proportions of blue marlin catch from 2003 to 2007, shifting to a combination of unassociated and drifting FAD sets from 2008 to 2016. Blue marlin bycatch does not display much variation in bycatch by quarter (Figure 22), particularly in comparison to rainbow runner (Figure 18), mahi mahi (Figure 20) and silky shark (Figure 24). Bycatches of these species were markedly lower in the third quarter of the year from 2010 onwards as a result of FAD closures. The FAD closures had less impact on blue marlin bycatch as a larger proportion of bycatch was accounted for by unassociated sets (Table 9).

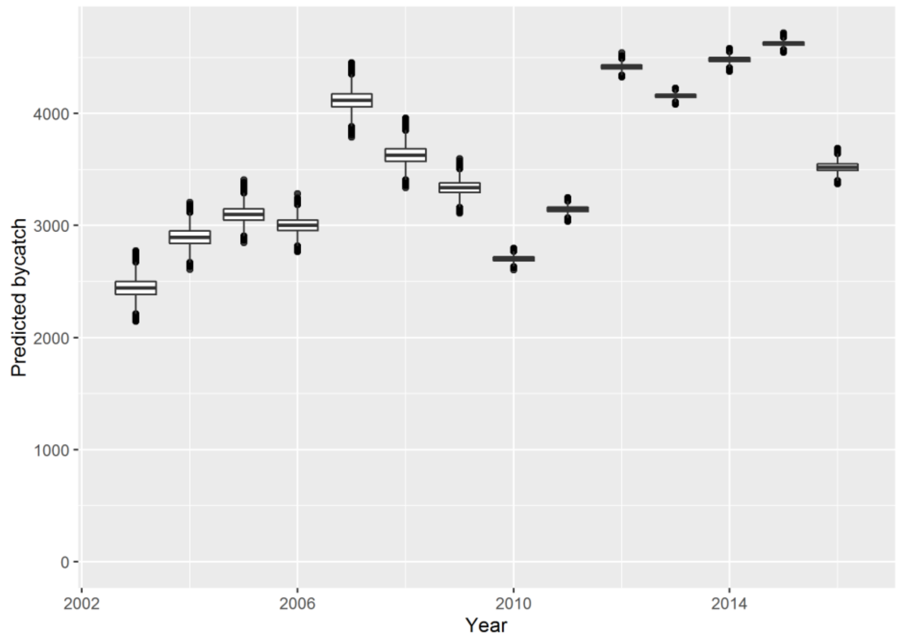


Figure 21 Predicted total annual blue marlin bycatch (individuals) by year for large-scale purse seine fleets.

Table 9 (left) Total estimated annual blue marlin bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated blue marlin bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	2,283	2,441	2,616	0.080	2.45
2004	2,741	2,894	3,059	0.090	2.72
2005	2,960	3,098	3,245	0.085	2.60
2006	2,873	3,001	3,138	0.090	2.45
2007	3,949	4,116	4,294	0.113	3.03
2008	3,468	3,629	3,795	0.088	2.59
2009	3,216	3,336	3,462	0.076	2.18
2010	2,655	2,701	2,750	0.052	1.82
2011	3,090	3,143	3,199	0.060	2.23
2012	4,364	4,416	4,470	0.077	2.68
2013	4,117	4,157	4,198	0.074	2.62
2014	4,428	4,481	4,534	0.079	2.52
2015	4,584	4,624	4,666	0.097	2.91
2016	3,433	3,521	3,612	0.075	2.19

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	5.3%	16.6%	38.4%	39.6%	0.1%	0.0%
2004	4.0%	16.9%	56.0%	22.9%	0.1%	0.0%
2005	4.6%	14.9%	41.6%	38.8%	0.1%	0.0%
2006	3.5%	18.6%	48.7%	29.1%	0.0%	0.0%
2007	2.6%	22.1%	36.1%	38.9%	0.2%	0.0%
2008	4.0%	37.0%	18.3%	40.5%	0.3%	0.0%
2009	3.2%	35.0%	23.6%	37.9%	0.2%	0.0%
2010	3.0%	24.9%	14.7%	56.3%	1.0%	0.1%
2011	3.9%	42.1%	11.2%	42.4%	0.4%	0.0%
2012	3.0%	36.0%	11.7%	49.1%	0.2%	0.0%
2013	1.6%	36.0%	12.1%	50.0%	0.2%	0.0%
2014	1.2%	38.7%	7.8%	52.1%	0.2%	0.0%
2015	1.6%	31.1%	7.9%	59.2%	0.3%	0.0%
2016	1.5%	37.5%	9.2%	51.5%	0.2%	0.0%

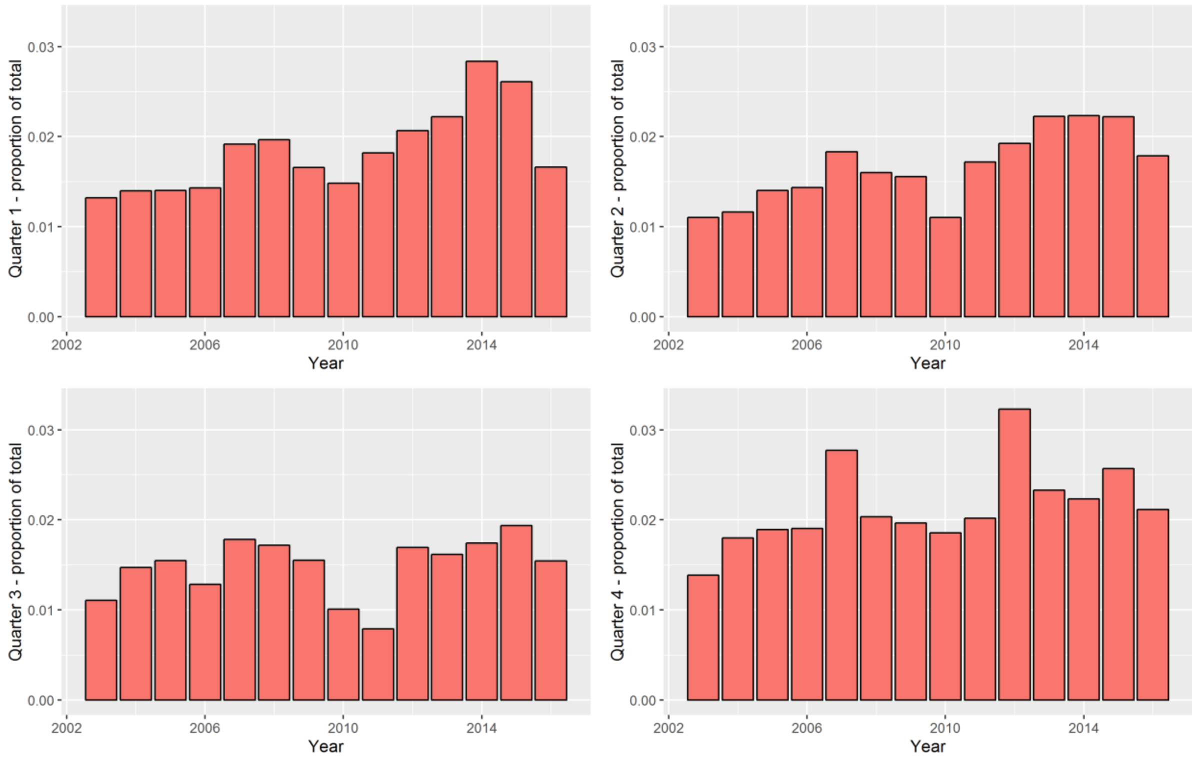


Figure 22 Quarterly blue marlin purse seine bycatch (as a proportion of total blue marlin bycatch from 2003 to 2016), by year for the first quarter (top left), second quarter (top right), third quarter (bottom left) and fourth quarter (bottom right).

7.3. Sharks and rays

Estimated total shark bycatch displayed a generally declining trend from 2004 to 2010, reducing from 70,000 to 36,000 individuals per year, and an increasing trend from 2012 to 2016 when it reached 68,000 individuals (Table 10). Shark bycatch estimates in 2010 and 2015 were lower than might be expected given the general trend, with shark bycatch in 2011 comparatively high. Silky shark accounted for 88 % of estimated shark bycatch from 2003 to 2016, with mantas and mobulid rays, and oceanic whitetip accounting for 5 and 1.6 % respectively.

Log sets accounted for the highest proportion of sharks and rays bycatch from 2003 to 2007, with drifting FAD sets accounting for the highest proportion from 2008 onwards (Table 11). The declining trend in shark bycatch from 2003 to 2007 was a result in the decline in log sets (Table 1), which have the highest probability of catching silky sharks (Figure 36, Annex). The relatively low levels of shark bycatch in 2010 and 2015 are a result of the reduced number of drifting FAD sets in these years, which have a relatively high chance of catching silky sharks (Figure 36, Annex). Conversely, the high shark bycatch in 2011 was due to the increase in drifting FAD sets, along with a general increase in the chance of catching silky sharks in that year regardless of set type (Figure 36, Annex). Uncertainty in shark bycatch estimates was highest pre-2010 when observer coverage was comparatively low, with 95 % confidence intervals of approximately ± 5 % (Table 11). The increase in observer coverage in 2010 reduced uncertainty in bycatch estimates, with 95 % confidence intervals of approximately ± 1.3 %.

Table 10 Median shark bycatch estimates (individuals) by species/species group for large-scale purse seine fleets. Species/species group accounting for less than < 2% of total shark bycatch have been grouped in to 'others'.

Year	Silky shark	Mantas & mobulids	Oceanic whitetip shark	Elasmobranchs nei	Others	Total
2003	42,951	2,187	2,073	10,093	1,650	**59,109**
2004	59,858	2,484	2,407	4,079	1,105	**70,038**
2005	55,283	2,174	1,449	1,744	740	**61,482**
2006	54,583	1,830	620	1,078	692	**58,894**
2007	51,385	2,169	939	820	748	**56,145**
2008	49,538	2,642	1,212	1,340	1,182	**56,129**
2009	42,830	2,045	421	764	838	**46,989**
2010	31,252	2,533	564	711	880	**35,953**
2011	51,947	2,762	463	1,175	691	**57,057**
2012	36,616	4,845	481	665	1,373	**43,992**
2013	41,476	3,586	419	743	846	**47,083**
2014	49,696	3,512	529	1,015	854	**55,622**
2015	40,323	2,940	556	2,045	723	**46,597**
2016	61,738	3,713	509	1,290	550	**67,883**
Species totals	**669,476**	**39,423**	**12,642**	**27,562**	**12,872**	**762,975**

Table 11 (left) Total estimated shark bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated shark bycatch (individuals) by association type.

Year	Estimated bycatch Low	Median	High	Bycatch rate per set	'000 mt
2003	55,447	59,109	63,062	1.947	59.36
2004	66,678	70,038	73,662	2.178	65.79
2005	58,695	61,482	64,390	1.681	51.54
2006	56,447	58,894	61,490	1.760	48.05
2007	53,337	56,145	59,233	1.545	41.35
2008	53,118	56,129	59,409	1.363	40.06
2009	45,084	46,989	48,978	1.065	30.77
2010	35,410	35,953	36,520	0.699	24.18
2011	56,168	57,057	57,940	1.092	40.47
2012	43,418	43,992	44,574	0.767	26.67
2013	46,588	47,083	47,600	0.842	29.72
2014	55,081	55,622	56,175	0.980	31.30
2015	46,201	46,597	47,015	0.974	29.30
2016	66,512	67,883	69,367	1.439	42.18

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	8.4%	18.5%	58.2%	14.9%	0.0%	0.0%
2004	5.1%	18.1%	70.1%	6.8%	0.0%	0.0%
2005	6.3%	17.0%	62.7%	14.0%	0.0%	0.0%
2006	4.2%	19.1%	66.1%	10.6%	0.0%	0.0%
2007	4.1%	21.9%	57.8%	16.0%	0.2%	0.0%
2008	7.6%	42.7%	32.4%	17.2%	0.1%	0.0%
2009	5.0%	43.2%	39.0%	12.6%	0.1%	0.0%
2010	5.6%	35.7%	31.7%	26.3%	0.7%	0.0%
2011	5.2%	54.8%	20.3%	19.4%	0.3%	0.0%
2012	5.0%	43.2%	25.9%	25.6%	0.3%	0.0%
2013	2.6%	48.9%	24.3%	24.0%	0.2%	0.0%
2014	2.1%	52.9%	18.4%	26.3%	0.2%	0.0%
2015	5.5%	51.4%	20.0%	22.8%	0.2%	0.0%
2016	3.1%	48.2%	14.4%	33.5%	0.7%	0.1%

7.3.1. Silky shark

Silky shark bycatch displays the same trends as the estimates for elasmobranch bycatch in general, as expected given that silky shark accounts for nearly 90 % of the estimated bycatch of sharks and rays (in terms of numbers). The summary of shark and ray bycatch above applies also to silky sharks. However it is worth noting that silky shark bycatch in the third quarter of the year declined significantly in 2010, as a result of the FAD closure (Figure 24). The reduction is not so pronounced as that for rainbow runner (Figure 18), given the higher proportions of silky shark caught in sets on unassociated schools (Table 1112).

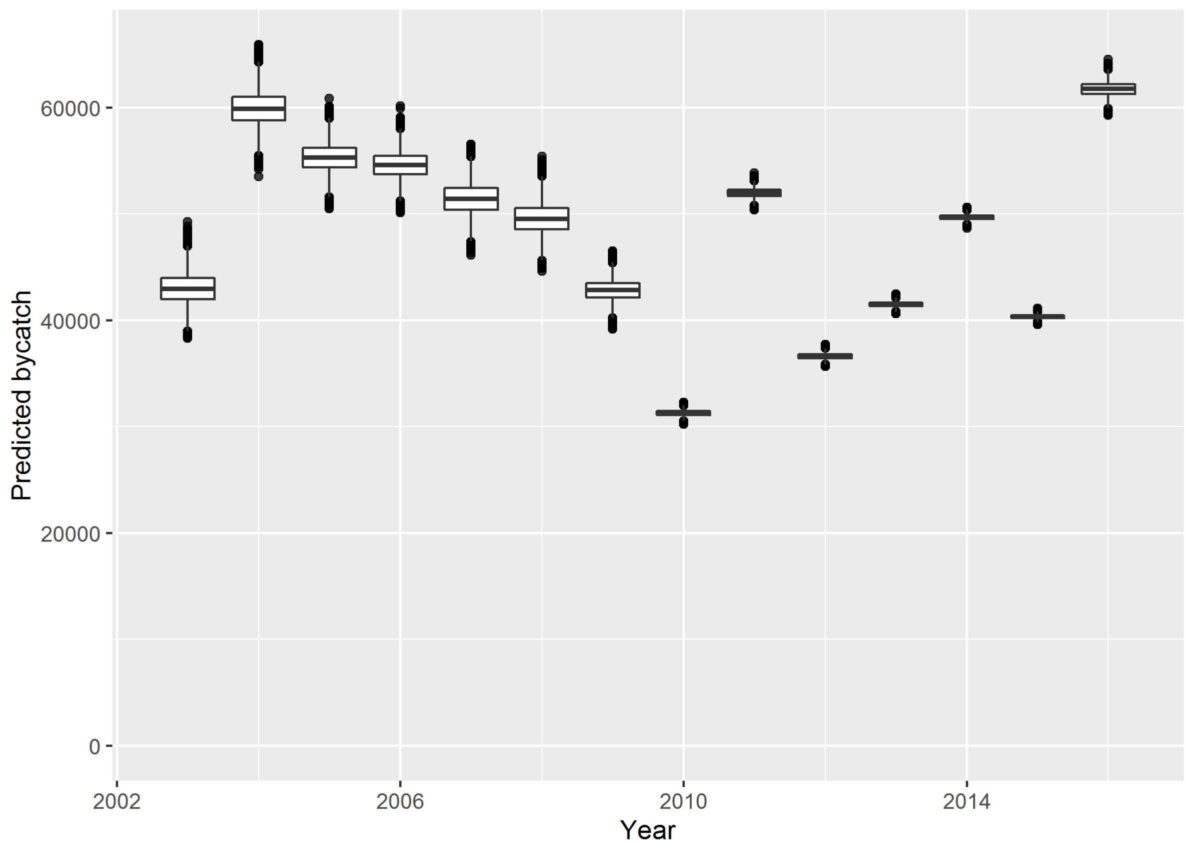


Figure 23 Predicted total annual bycatch of silky shark by year for large-scale purse seine fleets.

Table 12 (left) Total estimated annual silky shark bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated silky shark bycatch by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	40,160	42,951	46,023	1.415	43.13
2004	56,756	59,858	63,222	1.861	56.23
2005	52,631	55,283	58,078	1.511	46.34
2006	52,207	54,583	57,077	1.631	44.53
2007	48,632	51,385	54,351	1.414	37.84
2008	46,780	49,538	52,570	1.203	35.36
2009	40,991	42,830	44,714	0.971	28.04
2010	30,727	31,252	31,806	0.607	21.02
2011	51,091	51,947	52,820	0.994	36.85
2012	36,076	36,616	37,165	0.638	22.20
2013	41,001	41,476	41,981	0.742	26.18
2014	49,194	49,696	50,210	0.876	27.96
2015	39,965	40,323	40,688	0.843	25.35
2016	60,420	61,738	63,158	1.309	38.36

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	9.3%	18.5%	58.4%	13.7%	0.0%	0.0%
2004	4.8%	16.4%	73.3%	5.5%	0.0%	0.0%
2005	6.0%	17.6%	64.1%	12.2%	0.0%	0.0%
2006	4.1%	19.5%	67.8%	8.6%	0.0%	0.0%
2007	4.1%	22.3%	59.9%	13.5%	0.2%	0.0%
2008	7.6%	44.9%	33.6%	13.9%	0.1%	0.0%
2009	4.9%	44.3%	40.6%	10.0%	0.1%	0.0%
2010	5.8%	37.8%	34.9%	20.9%	0.6%	0.0%
2011	5.3%	56.3%	21.3%	16.9%	0.2%	0.0%
2012	5.0%	46.8%	28.8%	19.2%	0.2%	0.0%
2013	2.7%	51.6%	26.3%	19.3%	0.2%	0.0%
2014	2.1%	55.5%	19.5%	22.6%	0.2%	0.0%
2015	5.2%	53.8%	21.9%	18.8%	0.2%	0.0%
2016	3.1%	50.6%	15.1%	30.3%	0.8%	0.1%

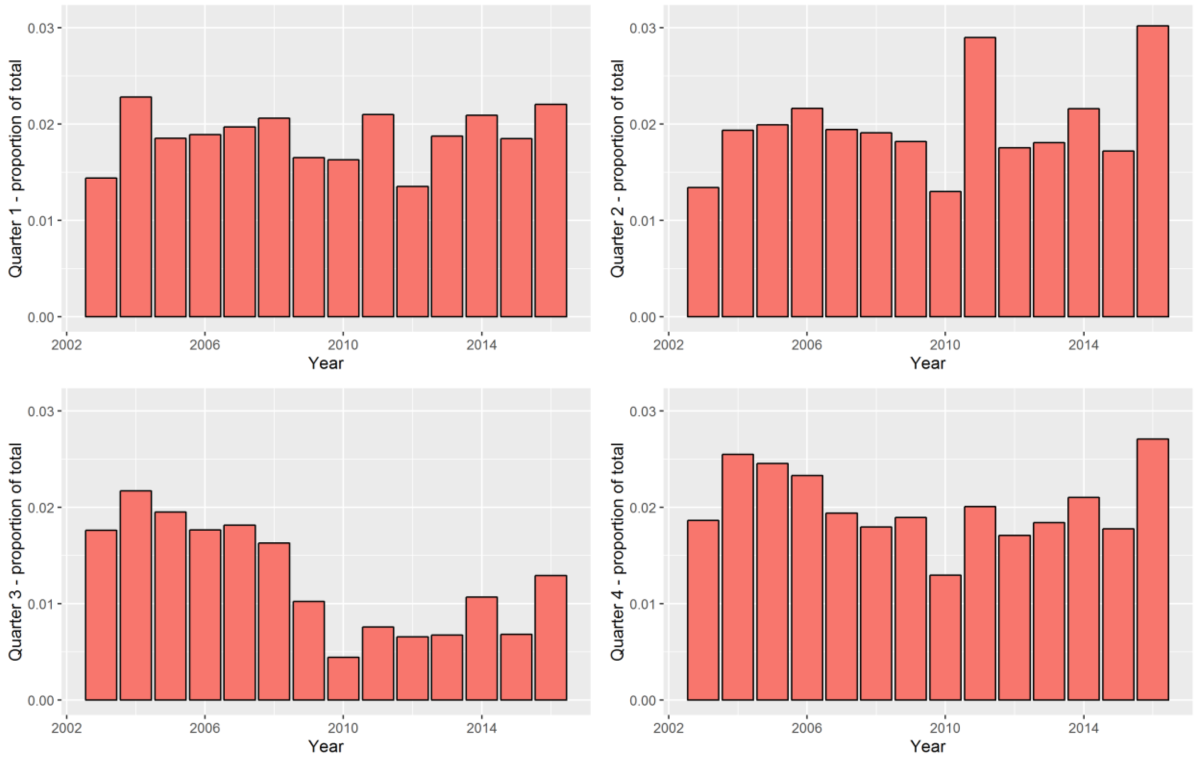


Figure 24 Quarterly silky shark purse seine bycatch (as a proportion of total silky shark bycatch from 2003 to 2016), by year for the first quarter (top left), second quarter (top right), third quarter (bottom left) and fourth quarter (bottom right).

7.4. Other species of special interest (marine mammals & turtles)

Estimated total turtle bycatch displayed a generally increasing trend from 2004 to 2013, from 130 to 390 individuals per year (Table 13). Bycatches in 2014 to 2016 represented a substantial decrease compared to preceding years, with average catches in the region of 240 individuals. Conversely, turtle bycatch in 2003 was higher than might be expected given the general temporal trends, at 340 individuals. Green turtle (24 %), olive ridley (23 %), loggerhead (20 %) and hawksbill turtles (16 %) accounted for the majority of turtle bycatch for the whole period (2003-2016) (Table 13). From 2003 to 2005, marine turtles nei (predominantly turtles - unspecified) accounted for more than 60 % of estimated turtle bycatch. Observers recorded the vast majority of turtle bycatch at a species level from 2006 onwards. Unassociated sets accounted for the highest proportion of turtle bycatch, with the exception of 2004 to 2006 where log sets accounted for the highest proportion (Table 14). Uncertainty in turtle bycatch estimates was highest pre-2010 when observer coverage was comparatively low, with 95 % confidence intervals of approximately ± 35 % (Table 14). The increase in observer coverage in 2010 reduced uncertainty in bycatch estimates, with 95 % confidence intervals of approximately ± 9 %.

