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Summary of longline fishery bycatch at a regional scale, 2003-2017

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Executive Summary

WCPFC has responsibilities 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; to minimize catch of non-target species; to protect biodiversity; and, to adopt, when necessary, conservation and management measures for non-target species to ensure the conservation of such species.

In this report we: summarise longline observer data held in SPC's master observer database related to bycatch, including information on fate (i.e. utilisation) and condition at release; fit statistical models to observer data to estimate catch rates; and, raise catch rates with aggregate effort data to estimate total catches for longline fisheries in the WCPFC Convention Area (WCPFC CA) within a simulation modelling framework. We estimated catches for 45 species or species groups, covering the full range of finfish, billfish, shark and ray, marine mammal and sea turtle species that have been recorded in longline observer data. We do not attempt to estimate catches for domestic longline fisheries in the west-tropical sector of the WCPFC-CA, as SPC holds little observer data for these fisheries.

Observer coverage in longline fisheries in the WCPFC CA, based on SPC's observer data holdings, was generally low from 2003 to 2017, with annual coverage rates ranging from 1 % to 4.5 % of total hooks set. Observer coverage varied both spatially and temporally, with a tendency for lower coverage in the high seas and higher coverage in EEZs. Observer coverage was particularly low in wide areas north of 10°N.

Hooks between floats (HBF) was a key predictor for many of our catch rate models. SPC holds HBF-disaggregated longline aggregate catch and effort data, with coverage of total effort ranging from 25 % in 2003 to 90% in 2016 and 2017. We used available HBF-disaggregated effort data to estimate the proportions of longline aggregate effort for different numbers of hooks between float, assuming that available HBF-disaggregated aggregate data is representative of the fisheries as a whole.

Estimated catch rates from the statistical models had high uncertainty for species that were less frequently caught by longliners. Coefficients of variation (CVs) ranged from 60 % to 350 % for sea turtles, 40 % for marine mammals, 7 % to 90 % for key shark species, 9 % to 65 % for billfish and 7 % to 66 % for finfish. Estimates of total catches are presented for the WCPFC CA as a whole, and disaggregated by region (south of 10°S, 10°S to 10°N, and north of 10°N) and deep and shallow set fisheries (> 10 HBF and ≤ 10 HBF respectively). We note that catch estimates for 2017 are based on observer data that was available in SPC's master database on 10th July. Data from some 2017 trips had not been uploaded at the time.

The analysis was complicated by the coverage of available observer data and, for some years, the coverage of HBF-specific aggregate data. Region-wide estimates north of 10°N are unlikely to be robust given that there are large areas in the region with limited observer data. We compared our catch estimates to previous WCPFC CA analyses of the longline observer data for a selection of species, including silky and oceanic whitetip shark.

The report concludes with recommendations to the Scientific Committee:

- The Scientific Committee note the difficulties in robust estimation of longline catches from observer data, given the very low levels of observer coverage, and for some years (2003-2008) the coverage of L_BEST_HBF data
- The Scientific Committee note that observer coverage levels in the region are generally less than 5%, though acknowledging that observer coverage can be expressed in a variety of units (e.g. trips with observers on board, hooks with observer onboard, hooks observed)
- The Scientific Committee take note of the regions of the WCPFC-CA with substantial fishing effort and low levels of available observer coverage, and the implications this has on (by)catch estimation at a regional level
- The Scientific Committee consider whether historic L_BEST_HBF aggregate data can be derived by members (where necessary), to support future analysis of longline observer data
- The Scientific Committee decide on whether these preliminary estimates of longline bycatch are suitable for public release in the context of the associated uncertainties, and
- The Scientific Committee consider the utility of the work presented here, and whether periodic future updates would be helpful.

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), and to adopt, when necessary, Conservation and Management Measures (CMMs) 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), and
- CMMs have been implemented for 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 (CMM2017-06).

Most of these CMMs encourage better reporting rates for 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. CMM 2007-01 on regional observer programme says in Attachment K, Annex C paragraph 6 that “No later than 30 June 2012, CCMs shall achieve 5% coverage of the effort in each fishery under the jurisdiction of the Commission (except for vessels provided for in paras 9 and 10). In order to facilitate the placement of observers the logistics may dictate that this be done on the basis of trips.”

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). Recently two papers on discards in global tuna fisheries and discards in marine fisheries were published (Gilman et al., 2017; Zeller et al., 2018).
- 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; Rice, 2012), 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 reports available for authorized fisheries department staff on SPC country web pages for Cook Islands, Fiji, French Polynesia,

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

Federated States of Micronesia, Marshall Islands, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, Vanuatu).

In this report we summarise SPC's longline observer data holdings and use them to estimate the catch and catch composition of the longline fisheries of the western and central Pacific Ocean at the regional level. We summarise observer data and estimate catches for all species, regardless of whether or not they are likely to be targeted or caught incidentally. However, our main objective is to estimate catches for species of special interest, and other species not covered by logsheet catch data and the methodology used to estimate catches reflects this.

2. Definitions

Catch

Throughout the report, we use catch to refer to all individuals recorded as caught by longline fisheries, regardless of their fate (retained vs. released/discarded) or at-vessel or at-release condition.

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), and 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, and
- 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.

It is particularly difficult to define bycatch when looking across the full range of longline fisheries across the WCPFC Convention Area. As such, we do not attempt to define 'bycatch'. We have summarised and analysed all catch, though we focus our efforts on species that are unlikely to be targeted.

Observer coverage

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

Coverage of HBF-specific aggregate data

We refer to HBF-specific aggregate catch and effort as 'L_BEST_HBF' data, in contrast to aggregate data with no HBF breakdown which we refer to as 'L_BEST'. 'L_BEST_HBF' effort coverage is defined as L_BEST_HBF effort (hooks) as a proportion of total reported aggregate effort from L_BEST (hooks). The current requirement for Cooperating Commission Members (CCMs) to report aggregate catch and effort by hooks between float (HBF) is defined in the Scientific Data to be provided to the Commission. The WCPFC requirement for the HBF breakdown has only become mandatory for operational data provisions since 2017. Where operational data provisions did not represent 100% coverage (which existed for certain CCMs not providing operational data prior to 2017), then the requirement was '*unraised longline catch and effort data stratified by the number of hooks between floats and the finest possible resolution of time period and geographic area shall also be provided*'.

West-tropical domestic fisheries
SPC holds very few observer data for domestic longline fisheries in the Philippines, Vietnam and Indonesia, which we refer to as west-tropical domestic fisheries. The available observer data held by SPC is unlikely to be representative of these fleets, due to large differences in the operational characteristics of the vessels, and the areas of operation. As such, in this report we do not attempt to estimate catches for the west-tropical domestic fisheries. The west-tropical domestic fisheries accounted for 20 % of total longline effort (hooks) in the WCPFC Convention Area from 2003 to 2017, and 11 % of total reported catches of albacore, bigeye, yellowfin, swordfish and sharks (based on SPC longline aggregate catch and effort data holdings).

Regions
We split the WCPFC Convention Area into three regions to allow spatially disaggregated summaries of estimated catches. The following regions were used: north temperate, >= 10°N; tropical >= 10°S and < 10°N; and, south temperate < 10°S.

Longline fishing strategy (deep / shallow)
Longline fishing was split between deep-set (> 10 HBF) and shallow-set (<= 10 HBF) based on the number of hooks between float, a proxy for the fishing depth of longline gear (Ward and Myers 2005, Bigelow et al., 2006). We note that this definition of deep vs. shallow setting was used to disaggregate catch estimates, but not used to estimate catches.

3. Data and methods

All exploratory data analyses, catch rate models and catch estimation simulation models were undertaken in R version 3.4.1 (R Core Team, 2017). The package 'RODBC' was used for extractions from SPC databases (Ripley and Lapsley, 2017). Multi-core processing was used where possible, using the package 'parallel' (R Core Team, 2017) to reduce computation time. R packages 'tidyr' (Wickham & Henry, 2018) and 'dplyr' (Wickham et al., 2017) were used extensively in data preparation and manipulation, with 'ggplot2' (Wickham, 2009) used for data visualisation and generation of some figures contained in this report.

3.1. Area and time period
This regional summary covers longline fishing from 2003 to 2017 in the WCPFC Convention Area (WCPFC-CA), including the region overlapping the IATTC convention area.

3.2. Species
In this report we provide a comprehensive summary of longline catches for finfish, shark, marine mammal and sea turtle species. We defined 45 species or groups of species, to cover the 400+ species codes that have been used by observers in longline catch records (Annex I). The number of species, or groups of species, is a compromise between minimizing the bias and uncertainty in catch estimates that comes from ignoring species-specific differences, and optimising the computing resources required. The quality of species-code level identification by observers is also a consideration. Where possible, we considered WCPFC key shark species and other species of special

interest (SSI) at a species level. We do not cover seabird bycatch in this report, as this will be covered by WCPFC Project 68 (Peatman and Smith, 2018).

We note that the development of observer training and the distribution of identification booklets have improved the species identification of the bycatch. However, recent genetic testing has indicated some misidentification between blue and black marlin in some instances. It can also be difficult to identify rare species that are not necessarily recorded in the identification guides.

3.3.Data sources

SPC holds aggregate catch and effort data for longline fisheries in the WCPFC-CA, stratified by year, month, flag, fleet, and 5° square, *i.e.* 'L_BEST' strata. The aggregate catch and effort data were used to provide total longline effort in the WCPFC-CA. SPC also holds HBF-specific aggregate catch and effort data for longline fisheries, i.e. L_BEST_HBF data. These data were used to apportion total longline effort by HBF (Section 3.4). Former shark-targeted longline fisheries in the Papua New Guinea (PNG) and Solomon Islands (SLB) EEZs are not included in aggregate longline catch and effort data held by SPC. As such, estimates of catches do not cover these fisheries.

Observers represent the most reliable source of data for estimating catches of non-target species and catches that are not retained as non-target species are rarely recorded in vessel logsheet data, and the released or discarded portion of catches are not covered in sampling at port.

SPC holds observer data from a variety of observer programmes, including *inter alia* WCPFC's regional observer programme (ROP), and national observer programmes. In this report we used all observer data held in SPC's master observer database that was located in the WCPFC-CA, with the exception of observer data from the former PNG and SLB shark-fisheries. There were limited instances of set records with missing information erroneous values for key variables i.e. HBF and set position. These values were interpolated based on within-trip moving averages.

The data extracts from SPC's aggregate catch and effort data and observer data holdings used in this report were extracted on 10th July 2018. We note that there remain longline observer data from trips in recent years that have yet to be received or not yet processed and incorporated in to SPC's observer data holdings (Williams et al., 2018).

3.4.Estimation of effort by HBF

We used available L_BEST_HBF data (HBF-specific aggregate effort data) to split 'L_BEST' aggregate effort data by HBF categories. We used an iterative procedure to estimate the proportion of effort by HBF, moving from the L_BEST strata to progressively coarser resolutions until HBF-specific effort data were available. The alternative strata are summarised in Table 22 (Annex 2). In summary, hook between float and 'L_BEST' strata specific effort, E_{h,L_BEST}, was given by

$$E_{h,L\_BEST} = \frac{\hat{E}_{h,alt}}{\sum_h \hat{E}_{h,alt}} E_{L\_BEST}$$

where E_{L_BEST} refers to reported L_BEST strata specific effort, and $\hat{E}_{h,alt}$ refers to reported HBF-specific effort at an alternative resolution (and h denotes HBF). The order of preference for the alternative strata was determined using the relative accuracy of estimated HBF-specific proportions, using L_BEST strata with at least 75 % coverage of reported HBF-specific aggregate data.

3.5. Clustering of aggregate catch composition data

Catch rates and compositions of longline vessels are influenced by a variety of variables, including the gear configuration and the fishing strategy of the vessel. We applied k-means clustering to aggregate longline catch data to partition longline effort into groups with similar species compositions as a proxy for both gear configuration and fishing strategy. The total number of individuals was extracted from longline aggregate catch data for albacore, bigeye, yellowfin, swordfish and sharks (all species of sharks combined). The clustering analysis was applied to the square-root of proportions for these species. The required number of clusters was based on the 'elbow method', i.e. identifying the point of inflection in variance explained with increasing number of clusters (Thorndike, 1953).