Bycatch of marine mammal displayed strong interannual variability, though bycatch was generally higher from 2003 to 2009 (averaging 1,200 individuals), and lower from 2010 to 2016 (averaging 550 individuals per year). Log sets accounted for the highest proportion of marine mammal bycatch from 2003 to 2008, with drifting FAD sets accounting for the highest proportion from 2009 onwards (Table 15) in relation with the change in the number of on log and drifting FAD sets in the region (Table 1). Uncertainty in marine mammal bycatch estimates was highest pre-2010 when observer coverage was lowest, with 95 % confidence intervals of approximately ± 50 % (Table 15). The increase in observer coverage in 2010 reduced uncertainty in bycatch estimates, with 95 % confidence intervals of approximately ± 25 %.

Table 13 Median turtle bycatch estimates (individuals) by species/species group for large-scale purse seine fleets.

Year	Green turtle	Olive ridley turtle	Loggerhead turtle	Hawksbill turtle	Marine turtles	Leatherback turtle	Total
2003	44	39	0	26	222	0	**340**
2004	0	16	0	16	85	11	**133**
2005	42	7	31	17	96	0	**201**
2006	22	69	28	33	14	13	**185**
2007	109	71	59	26	18	5	**298**
2008	47	40	109	34	6	8	**252**
2009	60	69	94	50	5	6	**292**
2010	59	43	60	42	9	8	**222**
2011	88	149	89	88	9	9	**432**
2012	88	89	65	62	18	10	**333**
2013	108	82	83	89	14	13	**390**
2014	64	70	33	51	15	11	**246**
2015	98	49	59	29	6	6	**247**
2016	50	58	51	15	12	20	**212**
Species totals	**881**	**852**	**761**	**579**	**530**	**120**	**3,782**

Table 14 (left) Total estimated turtle bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated turtle bycatch (individuals) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	229	340	471	0.011	0.34
2004	79	133	204	0.004	0.12
2005	135	201	282	0.006	0.17
2006	126	185	256	0.006	0.15
2007	210	298	412	0.008	0.22
2008	174	252	344	0.006	0.18
2009	216	292	382	0.007	0.19
2010	204	222	242	0.004	0.15
2011	406	432	461	0.008	0.31
2012	310	333	357	0.006	0.20
2013	371	390	411	0.007	0.25
2014	227	246	267	0.004	0.14
2015	233	247	262	0.005	0.16
2016	173	212	258	0.004	0.13

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	7.1%	16.8%	22.3%	53.8%	0.0%	0.0%
2004	18.6%	0.0%	48.5%	32.9%	0.0%	0.0%
2005	9.8%	5.9%	53.2%	30.6%	0.5%	0.0%
2006	6.5%	20.6%	41.2%	31.7%	0.0%	0.0%
2007	4.7%	12.9%	22.5%	59.5%	0.3%	0.0%
2008	6.4%	15.2%	4.8%	73.2%	0.4%	0.0%
2009	3.2%	24.8%	33.9%	37.8%	0.3%	0.0%
2010	2.7%	12.1%	8.6%	76.6%	0.0%	0.0%
2011	3.9%	34.5%	7.1%	54.0%	0.5%	0.0%
2012	4.7%	21.8%	18.9%	54.2%	0.3%	0.0%
2013	2.9%	18.6%	11.7%	66.6%	0.3%	0.0%
2014	2.0%	24.1%	12.1%	61.7%	0.0%	0.0%
2015	3.6%	28.7%	8.5%	59.2%	0.0%	0.0%
2016	1.0%	25.3%	4.1%	69.1%	0.5%	0.0%

Table 15 (left) Total estimated marine mammal bycatch in individuals (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated marine mammal bycatch (individuals) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	419	832	1,556	0.027	0.84
2004	1,038	1,638	2,420	0.051	1.54
2005	443	795	1,404	0.022	0.67
2006	980	1,510	2,205	0.045	1.23
2007	647	1,172	2,046	0.032	0.86
2008	627	1,254	2,303	0.030	0.90
2009	1,114	1,649	2,419	0.037	1.08
2010	406	490	607	0.010	0.33
2011	531	620	729	0.012	0.44
2012	587	696	829	0.012	0.42
2013	792	872	970	0.016	0.55
2014	344	412	500	0.007	0.23
2015	412	469	548	0.010	0.29
2016	202	331	670	0.007	0.21

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	31.1%	2.1%	59.2%	7.4%	0.3%	0.0%
2004	8.4%	18.1%	62.9%	8.4%	2.3%	0.0%
2005	17.0%	5.4%	72.3%	5.4%	0.0%	0.0%
2006	9.8%	17.4%	56.9%	15.9%	0.0%	0.0%
2007	13.6%	20.7%	43.0%	21.7%	1.0%	0.0%
2008	17.3%	30.6%	47.6%	4.0%	0.4%	0.0%
2009	11.2%	38.6%	35.7%	14.3%	0.2%	0.0%
2010	22.3%	37.7%	16.3%	20.3%	3.3%	0.0%
2011	16.7%	56.0%	9.4%	16.4%	1.5%	0.0%
2012	6.0%	45.5%	32.4%	15.1%	1.0%	0.0%
2013	5.9%	60.2%	22.0%	11.6%	0.3%	0.0%
2014	11.2%	35.7%	25.2%	26.9%	1.0%	0.0%
2015	4.9%	60.9%	20.2%	13.0%	0.9%	0.0%
2016	12.2%	45.2%	24.5%	17.7%	0.4%	0.0%

8. Recommendations

We recommend that:

- The Scientific Committee note the estimates of bycatch of large-scale purse seine fleets operating in the WCPFC-CA;
- The Scientific Committee note the strong effect of the relative and absolute levels of purse seine effort by association type on estimated bycatch, in particular the marked reductions in bycatches of some species/species groups during FAD closures;
- Future work should include the use of available observer data for the domestic Philippines purse seine fishery to estimate bycatches for this fleet;
- The Scientific Committee should also consider whether observer data for the domestic Philippines purse seine fishery is likely to be representative of bycatch compositions and rates for Indonesian and Vietnamese purse seine fleets, and so be used as the basis of indicative bycatch estimates for these fleets;
- Future work should consider the inclusion of fate information for species/species groups that are commonly released/discarded, particularly species of special interest.

Furthermore, we recommend that measures be implemented at different levels to improve the data quality to produce more reliable bycatch estimates in both weight and number:

- Improve data acquisition by:
    - improving observer training to better estimate visually the number and the weight of fish;
    - implementing independent procedures (e.g. cameras) to conduct a second estimate to validate and improve observer visual estimates;
    - measuring length of bycatch species more systematically for a representative number of fish per sets;
    - improving species identification; and,
    - improving the observer debriefing process on bycatch (e.g. compare bycatch average weight determined from observer visual estimates of number/weight and average weight determined from the length measurements of the same set to identify inconsistencies in the number/weight estimates).
- Improve data processing by:
    - reviewing the SPC procedure to determine number and weight of bycatch when data has not been collected by the observers;
    - establishing appropriate length-weight relationships for the bycatch species;
    - incorporating existing quality flags in the database; and,
    - implementing new data quality flags with the observer debriefers.
- Improve data quality checks by:
    - implementing measures to detect and minimise data entry errors in all data fields and particularly species codes, length measurements, weights and numbers.

9. References

Amandè, M. J., Chassot, E., Chavance, P., Murua, H., Molina, A. D. de, and Bez, N. 2012. Precision in bycatch estimates: the case of tuna purse-seine fisheries in the Indian Ocean. ICES Journal of Marine Science: Journal du Conseil, 69: 1501–1510.

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., and Ochi, D. 2014. Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures. FAO Fisheries and Aquaculture Technical Paper, 588: 1–199.

Efron, B., and Tibshirani, R. J. 1994. An Introduction to the Bootstrap. Monograhs on Statistics and Applied Probability. Chapman & Hall/CRC. 456 pp. https://www.crcpress.com/An-Introduction-to-the-Bootstrap/Efron-Tibshirani/p/book/9780412042317 (Accessed 26 June 2017).

Fitzsimmons, L., Clarke, S., Caillot, S., and Nicol, S. 2015. Redevelopment of the Bycatch Management Information System (BMIS). 11th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC11, Pohnpei, Federated States of Micronesia, 5-13 August 2015, EB-IP-07: 1–9.

Gillett, R. 2011. Bycatch in small-scale tuna fisheries - a global study. FAO Fisheries and Aquaculture Technical Paper, 560: 1–116.

Hall, M., and Roman, M. 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper, 568: 1–249.

Hin, L.-Y., and Wang, Y.-G. 2009. Working-correlation-structure identification in generalized estimating equations. Statistics in Medicine, 28: 642–658.

Højsgaard, S., Halekoh, U., and Yan, J. 2006. The R Package geepack for Generalized Estimating Equations. Journal of Statistical Software, 15: 1–11.

Lawson, T. A. 2011. Estimation of catch rates and catches of key shark species in tuna fisheries of the Western and Central Pacific Ocean using observer data. 7th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC7, Pohnpei, Federated States of Micronesia, 9-17 August 2011, WCPFC-SC7-2011: 1–51.

Oceanic Fisheries Programme of the Secretariat of the Pacific Community. 2010. Non-target species interactions with the tuna fisheries of the Western and Central Pacific Ocean. 6th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC6, Nuku'alofa, Tonga, 10-19 August 2010, WCPFC-SC6-2010: 1–59.

Peatman, T., and Pilling, G. 2016. Monte Carlo simulation modelling of purse seine catches of silky and oceanic whitetip sharks. 12th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC12, Bali, Indonesia, 3-11 August 2016, EB WP 03: 1–17.

Pilling, G., Nicol, S., and Harley, S. 2012. Estimation of catches and fate of edible bycatch species taken in the equatorial purse seine fishery. 8th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC8, Busan, Republic of Korea, 7-15 August 2012, WCPFC-SC8-2012: 1–13.

Pilling, G., Harley, S., Nicol, S., Williams, P. G., and Hampton, J. 2013. Estimation of catches and condition of edible bycatch species taken in the equatorial purse seine fishery. 9th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC9, Pohnpei, Federated States of Micronesia, 6-14 August 2013, WCPFC-SC9-2013/EB-IP-02: 1–15.

Pilling, G. M., Harley, S. J., Nicol, S., Williams, P., and Hampton, J. 2015. Can the tropical Western and Central Pacific tuna purse seine fishery contribute to Pacific Island population food security? Food Security, 7: 67–81.

R Development Core team. 2015. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Reynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C., and Wang, W. 2002. An Improved In Situ and Satellite SST Analysis for Climate. Journal of Climate, 15: 1609–1625.

Stone, M. 1974. Cross-Validatory Choice and Assessment of Statistical Predictions. Journal of the Royal Statistical Society. Series B (Methodological), 36: 111–147.

Western and Central Pacific Fisheries Commission. 2008. Conservation and management measure for bigeye and yellowfin tuna in the Western and Central Pacific Ocean. 5th regular session of the Western and Central Pacific Fisheries Commission, Busan, Republic of Korea, 8-12 December 2008, Conservation and Management Measure 2008-01: 1–42.

Western and Central Pacific Fisheries Commission. 2012. Conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean. 9th regular session of the Western and Central Pacific Fisheries Commission, Manila, Philippines, 2-6 December 2012, Conservation and Management Measure 2012-01: 1–18.

Western and Central Pacific Fisheries Commission. 2016. Conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean. 13th regular session of the Western and Central Pacific Fisheries Commission, Denarau Island, Fiji, 5-9 December 2016, Conservation and Management Measure 2016-01: 1–22.

Annex 1. Detailed composition of the bycatch groups in decreasing order of their occurrence in number of sets (over a total of 265,735 sets).

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
Rainbow runner	Elagatis bipinnulata	finfish	RRU	Rainbow runner	Elagatis bipinnulata	Carangidae	64718
Silky shark	Carcharhinus falciformis	shark & ray	FAL	Silky shark	Carcharhinus falciformis	Carcharhinidae	46562
Oceanic triggerfish	Balistidae	finfish	TRI	Oceanic triggerfish	Balistidae	Balistidae	41337
			CNT	Ocean triggerfish (spotted)	Canthidermis maculata	Balistidae	
			MEN	Black triggerfish	Melichthys niger	Balistidae	
Mackerel scad	Decapturus macarellus	finfish	MSD	Mackerel scad / saba	Decapturus macarellus	Carangidae	32960
Mahi mahi	Coryphaena hippurus	finfish	DOL	Mahi mahi / dolphinfish	Coryphaena hippurus	Coryphaenidae	28256
Wahoo	Acanthocybium solandri	finfish	WAH	Wahoo	Acanthocybium solandri	Scombridae	17736
Blue marlin	Makaira nigricans	finfish	BUM	Blue marlin	Makaira nigricans	Istiophoridae	16341
Frigate & bullet tunas	Auxis thazard & A. rochei	finfish	FRI	Frigate tuna	Auxis thazard	Scombridae	11052
			BLT	Bullet tuna	Auxis rochei	Scombridae	
			FRZ	Frigate - bullet tunas	Auxis thazard - A. rochei	Scombridae	
Mantas & mobulids	Mobulidae	shark & ray	MAN	Manta rays	Mobulidae	Mobulidae	10425
			RMV	Mobula (devil ray)	Mobula spp.	Mobulidae	
			RMB	Giant manta	Manta birostris	Mobulidae	
			RMJ	Manta ray	Mobula japanica	Mobulidae	
			RMT	Chilean devil ray	Mobula tarapacana	Mobulidae	
			RMO	Smoothtail mobula	Mobula tarapacana	Mobulidae	
			RME	Longhorned mobula	Mobula eregoodootenkee	Mobulidae	
Barracudas	Sphyraenidae	finfish	GBA	Great barracuda	Sphyraena barracuda	Sphyraenidae	9913
			BAR	Barracudas (unidentified)	Sphyraena spp.	Sphyraenidae	
			BAB	Blackfin barracuda	Sphyraena genie	Sphyraenidae	
			BAC	Barracuda (s. jello)	Sphyraena jello	Sphyraenidae	
			BAN	Barracuda (s. putnamiae)	Sphyraena putnamiae	Sphyraenidae	
Black marlin	Makaira indica	finfish	BLM	Black marlin	Makaira indica	Istiophoridae	8436
Sea chubs	Kyphosidae	finfish	KYC	Drummer (blue chub)	Kyphosus cinerascens	Kyphosidae	4690
			KYB	Brown chub	Kyphosus bigibbus	Kyphosidae	
Striped marlin	Tetrapturus audax	finfish	MLS	Striped marlin	Tetrapturus audax	Istiophoridae	4031
Trevallies	Caranx spp	finfish	CXS	Bigeye trevally	Caranx sexfasciatus	Carangidae	3705
			TRE	Trevallies (jacks)	Caranx spp.	Carangidae	
			CXR	Bar jack (c. ruber)	Caranx ruber	Carangidae	
Kawakawa	Euthynnus affinis	finfish	KAW	Kawakawa	Euthynnus affinis	Scombridae	2942
Pomfrets	Bramidae	finfish	BRZ	Pomfrets - ocean breams	Bramidae	Bramidae	2174
			POA	Ray's bream / atlantic pomfret	Brama brama	Bramidae	
			TST	Sickle pomfret	Taractichthys steindachneri	Bramidae	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			EBS	Brilliant pomfret	Eumegistus illustris	Bramidae	
			BRA	Bramid species	Brama spp	Bramidae	
			TAL	Big-scaled pomfret	Taractichthys longipinnis	Bramidae	
			BRU	Southern rays bream	Brama australis	Bramidae	
Filefishes	Monacanthidae	finfish	FLF	Filefishes	Cantherines(=Navodon)spp	Monacanthidae	2092
			ALM	Filefish (unicorn leatherjacket)	Aluterus monoceros	Monacanthidae	
			ALN	Filefish (scribbled leatherjacket)	Aluterus scriptus	Monacanthidae	
Oceanic whitetip shark	Carcharhinus longimanus	shark & ray	OCS	Oceanic whitetip shark	Carcharhinus longimanus	Carcharhinidae	1777
Pelagic stingray	Dasyatis violacea	shark & ray	PLS	Pelagic stingray	Dasyatis violacea	Dasyatidae	1727
Elasmobranchs nei	Elasmobranchii nei	shark & ray	CCL	Blacktip shark	Carcharhinus limbatus	Carcharhinidae	1658
			SHK	Sharks	Elasmobranchii	unspecified	
			BRO	Bronze whaler shark	Carcharhinus brachyurus	Carcharhinidae	
			BLR	Blacktip reef shark	Carcharhinus melanopterus	Carcharhinidae	
			CCG	Galapagos shark	Carcharhinus galapagensis	Carcharhinidae	
			ALS	Silvertip shark	Carcharhinus albimarginatus	Carcharhinidae	
			CCP	Sandbar shark	Carcharhinus plumbeus	Carcharhinidae	
			AML	Grey reef shark	Carcharhinus amblyrhynchos	Carcharhinidae	
			HOR	Izak catshark	Holohalaelurus regani	Scyliorhinidae	
			CCE	Bull shark	Carcharhinus leucas	Carcharhinidae	
			CCA	Bignose shark	Carcharhinus altimus	Carcharhinidae	
			DUS	Dusky shark	Carcharhinus obscurus	Carcharhinidae	
			TIG	Tiger shark	Galeocerdo cuvier	Carcharhinidae	
			SKX	Sharks - rays - skates	Elasmobranchii	unspecified	
			STT	Rays (dasyatididae)	Dasyatididae	Dasyatidae	
			SKA	Raja rays nei	Raja spp	Rajidae	
			BAI	Rays - skates and mantas	Batoidimorpha (Hypotrmata)	unspecified	
			STI	Rays (torpedinidae - narkidae)	Torpedinidae narkidae dasyatid	Dasyatidae	
			SKH	Sharks nei	Selachimorpha (Pleurotremata)	unspecified	
			ISB	Cookie cutter shark	Isistius brasiliensis	Squalidae	
			BSK	Basking shark	Cetorhinus maximus	Cetorhinidae	
			TRB	Whitetip reef shark	Triaenodon obesus	Carcharhinidae	
			NTC	Broadsnouted sevengill shark	Notorynchus cepedianus	Hexanchidae	
			LMP	Megamouth shark	Megachasma pelagios	Megachasmidae	
			SRX	Rays - stingrays - mantas	Rajiformes	unspecified	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			SCK	Seal shark / black shark	Dalatias licha	Squalidae	
			RAJ	Skate	Rajidae	Rajidae	
			GAG	School shark	Galeorhinus galeus	Triakidae	
			ODH	Bigeye sand shark	Odontaspis noronhai	Odontaspididae	
			WSH	Great white shark	Carcharodon carcharias	Lamnidae	
			DOP	Spurdog	Squalus megalops	Squalidae	
			DGS	Spiny dogfish	Squalus acanthias	Squalidae	
			CNX	Whitenose shark	Nasolamia velox	Carcharhinidae	
			SUN	Ocellated angelshark	Squatina tergocellatoides	Squatinidae	
			SSQ	Velvet dogfish	Scymnodon squamulosus	Squalidae	
			CPS	Carpet shark	Cephaloscyllium isabellum	Scyliorhinidae	
			PSK	Crocodile shark	Pseudocarcharias kamoharai	Pseudocarchariidae	
			DCA	Shovelnose dogfish	Deania calcea	Squalidae	
Whale shark	Rhincodon typus	shark & ray	RHN	Whale shark	Rhincodon typus	Rhincodontidae	1635
Batfishes	Platax spp	finfish	BAT	Batfishes	Platax spp	Ephippidae	1514
			BAO	Longfin batfish	Platax teira	Ephippidae	
Sailfish (indo-pacific)	Istiophorus platypterus	finfish	SFA	Sailfish (indo-pacific)	Istiophorus platypterus	Istiophoridae	1498
Golden trevally	Gnathanodon speciosus	finfish	GLT	Golden trevally	Gnathanodon speciosus	Carangidae	1433
Marine fishes nei	Teleosts nei	finfish	GSE	Soapfish	Grammistes sexlineatus	Serranidae	1342
			LGH	Pelagic puffer	Lagocephalus lagocephalus	Tetraodontidae	
			OTH	Other fish	Teleostii	unspecified	
			GES	Snake mackerel	Gempylus serpens	Gempylidae	
			LOP	Crestfish/unicornfish	Lophotus capellei	Lophotidae	
			ABU	Sargent major	Abudefduf saxatilis	Pomacentridae	
			SAP	Saury (sanma)	Cololabis saira	Scomberesocidae	
			PSC	Man-o-war fish	Psenes cyanophrys	Nomeidae	
			OIL	Oilfish	Ruvettus pretiosus	Gempylidae	
			LAG	Opah (moonfish)	Lampris guttatus	Lampridae	
			CBG	Drift fish	Cubiceps gracilis	Nomeidae	
			RRG	Oarfishes nei	Regalecidae	Regalecidae	
			LEC	Escolar	Lepidocybium flavobrunneum	Gempylidae	
			WHA	Hapuku (hapuku wreckfish)	Polyprion oxygeneios	Polyprionidae	
			GEM	Gemfish (southern/ silver kingfish)	Rexea solandri	Gempylidae	
			STL	Ocean anchovy	Stolephorus punctifer	Engraulidae	
			MIL	Milkfish	Chanos chanos	Chanidae	
			DOD	Gizzard shad (konoshiro)	Clupanodon punctatus	Clupeidae	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			REM	Remora	Remora spp.	Echeneidae	
			CSX	Bigeye trevalley	Caranx sexfasciatus	Scyliorhinidae	
			RUD	Orange-freckled flathead	Ratabulus diversidens	Platycephalidae	
			ALX	Longsnouted lancetfish	Alepisaurus ferox	Alepisauridae	
			DIY	Porcupine fish (spot-fin)	Diodon hystrix	Diodontidae	
			CEO	Rudderfish	Centrolophus niger	Centrolophidae	
			DIO	Porcupine fishes	Diodontidae	Diodontidae	
			ECN	Suckerfish - remoras	Echeneidae	Echeneidae	
			ALJ	Porcupine fish	Allomycterus jaculiferus	Diodontidae	
			NED	Needlefishes	Tylosurus spp	Belonidae	
			PRP	Roudi escolar	Promethichthys prometheus	Gempylidae	
			CFW	Pompano dolphinfish	Coryphaena equiselis	Coryphaenidae	
			BUP	Pacific rudderfish	Psenopsis anomala	Centrolophidae	
			ALO	Shortsnouted lancetfish	Alepisaurus brevirostris	Alepisauridae	
			CYE	Burrfish	Cyclichthys echinatus	Diodontidae	
			FLY	Flying fishes	Exocoetidae	Exocoetidae	
			PLZ	Right-eyed flounders	Pleuronectidae	Pleuronectidae	
			CHP	South american pilchard	Sandinops sagax	Clupeidae	
			CUT	Hairtails - cutlassfishes	Trichiuridae	Trichiuridae	
			BTF	Batfish	Halieutaea maoria	Ogcocephalidae	
			SNK	Barracouta (snoek)	Thyrsites atun	Gempylidae	
			BEC	Red sea catfish	Bagre pinnimaculatus	Ariidae	
			RIB	Morid cod (ribaldo)	Mora moro	Moridae	
			TRX	Dealfishes	Trachypteroidei	Trachipteridae	
			PUX	Puffers	Tetraodontidae	Tetraodontidae	
			SAR	Sarotherodon galilaeus	Sarotherodon galilaeus	Cichlidae	
			CBA	Cobia	Rachycentron canadum	Rachycentridae	
			BDL	Elongate frostfish	Benthodesmus elongatus	Trichiuridae	
			TRP	Dealfish (trachipterus spp.)	Trachipterus spp.	Trachipteridae	
			LLL	Crestfish	Lophotus lacepede	Lophotidae	
			SXH	Black mackerel	Scombrolabrax heterolepis	Scombrolabracidae	
			MLB	Pikey bream	Acanthopagrus berda	Sparidae	
			PUA	Pufferfish	Sphoeroides pachygaster	Tetraodontidae	
			RWA	Rainbow sardines	Dussumieria spp	Clupeidae	
			TUT	Tubbia tasmanica	Tubbia tasmanica	Centrolophidae	
			NEN	Black gemfish	Nesiarchus nasutus	Gempylidae	
			REL	Oarfish	Regalecus glesne	Regalecidae	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			PTA	Keeltail needlefish	Platybelone argalus	Belonidae	
			PLH	Plectrochilus erythrurus	Plectrochilus erythrurus	Trichomycteridae	
			MOR	Moridae	Moridae	Moridae	
			CLP	Herrings - sardines	Clupeidae	Clupeidae	
			ALI	Lancetfishes	Alepisaurus spp.	Alepisauridae	
			F19	Filefishes (family)	Monacanthidae	unspecified	
			FIT	Flutemouths	Fistularia spp	Fistulariidae	
			DOS	Wolf-herrings	Chirocentrus spp	Chirocentridae	
			PLC	Flathead chub	Platygobio gracilis	Cyprinidae	
			BWH	Moontail bullseye	Priacanthus hamrur	Priacanthidae	
			THE	Therapon perches	Therapon spp	Terapontidae	
			ANM	Slender snipe eel	Nemichthys scolopaceus	Nemichthyidae	
			SIG	Luminous hake	Steindachneria argentea	Merlucciidae	
			EWO	Eightbar grouper	Epinephelus octofasciatus	Serranidae	
			POK	Saithe (pollock)	Pollachius virens	Gadidae	
			PON	Ponyfishes (slipmouths)	Leiognathidae	Leiognathidae	
			LHP	Callochromis macrops	Callochromis macrops	Cichlidae	
			HWK	Kai soldierfish	Ostichthys kaianus	Holocentridae	
			FIO	Bluespotted cornetfish	Fistularia commersonii	Fistulariidae	
			SDY	Deepbody sardinella	Sardinella Brachysoma	Clupeidae	
			LVK	Common bluestripe snapper	Lutjanus kasmira	Lutjanidae	
			THM	Black snoek	Thyrsitoides marleyi	Gempylidae	
			SML	Apteronotidae	Sternarchorhamphus muelleri	Apteronotidae	
			TAK	Jackass morwong	Nemadactylus macropterus	Cheilodactylidae	
			ANX	Anchovies	Engraulidae	Engraulidae	
			XFT	Blue-toothed tuskfish	Xiphocheilus typus	Labridae	
			MLL	Smooth whiptail	Malacocephalus laevis	Macrouridae	
			FIP	Red cornetfish	Fistularia petimba	Fistulariidae	
			PIL	Sardine / european pilchard	Sardina pilchardus	Clupeidae	
			SLK	Sand whiting	Sillago ciliata	Sillaginidae	
			MOB	Monocle breams	Scolopsis spp	Nemipteridae	
			CMZ	Manefish	Caristius macropus	Caristiidae	
			SSR	Red bait	Pyura stolonifera	Pyuridae	
			LUB	Emporer red snapper	Lutjanus Sebae	Lutjanidae	
			EGD	Pencil cardinal	Epigonus denticulatus	Epigonidae	
			BOX	Scabbard fish	Aphanopus spp	Trichiuridae	
			LOC	Cyprinidae	Labeo victorianus	Cyprinidae	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			SNX	Snappers - jobfishes	Lutjanidae	Lutjanidae	
			FRC	Carp prettyfin	Fraudella carassiops	Plesiopidae	
			SKY	Kimberley grunter	Syncomistes kimberleyensis	Terapontidae	
			TDF	Toadfishes nei	Batrachoides spp	Batrachoididae	
			PIA	Southern african pilchard	Sardinops ocellatus	Clupeidae	
			PZB	Barracudinas	Paralepididae	Paralepididae	
			GPF	Shrimp flounder	Gastropsetta frontalis	Paralichthyidae	
			NMW	Drift fishes nei	Nomeus spp	Nomeidae	
			RSS	Goldlined seabream (sea bream)	Rhabdosargus sarba	Sparidae	
			SPD	Blue sprat	Spratelloides delicatulus	Clupeidae	
			UFT	Goldribbon soapfish	Aulacocephalus temmincki	Serranidae	
			TFD	Frogfishes - toadfishes	Batrachoididae spp	Batrachoididae	
			GMQ	Japanese large-eye bream	Gymnocranius euanus	Lethrinidae	
			GEP	Snake mackerels and escolars	Gempylidae	Gempylidae	
			SNA	Snappers (lutjanidae)	Lutjanus spp.	Lutjanidae	
			OMW	Omosudid	Omosudis lowei	Omosudidae	
			SPR	European sprat	Sprattus sprattus	Clupeidae	
Sunfish	Molidae	finfish	RZV	Slender sunfish	Ranzania laevis	Molidae	1309
			MOX	Ocean sunfish	Mola mola	Molidae	
			MRW	Sharptail mola	Masturus lanceolatus	Molidae	
			MOP	Sunfish	Mola spp	Molidae	
Amberjacks	Seriola spp	finfish	YTC	Amberjack / giant yellowtail	Seriola lalandi	Carangidae	1215
			AMX	Amberjacks	Seriola spp	Carangidae	
			AMB	Greater amberjack	Seriola dumerili	Carangidae	
			YTL	Amberjack (longfin yellowtail)	Seriola rivoliana	Carangidae	
Marine mammal	Marine mammal	marine mammal	FAW	False killer whale	Pseudorca crassidens	Delphinidae	1000
			MAM	Marine mammal	Mammalia	unspecified	
			RTD	Dolphin - rough-toothed	Steno bredanensis	Delphinidae	
			DBO	Bottlenose dolphin	Tursiops truncatus	Delphinidae	
			DSI	Spinner dolphin	Stenella longirostris	Delphinidae	
			DBZ	Indo-pacific bottlenose dolphin	Tursiops aduncus	Delphinidae	
			DRR	Risso's dolphin	Grampus griseus	Delphinidae	
			DCO	Common dolphin	Delphinus delphis	Delphinidae	
			BRW	Bryde's whale	Balaenoptera Edeni	Balaenopteridae	
			SHW	Short-finned pilot whale	Globicephala macrorhynchus	Delphinidae	

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
			HUW	Humpback whale	Megaptera novaeangliae	Balaenopteridae	
			MEW	Melon-headed whale	Peponocephala electra	Delphinidae	
			SIW	Sei whale	Balaenoptera borealis	Balaenopteridae	
			DST	Striped dolphin	Stenella coeruleoalba	Delphinidae	
			DSP	Spotted dolphins	Stenella spp.	Delphinidae	
			DLP	Dolphins / porpoises	Delphinidae	Delphinidae	
			DCZ	Long-beaked common dolphin	Delphinus capensis	Delphinidae	
			F43	Common dolphin		unspecified	
			ODN	Toothed whales (blackfish)	Odontoceti	unspecified	
			DPN	Dolphin - spotted	Stenella attenuata	Delphinidae	
			KPW	Pygmy killer whale	Feresa attenuata	Delphinidae	
			MYS	Baleen whales nei	Mysticeti	unspecified	
			SPW	Sperm whale	Physeter macrocephalus	Physeteridae	
			FRD	Dolphin - fraser's	Lagenodelphis hosei	Delphinidae	
			KIW	Killer whale	Orcinus orca	Delphinidae	
			MEP	Beaked whales	Mesoplodon spp	Ziphiidae	
			BBW	Beaked whale - blainville’s	Mesoplodon densirostris	Ziphiidae	
			GLO	Pilot whales	Globicephala spp	Delphinidae	
			PYW	Pygmy sperm whale	Kogia breviceps	Kogiidae	
			TGW	Ginkgo-toothed beaked whale	MesoplodonGinkgodens	Ziphiidae	
			WLE	Whale	Cetacea	unspecified	
			BCW	Beaked whale - cuvier's	Ziphius cavirostris	Ziphiidae	
			BLW	Blue whale	Balaenoptera musculus	Balaenopteridae	
			DDU	Dusky dolphin	Lagenorhynchus obscurus	Delphinidae	
			MIW	Minke whale	Balaenoptera acutorostrata	Balaenopteridae	
			PHR	Porpoise - harbor	Phocoena phocoena	Phocoenidae	
			RNW	Dolphin - n. right whale	Lissodelphis borealis	Delphinidae	
Carangids nei	Carangidae nei	finfish	BIS	Bigeye scad	Selar crumenophthalmus	Carangidae	949
			USE	Cottonmouth jack	Uraspis secunda	Carangidae	
			NAU	Pilot fish	Naucrates ductor	Carangidae	
			CRF	Bar jack (c. ferdau)	Carangoides ferdau	Carangidae	
			CGX	Carangidae (trevallies)	Carangidae	Carangidae	
			JAX	Jack and horse mackerels nei	Trachurus spp	Carangidae	
			TRZ	Trevally	Pseudocaranx dentex	Carangidae	
			TBA	Smallspotted dart	Trachinotus baillonii	Carangidae	
			RUS	Indian scad	Decapterus russelli	Carangidae	
Triple-tail	Lobotes surinamensis	finfish	LOB	Triple-tail	Lobotes surinamensis	Lobotidae	912

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
Scombrids nei	Scombridae nei	finfish	MAX	Mackerel	Scombridae	Scombridae	883
			COM	Spanish mackerel (narrow-barred)	Scomberomorus commerson	Scombridae	
			MAS	Slimy mackerel	Scomber japonicus	Scombridae	
			PBF	Pacific bluefin tuna	Thunnus orientalis	Scombridae	
			BUK	Butterfly tuna / kingfish	Gasterochisma melampus	Scombridae	
			SLT	Slender tuna	Allothunnus fallai	Scombridae	
			SBF	Southern bluefin tuna	Thunnus maccoyii	Scombridae	
			DOT	Dogtooth tuna	Gymnosarda unicolor	Scombridae	
			BKJ	Black skipjack	Euthynnus lineatus	Scombridae	
			MAC	Atlantic mackerel	Scomber scombrus	Scombridae	
			BFT	Atlantic bluefin tuna	Thunnus thynnus	Scombridae	
			LOT	Longtail tuna	Thunnus tonggol	Scombridae	
			BAU	Australian bonito	Sarda australis	Scombridae	
			MAZ	Scombrids	Scomber spp	Scombridae	
			MAA	Blue mackerel	Scomber australasicus	Scombridae	
Albacore	Thunnus alalunga	finfish	ALB	Albacore tuna	Thunnus alalunga	Scombridae	710
Swordfish	Xiphias gladius	finfish	SWO	Swordfish	Xiphias gladius	Xiphiidae	641
Short-billed spearfish	Tetrapturus angustirostris	finfish	SSP	Short-billed spearfish	Tetrapturus angustirostris	Istiophoridae	432
Green turtle	Chelonia mydas	turtle	TUG	Green turtle	Chelonia mydas	Cheloniidae	358
Olive ridley turtle	Lepidochelys olivacea	turtle	LKV	Olive ridley turtle	Lepidochelys olivacea	Cheloniidae	347
Loggerhead turtle	Caretta caretta	turtle	TTL	Loggerhead turtle	Caretta caretta	Cheloniidae	292
Hawksbill turtle	Eretmochelys imbricata	turtle	TTH	Hawksbill turtle	Eretmochelys imbricata	Cheloniidae	232
Thresher sharks	Alopiidae	shark & ray	BTH	Bigeye thresher	Alopias superciliosus	Alopiidae	217
			THR	Thresher sharks nei	Alopias spp.	Alopiidae	
			PTH	Pelagic thresher	Alopias pelagicus	Alopiidae	
			ALV	Thresher	Alopias vulpinus	Alopiidae	
Mako sharks	Isurus spp	shark & ray	MAK	Mako sharks	Isurus spp.	Lamnidae	210
			SMA	Short finned mako	Isurus oxyrhinchus	Lamnidae	
			LMA	Long finned mako	Isurus paucus	Lamnidae	
Hammerhead sharks	Sphyrnidae	shark & ray	SPK	Great hammerhead	Sphyrna mokarran	Sphyrnidae	177
			SPL	Scalloped hammerhead	Sphyrna lewini	Sphyrnidae	
			SPN	Hammerhead sharks	Sphyrna spp.	Sphyrnidae	
			SPZ	Smooth hammerhead	Sphyrna zygaena	Sphyrnidae	
			EUB	Winghead shark	Eusphyra blochii	Sphyrnidae	
Marine turtle	Testudinata	turtle	TTX	Marine turtle	Testudinata	unspecified	112

name (group)	scientific name (group)	category	code (species)	name (species)	scientific name (species)	family (species)	total
Blue shark	Prionace glauca	shark & ray	BSH	Blue shark	Prionace glauca	Carcharhinidae	110
Leatherback turtle	Dermochelys coriacea	turtle	DKK	Leatherback turtle	Dermochelys coriacea	Dermochelyidae	44
Billfishes nei	Istophoridae - Xiphiidae	finfish	MAR	Marlin	Istophoridae - Xiphiidae	Istiophoridae	24

Annex 2. Issues on data quality on bycatch weights and numbers recorded in the observer database.

The observers visually estimate catch of target and non-target species in both number of specimens and weight, using their own judgement. When time allows they also measure a number of specimens for each species. The data recorded on paper by observers is then entered in the database by data entry staff in countries or at WCPFC, FFA or SPC. Once entered, when data are incomplete, i.e. when only one value is reported by the observers (number or weight), the other value is then estimated by SPC, using an average weight calculated for each species.
Data quality issues can arise at the different steps of this procedure.

It can be particularly difficult to provide accurate visual estimates of the number and weight of the catch, especially when large quantities are involved. No formal training exists to help observers to estimate the quantities and no independent method is available at the moment to obtain a second estimate that would help validating and giving feedback to improve the accuracy of observer estimates. Some of the poor estimates can be detected by dividing the weight estimated by the number estimated; the average weight thus obtained should be reasonable otherwise it indicates a poor estimate of one or the other value (weight or number); there is obviously an error somewhere when the average weight of a rainbow runner is higher than 50 kg. We also expect that the distribution of the average weights derived from visual estimates (Figure 25) is similar to the distribution of the average weights derived from length distribution of the fish measured and length-weight conversion factors (Figure 26). The length measurements clearly indicate that most of the blue marlins caught weight on average between 40 and 140 kg with much less records outside these limits while the average weights derived from visual estimates indicate that most of the blue marlins would be between 0 and 100 kg. Poor estimates exist but they are difficult to identify and even if they are spotted, which values should be trusted? The number or the weight? Improving the visually estimates weights and numbers will be very challenging but appears critical to improve the quality of the bycatch data.

When entering the data some typing mistakes are also possible and if some automatic checking is conducted they probably need to be increased to improve the quality of the data.

When only one value is reported by the observers (number or weight), the other value is estimated using an average weight calculated for each species. The average weight is estimated using the measured length of the fish caught during the set and existing length-weight relationships from the literature or from previous sampling for the species of interest. If fish were not measured during a set, the average weight is estimated based on length measurements of fish of the same species for the same set type over a larger time period according to the data available (month/year, quarter/year, and year), or from fish from the same species from the same year. Increasing the number of fish measured and making sure that a representative number of fish are measured would allow improving the estimates. Another area of improvement for those data is the length-weight relationship used. Except for the most common species, length-weight relationships were not established based on samples from the WCPFC and we have to rely on global literature for those conversion factors. Length-weight relationships are sometimes not suitable for our dataset as they can be based on a small number of specimens, based on an unsuitable range of length and weight, based on data from another ocean. Engaging in a new campaign of length and weight measurements for bycatch species in the region would improve the accuracy of the data.

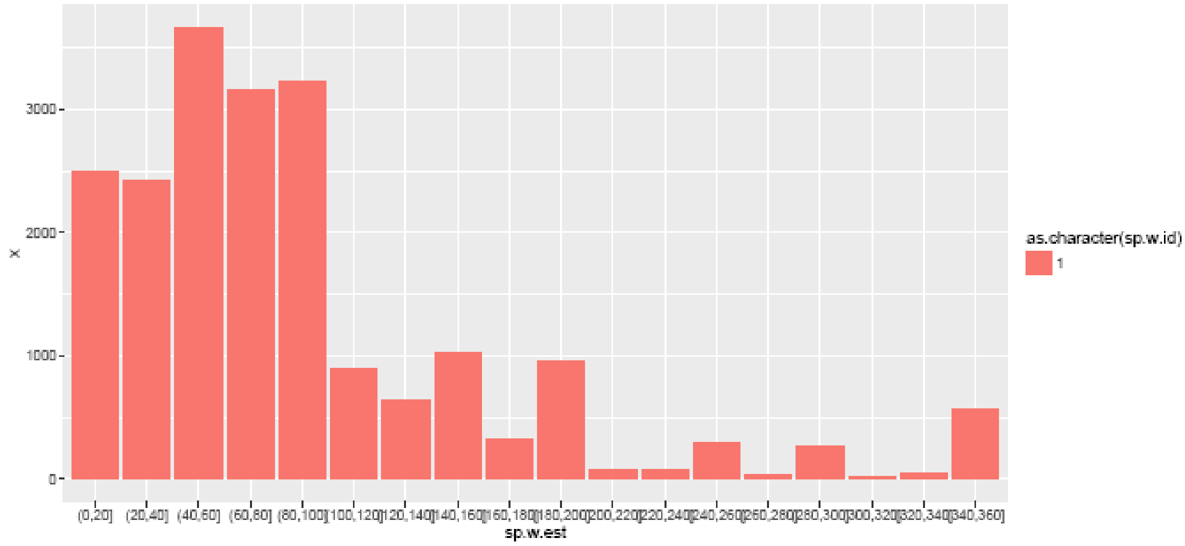


Figure 25. Distribution of the average weight of blue marlin calculated by dividing weight by number of observer visual estimates (1).

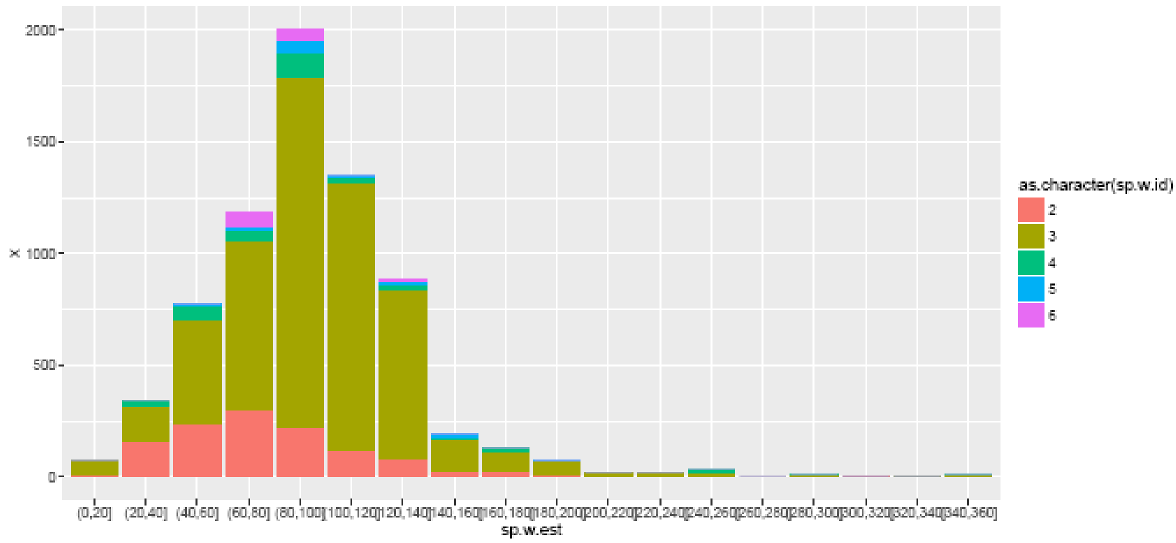


Figure 26. Distribution of the average weight of blue marlin calculated using length distribution of the fish measured and length-weight conversion. Fish measured during the set (2), fish measured during the same month/year and set type (3), fish measured during the same quarter/year and set type (4), fish measured during the same year and set type (5), fish measured during the same year (6).

Annex 3. Statistical models of bycatch presence/absence

Species-specific presence/absence of bycatch was modelled using logistic models with a logit link:

$$presence_{ij} \sim \text{Bernoulli}(\mu_{ij}),$$
$$\log\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + \beta_1 year_{ij} + \beta_2 quarter_{ij} + \beta_3 association_{ij} + f(SST_{ij})$$

where $presence$ denotes whether individuals of a given bycatch species/species group were observed, μ denotes the estimated probability that organisms of a given species were present, i and j subscripts denote observer trip and set number respectively and f was a natural cubic spline, with 4 knots. Explanatory variables used in the model were the year, the quarter, the association (i.e. set type) and the sea surface temperature (SST). The approximate significance of model terms was calculated using Wald tests. All explanatory variables were kept in the model, regardless of their significance.

The presence/absence models were fitted using Generalised Estimating Equations to account for correlated residuals. Exchangeable and autoregressive correlation structures were both considered to be potentially appropriate choices. Models for a selection of finfish (rainbow runner, mahi-mahi) and shark species (silky shark and oceanic whitetip shark) were fitted with both correlation structures. Comparison of correlation information criterion (Hin and Wang, 2009) values supported the use of the exchangeable correlation structure within observer trips, *i.e.* where residuals from the same observer trip were correlated, with a shared correlation parameter for all observer trips. The models were implemented in the statistical software R (version 3.2.3) using the geepack package (Højsgaard *et al.*, 2006). Two-fold cross validation was used to assess the predictive accuracy of the fitted models, using the caret package (Stone, 1974). To summarise, the observer data was split into two 'folds' (or subsets), maintaining (approximately) equal numbers of sets in each strata in the two folds. The model was fitted to the first fold (the training dataset) and then used to predict presence/absence for records in the second fold (the testing dataset). This process was then repeated using the second fold as the training dataset and the first fold as the testing dataset. The predicted probability of bycatch presence was then aggregated by strata (year, quarter and association type), and compared to the observed proportion of sets with bycatch present on a strata-specific basis.

Initial model runs were also used to explore the inclusion of chlorophyll-a concentration, as a proxy for primary productivity, and distance to shore, using natural cubic splines. The fitted splines were either insignificant, or in limited cases significant but weak or nonsensical relationships with bycatch presence. Regardless, any improvements to predictive capability were not substantial enough to be detectable in the cross validation exercise. Consequently, chlorophyll-a and distance to shore were not included in the final models for presence/absence.

It is important to note that skunk sets were included in the modelled dataset. As such sets on unassociated, and to a lesser extent whale associated, schools might be expected to have a lower probability of bycatch presence as a result of the greater chance of a skunk set.