3.6. Catch rate models

We used Generalised Estimating Equations (GEEs) to model catch rates, in order to account for correlation between observations within observer trips. Catch rate models were fitted to each of the 45 species / species groups, except for whale shark for which there were < 10 recorded catch events in the dataset. Models were fitted using the R package 'geepack' (Højsgaard et al., 2006). GEEs allow 'marginal' predictions of mean catch rate distributions for different combinations of explanatory variables at a population-level, i.e. a mean catch rate and uncertainty across all effort for the combination of explanatory variable values. This is in contrast to mixed effects models that are commonly used in catch rate analyses, were conditional predictions are more readily available, *e.g.* vessel specific predictions for a model with a random intercept for vessel ID. An 'exchangeable' working correlation structure was used where possible, where residuals from observations from the same observer trip are correlated, with a shared correlation parameter for all observer trips. It was not possible to fit models with exchangeable correlation structures for some models. In these instances we assumed independence between residuals within trips (see Table 23). We note that alternative correlation structures were considered in exploratory model runs, including exchangeable, autoregressive and independence within-trip correlation. Parameter estimates and standard errors (based on sandwich variance estimators) were generally insensitive to the choice of working correlation structure.

Poisson-like error structures were used where possible, with a two stage delta-lognormal modelling approach implemented if necessary to account for zero-inflation (Table 23). Explanatory variables included in the models were: year, sea-surface temperature (SST) and HBF, included as cubic splines; and a categorical variable for the species composition cluster for the 'L_BEST' strata. The year effect was modelled as a spline rather than a categorical variable to prevent over-fitting to temporal variation in catch rates and allow for a relationship between subsequent year effects. SST and HBF were included as splines to account for potential non-linearity in effects on catch rates. Species composition cluster was included to account for the effects of fishing strategy and targeting on catch composition.

The specification of the Poisson-like models was

$$E[Y_{ij}] = \mu_{ij} \qquad\qquad Var[Y_{ij}] = \phi\, \mu_{ij}$$

$$\ln \mu_{ij} = \ln(thooks_{ij}) + \beta_0 + \beta_1 cluster_{ij} + f_1(year_{ij}) + f_2(HBF_{ij}) + f_3(SST_{ij})$$

where Y_{ij} denotes observed catch rate (individuals per thousand hooks), subscripts i and j refer to observer trip and set number respectively, f_n represent natural cubic splines and ϕ is a variance inflation parameter.

The specification of the delta-lognormal models was:

(presence-absence component)

$$E[P_{ij}] = \gamma_{ij} \qquad Var[P_{ij}] = \phi\, \gamma_{ij}(1-\gamma_{ij})$$
$$\ln\left(\frac{\gamma_{ij}}{1-\gamma_{ij}}\right) = \beta_0 + \beta_1 cluster_{ij} + f_1(year_{ij}) + f_2(HBF_{ij}) + f_3(SST_{ij})$$

(positives component i.e. catch rate when present)

$$E[N_{ij}] = \eta_{ij} \qquad Var[N_{ij}] = \sigma^2$$
$$\ln(\eta_{ij}) = \beta_0 + \beta_1 cluster_{ij} + f_1(year_{ij}) + f_2(HBF_{ij}) + f_3(SST_{ij})$$

where P_{ij} denotes whether individuals (of the species concerned) were caught, N_{ij} denotes the observed catch rate (numbers per '000 hooks), and the overall estimated mean catch rate ζ_{ij} is given by $\zeta_{ij} = \gamma_{ij}\,\eta_{ij}$.

All explanatory variables were retained in catch rate models regardless of statistical significance. We did not include, or test for, interactions between explanatory variables. Exploratory model runs were undertaken with a range of candidate environmental and oceanographic variables, including chlorophyll-a concentration (NASA, 2014), temperature at depth (Saha et al., 2006)[2], and sea surface height anomaly. SST was retained as the sole oceanography covariate as variance inflation factors indicated strong multi-collinearity between SST and the alternative variables. Furthermore, SST was considered to be more interpretable than the alternatives, i.e. as a proxy for thermal habitat preference.

Other variables have been demonstrated to have a strong effect on catch rates of species caught in longline fisheries, including *inter alia* the diurnal phase when gear is set or soaking, and the shape and size of hooks (e.g. Bigelow et al., 2006; Gilman et al., 2006, 2008). However, we could only include explanatory variables if they were available in aggregate catch and effort datasets held by SPC, or available in external datasets that could be linked back to aggregate data (*e.g.* oceanographic variables).

3.7. Catch estimation

We used a Monte-Carlo simulation modelling framework to estimate longline catches by raising estimated catch-rates (see Section 3.6) by estimated HBF-specific effort (see Section 3.4).

First, HBF-specific longline effort surfaces (Section 3.4) were aggregated to the resolution of the simulation model, i.e. year, SST, HBF, catch composition cluster and region. The first four variables were explanatory variables in catch-rate models, and region definitions are as described in Section 2. SSTs were mean monthly values per 5° grid, rounded to the nearest ⅓ °C to keep simulation model strata at practical levels.

Simulation strata-specific catch-rate distribution hyper-parameters (means and standard errors) were estimated from species (or species group) specific catch-rate models, i.e. using estimated μ for

[2] GODAS data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/.

Poisson models, and γ and η for the delta-lognormal approach, and their associated standard errors (see Section 3.6). A thousand random samples were drawn from these catch rate distributions for each simulated strata (we provide more detail below as to how exactly this was done). The random samples of catch rates were then applied to the (estimated) effort within the strata to generate 1,000 catch estimates for each simulation model strata. Catch estimates were aggregated at a variety of resolutions, e.g. WCPO-wide, deep-set fishing north of 10°N etc., and median and 95 % confidence intervals extracted (based on the lower 2.5% and upper 97.5 % percentiles of the catch estimates). Note that preliminary simulation runs for a subset of species indicated that estimated 95 % confidence intervals stabilised with 1,000 random draws for species with low observed catch rates.

We now return to how random samples were drawn from modelled catch rate distributions. First, we note that catch rates in 'adjacent' model strata are not likely to be independent. For example, if a catch rate draw is high for a given year, HBF and species composition cluster at 15°C (relative to the mean of the catch rate distribution), then catch rates are unlikely to be low for the same year, HBF and species composition cluster combination and 16°C. Instead of drawing directly from predicted strata-specific catch rate distributions, we thus drew 1,000 random samples from a uniform distribution on the interval (0, 1) for each year and region combination. These were then used as percentiles for the catch-rate distribution draws for simulated strata within the year and region combination in question, and the corresponding value extracted from the distribution. For example, let us say that for the tropical region and for 2003, the percentile draws from the uniform distribution were $\boldsymbol{p} = (p_1, p_2, \dots, p_{1,000}) = (0.5, 0.4, \dots, 0.9)$. Then, for all combinations of HBF, cluster and SST within the tropical region in 2003, the first catch rate draw from these model-strata specific catch rate distributions would be the 50th percentile, then 40th percentile, and so on. We note that catch rate draws were species independent.

3.8. Catch unit

Longline observers record catch data specific to each individual caught. As such, the natural catch unit for the estimation of catches is numbers of individuals. We also converted estimated catch numbers to weight using estimates of average weight (Table 24). The estimates of average weight were based on either direct measurements of whole weight (where available), or using length measurements and length weight parameters to estimate weight. Where possible we calculated average weights for each combination of region and strategy. It is not clear whether available length measurements are representative of catches. For example, downwards bias in length measurements might be expected if larger individuals are cut off the line, e.g. shark species. As such, the estimates of catch numbers are likely to be more reliable than catch weight estimates.

4. Coverage of available data

4.1. Observer coverage

CCMs were required by the 30th of June 2012 to achieve 5% coverage in each longline fishery under the jurisdiction of the Commission as stipulated in WCPFC CMM 2007-01.

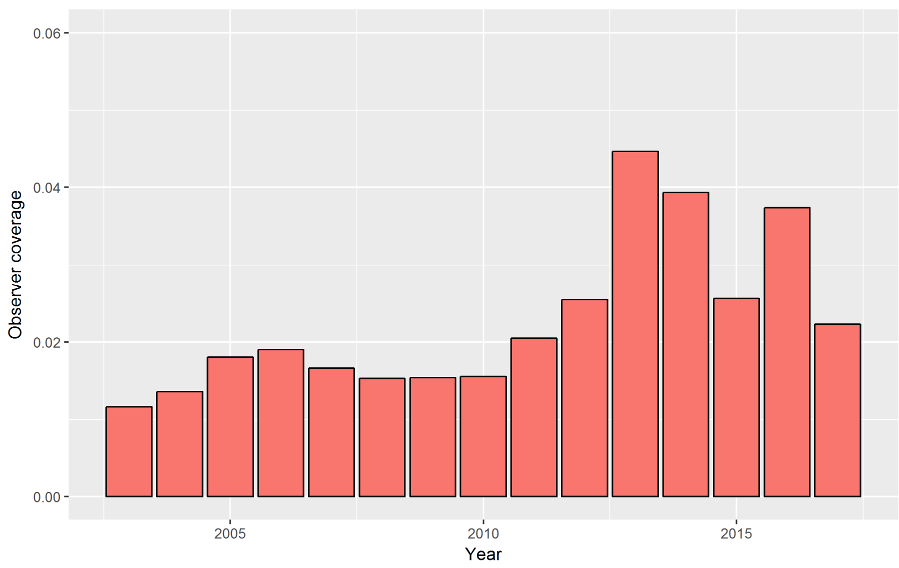


Figure 1 Overall annual observer coverage (proportion of number of hooks) of longline fleets in the WCPFC-CA. Effort from west-tropical domestic fisheries was excluded.

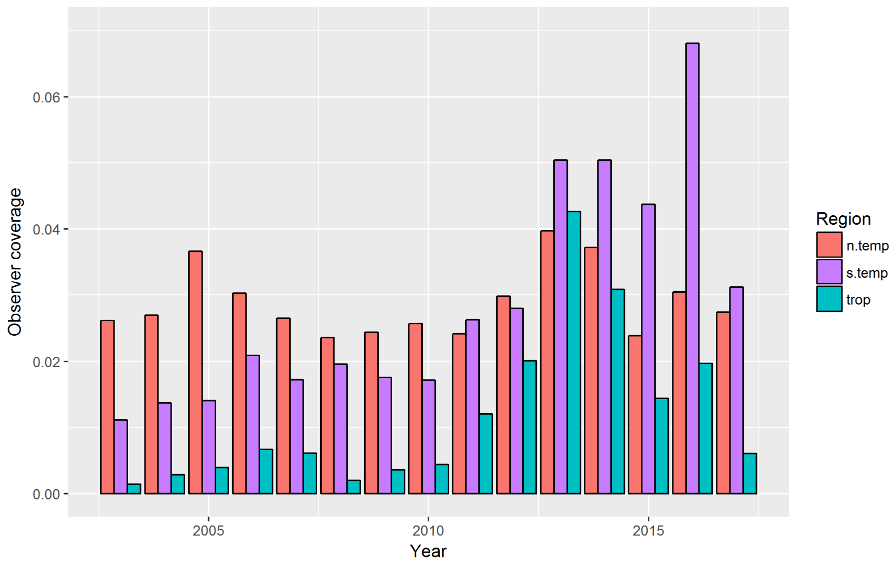
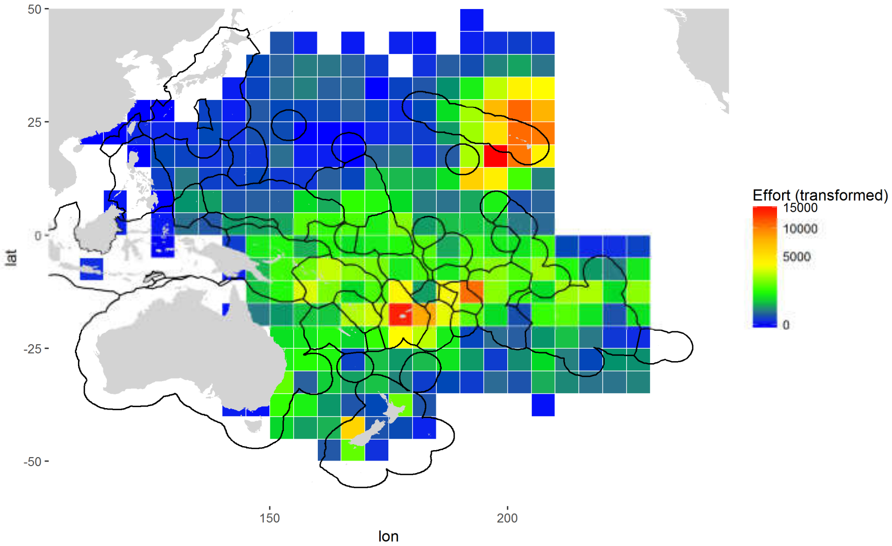


Figure 2 Annual observer coverage (proportion of number of hooks) per longline fleets in the WCPFC-CA.