Finally, as mentioned in Section 3.8, attempts to fit models to bycatch when present were unsuccessful. For completeness, these models were lognormal generalized additive models (GAMs) for finfish bycatch (tonnes), and negative binomials of billfish and shark bycatch (individuals). Explanatory variables considered were year, quarter, association type, sea surface temperature, chlorophyll-a concentration, distance to shore, and target catch (tonnes). Mixed effect models with random intercepts for observer code were also tested. Fitted bycatch estimates displayed no, or at best a very weak, correlation to observed bycatch.

Annex 4. Effect plots of bycatch presence/absence models.

Finfish

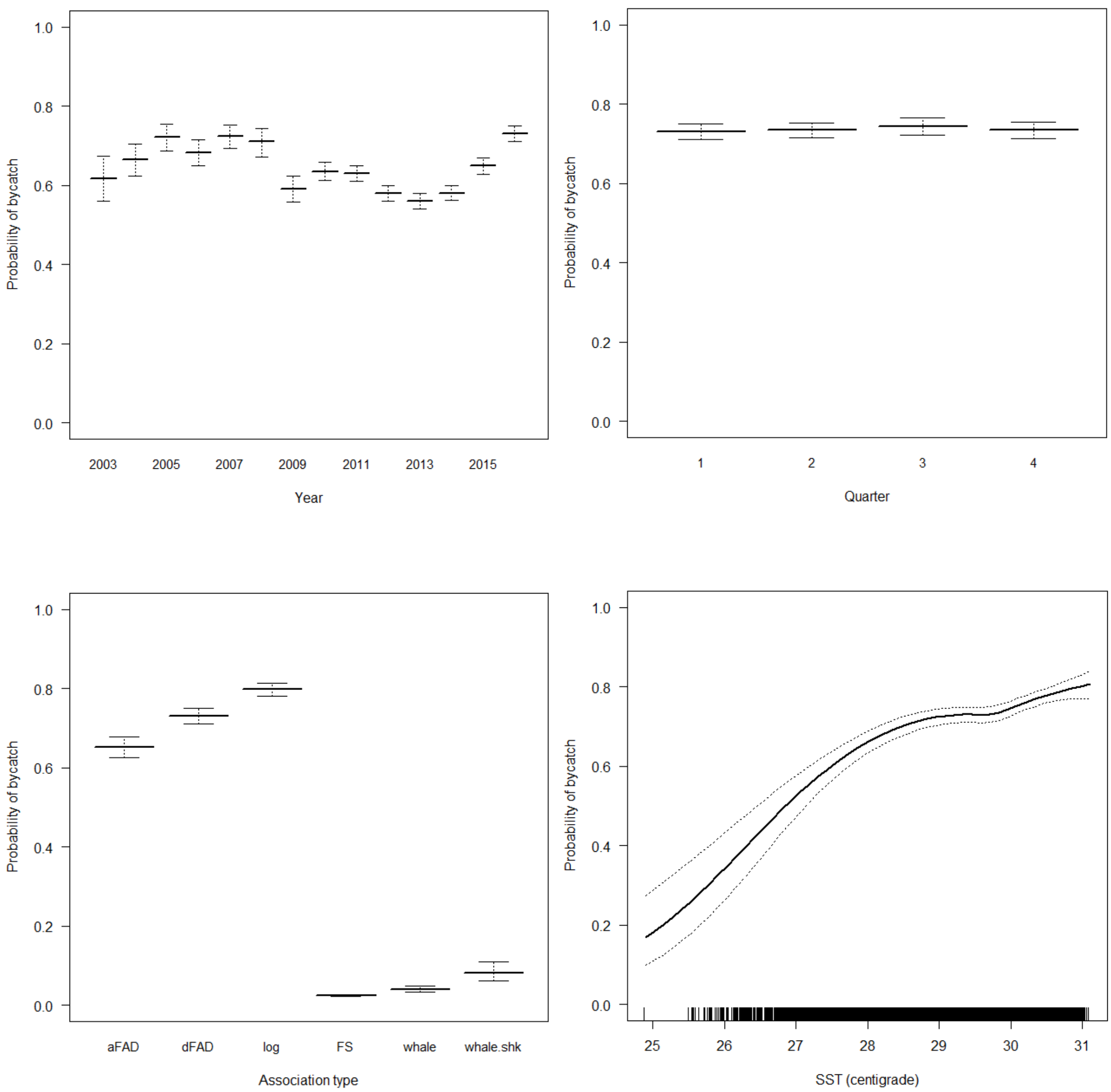


Figure 27 Predicted probability (mean +/- 2 s.e.) of rainbow runner bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty of means includes uncertainty from all model terms.

Table 16 Approximate significance of terms for the model of rainbow runner presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	735.9	< 2.2e-16
qtr	3	753	< 2.2e-16
association	5	18812.1	< 2.2e-16
ns(sst, df = 4)	4	166.1	< 2.2e-16

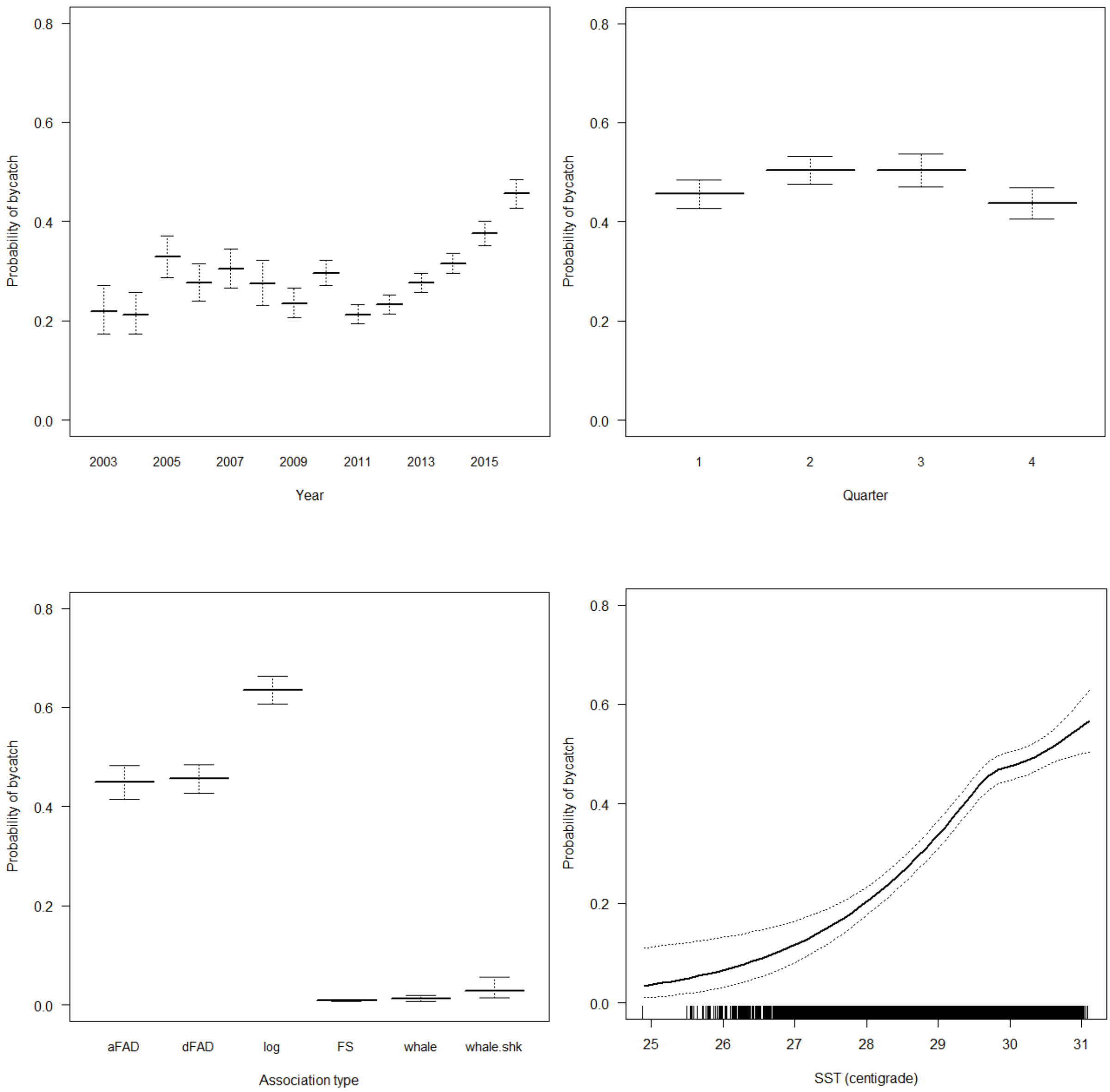


Figure 28 Predicted probability (mean +/- 2 s.e.) of mackerel scad bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 17 Approximate significance of terms for the model of mackerel scad presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	403.6	< 2.2e-16
qtr	3	385.8	< 2.2e-16
association	5	6517.2	< 2.2e-16
ns(sst, df = 4)	4	446.6	< 2.2e-16

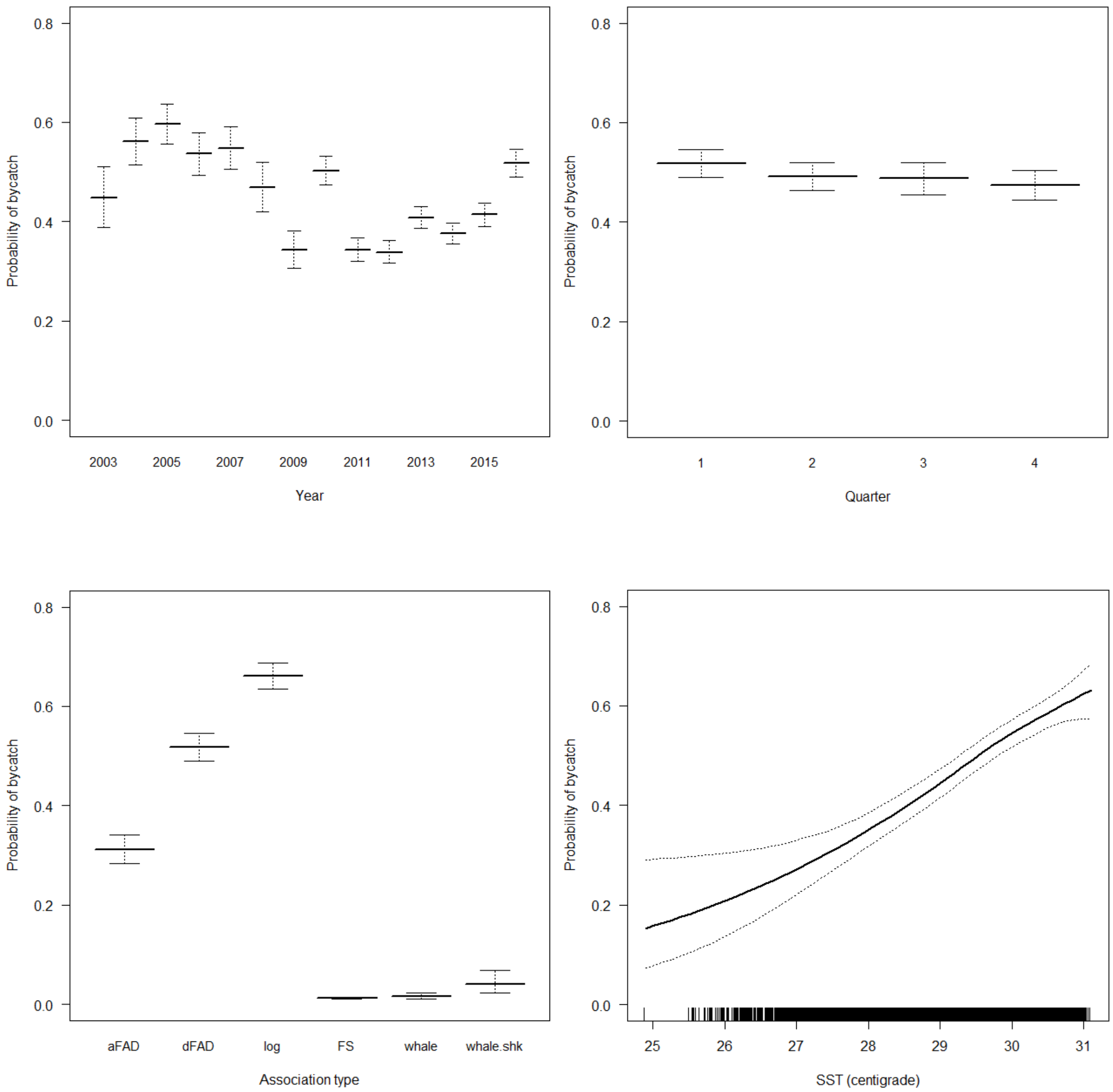


Figure 29 Predicted probability (mean +/- 2 s.e.) of oceanic triggerfish bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 18 Approximate significance of terms for the model of oceanic triggerfish presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	778	< 2.2e-16
qtr	3	596.9	< 2.2e-16
association	5	10296.8	< 2.2e-16
ns(sst, df = 4)	4	267.3	< 2.2e-16

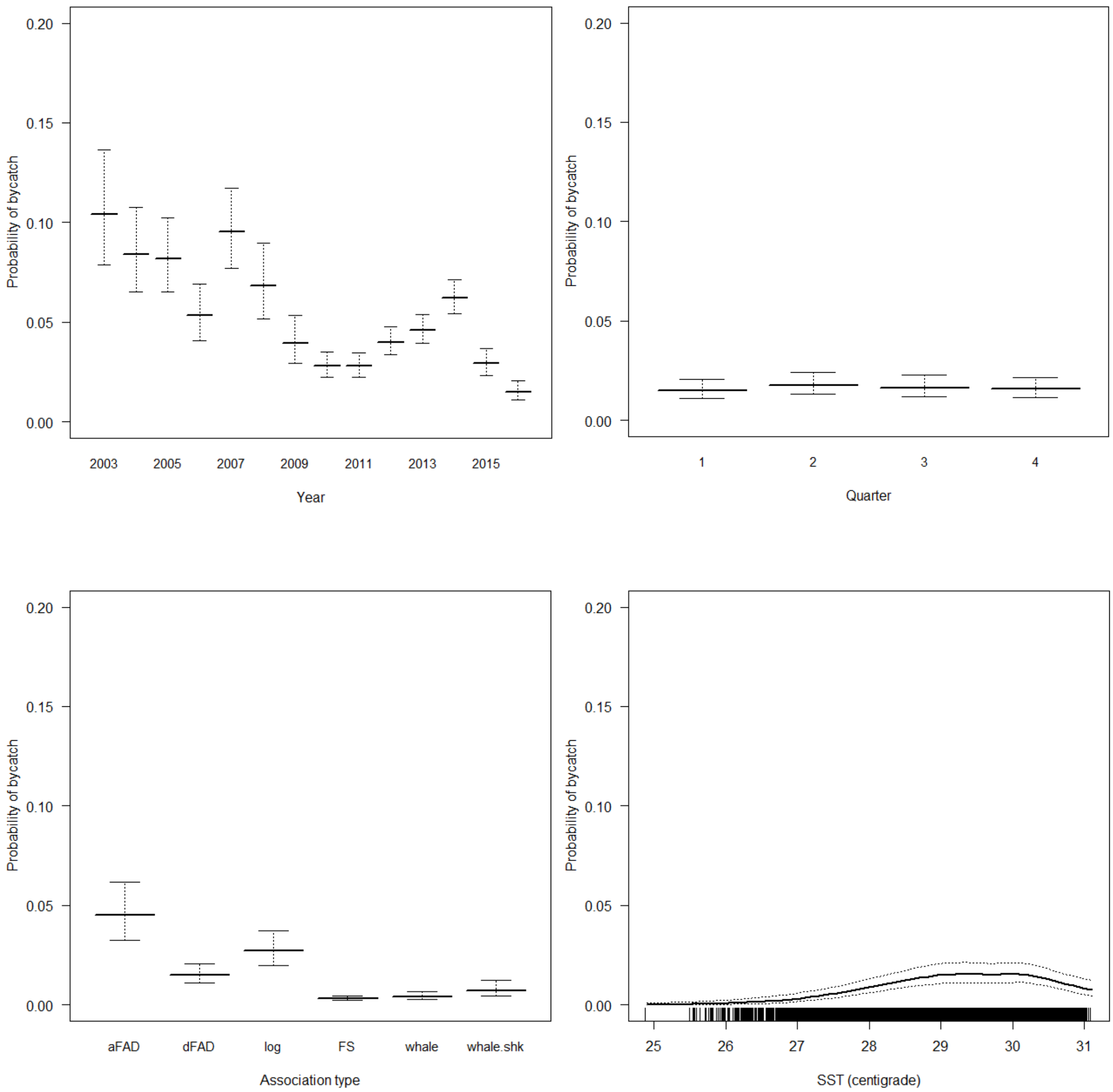


Figure 30 Predicted probability (mean +/- 2 s.e.) of frigate and bullet tuna bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 19 Approximate significance of terms for the model of frigate and bullet tuna presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	673.84	< 2.2e-16
qtr	3	32.16	4.85E-07
association	5	2179.11	< 2.2e-16
ns(sst, df = 4)	4	44.38	5.35E-09

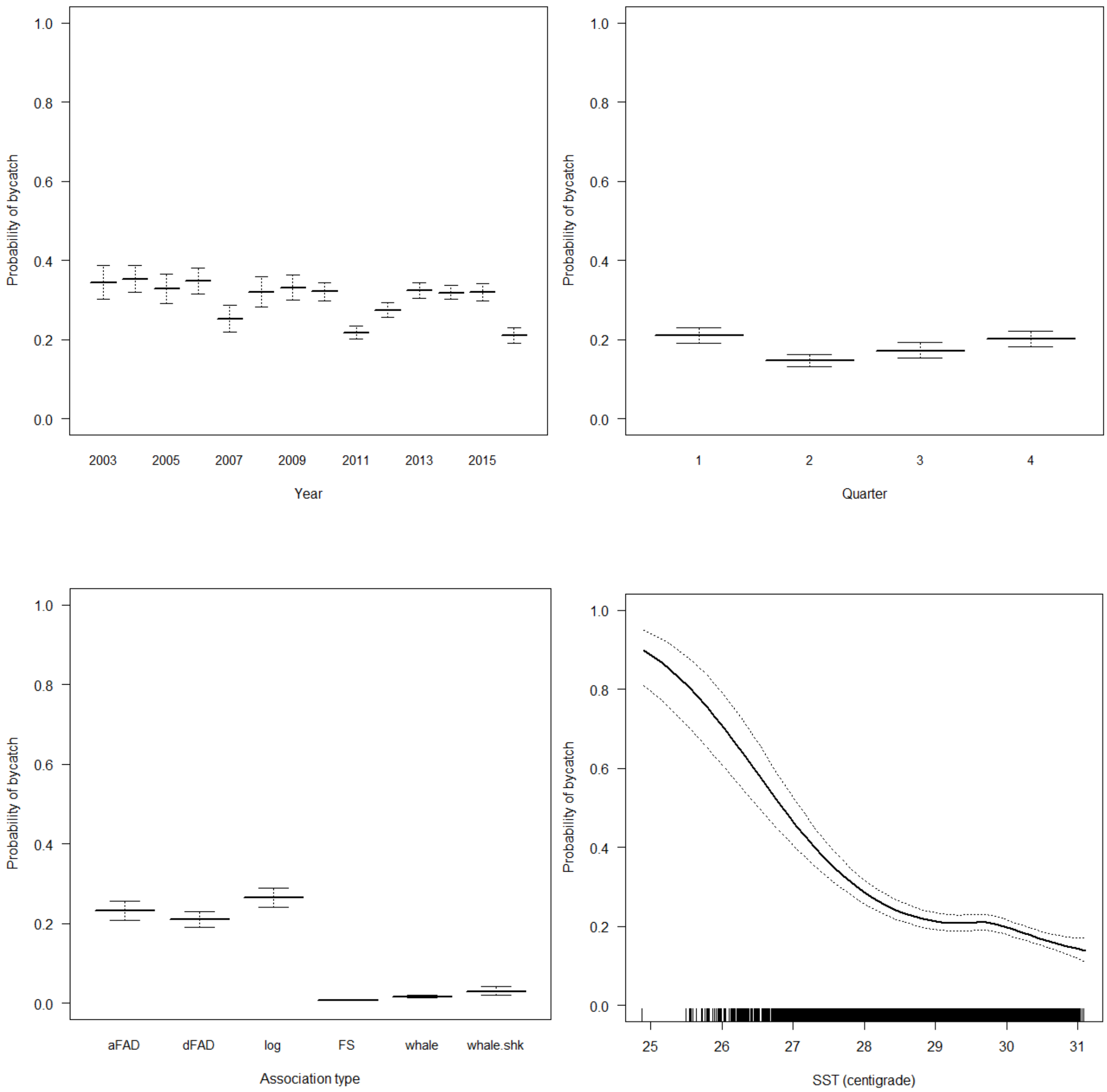


Figure 31 Predicted probability (mean +/- 2 s.e.) of mahi mahi bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 20 Approximate significance of terms for the model of mahi mahi presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	498.6	< 2.2e-16
qtr	3	562.1	< 2.2e-16
association	5	9338.7	< 2.2e-16
ns(sst, df = 4)	4	183.9	< 2.2e-16