Observer coverage over the whole Convention Area tends to be consistent from 2003 – 2010 around 1 to 1.5 % before reaching a maximum of ~4.5 % in 2013 and then varying between 2 and 4 % up to 2017 (Figure 1). This does not include coverage through electronic monitoring programmes.

However, observer coverage was not distributed evenly among the fisheries and in the WCPFC-CA (Figure 2, Figure 3, Figure 4). SPC hold little observer data for the west tropical domestic longline fisheries (Figure 3). Observer coverage rate varies between 2.5 and 4% in the north temperate fisheries between 2003 and 2017 (Figure 2), however it is mainly concentrated around Hawaii where it reaches ~20 % (Figure 4). Observer coverage in the south temperate fisheries was between 1 and 2 % from 2003 to 2010 and has stayed above 2 % since then; it reached the target value of 5 % in 2013, 2014 and 2016 (Figure 2). The observer coverage rate in the tropical longline fisheries was below 1 % from 2003 to 2010 and has been maintained above this value since, reaching more than 4 % in 2013 (Figure 2).

(a) Observed effort



(b) Reported effort

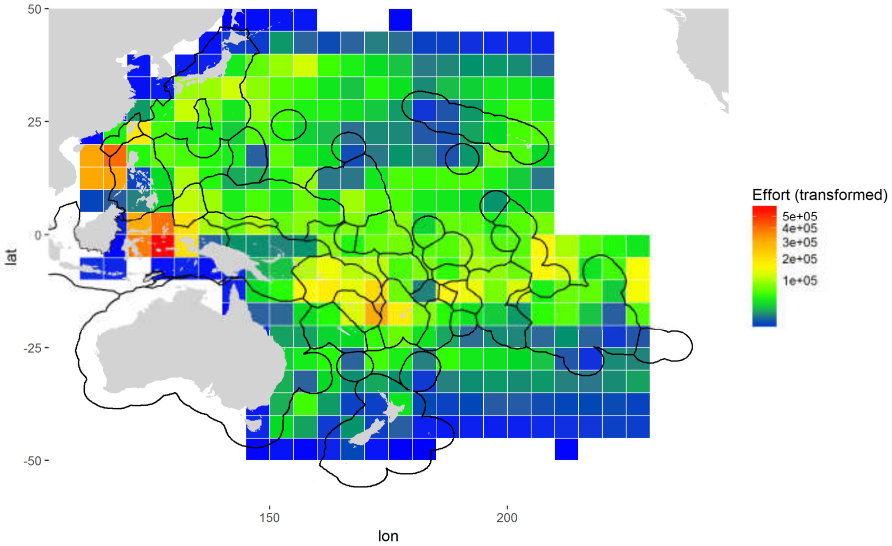


Figure 3 (a) Observed effort and (b) total reported fishing effort (bottom) in number of hooks (square root transformed) for longliners during the 2003-2016 time period in the WCPFC-CA. Note that scales are different on the 2 figures.

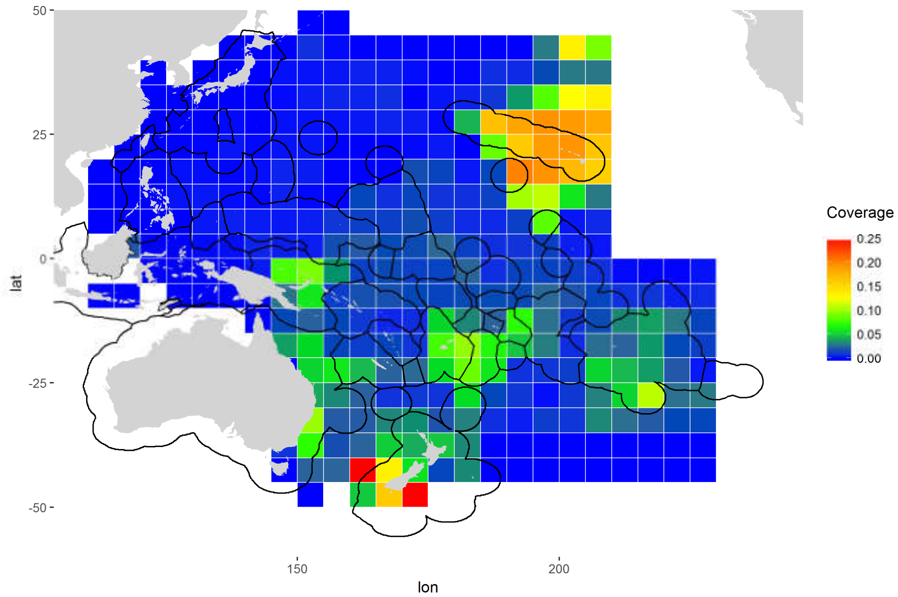


Figure 4 Observer coverage (proportion of hooks) of longline fleets in the WCPFC-CA from 2003 to 2017. Cells with coverage above 25 % were capped at 25 % to facilitate interpretation.

4.2. Coverage of HBF specific aggregate data

From 2003 to 2006, coverage of L_BEST_HBF varied between 25% and 35% of total aggregate effort (Figure 5). From 2006 onwards the coverage of L_BEST_HBF increased, and since 2009 has remained between 60 and 90 %. However, this level of coverage is not distributed evenly among the fisheries and in the WCPFC-CA (Figure 6). Coverage of HBF is close to zero in the west tropical domestic fisheries and in the southern part of the area, east of New Zealand (Figure 6).

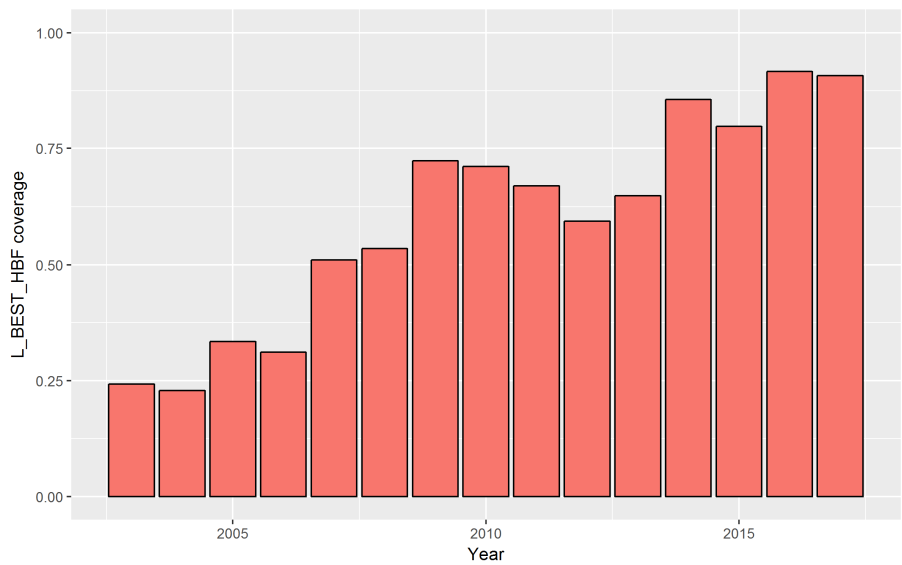


Figure 5 Overall annual coverage of L_BEST_HBF aggregate data (proportion of number of hooks) of longline fleets in the WCPFC-CA from 2003 to 2017. Effort from west-tropical domestic fisheries was excluded.

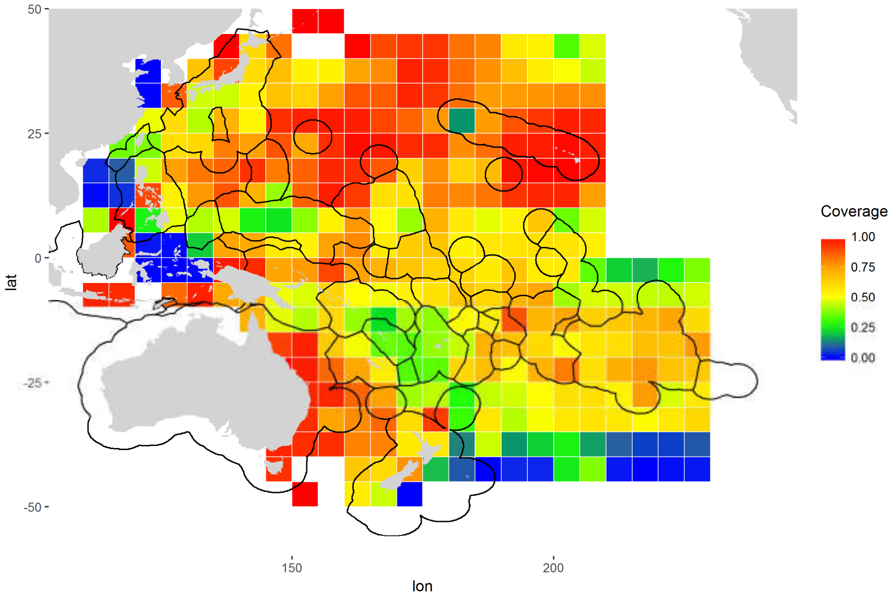


Figure 6 Spatial coverage of L_BEST_HBF aggregate data (proportion of number of hooks) of longline fleets in the WCPFC-CA from 2003 to 2017

Table 1 provides an overview of reported effort by aggregate catch composition cluster (Section 3.5), and Table 2 provides an overview of the estimated breakdown of effort by deep and shallow sets (Section 3.4).

Table 1 Effort ('000,000 hooks) by (L_BEST) aggregate catch composition cluster and year. Cluster names characterise the dominant species in the clusters, in decreasing proportions. E.g. ALB-YFT = predominantly albacore, and to a lesser extent, yellowfin. Effort from the west-tropical domestic fisheries is not included.