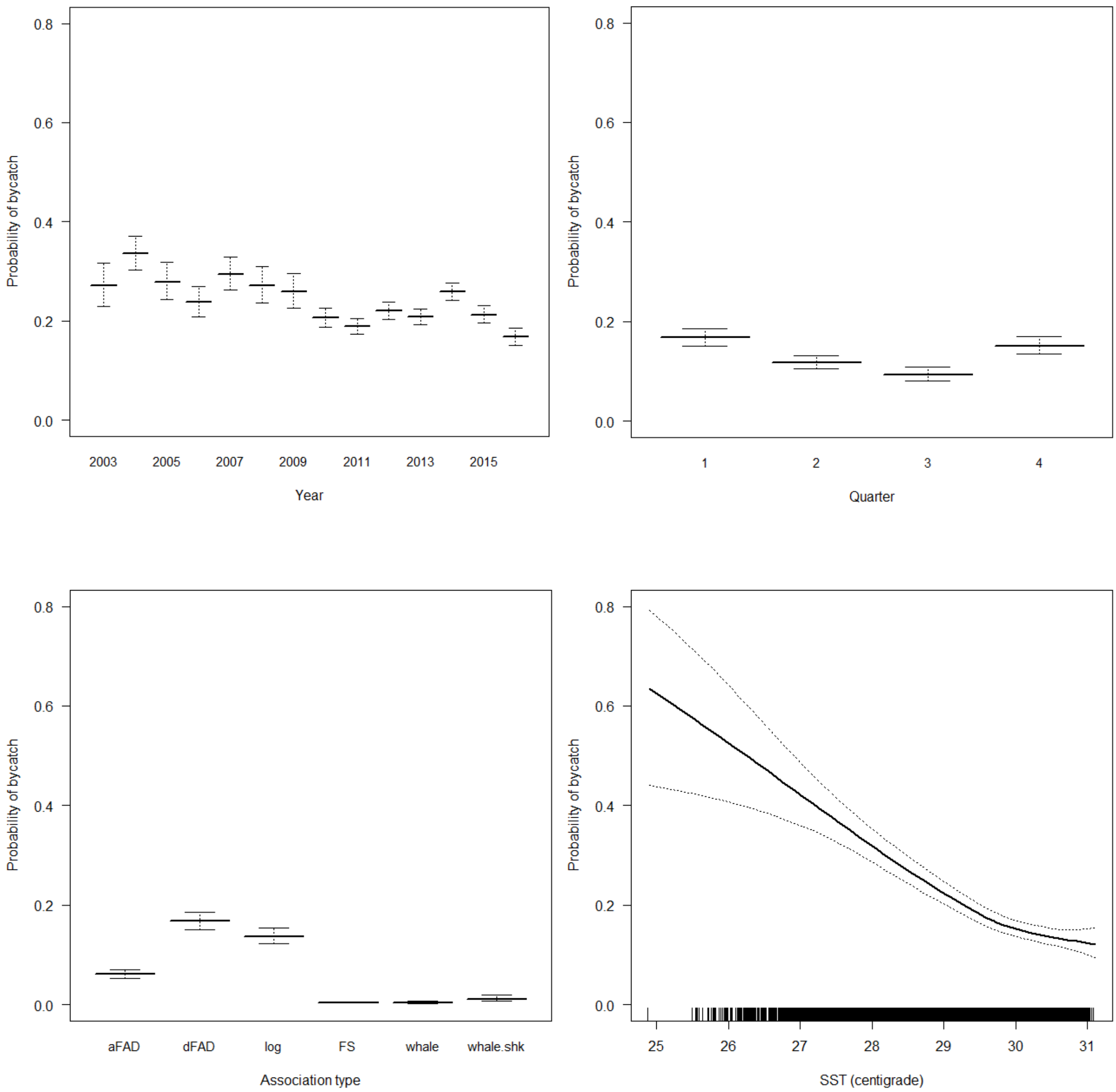


Figure 32 Predicted probability (mean +/- 2 s.e.) of wahoo bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 21 Approximate significance of terms for the model of wahoo presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	262.1	< 2.2e-16
qtr	3	660.6	< 2.2e-16
association	5	6750.1	< 2.2e-16
ns(sst, df = 4)	4	355.7	< 2.2e-16

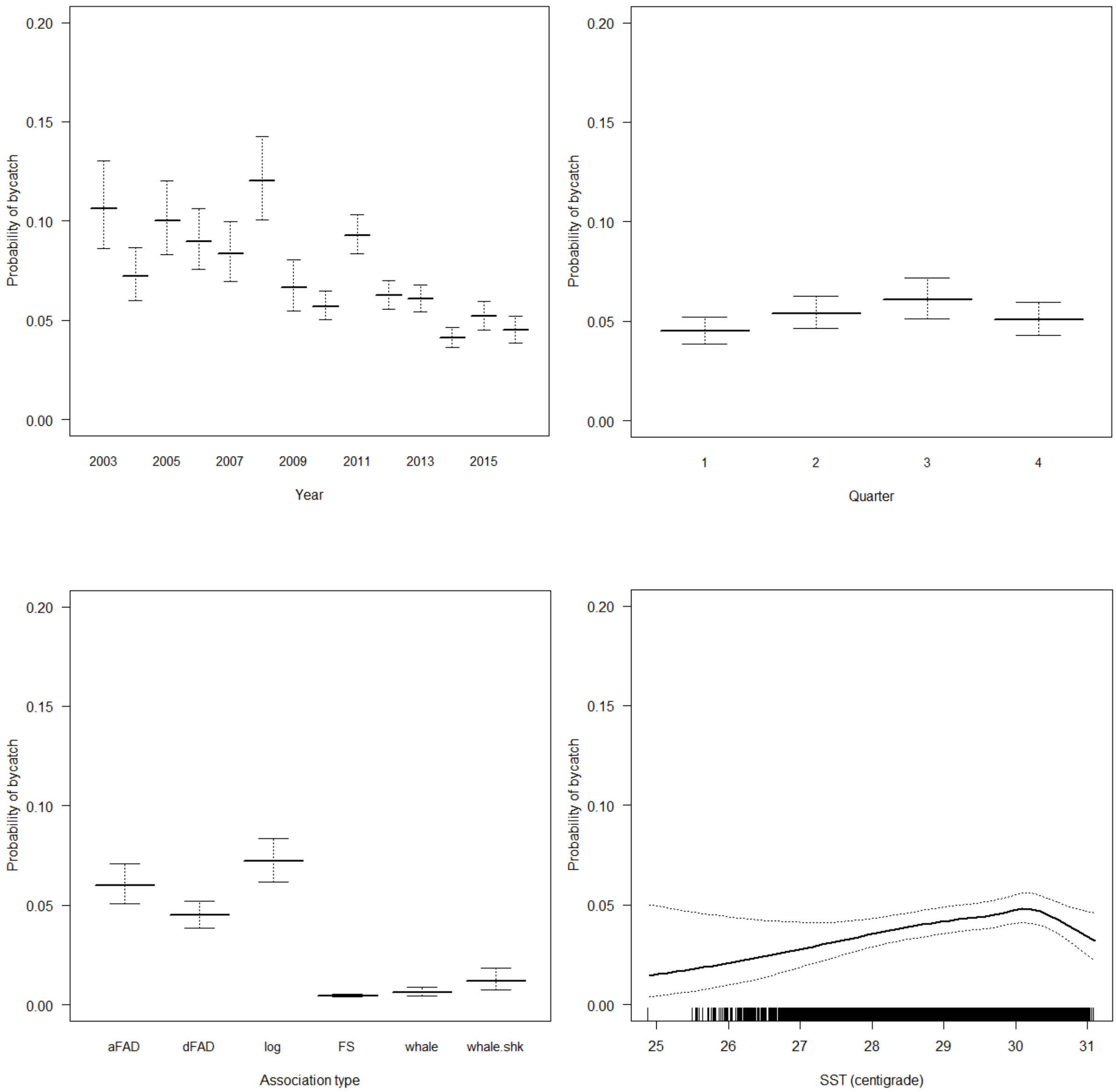


Figure 33 Predicted probability (mean +/- 2 s.e.) of barracuda bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 22 Approximate significance of terms for the model of barracuda presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	766.9	< 2.2e-16
qtr	3	87.4	< 2.2e-16
association	5	3798.3	< 2.2e-16
ns(sst, df = 4)	4	19.4	0.000657

Billfish

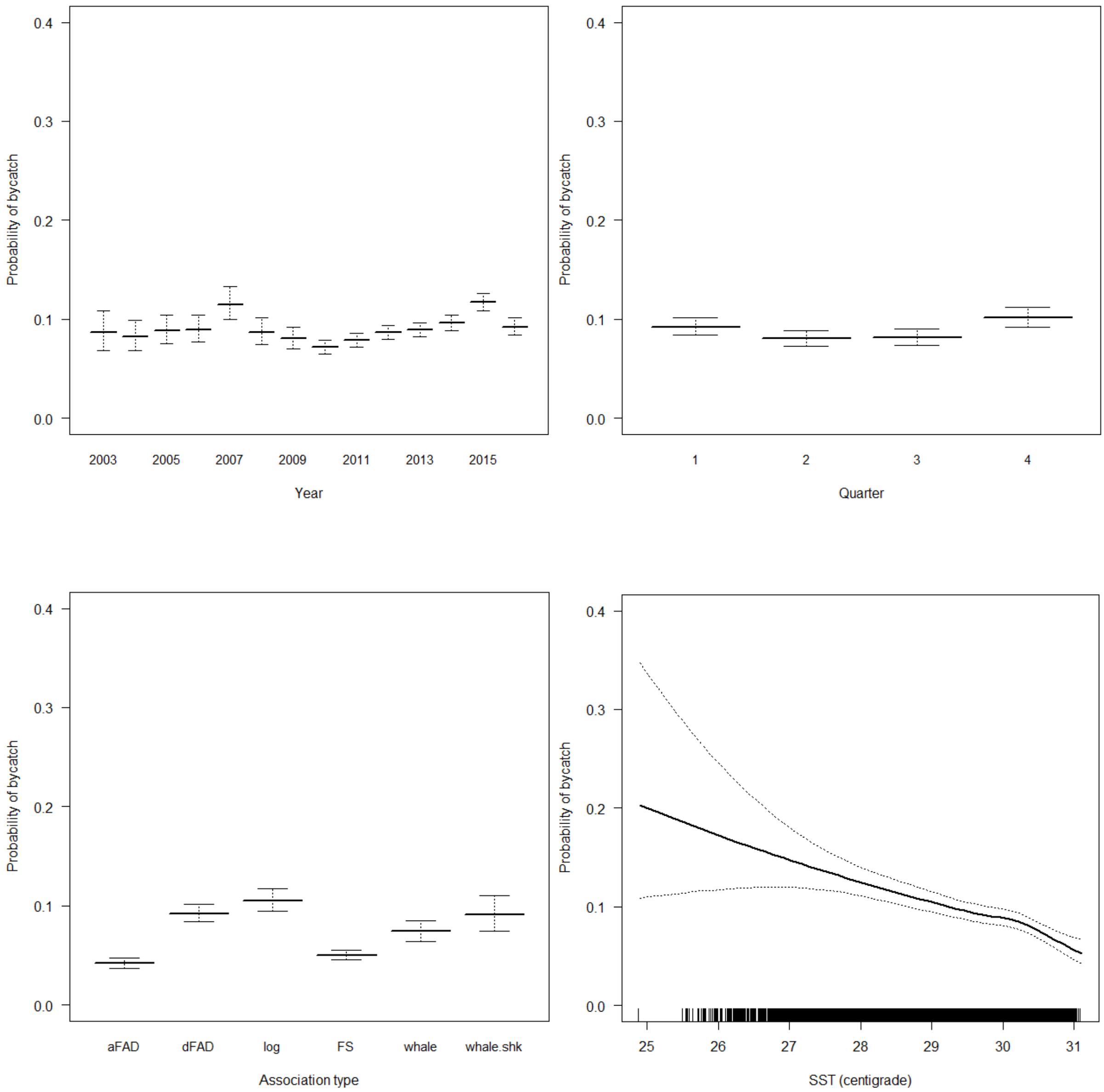


Figure 34 Predicted probability (mean +/- 2 s.e.) of blue marlin bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 23 Approximate significance of terms for the model of blue marlin presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	104.55	< 2.2e-16
qtr	3	129.46	< 2.2e-16
association	5	1235.83	< 2.2e-16
ns(sst, df = 4)	4	115.89	< 2.2e-16

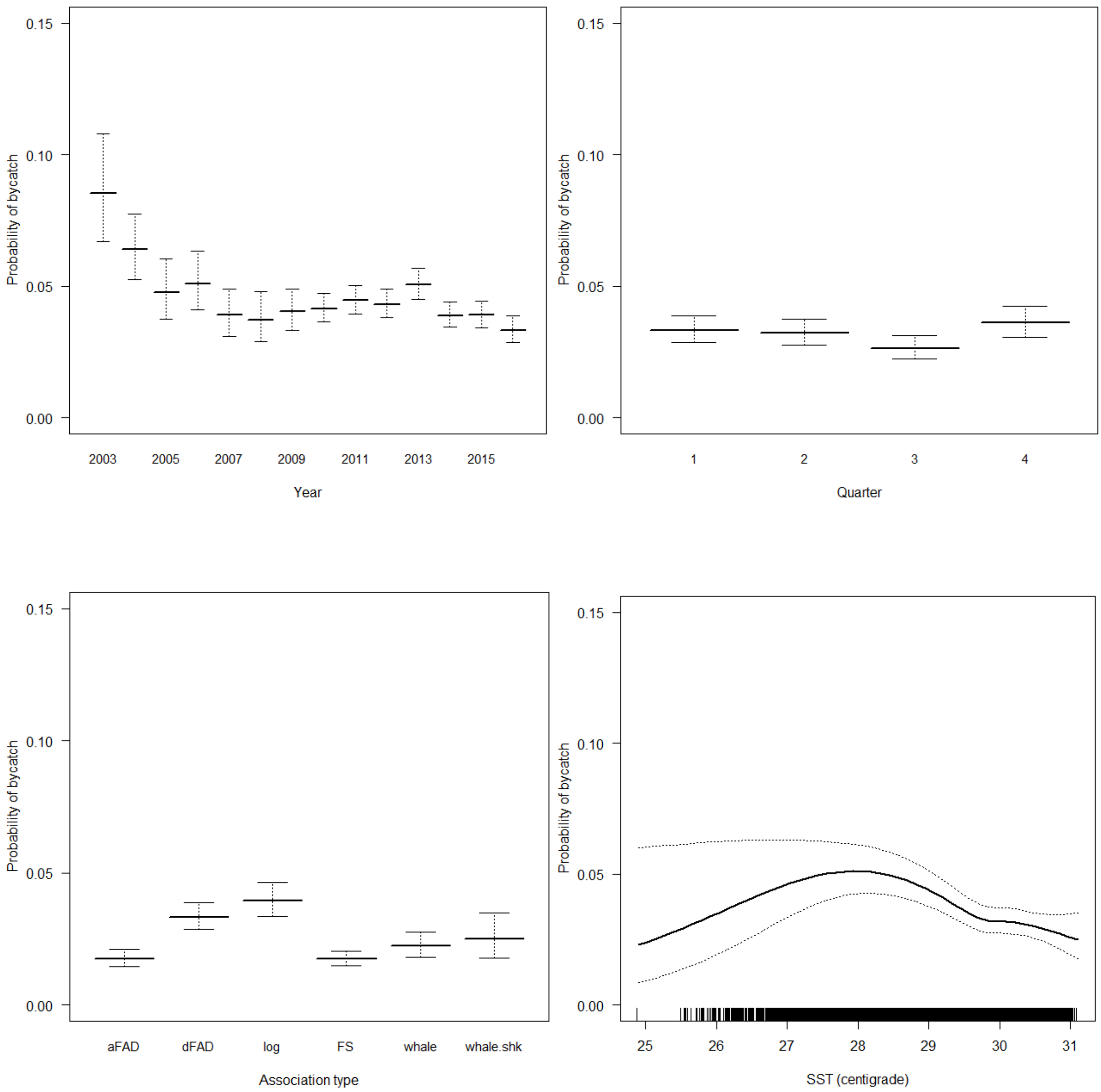


Figure 35 Predicted probability (mean +/- 2 s.e.) of black marlin bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 24 Approximate significance of terms for the model of blue marlin presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	119.43	< 2.2e-16
qtr	3	81.47	< 2.2e-16
association	5	632.9	< 2.2e-16
ns(sst, df = 4)	4	80.8	< 2.2e-16

Sharks and rays

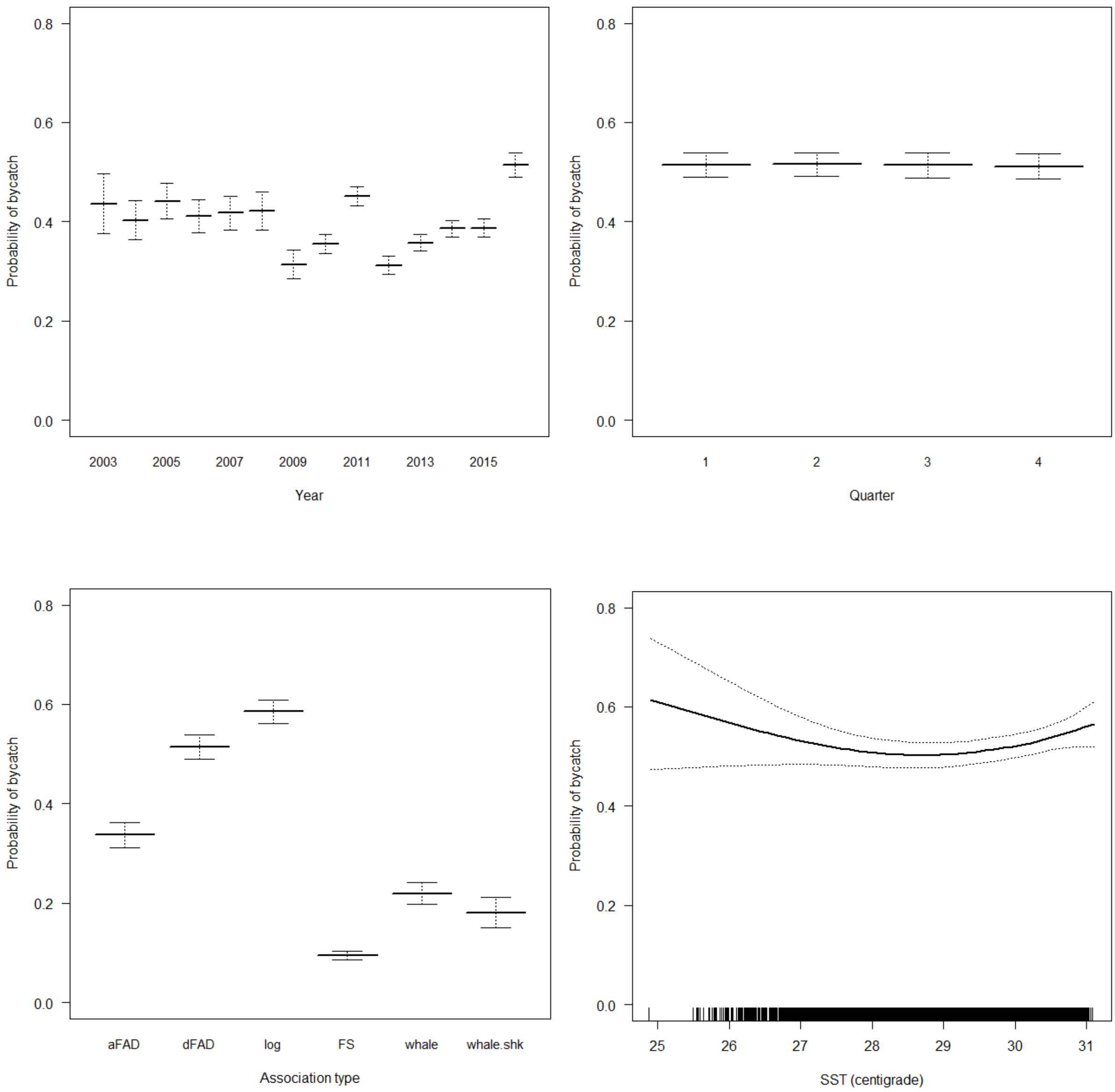


Figure 36 Predicted probability (mean +/- 2 s.e.) of silky shark bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 25 Approximate significance of terms for the model of silky shark presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	666.8	< 2.2e-16
qtr	3	462.6	< 2.2e-16
association	5	12248	< 2.2e-16
ns(sst, df = 4)	4	20	0.000501

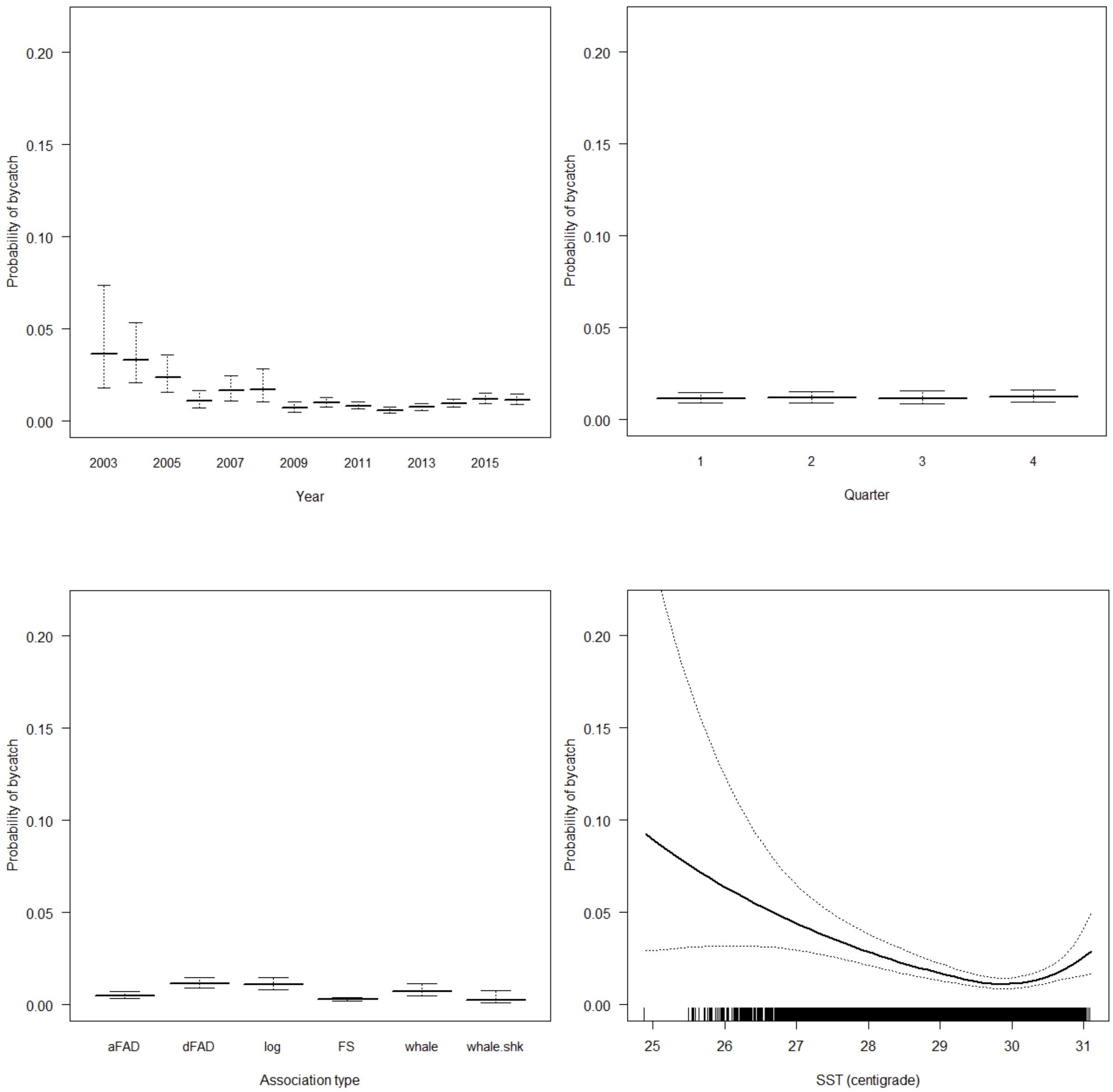


Figure 37 Predicted probability (mean +/- 2 s.e.) of oceanic whitetip bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 26 Approximate significance of terms for the model of oceanic whitetip presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	104.98	2.22E-16
qtr	3	13.04	0.004561
association	5	408.22	< 2.2e-16
ns(sst, df = 4)	4	82.66	< 2.2e-16

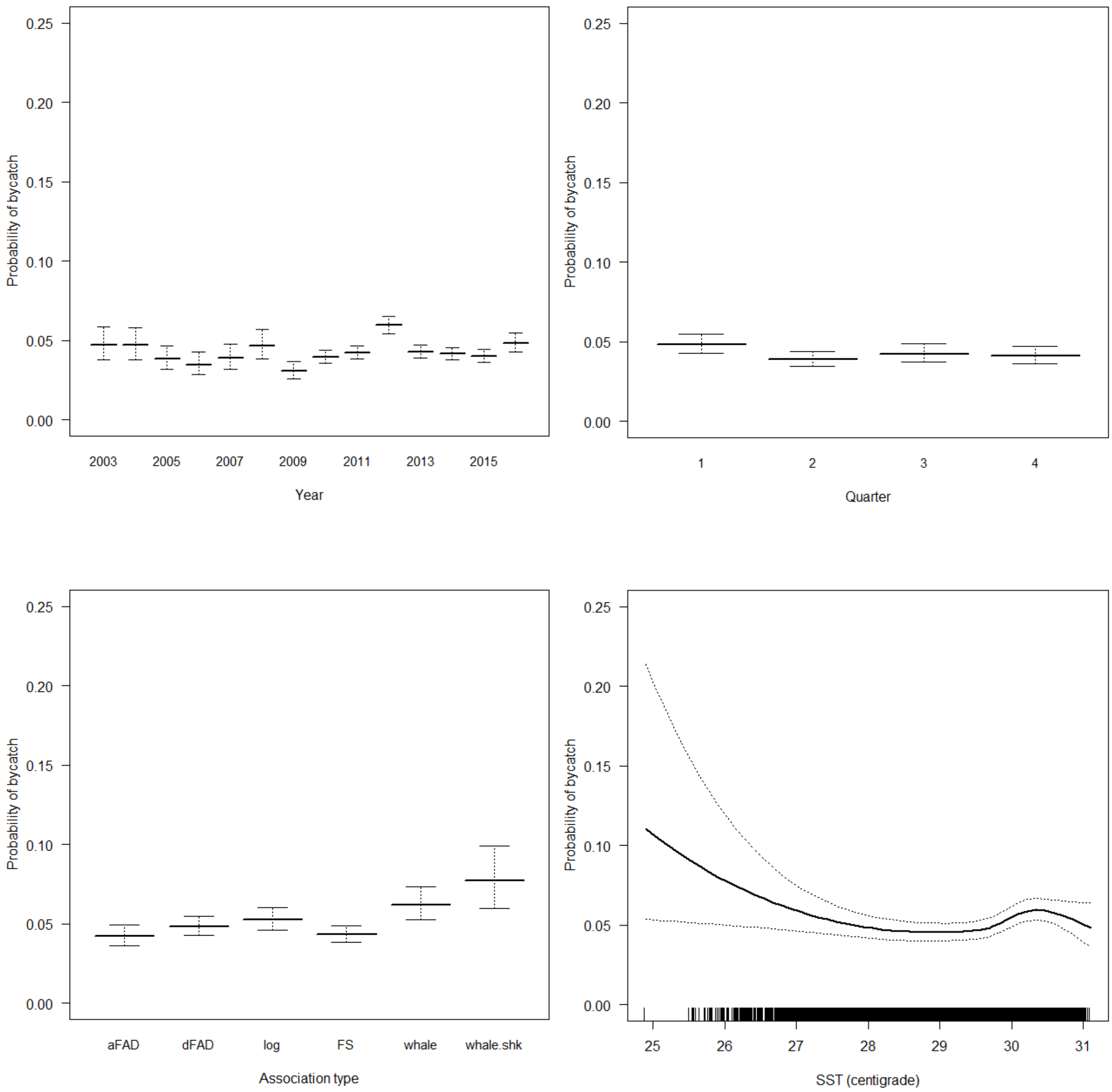


Figure 38 Predicted probability (mean +/- 2 s.e.) of manta and mobulid ray bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 27 Approximate significance of terms for the model of manta and mobulid ray presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	123.336	< 2.2e-16
qtr	3	44.506	1.18E-09
association	5	82.715	2.22E-16
ns(sst, df = 4)	4	57.613	9.20E-12

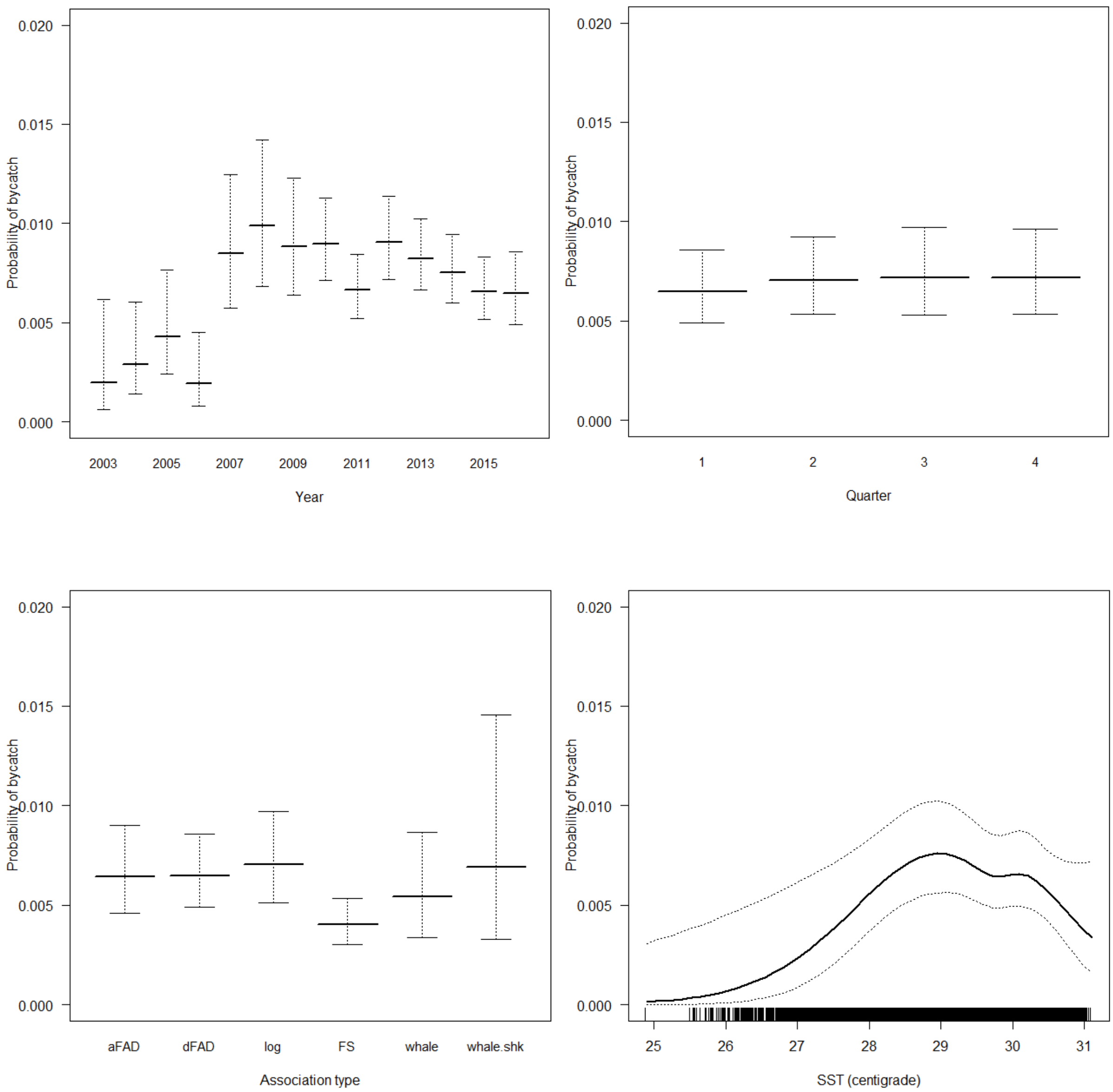


Figure 39 Predicted probability (mean +/- 2 s.e.) of pelagic stringray bycatch against year (top left), quarter (top right), association type (bottom left) and sea surface temperature (SST – bottom right). Reference levels for terms were year = 2016, quarter = 1, association type = dFAD, and SST = 29.7. Uncertainty in means includes uncertainty from all model terms.

Table 28 Approximate significance of terms for the model of pelagic stingray presence/absence.

Term	Df	χ^2	P(>|Chi|)
yy	13	45.519	1.71E-05
qtr	3	1.89	0.59551
association	5	70.287	8.94E-14
ns(sst, df = 4)	4	10.925	0.02743

Annex 5. Estimated bycatch for selected species and species groups

Finfish

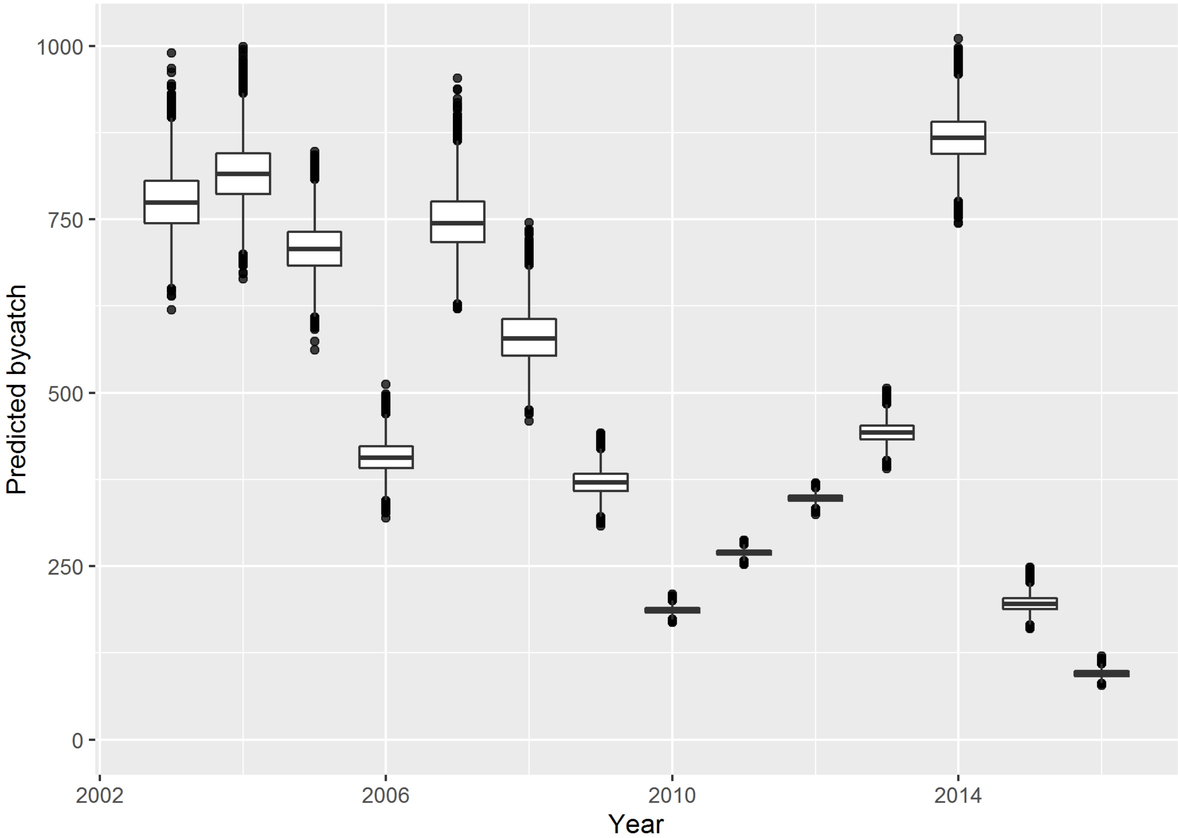


Figure 40 Predicted total annual frigate & bullet tuna bycatch (metric tonnes) by year for large-scale purse seine fleets.

Table 29 (left) Total estimated annual frigate & bullet tuna bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated frigate & bullet tuna bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	693	774	869	0.026	0.78
2004	735	815	909	0.025	0.77
2005	640	707	781	0.019	0.59
2006	364	406	455	0.012	0.33
2007	667	745	838	0.020	0.55
2008	512	578	662	0.014	0.41
2009	337	371	409	0.008	0.24
2010	177	187	197	0.004	0.13
2011	261	269	279	0.005	0.19
2012	337	348	359	0.006	0.21
2013	415	443	474	0.008	0.28
2014	804	867	935	0.015	0.49
2015	175	196	220	0.004	0.12
2016	86	95	107	0.002	0.06

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	33.3%	9.6%	40.3%	16.9%	0.0%	0.0%
2004	30.0%	8.0%	54.4%	7.7%	0.0%	0.0%
2005	32.5%	7.1%	46.0%	14.3%	0.0%	0.0%
2006	18.8%	10.0%	56.5%	14.7%	0.0%	0.0%
2007	26.6%	10.6%	44.9%	17.9%	0.0%	0.0%
2008	38.0%	21.5%	24.0%	16.5%	0.0%	0.0%
2009	35.0%	21.3%	29.5%	14.1%	0.0%	0.0%
2010	29.3%	15.1%	18.3%	37.3%	0.0%	0.0%
2011	22.5%	25.1%	17.2%	35.2%	0.0%	0.0%
2012	25.4%	23.5%	23.0%	28.1%	0.0%	0.0%
2013	45.1%	17.3%	17.0%	20.5%	0.0%	0.0%
2014	70.2%	9.3%	8.3%	12.1%	0.1%	0.0%
2015	54.3%	16.2%	11.0%	18.4%	0.2%	0.0%
2016	23.6%	26.9%	15.2%	34.2%	0.1%	0.0%

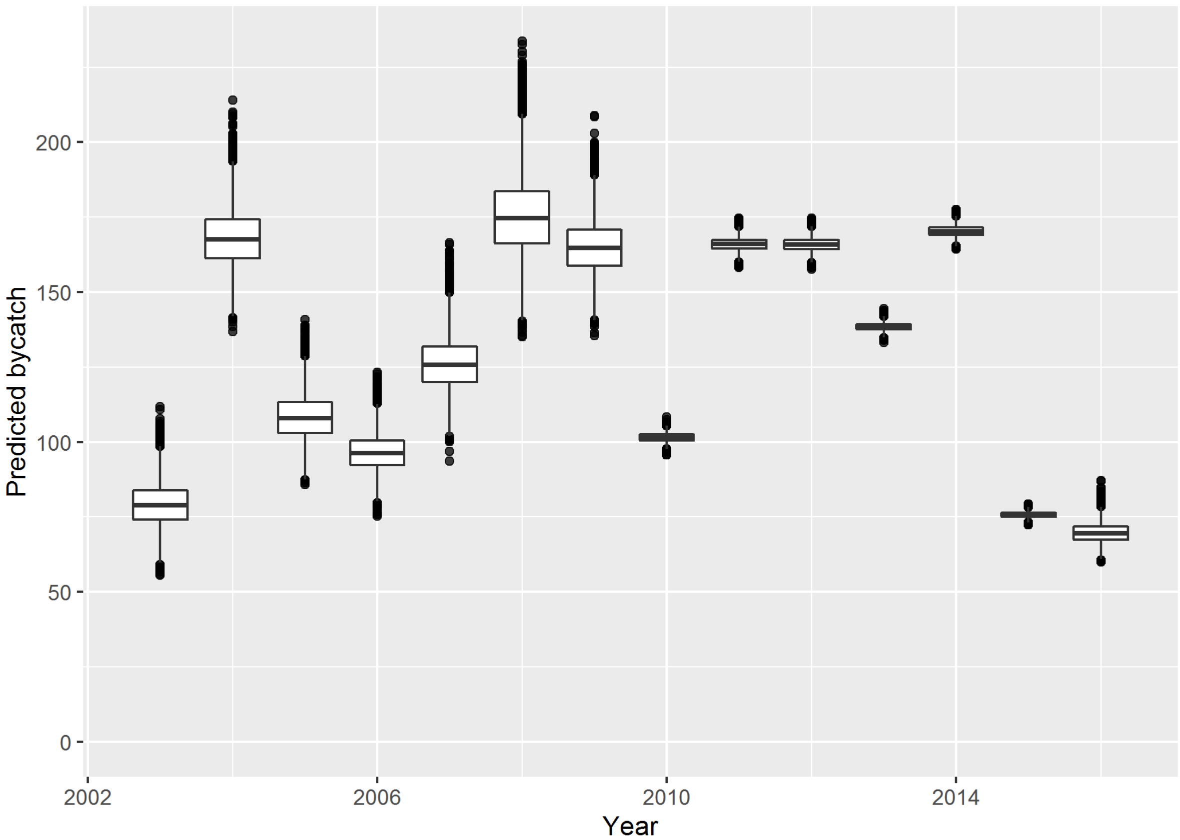


Figure 41 Predicted total annual wahoo bycatch (metric tonnes) by year for large-scale purse seine fleets.

Table 30 (left) Total estimated annual wahoo bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated wahoo bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	66	79	95	0.003	0.08
2004	150	168	189	0.005	0.16
2005	95	108	125	0.003	0.09
2006	86	96	109	0.003	0.08
2007	110	126	146	0.003	0.09
2008	153	175	203	0.004	0.12
2009	148	165	184	0.004	0.11
2010	99	102	104	0.002	0.07
2011	162	166	171	0.003	0.12
2012	162	166	171	0.003	0.10
2013	136	138	141	0.002	0.09
2014	167	170	174	0.003	0.10
2015	74	76	78	0.002	0.05
2016	64	69	77	0.001	0.04

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	7.5%	37.6%	50.6%	4.2%	0.0%	0.0%
2004	6.0%	34.2%	58.2%	1.6%	0.0%	0.0%
2005	7.7%	33.7%	54.9%	3.6%	0.0%	0.0%
2006	4.7%	37.4%	55.4%	2.5%	0.0%	0.0%
2007	4.4%	45.7%	46.5%	3.5%	0.0%	0.0%
2008	4.4%	73.5%	19.0%	3.1%	0.0%	0.0%
2009	5.2%	68.7%	23.1%	3.0%	0.0%	0.0%
2010	10.3%	60.7%	21.5%	7.5%	0.0%	0.0%
2011	3.9%	77.2%	14.5%	4.4%	0.0%	0.0%
2012	6.8%	79.9%	10.3%	2.9%	0.0%	0.0%
2013	1.5%	83.6%	11.6%	3.3%	0.0%	0.0%
2014	1.1%	87.5%	8.0%	3.5%	0.0%	0.0%
2015	4.1%	78.6%	12.5%	4.8%	0.0%	0.0%
2016	2.7%	82.9%	9.9%	4.5%	0.0%	0.0%

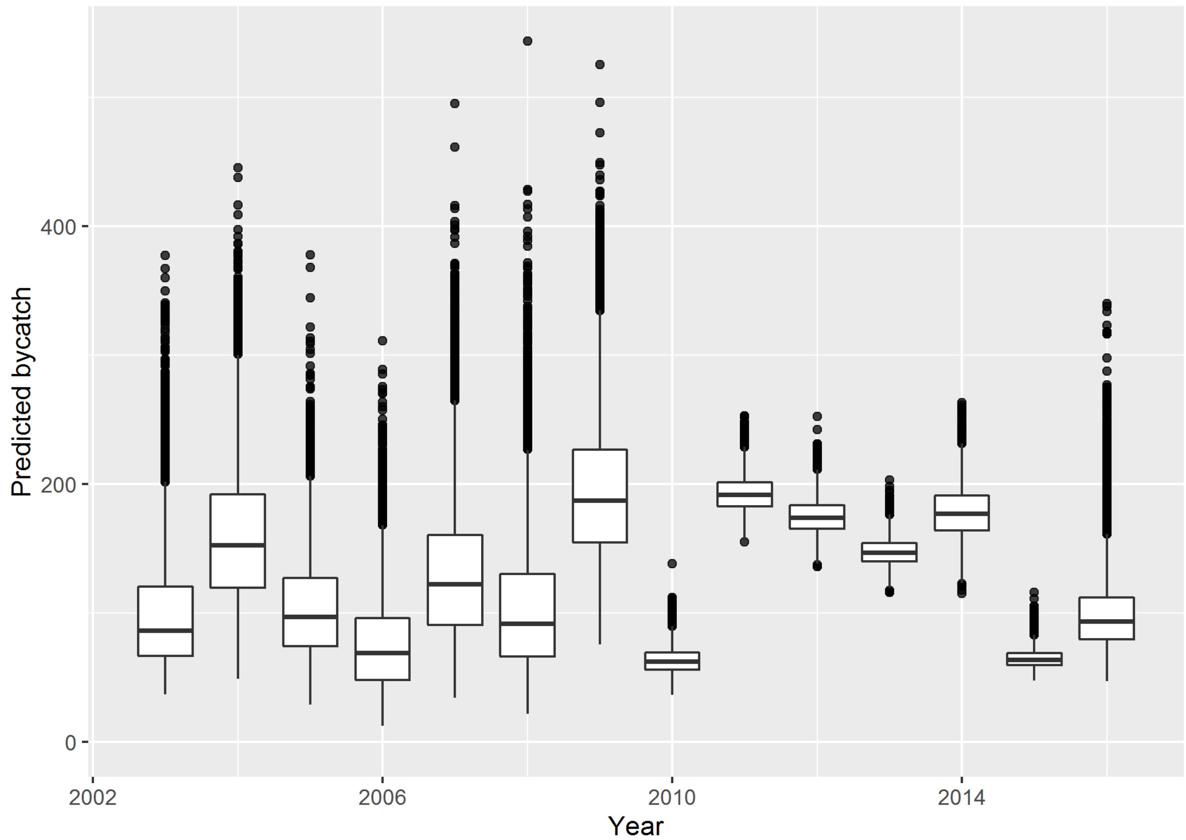


Figure 42 Predicted total annual kawakawa bycatch (metric tonnes) by year for large-scale purse seine fleets.