Year	ALB	ALB-YFT	BET-SHK-YFT	BET-YFT	BET-YFT-ALB	SHK-SWO	SWO-SHK	YFT-BET
2003	197.3	99.0	70.6	145.4	115.4	28.1	5.9	188.1
2004	200.5	117.2	86.2	173.4	101.6	71.6	19.1	98.8
2005	203.7	86.1	56.0	145.7	92.0	70.5	26.9	85.3
2006	223.7	62.0	68.8	149.9	77.6	94.7	13.4	67.7
2007	192.2	79.5	77.6	143.5	59.7	123.3	27.7	119.0
2008	202.9	82.4	79.8	157.5	54.1	146.3	10.2	106.6
2009	250.1	94.6	84.3	125.1	44.2	145.8	8.7	130.8
2010	276.3	123.0	85.5	82.5	76.1	97.8	7.3	139.6
2011	214.5	145.8	131.1	82.2	91.7	148.2	5.6	121.4
2012	299.2	124.4	97.9	119.6	121.2	126.4	9.1	111.1
2013	294.4	111.9	86.9	90.4	82.6	64.3	11.7	94.2
2014	214.5	159.2	75.7	119.6	58.7	83.7	12.6	117.8
2015	180.9	198.0	82.0	91.7	89.1	68.4	15.8	158.1
2016	165.4	187.0	85.3	83.0	48.8	63.2	7.8	131.9
2017	209.5	178.3	112.8	67.6	27.4	34.5	6.9	138.8

Table 2 Effort ('000,000 hooks) by year, region and deep v shallow set, from 2003 to 2016. The breakdown between deep and shallow effort is estimated (see Section 3.4). Effort from the west-tropical domestic fisheries is not included.

	n.temp		trop		s.temp		WCPFC-CA		
Year	**shallow**	**deep**	**shallow**	**deep**	**shallow**	**deep**	**shallow**	**deep**	**Total**
2003	82.4	162.8	45.1	291.1	59.7	208.6	187.2	662.5	849.8
2004	100.4	174.8	24.9	321.4	58.1	188.8	183.4	685.0	868.4
2005	106.1	159.1	3.3	285.6	42.3	169.8	151.7	614.5	766.2
2006	104.9	163.7	6.7	270.4	28.8	183.5	140.4	617.6	758.0
2007	163.8	152.2	49.3	257.2	28.3	171.6	241.4	581.1	822.5
2008	178.5	164.0	33.5	247.7	19.0	197.1	231.0	608.8	839.9
2009	187.8	136.6	64.9	231.5	25.8	236.9	278.6	605.0	883.6
2010	138.9	134.2	48.3	247.4	35.1	284.3	222.3	665.8	888.1
2011	166.1	155.4	47.2	289.0	33.4	249.3	246.8	693.7	940.4
2012	127.9	172.0	72.8	311.9	18.0	306.3	218.7	790.2	1008.9
2013	72.0	163.5	40.1	260.2	14.5	285.9	126.5	709.7	836.2
2014	98.6	160.4	21.4	281.3	12.9	267.3	132.9	709.0	841.9
2015	101.1	167.5	12.1	351.5	11.6	240.1	124.8	759.1	883.9
2016	93.7	185.7	6.7	265.8	10.6	209.9	111.0	661.4	772.3
2017	68.8	187.4	12.2	222.4	11.2	273.7	92.3	683.6	775.8

5. Catch species frequency, diversity and vertical distribution

Observed catch composition varied strongly between set types between deep and shallow sets (Figure 7).

Swordfish, blue shark, escolars, mahi mahi, yellowfin, longsnouted lancetfish and bigeye were the most frequently caught species recorded by observers, in descending order of prevalence in shallow sets (Figure 7). In deep sets the most frequently caught species recorded by observers, in descending order of prevalence, were bigeye, escolars, yellowfin, blue shark, longsnouted lancetfish, albacore mahi mahi, wahoo, pomfrets and skipjack (Figure 7). Other species and species groups were observed in less than 4 sets out of 10.

The frequently caught species described above for shallow sets reflect mainly fisheries in the north temperate region where observer coverage is highest (Figure 8). These fisheries clearly target swordfish. However, in the south temperate shallow set fisheries the most frequent species are tuna with, in descending order of prevalence, albacore, yellowfin, bigeye, wahoo, escolars, skipjack, mahi mahi (Figure 8). In tropical shallow set fisheries, the most frequent species in descending order of prevalence are silky shark, yellowfin, swordfish, great barracuda, sailfish, blue marlin, mahi mahi (Figure 8).

In the deep set fisheries the most frequent species are, in descending order of prevalence, albacore, yellowfin, bigeye and wahoo in the south temperate fisheries, bigeye, yellowfin, escolars, wahoo in tropical fisheries and bigeye, longsnouted lancetfish, blue shark, escolars in the north temperate fisheries (Figure 9).

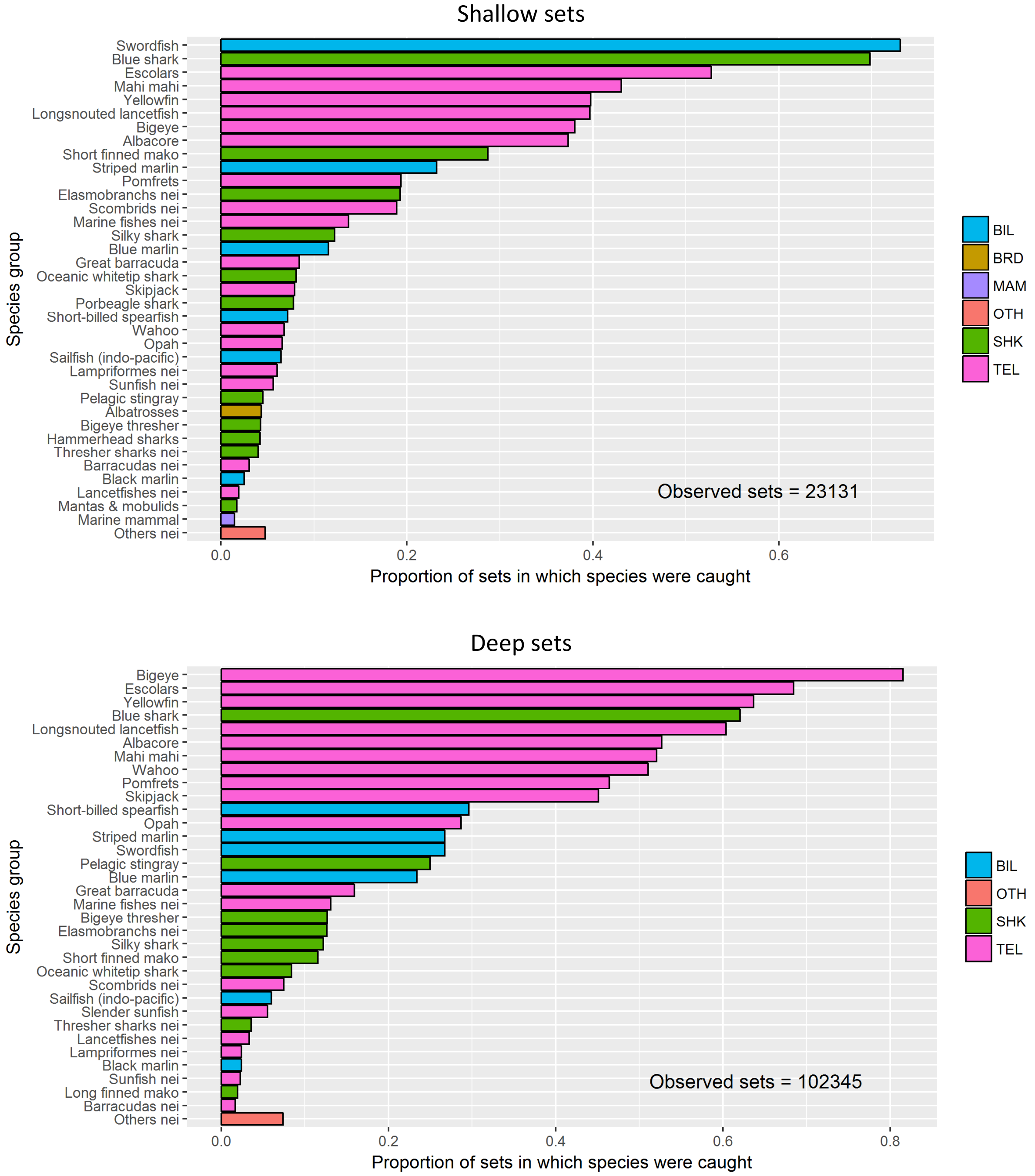


Figure 7 The proportion of longline shallow (top) and deep sets (bottom) with observed catch against species/species group. Rarely observed species have been grouped in to ‘others nei’. Bar colour denotes billfish (BIL), marine mammals (MAM), others nei (OTH), shark species (SHK), teleosts or fish (TEL), turtles (TTX) and tuna (TUN).

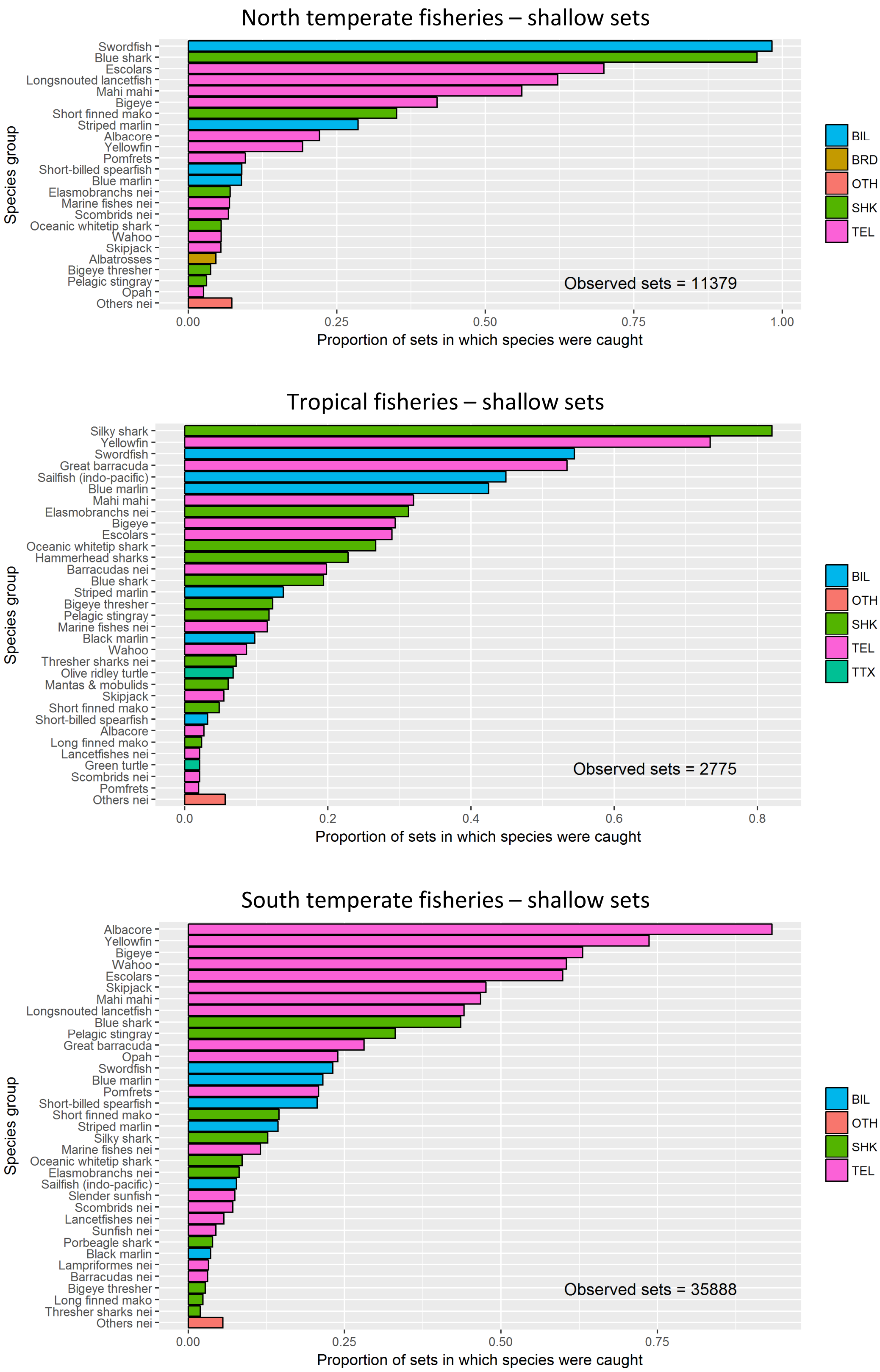


Figure 8 The proportion of longline shallow sets in north temperate (top), tropical (middle) and south temperate (bottom) fisheries with observed catch against species/species group. Rarely observed species have been grouped in to 'others nei'. Bar colours as in Figure 7.

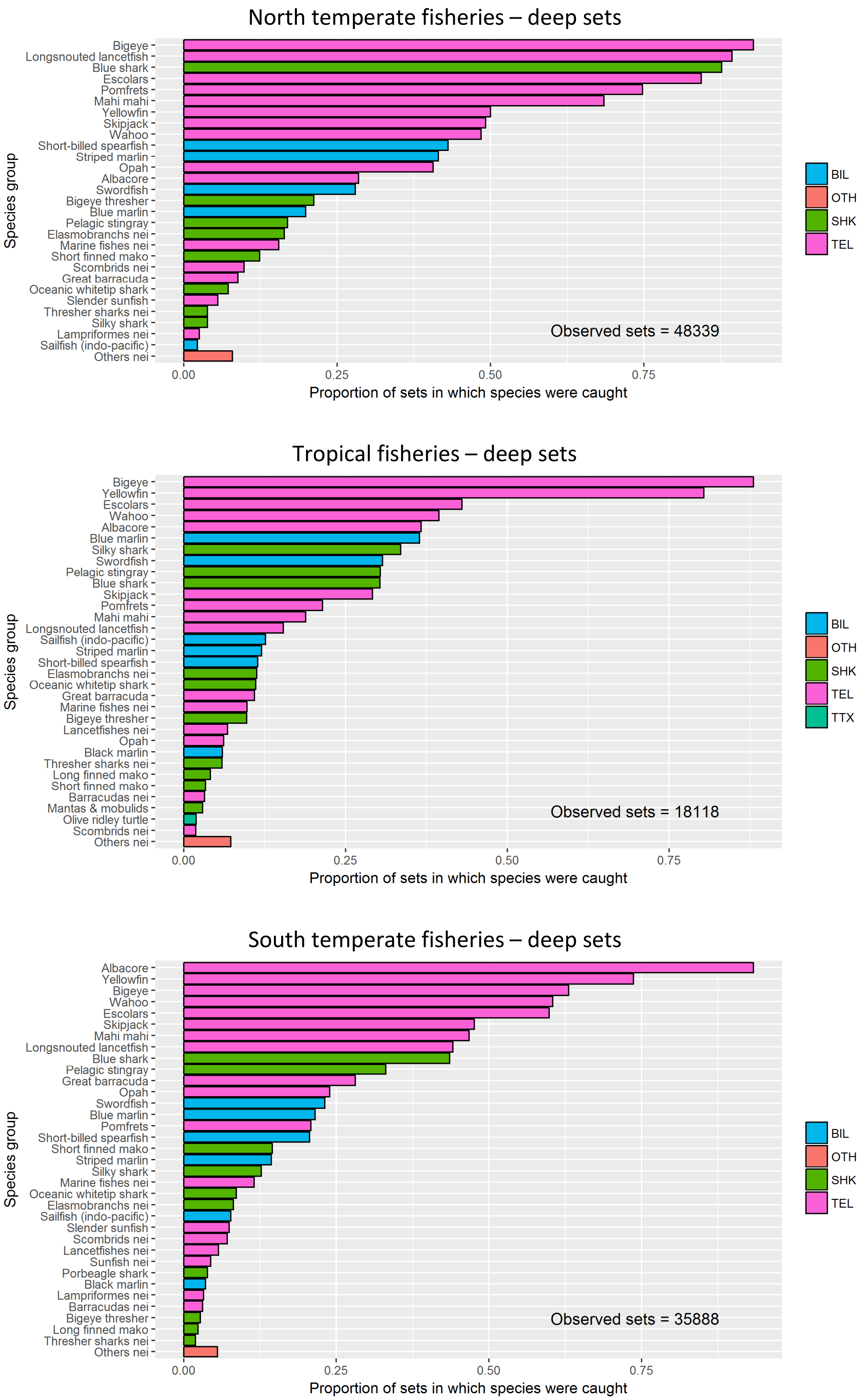


Figure 9 The proportion of longline deep sets in north temperate (top), tropical (middle) and south temperate (bottom) fisheries with observed catch against species/species group. Rarely observed species have been grouped in to 'others nei'. Bar colours as in Figure 7.

The number of species codes used by observers provides a proxy for the species diversity of catches, including bycatch. From one to 20 different species were observed on a single longline set. A lower number of species codes were recorded in shallow sets with most of the sets including 3 to 11 species compared to deep sets where generally 5 to 14 species were recorded. For shallow sets, south temperate and tropical fisheries demonstrated a similar trend with generally 3 to 11 species per set while generally 4 to 9 species were observed per set in the north temperate fisheries. For deep sets, more species were observed in the north temperate fisheries (7-14) than in the south temperate (6-11) and tropical fisheries (5-11). More species are observed in longline sets (2-14) than in purse seine sets (1-11) (Peatman et al., 2017).

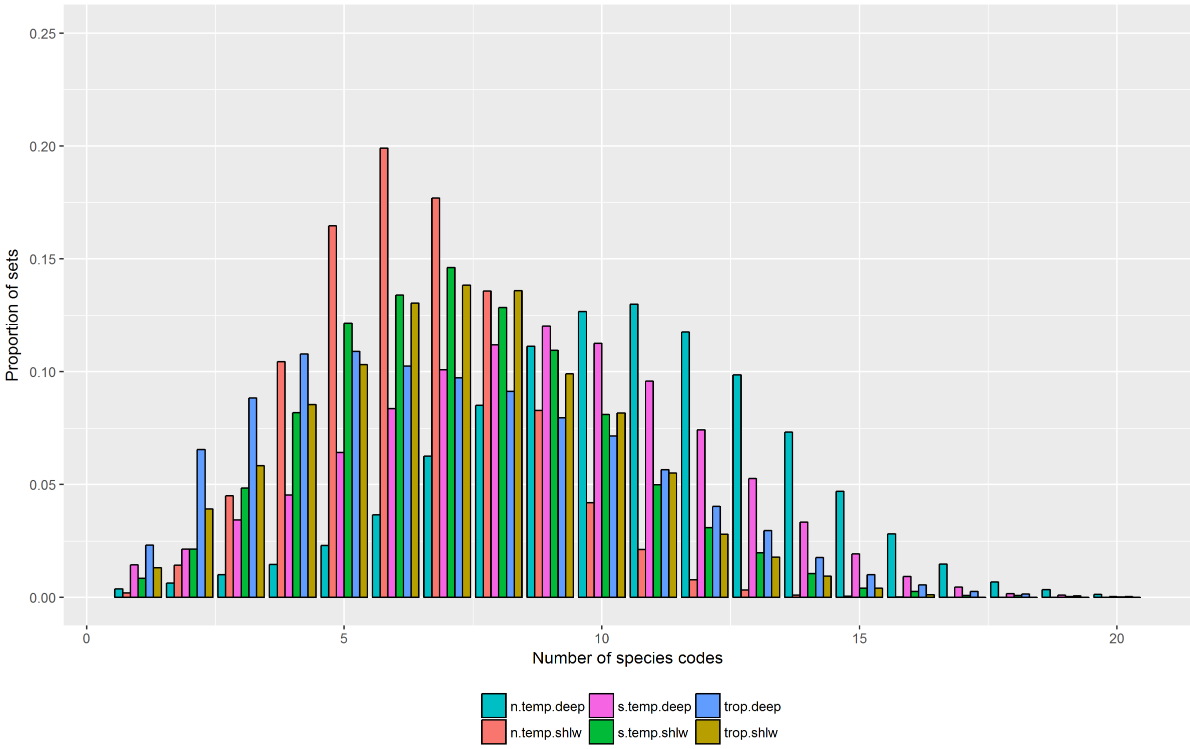


Figure 10 Number of distinct species codes used in observer catch estimates (per set) by longline fisheries.

For each fish caught on a longline, the observers record the position of the hook (between two floats) where the fish was caught. A hook close to a float will be shallow while a hook far away from a float will be deep. This information provides insights in the interaction between the fish and the gear and can be used to set hooks at chosen depths to mitigate catch of unwanted species. Examining the CPUE according to hook position, we determined four different patterns in fish vertical distribution (Figure 11):

- Fish caught preferentially closer to the surface on the shallowest hooks, illustrated by dolphinfish, include blue marlin, striped marlin, sailfish, shortbill spearfish, blue shark, silky shark, oceanic white-tip shark, porbeagle shark, great barracuda, rainbow runner, wahoo, southern bluefin tuna, skipjack, olive ridley turtle, green turtle;
- Fish caught preferentially at intermediate depths, illustrated by albacore tuna, include yellowfin tuna, longsnouted lancetfish, black marlin, bigeye thresher shark, opah/moonfish, pelagic stingray, slender sunfish;
- Fish caught preferentially on the deepest hooks, illustrated by bigeye tuna, include pomfrets; and,
- Fish caught indifferently at all depth, illustrated by the longfin mako shark.

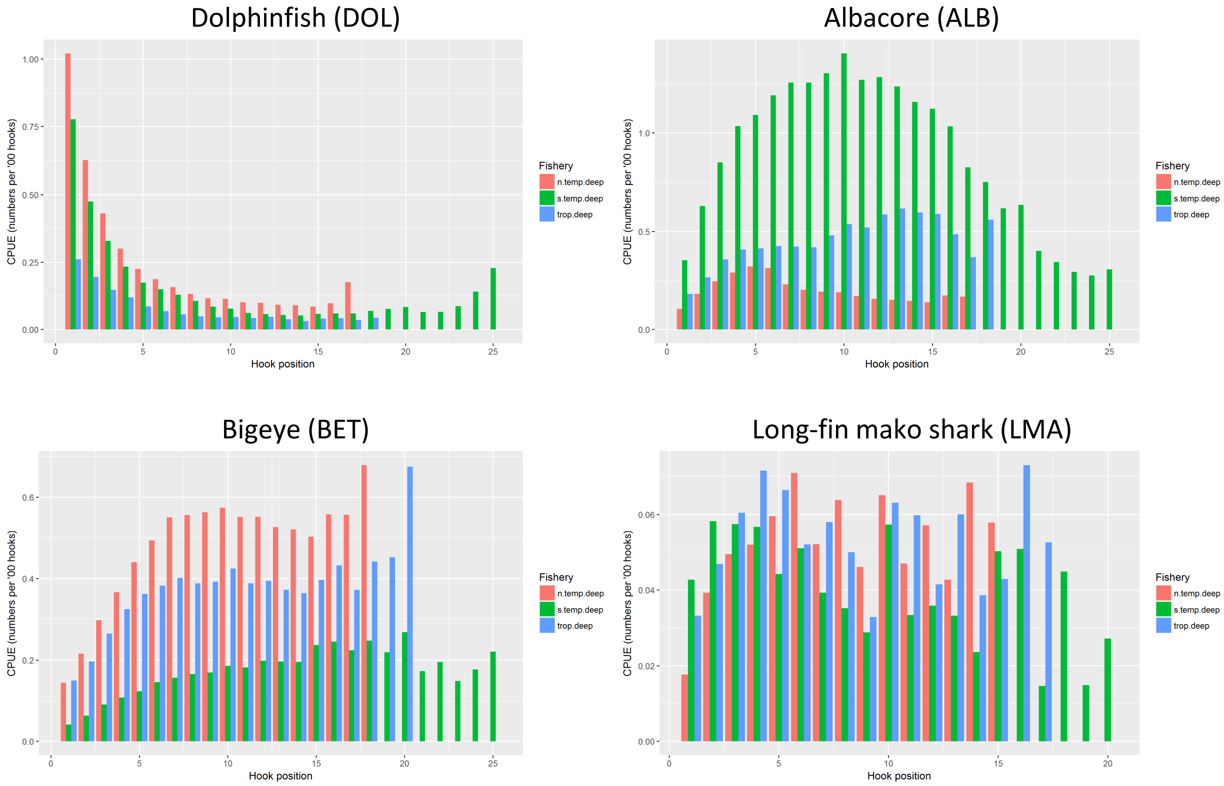


Figure 11 CPUE in numbers per hundred hooks according to the hook position for dolphinfish, albacore, bigeye and long-fin mako shark. Smaller numbers indicate shallow hooks, while larger numbers indicate deep hooks.