Table 31 (left) Total estimated annual kawakawa bycatch in metric tonnes (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated kawakawa bycatch (metric tonnes) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	47	86	222	0.003	0.09
2004	76	152	289	0.005	0.14
2005	45	97	202	0.003	0.08
2006	25	69	168	0.002	0.06
2007	54	122	263	0.003	0.09
2008	41	92	241	0.002	0.07
2009	111	187	323	0.004	0.12
2010	46	62	87	0.001	0.04
2011	169	191	222	0.004	0.14
2012	151	174	205	0.003	0.11
2013	129	147	171	0.003	0.09
2014	143	177	222	0.003	0.10
2015	53	64	82	0.001	0.04
2016	60	93	186	0.002	0.06

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	58.0%	1.2%	29.4%	11.4%	0.0%	0.0%
2004	10.4%	1.2%	75.9%	12.5%	0.0%	0.0%
2005	7.2%	30.6%	39.8%	22.4%	0.0%	0.0%
2006	4.9%	3.3%	76.5%	15.2%	0.0%	0.0%
2007	5.0%	13.2%	36.7%	45.1%	0.0%	0.0%
2008	39.9%	8.7%	43.6%	7.8%	0.0%	0.0%
2009	35.9%	20.5%	38.0%	5.6%	0.0%	0.0%
2010	19.2%	11.6%	25.1%	44.0%	0.0%	0.0%
2011	21.0%	29.1%	7.5%	41.3%	1.0%	0.0%
2012	19.4%	21.1%	23.1%	36.3%	0.0%	0.0%
2013	18.1%	28.0%	24.3%	29.7%	0.0%	0.0%
2014	46.9%	10.6%	10.1%	32.3%	0.1%	0.0%
2015	9.5%	27.3%	20.0%	43.2%	0.0%	0.0%
2016	13.1%	11.3%	17.8%	57.8%	0.0%	0.0%

Billfish

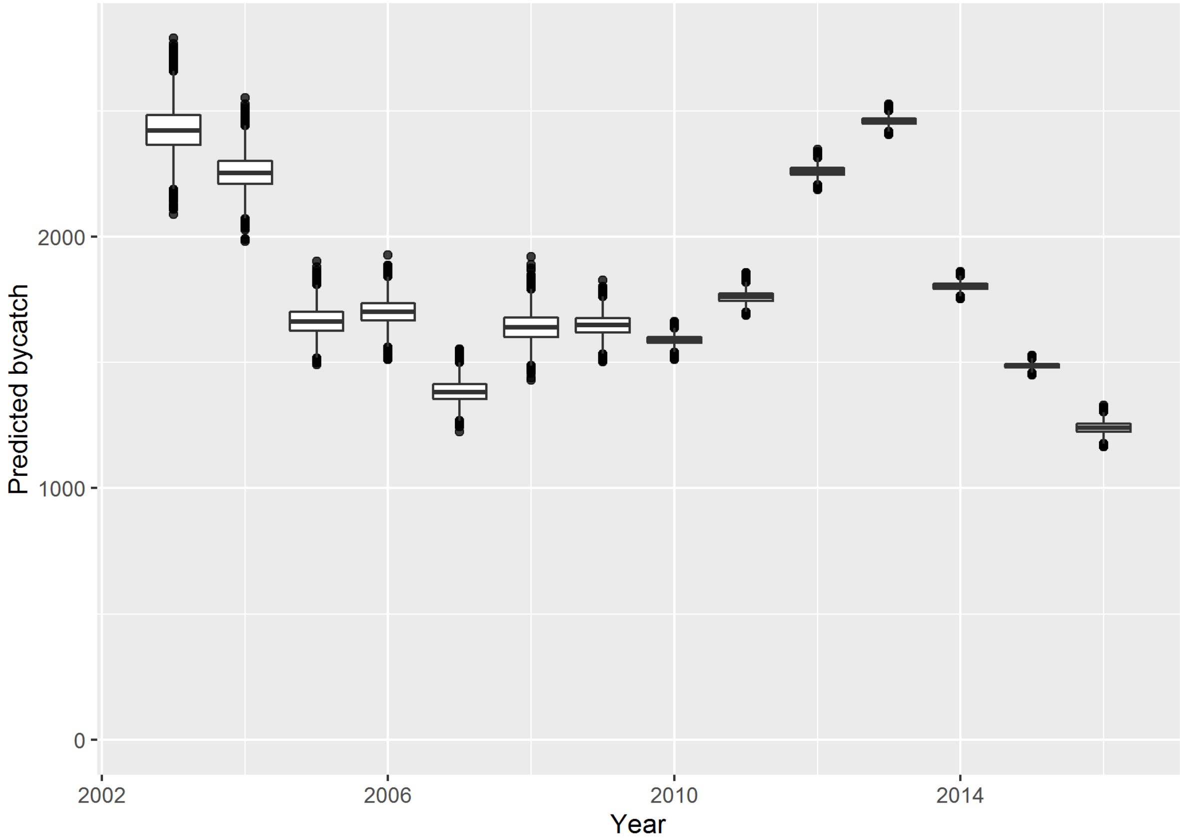


Figure 43 Predicted total annual black marlin bycatch (numbers) by year for large-scale purse seine fleets.

Table 32 (left) Total estimated annual black marlin bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated black marlin bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	2,257	2,423	2,604	0.080	2.43
2004	2,126	2,255	2,398	0.070	2.12
2005	1,563	1,663	1,775	0.045	1.39
2006	1,604	1,702	1,809	0.051	1.39
2007	1,302	1,383	1,475	0.038	1.02
2008	1,534	1,639	1,758	0.040	1.17
2009	1,567	1,649	1,735	0.037	1.08
2010	1,554	1,589	1,626	0.031	1.07
2011	1,718	1,760	1,805	0.034	1.25
2012	2,222	2,261	2,302	0.039	1.37
2013	2,431	2,460	2,492	0.044	1.55
2014	1,776	1,804	1,835	0.032	1.02
2015	1,467	1,488	1,509	0.031	0.94
2016	1,198	1,240	1,287	0.026	0.77

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	6.3%	15.4%	38.7%	39.5%	0.0%	0.0%
2004	4.2%	17.3%	59.2%	19.3%	0.1%	0.0%
2005	5.3%	13.9%	43.6%	37.1%	0.1%	0.0%
2006	4.1%	17.2%	50.0%	28.6%	0.0%	0.1%
2007	4.5%	19.9%	37.2%	38.1%	0.2%	0.0%
2008	4.2%	37.0%	19.7%	39.1%	0.1%	0.0%
2009	4.0%	36.1%	24.8%	34.8%	0.3%	0.0%
2010	4.1%	22.2%	15.1%	57.8%	0.6%	0.0%
2011	5.1%	44.2%	11.6%	38.9%	0.2%	0.0%
2012	3.1%	34.1%	11.2%	51.4%	0.2%	0.0%
2013	1.4%	37.6%	11.9%	48.9%	0.1%	0.0%
2014	1.0%	39.0%	7.4%	52.4%	0.1%	0.0%
2015	2.2%	27.2%	8.7%	61.2%	0.7%	0.0%
2016	2.1%	38.5%	10.2%	49.0%	0.2%	0.1%

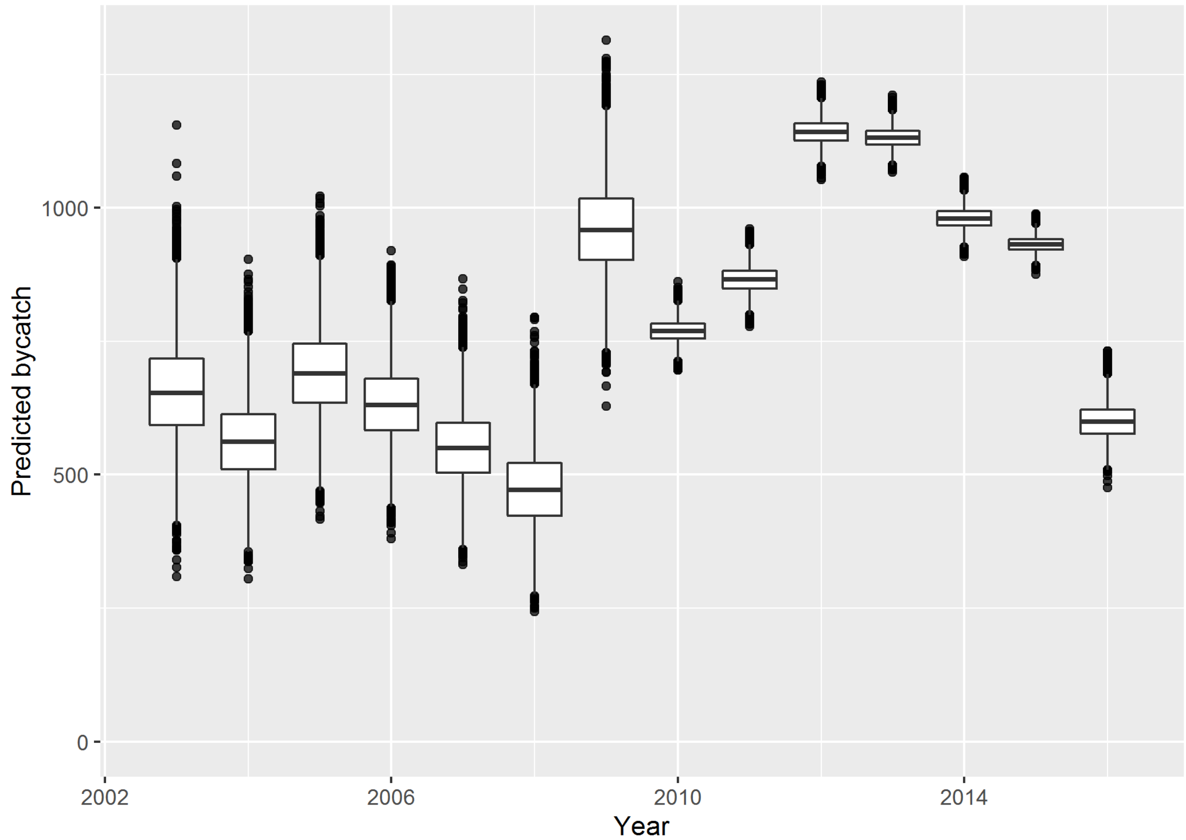


Figure 44 Predicted total annual striped marlin bycatch (numbers) by year for large-scale purse seine fleets.

Table 33 (left) Total estimated annual striped marlin bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated striped marlin bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	483	653	848	0.022	0.66
2004	423	562	720	0.017	0.53
2005	539	689	860	0.019	0.58
2006	497	631	785	0.019	0.51
2007	422	550	697	0.015	0.40
2008	338	471	628	0.011	0.34
2009	800	959	1,138	0.022	0.63
2010	728	769	811	0.015	0.52
2011	820	866	913	0.017	0.61
2012	1,098	1,142	1,191	0.020	0.69
2013	1,095	1,132	1,170	0.020	0.71
2014	942	980	1,019	0.017	0.55
2015	904	932	961	0.019	0.59
2016	539	599	671	0.013	0.37

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	2.3%	13.6%	32.6%	51.3%	0.2%	0.0%
2004	3.1%	17.1%	67.4%	12.2%	0.2%	0.0%
2005	3.3%	6.8%	33.0%	56.9%	0.1%	0.0%
2006	4.4%	9.8%	52.2%	33.6%	0.0%	0.0%
2007	2.4%	22.5%	25.2%	49.5%	0.4%	0.0%
2008	3.7%	52.5%	7.3%	36.5%	0.0%	0.0%
2009	3.1%	54.0%	12.9%	29.7%	0.2%	0.0%
2010	3.0%	26.2%	19.2%	50.2%	1.3%	0.0%
2011	5.2%	48.6%	9.9%	36.0%	0.2%	0.0%
2012	2.8%	35.5%	11.1%	50.2%	0.4%	0.0%
2013	2.8%	32.3%	11.6%	53.2%	0.1%	0.0%
2014	0.5%	42.4%	7.1%	49.8%	0.2%	0.0%
2015	1.4%	33.4%	5.7%	59.2%	0.3%	0.0%
2016	4.0%	24.5%	15.1%	56.0%	0.3%	0.0%

Sharks and rays

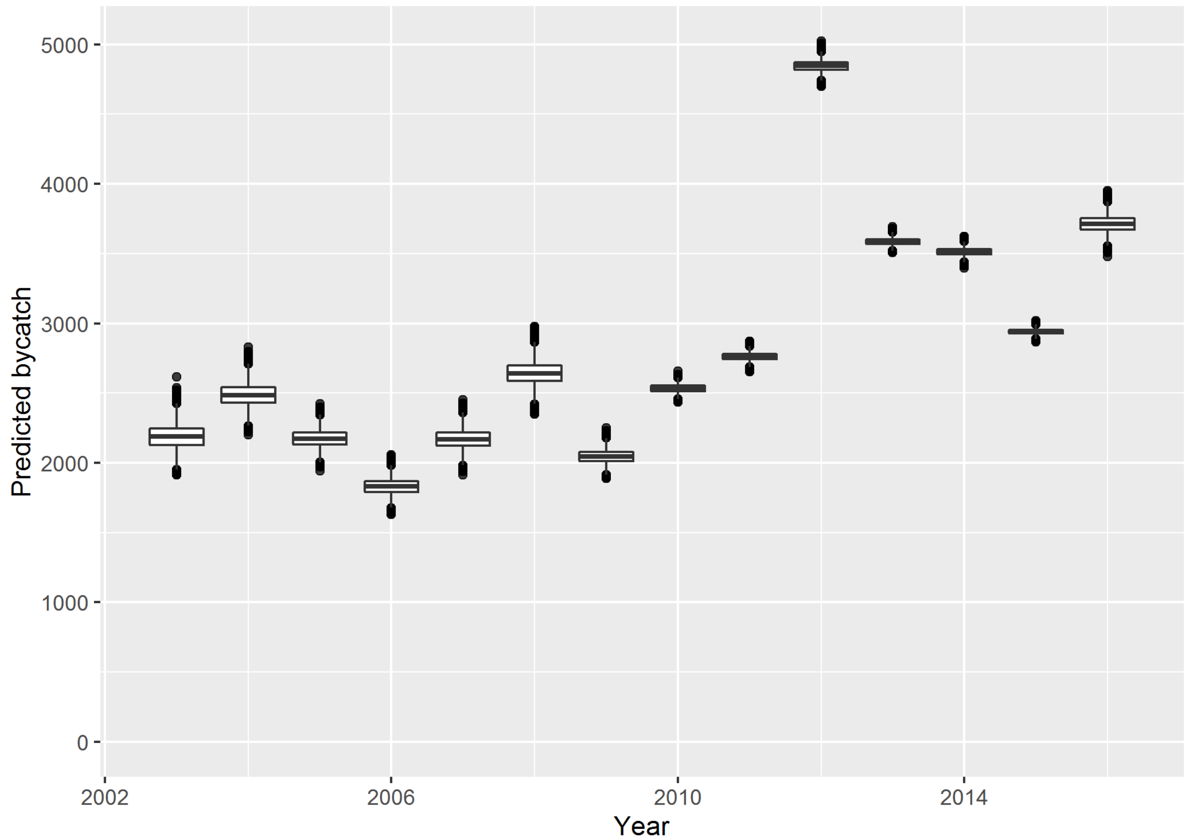


Figure 45 Predicted total annual manta & mobulid ray bycatch (numbers) by year for large-scale purse seine fleets.

Table 34 (left) Total estimated annual manta & mobulid ray bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated manta & mobulid ray bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	2,025	2,187	2,364	0.072	2.20
2004	2,333	2,484	2,653	0.077	2.33
2005	2,055	2,174	2,305	0.059	1.82
2006	1,726	1,830	1,946	0.055	1.49
2007	2,038	2,169	2,314	0.060	1.60
2008	2,485	2,642	2,817	0.064	1.89
2009	1,955	2,045	2,142	0.046	1.34
2010	2,480	2,533	2,592	0.049	1.70
2011	2,710	2,762	2,818	0.053	1.96
2012	4,773	4,845	4,927	0.084	2.94
2013	3,540	3,586	3,636	0.064	2.26
2014	3,458	3,512	3,568	0.062	1.98
2015	2,902	2,940	2,979	0.061	1.85
2016	3,600	3,713	3,834	0.079	2.31

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	7.8%	11.0%	26.4%	54.7%	0.0%	0.1%
2004	5.8%	12.6%	47.1%	34.4%	0.0%	0.0%
2005	7.8%	10.9%	32.2%	49.0%	0.1%	0.0%
2006	6.0%	14.6%	35.8%	43.6%	0.0%	0.0%
2007	4.5%	14.4%	28.5%	52.4%	0.1%	0.0%
2008	8.3%	24.7%	14.1%	52.7%	0.3%	0.0%
2009	5.8%	26.8%	18.6%	48.6%	0.2%	0.0%
2010	4.3%	12.3%	8.8%	73.2%	1.3%	0.1%
2011	4.6%	28.7%	8.3%	57.9%	0.5%	0.0%
2012	4.2%	22.5%	9.4%	63.3%	0.6%	0.0%
2013	1.7%	26.1%	6.4%	65.5%	0.3%	0.0%
2014	1.5%	23.6%	7.0%	67.7%	0.3%	0.0%
2015	4.6%	21.0%	6.1%	68.1%	0.3%	0.0%
2016	2.0%	19.4%	4.0%	73.9%	0.4%	0.3%

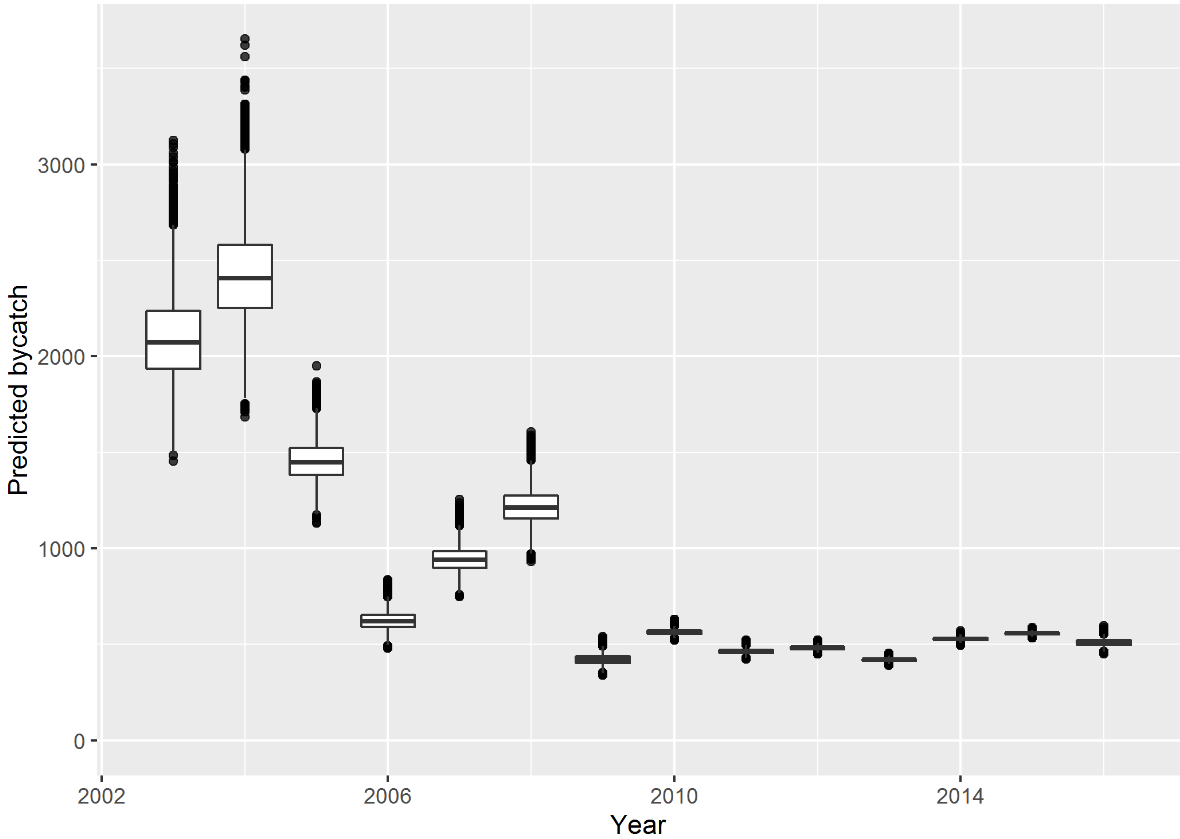


Figure 46 Predicted total annual oceanic whitetip bycatch (numbers) by year for large-scale purse seine fleets.

Table 35 (left) Total estimated annual oceanic whitetip bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated oceanic whitetip bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	1,709	2,073	2,586	0.068	2.08
2004	1,988	2,407	2,947	0.075	2.26
2005	1,267	1,449	1,675	0.040	1.21
2006	537	620	724	0.019	0.51
2007	822	939	1,083	0.026	0.69
2008	1,052	1,212	1,405	0.029	0.87
2009	373	421	476	0.010	0.28
2010	542	564	591	0.011	0.38
2011	439	463	490	0.009	0.33
2012	465	481	500	0.008	0.29
2013	404	419	436	0.007	0.26
2014	512	529	546	0.009	0.30
2015	543	556	571	0.012	0.35
2016	477	509	547	0.011	0.32

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	7.0%	15.9%	63.7%	13.2%	0.0%	0.2%
2004	4.7%	14.6%	74.2%	6.6%	0.0%	0.0%
2005	6.1%	18.4%	61.5%	13.9%	0.0%	0.0%
2006	4.1%	15.7%	68.8%	11.4%	0.0%	0.0%
2007	4.0%	23.6%	57.3%	15.1%	0.0%	0.0%
2008	10.9%	40.8%	31.1%	17.1%	0.1%	0.0%
2009	4.7%	39.0%	38.5%	17.8%	0.0%	0.0%
2010	4.0%	36.0%	22.9%	36.7%	0.5%	0.0%
2011	6.3%	48.6%	21.6%	22.9%	0.6%	0.0%
2012	22.5%	28.4%	20.9%	28.2%	0.0%	0.0%
2013	3.1%	48.8%	26.1%	22.0%	0.0%	0.0%
2014	1.5%	53.9%	12.4%	32.2%	0.0%	0.0%
2015	3.0%	49.1%	10.7%	37.2%	0.0%	0.0%
2016	3.2%	53.2%	12.2%	30.8%	0.6%	0.0%

Other species of special scientific interest

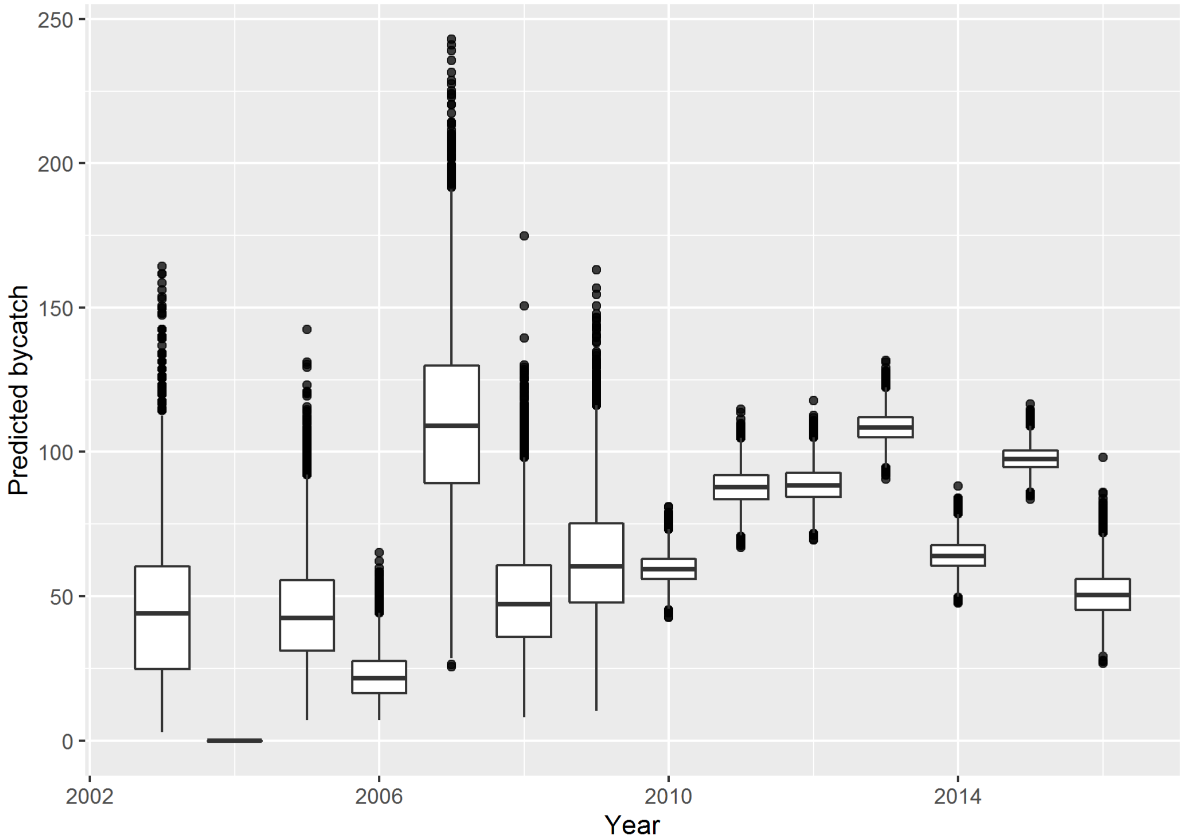


Figure 47 Predicted total annual green turtle bycatch (numbers) by year for large-scale purse seine fleets.