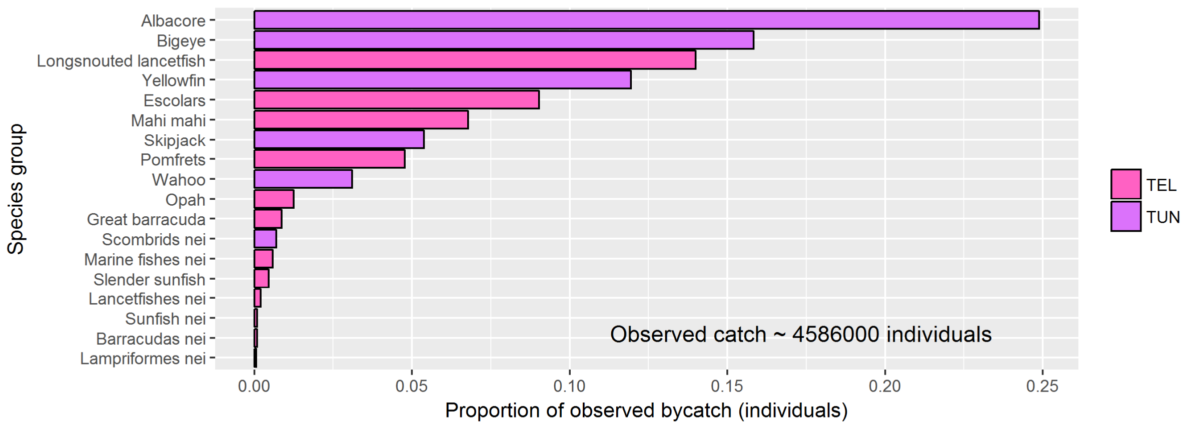
6. Catch composition and fate

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

6.1. Finfish

Albacore, bigeye and longsnouted lancetfish accounted for more than ~ 15% each of observed finfish catch, not including billfish, from 2003 to 2017 in the deep-set longline fisheries (Figure 12), with albacore accounting for the greatest proportion with ~25% of the catch. Yellowfin, escolars, mahi mahi and skipjack accounted for 5-12% each. The most abundant species caught in deep sets varied according to the fisheries with longsnouted lancetfish and bigeye accounting for more than 20% each in the north temperate fisheries, Albacore accounting for more than 50% of the catch in the south temperate fisheries and yellowfin and bigeye accounting for more than 20% of the catch in the tropical fisheries.

Deep sets



Shallow sets

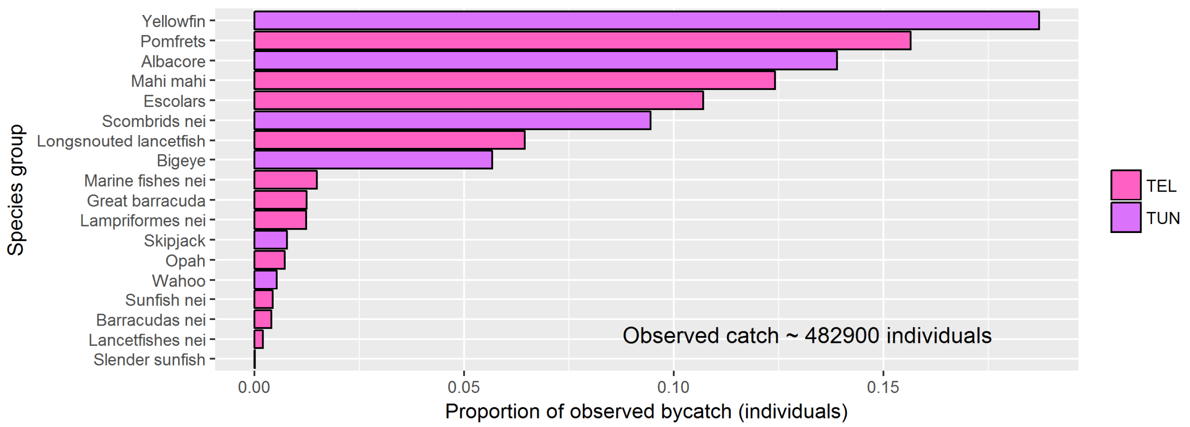


Figure 12 Proportion of observed finfish catch (number of fish) by species/species group in the longline fisheries in deep sets (top) and shallow sets (bottom). Bar colours as in Figure 7.

Yellowfin accounted for ~18% of the catch of observed finfish catch, not including billfish, from 2003 to 2017 in the shallow set longline fisheries (Figure 12). Albacore, pomfrets, mahi mahi, escolars, longsnouted lancetfish, Scombrids unidentified and bigeye accounted for 5-15% each. The most abundant species caught in shallow sets varied according to the fisheries with mahi mahi and escolars accounting for more than 20% each in the north temperate fisheries, yellowfin and pomfrets accounting for more than 20% each of the catch in the south temperate fisheries and yellowfin accounting for ~45% of the catch in the tropical fisheries.

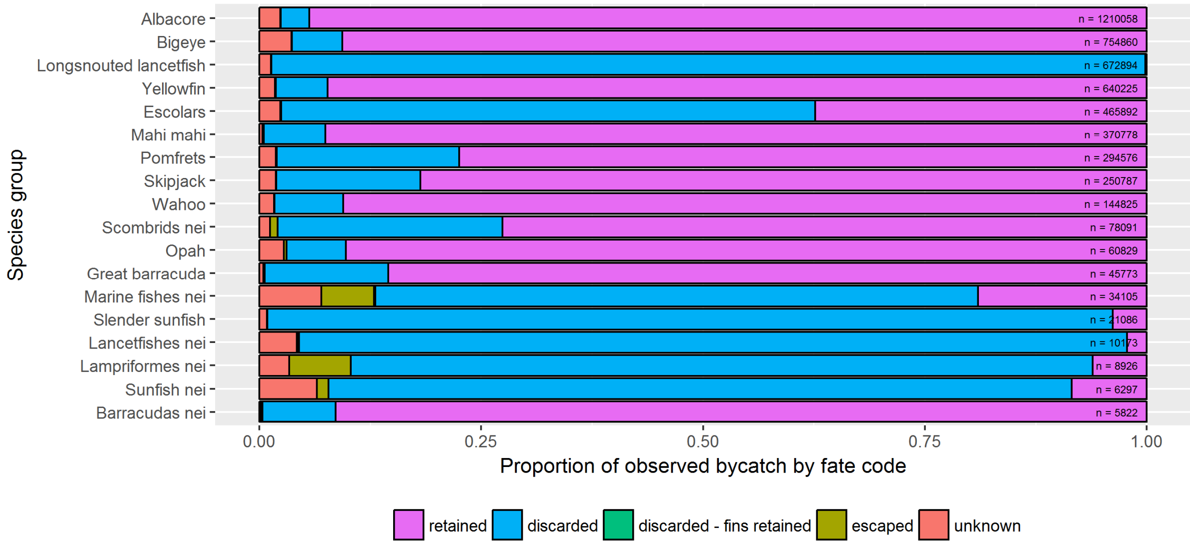


Figure 13 Recorded fate of observed finfish catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = … for each species/group).

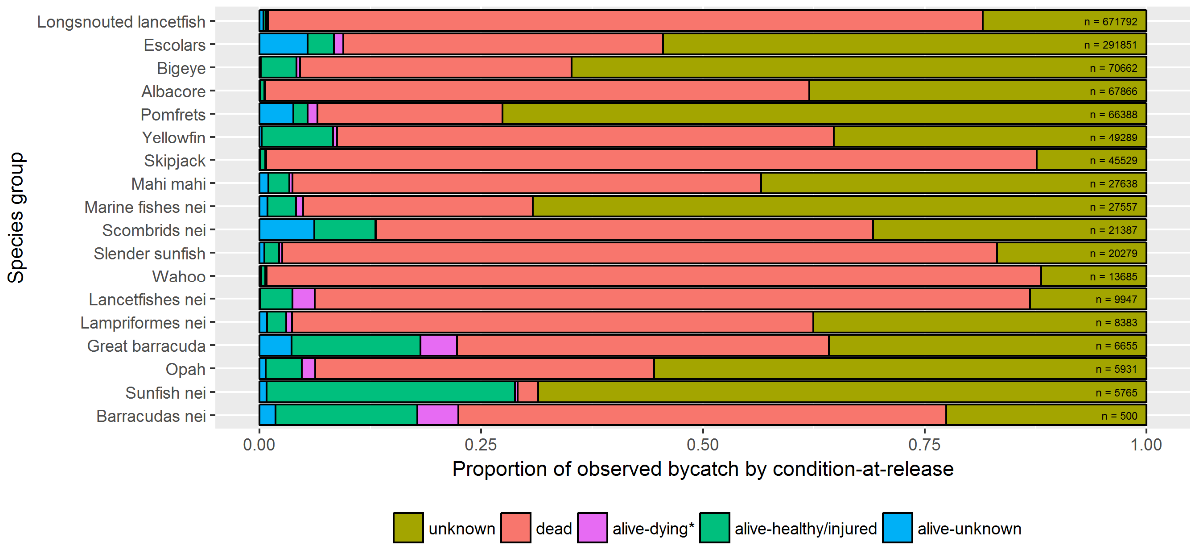


Figure 14 Recorded condition at release of observed finfish catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = … for each species/group). Note – alive-dying* is individuals that alive but considered unlikely to survive.

For most finfish species 75-90 % of observed catch was retained (Figure 13). However, for some species discarding rate was high: over 60 % of observed catch of lancetfish, escolars and sunfish were discarded from 2003 to 2017.

For discarded species, 75 to 95% of the catch was of unknown condition or dead (Figure 14); only a small number of species demonstrated some potential survival at release with ~ 30 % of sunfish nei (not elsewhere included), ~20% of barracudas and ~ 10% of yellowfin released alive.

6.2.Billfish

Short-billed spearfish, striped marlin and swordfish accounted each for more than 20% of the observed billfish catch in deep-set longline fisheries between 2003 and 2017 (Figure 15). Blue marlin accounted for ~17%. The most abundant species caught in deep sets varied according to the fisheries, with short-billed spearfish and striped marlin accounting for more than 20% each in the north temperate fisheries, swordfish, short-billed spearfish and blue marlin accounting for more than 20% each in the south temperate fisheries, and blue marlin and swordfish accounting for more than 20% each in the tropical fisheries.

Swordfish accounted for ~90% of the catch of observed billfish catch from 2003 to 2017 in the shallow set longline fisheries (Figure 15). Proportion of swordfish was higher than 95% in the north temperate shallow fisheries and higher than 75% in the south temperate shallow fisheries. In the tropical shallow fisheries swordfish, sailfish and blue marlin each accounted for more than 20% of the catch of billfish.

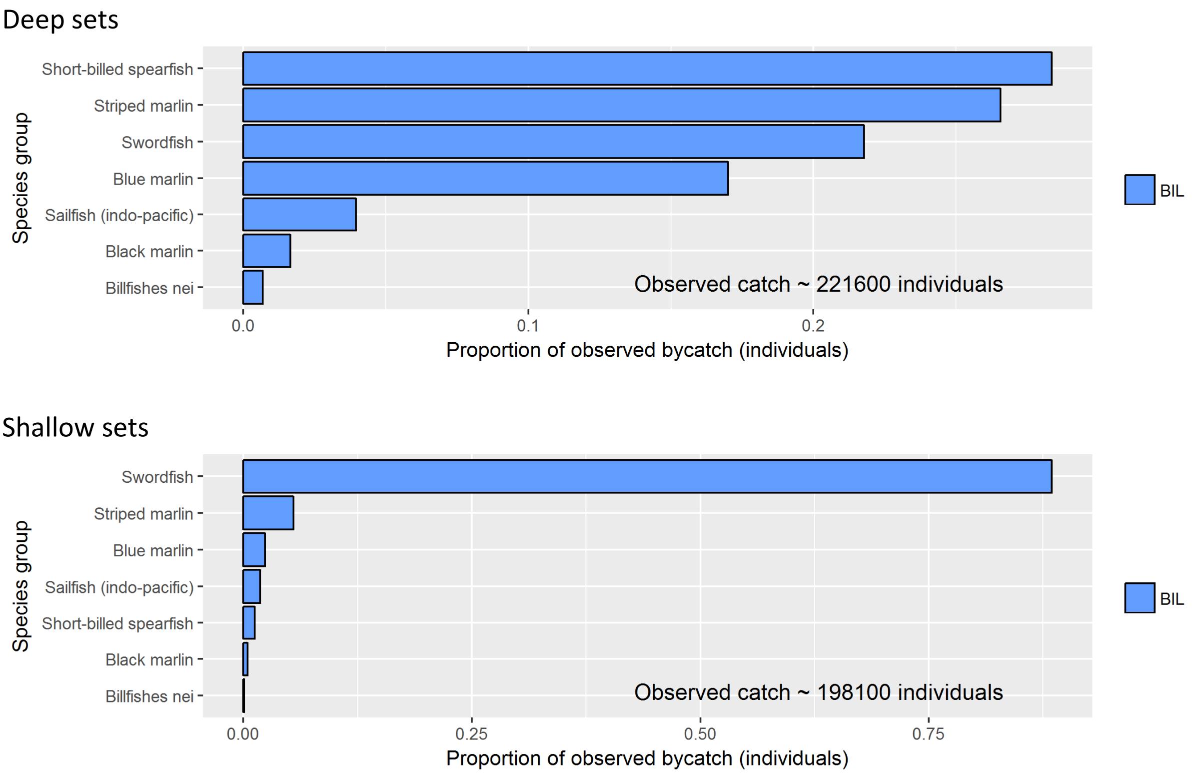


Figure 15 Proportion of observed billfish catch (number of fish) by species/species group in the longline fisheries in deep sets (top) and shallow sets (bottom). Bar colours as in Figure 7.

For all billfish species more than 80 % of observed catch was retained (Figure 16) but 75% of other billfish (mostly unidentified) were discarded. For discarded species, the potential survival was low with less than 5% of billfish released alive healthy or injured; sailfish and black marlin demonstrated the highest percentages (Figure 17).

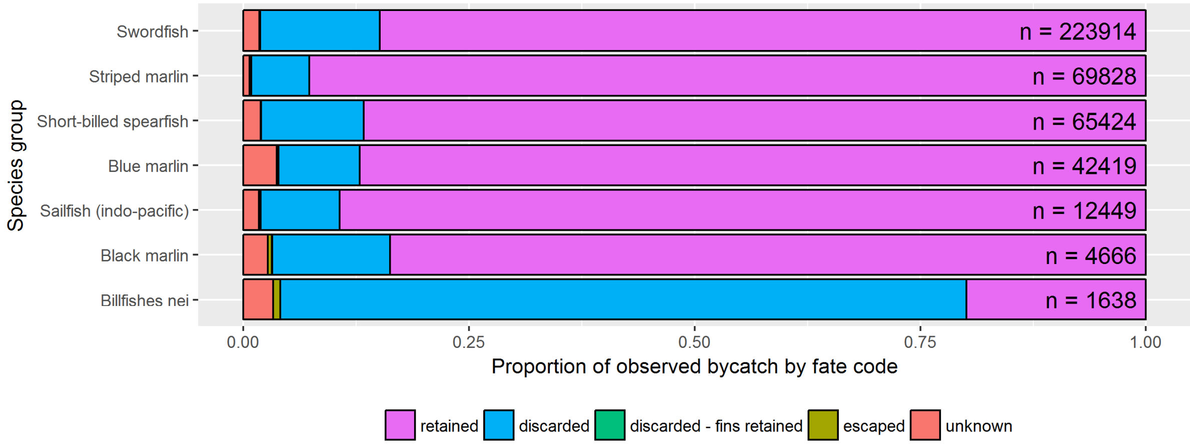


Figure 16 Recorded fate of observed billfish catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = …).

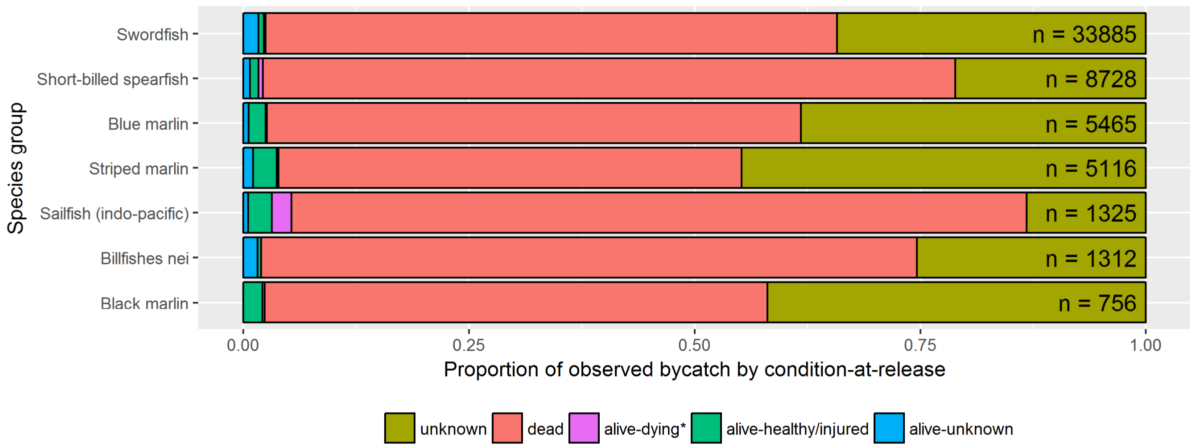


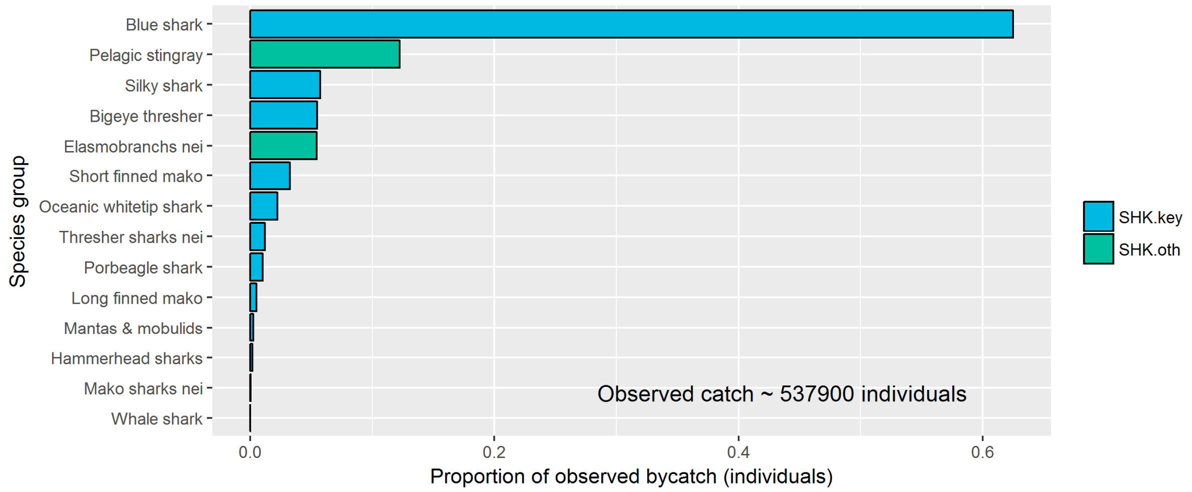
Figure 17 Recorded condition at release of observed billfish catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = … for each species/group). Note – alive-dying* is individuals that alive but considered unlikely to survive.

6.3.Sharks and rays

Blue shark accounted for more than 60% of the observed shark catch in deep-set longline fisheries between 2003 and 2017 (Figure 18); pelagic stingray accounted for ~12%. The most abundant species caught in deep sets varied according to the fisheries with blue shark accounting for 50-75% in the south and north temperate fisheries respectively, while pelagic stingray and silky shark accounted each for more than 25% of the sharks and rays catch in the tropical deep fisheries.

Blue shark accounted for more than 60% of the catch of observed sharks and rays catch from 2003 to 2017 in the shallow set longline fisheries (Figure 18); silky shark accounted for ~25%. The most abundant species caught in shallow sets varied according to the fisheries with blue shark accounting for 70-90% in the south and north temperate fisheries respectively, while silky shark accounted for more than 80% of the sharks and rays catch in the tropical shallow fisheries.

Deep sets



Shallow sets

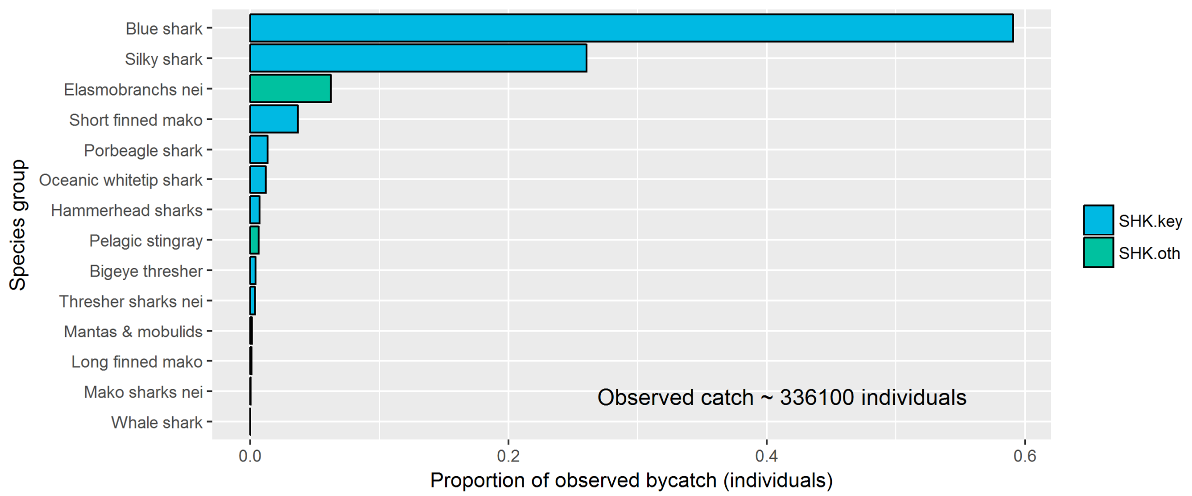


Figure 18 Proportion of observed sharks and rays catch (number of fish) by species/species group in the longline fisheries in deep sets (top) and shallow sets (bottom). Bar colours as in Figure 7.

Silky sharks and hammerhead sharks were retained at more than 70% but other species were mostly discarded (Figure 19). Fins only were retained for ~25% of the thresher sharks, for ~20% of the long-fined mako shark and for 5-15% each for oceanic white-tip, hammerhead sharks, blue sharks, short-fined mako and silky shark, from 2003 to 2017 (Figure 19).

It is difficult to estimate the potential survival of the sharks and rays discarded as the information on the condition at release is unknown for 40-90% of the specimens according to the species. Available information indicate that 10-35% of long-fined mako, manta rays, silky sharks, pelagic stingray and oceanic white-tip are released alive healthy or injured (Figure 20).

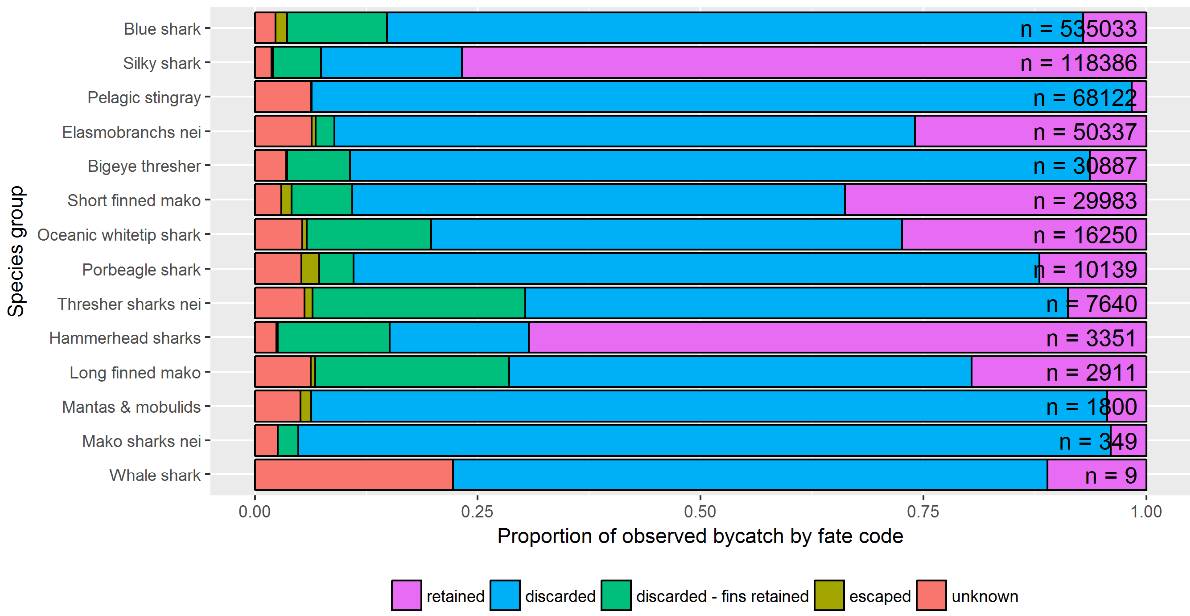


Figure 19 Recorded fate of observed sharks and rays catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = …).