Table 36 (left) Total estimated annual green turtle bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated green turtle bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	3	44	104	0.001	0.04
2004	0	0	0	0.000	0.00
2005	15	42	85	0.001	0.04
2006	10	22	41	0.001	0.02
2007	56	109	175	0.003	0.08
2008	19	47	93	0.001	0.03
2009	28	60	107	0.001	0.04
2010	50	59	70	0.001	0.04
2011	76	88	101	0.002	0.06
2012	77	88	101	0.002	0.05
2013	99	108	119	0.002	0.07
2014	54	64	75	0.001	0.04
2015	90	98	106	0.002	0.06
2016	37	50	68	0.001	0.03

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	0.0%	0.0%	23.6%	76.4%	0.0%	0.0%
2004	NA	NA	NA	NA	NA	NA
2005	8.4%	0.0%	76.2%	15.4%	0.0%	0.0%
2006	48.6%	27.4%	0.0%	24.0%	0.0%	0.0%
2007	3.1%	13.1%	19.6%	64.1%	0.0%	0.0%
2008	12.1%	0.0%	25.7%	62.1%	0.0%	0.0%
2009	5.2%	32.7%	44.8%	17.3%	0.0%	0.0%
2010	3.0%	11.0%	4.2%	81.7%	0.0%	0.0%
2011	0.0%	33.0%	2.3%	64.7%	0.0%	0.0%
2012	3.2%	21.1%	21.8%	54.0%	0.0%	0.0%
2013	0.9%	18.7%	11.5%	68.0%	0.9%	0.0%
2014	3.1%	29.0%	5.0%	62.8%	0.0%	0.0%
2015	2.5%	25.8%	8.7%	62.9%	0.0%	0.0%
2016	0.0%	26.1%	12.6%	59.3%	2.0%	0.0%

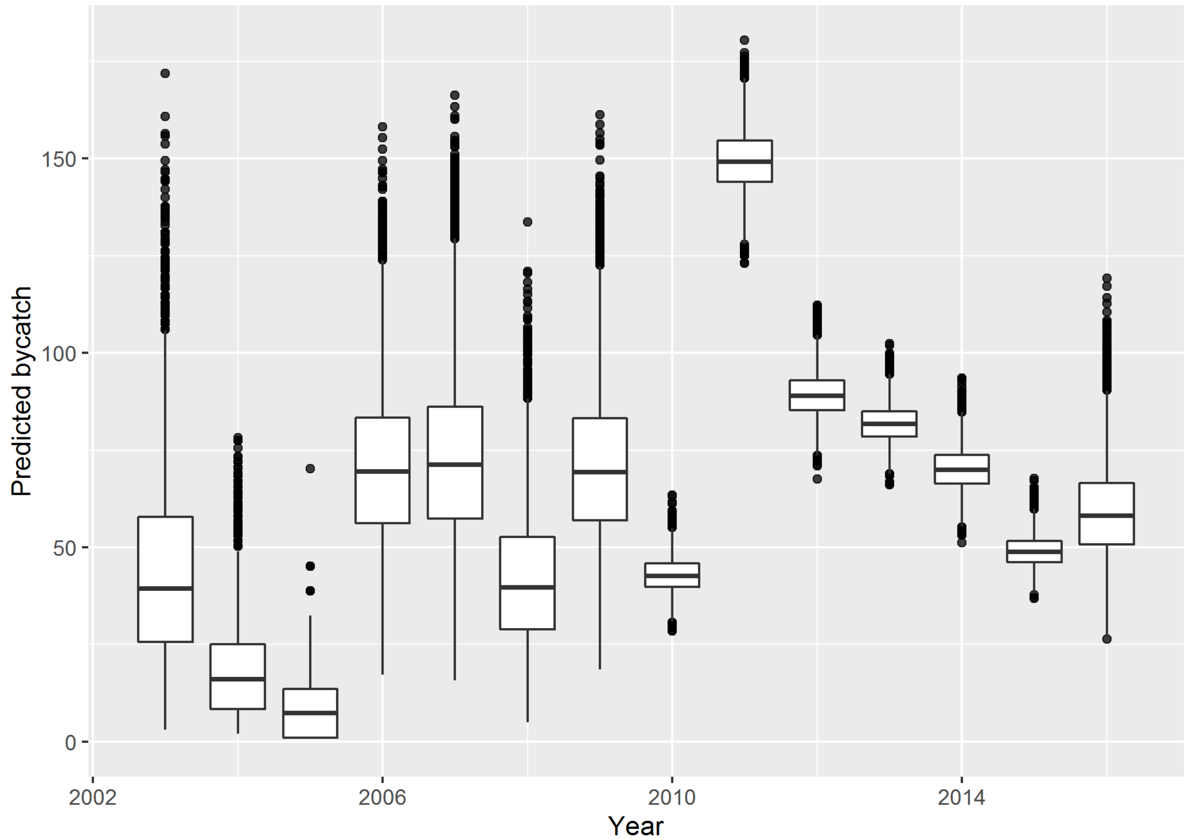


Figure 48 Predicted total annual olive ridley turtle bycatch (numbers) by year for large-scale purse seine fleets.

Table 37 (left) Total estimated annual olive ridley turtle bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated olive ridley turtle bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	3	39	99	0.001	0.04
2004	2	16	47	0.000	0.02
2005	1	7	26	0.000	0.01
2006	36	69	114	0.002	0.06
2007	35	71	119	0.002	0.05
2008	12	40	79	0.001	0.03
2009	37	69	114	0.002	0.05
2010	35	43	52	0.001	0.03
2011	134	149	165	0.003	0.11
2012	78	89	101	0.002	0.05
2013	73	82	92	0.001	0.05
2014	60	70	81	0.001	0.04
2015	42	49	58	0.001	0.03
2016	39	58	85	0.001	0.04

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
2004	0.0%	0.0%	54.3%	45.7%	0.0%	0.0%
2005	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
2006	2.7%	15.8%	42.4%	39.0%	0.0%	0.0%
2007	9.8%	13.2%	14.6%	62.4%	0.0%	0.0%
2008	0.0%	21.3%	0.0%	78.7%	0.0%	0.0%
2009	6.6%	30.9%	23.9%	38.7%	0.0%	0.0%
2010	4.1%	11.9%	28.2%	55.7%	0.0%	0.0%
2011	6.6%	34.6%	8.2%	49.9%	0.7%	0.0%
2012	6.8%	12.8%	15.5%	64.8%	0.0%	0.0%
2013	3.7%	17.9%	18.0%	60.4%	0.0%	0.0%
2014	2.9%	26.3%	15.7%	55.1%	0.0%	0.0%
2015	8.2%	18.5%	7.7%	65.6%	0.0%	0.0%
2016	3.9%	27.5%	0.0%	68.6%	0.0%	0.0%

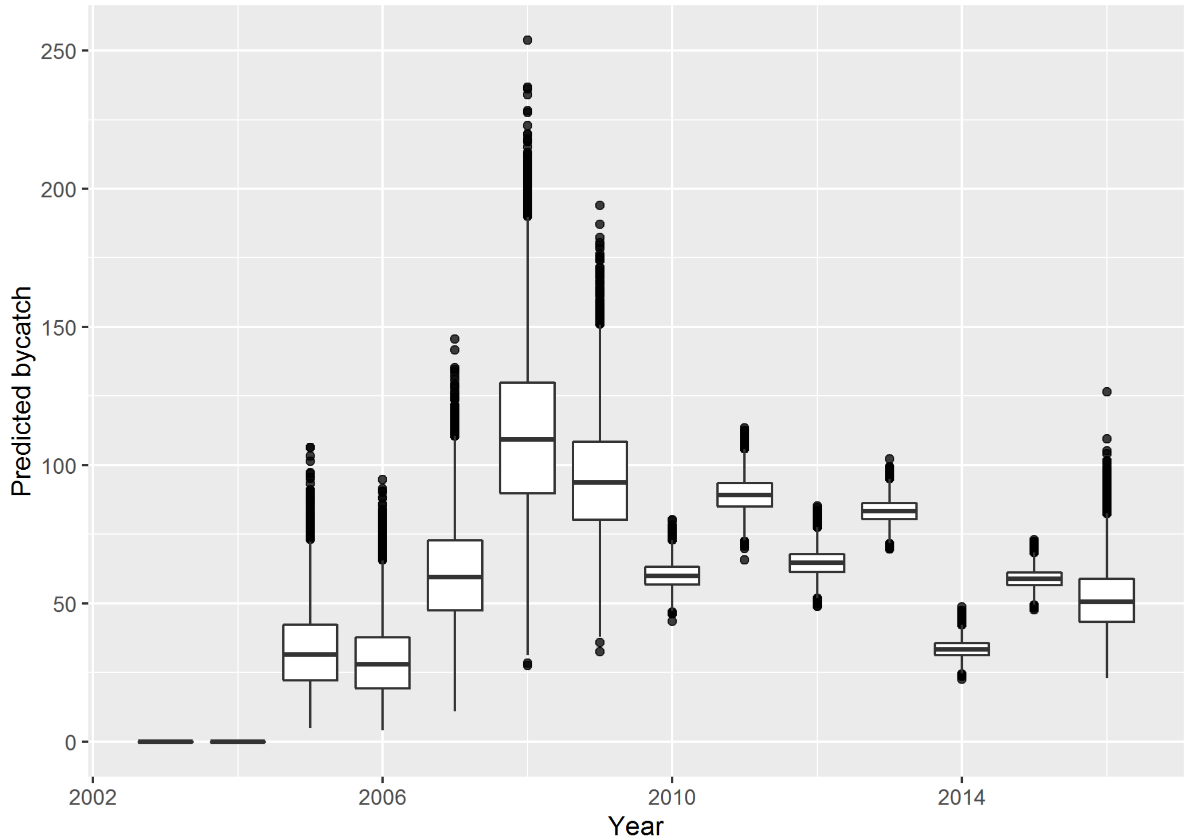


Figure 49 Predicted total annual loggerhead turtle bycatch (numbers) by year for large-scale purse seine fleets.

Table 38 (left) Total estimated annual loggerhead turtle bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated loggerhead turtle bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	0	0	0	0.000	0.00
2004	0	0	0	0.000	0.00
2005	10	31	66	0.001	0.03
2006	8	28	60	0.001	0.02
2007	29	59	101	0.002	0.04
2008	58	109	176	0.003	0.08
2009	56	94	140	0.002	0.06
2010	51	60	70	0.001	0.04
2011	78	89	102	0.002	0.06
2012	56	65	75	0.001	0.04
2013	75	83	92	0.001	0.05
2014	28	33	40	0.001	0.02
2015	52	59	66	0.001	0.04
2016	32	51	79	0.001	0.03

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	NA	NA	NA	NA	NA	NA
2004	NA	NA	NA	NA	NA	NA
2005	0.0%	0.0%	72.2%	27.8%	0.0%	0.0%
2006	0.0%	28.3%	20.6%	51.1%	0.0%	0.0%
2007	6.9%	19.6%	0.0%	73.5%	0.0%	0.0%
2008	3.5%	25.1%	0.0%	70.5%	0.9%	0.0%
2009	2.2%	10.0%	27.4%	60.3%	0.0%	0.0%
2010	0.0%	9.8%	3.4%	86.9%	0.0%	0.0%
2011	1.7%	48.2%	1.9%	48.3%	0.0%	0.0%
2012	0.0%	33.2%	17.7%	49.1%	0.0%	0.0%
2013	0.0%	20.4%	7.8%	71.8%	0.0%	0.0%
2014	0.0%	25.7%	4.3%	70.0%	0.0%	0.0%
2015	3.5%	40.4%	6.3%	49.8%	0.0%	0.0%
2016	0.0%	22.6%	4.5%	72.9%	0.0%	0.0%

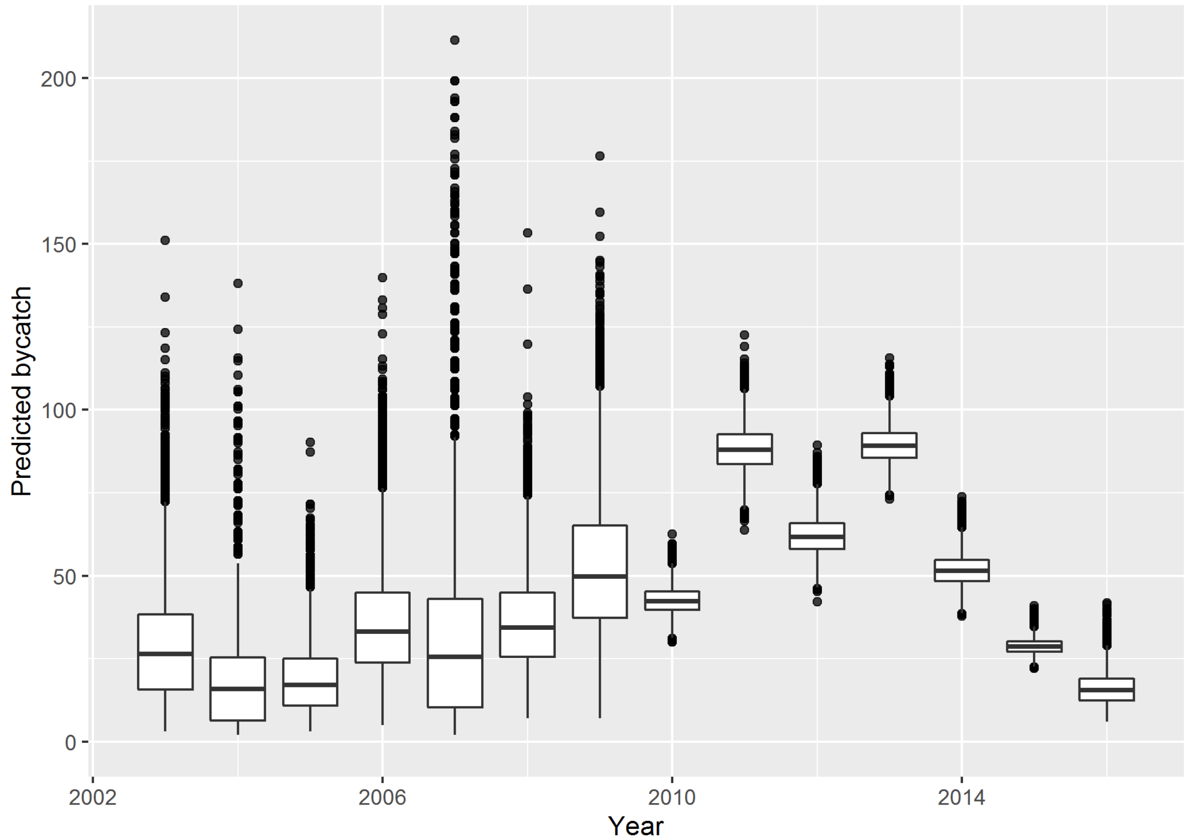


Figure 50 Predicted total annual hawksbill turtle bycatch (numbers) by year for large-scale purse seine fleets.

Table 39 (left) Total estimated annual hawksbill turtle bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated hawksbill turtle bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	3	26	69	0.001	0.03
2004	2	16	58	0.000	0.01
2005	3	17	44	0.000	0.01
2006	11	33	76	0.001	0.03
2007	2	26	107	0.001	0.02
2008	12	34	70	0.001	0.02
2009	20	50	100	0.001	0.03
2010	35	42	51	0.001	0.03
2011	76	88	102	0.002	0.06
2012	52	62	75	0.001	0.04
2013	80	89	101	0.002	0.06
2014	43	51	62	0.001	0.03
2015	25	29	34	0.001	0.02
2016	8	15	27	0.000	0.01

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	21.2%	28.7%	0.0%	50.1%	0.0%	0.0%
2004	0.0%	0.0%	66.2%	33.8%	0.0%	0.0%
2005	0.0%	15.7%	0.0%	84.3%	0.0%	0.0%
2006	0.0%	16.3%	51.2%	32.4%	0.0%	0.0%
2007	0.0%	0.0%	71.7%	28.3%	0.0%	0.0%
2008	17.5%	0.0%	0.0%	82.5%	0.0%	0.0%
2009	0.0%	20.5%	45.0%	34.5%	0.0%	0.0%
2010	0.0%	21.4%	4.5%	74.1%	0.0%	0.0%
2011	6.1%	11.9%	13.4%	68.5%	0.0%	0.0%
2012	11.3%	18.4%	19.5%	50.9%	0.0%	0.0%
2013	7.2%	16.2%	12.9%	63.7%	0.0%	0.0%
2014	0.0%	22.1%	22.5%	55.4%	0.0%	0.0%
2015	1.6%	24.2%	8.8%	65.4%	0.0%	0.0%
2016	0.0%	10.9%	0.0%	89.1%	0.0%	0.0%

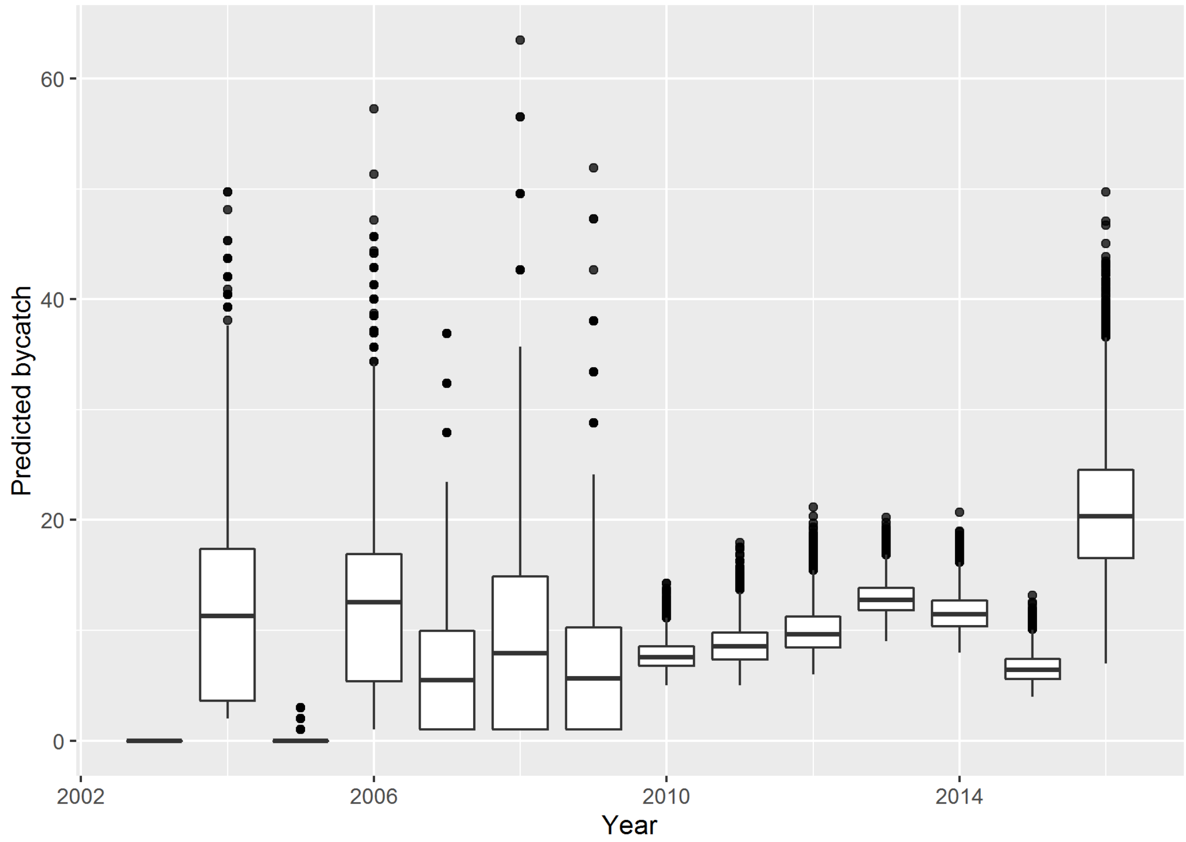


Figure 51 Predicted total annual leatherback turtle bycatch (numbers) by year for large-scale purse seine fleets.

Table 40 (left) Total estimated annual leatherback turtle bycatch in numbers (median, and lower and upper 95 % confidence intervals) for large-scale purse seine fleets. Average annual bycatch rates by set and '000 metric tonnes of target catch are also included. (right) Proportion of annual estimated leatherback turtle bycatch (numbers) by association type.

	Estimated bycatch			Bycatch rate per	
Year	Low	Median	High	set	'000 mt
2003	0	0	0	0.000	0.00
2004	2	11	28	0.000	0.01
2005	0	0	2	0.000	0.00
2006	1	13	31	0.000	0.01
2007	1	5	19	0.000	0.00
2008	1	8	29	0.000	0.01
2009	1	6	24	0.000	0.00
2010	6	8	11	0.000	0.01
2011	6	9	13	0.000	0.01
2012	6	10	15	0.000	0.01
2013	10	13	16	0.000	0.01
2014	9	11	15	0.000	0.01
2015	4	6	9	0.000	0.00
2016	10	20	34	0.000	0.01

Year	aFAD	dFAD	log	FS	whale	whale.shk
2003	NA	NA	NA	NA	NA	NA
2004	23.3%	0.0%	76.7%	0.0%	0.0%	0.0%
2005	NA	NA	NA	NA	NA	NA
2006	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
2007	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
2008	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
2009	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
2010	34.2%	0.0%	0.0%	65.8%	0.0%	0.0%
2011	0.0%	74.8%	25.2%	0.0%	0.0%	0.0%
2012	0.0%	82.1%	0.0%	17.9%	0.0%	0.0%
2013	0.0%	28.4%	0.0%	71.6%	0.0%	0.0%
2014	0.0%	20.4%	0.0%	79.6%	0.0%	0.0%
2015	0.0%	46.5%	29.5%	24.0%	0.0%	0.0%
2016	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%