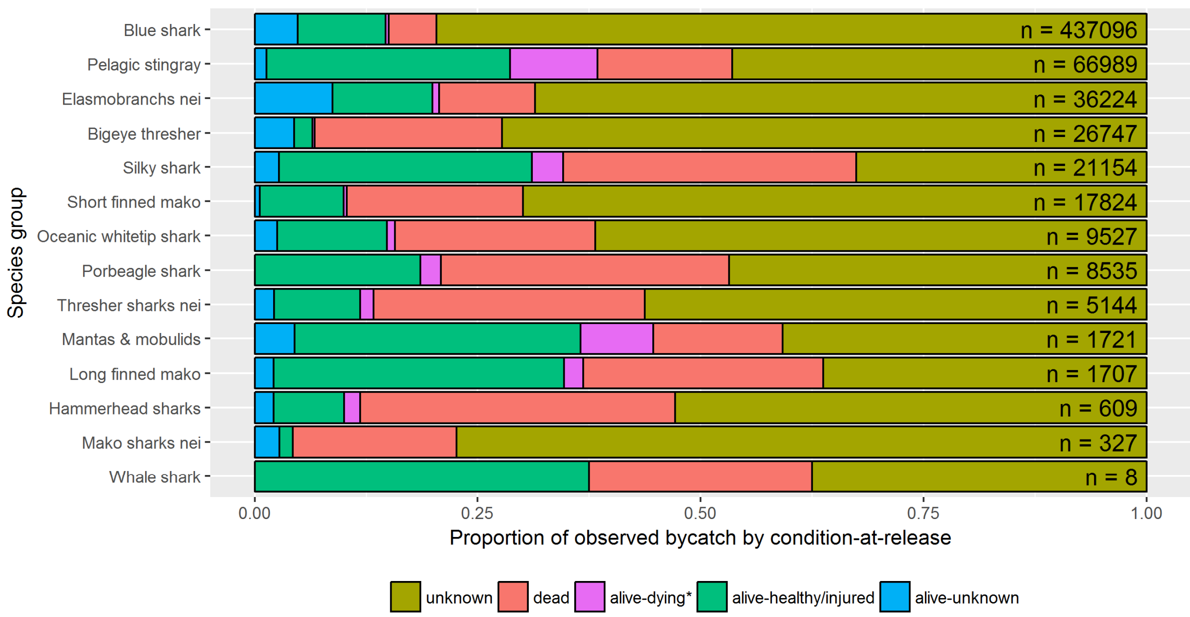
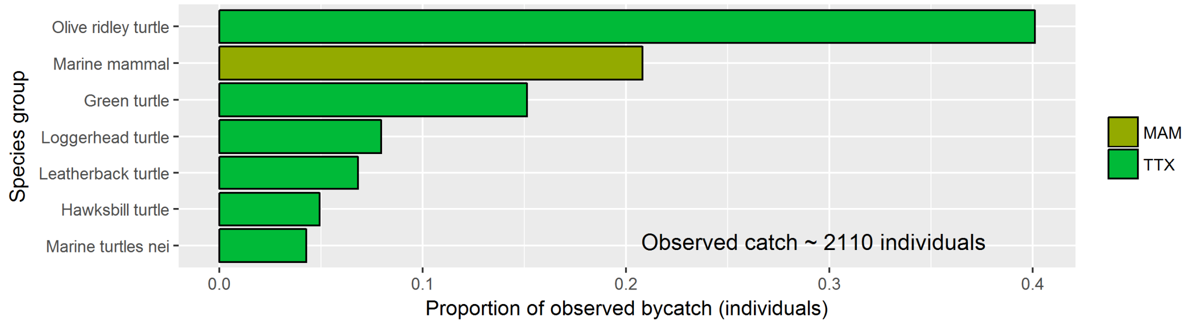


Figure 20 Recorded condition at release of observed sharks and rays catch by species/species group, as a proportion of total observed catch (number of fish) for the species/species group in the longline fisheries. The number of records is provided (n = … for each species/group). Note – alive-dying* is individuals that alive but considered unlikely to survive.

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

Olive ridley turtles and marine mammals were the most caught of the marine mammal and sea turtle species / groups for both the deep and shallow set fisheries between 2003 and 2017 (Figure 21). Sea turtles and marine mammals were mainly discarded but there are instances where individuals were retained (Figure 20). 20 to 30% of the turtles were released alive healthy or injured (Figure 23), and we note that conditions at vessel and at release were generally better for sea turtles caught by shallow sets (also see Common Oceans, 2017).

Deep sets



Shallow sets

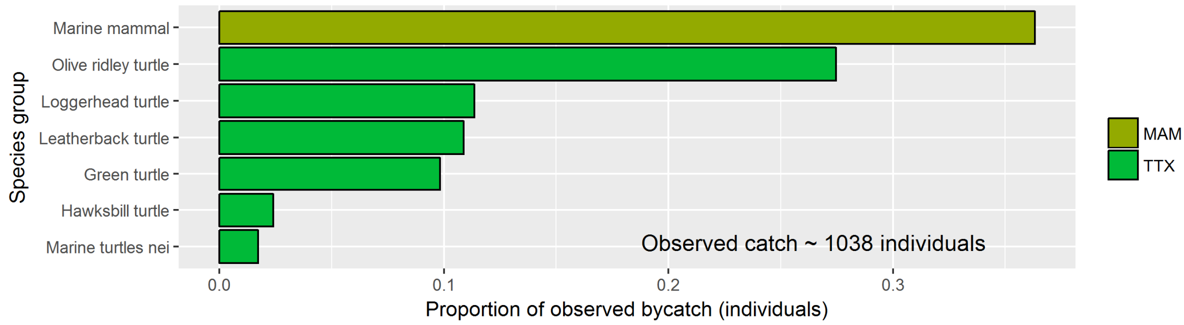


Figure 21 Proportion of observed marine mammals and sea turtles (number of specimens) by species/species group in the longline fisheries in deep sets (top) and shallow sets (bottom). Bar colours as in Figure 7.

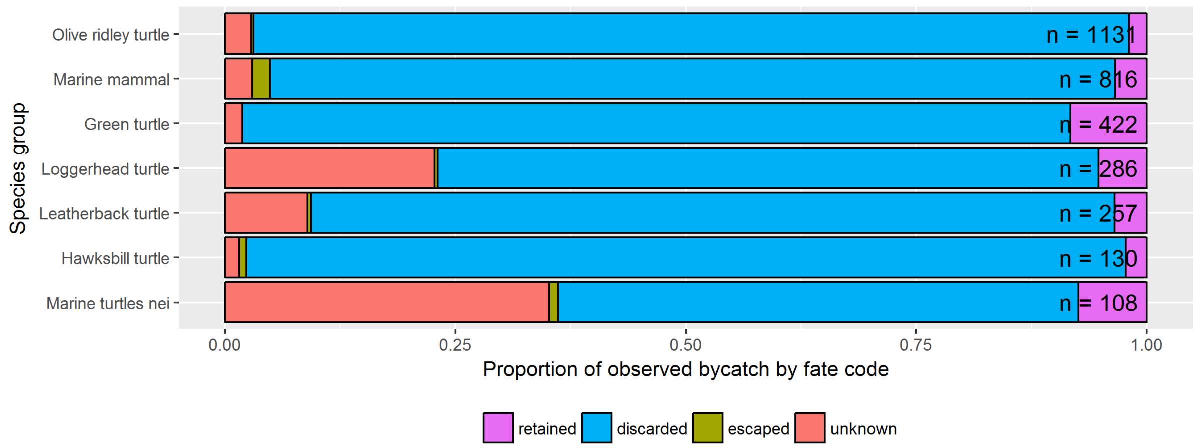


Figure 22 Recorded fate of observed species of marine mammals and sea turtles catch by species/species group, as a proportion of total observed catch (number of specimens) for the species/species group in the longline fisheries. The number of records is provided (n = …).

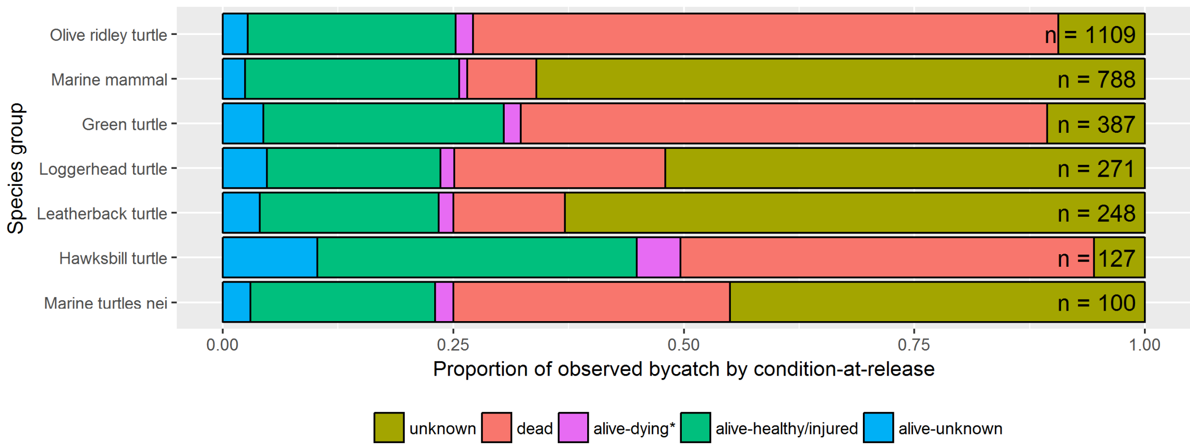


Figure 23 Recorded condition at release of observed species of marine mammals and sea turtles catch by species/species group, as a proportion of total observed catch (number of specimens) for the species/species group in the longline fisheries. The number of records is provided (n = … for each species/group). Note – alive-dying* is individuals that alive but considered unlikely to survive.

7. Uncertainty in estimated catch rates

Median coefficients of variation (CVs) of simulation model strata specific catch rate estimates were calculated for each species, as a general measure of their uncertainty (Table 25). We note that species-specific CVs vary from strata to strata, with variation predominantly driven by the estimated catch rate. Strata with low catch rates will generally have higher CVs and vice versa, in much the same way as the tendency for species with lower catch rates to have higher CVs compared to species with higher catch rates (e.g. Lawson, 2006). CVs for sea turtles ranged from (leatherback turtle) 60 % to 350 % (hawksbill turtle). CVs for key shark species / species groups ranged from 7 % (blue shark) to 90 % (mako sharks nei). CVs for billfish ranged from 9 % (swordfish, striped marlin) to 65 % (black marlin). CVs for finfish ranged from 7 % (bigeye, escolars) to 66 % (barracudas nei, slender sunfish).

8. Catch estimates

Annual catch estimates for finfish (excluding billfish), billfish, sharks and rays, marine mammals and turtles are provided in Table 3. It is important to note that these catch estimates do not include catches of the west-tropical domestic fisheries (Indonesia, Vietnam and Philippines) or the PNG and SLB shark fisheries (see Section 2). We provide species-specific estimates of catches for finfish, billfish, sharks and rays and turtles in the following subsections in both numbers and weight. Equivalent tables with region and strategy specific catch estimates (numbers only) are provided in Annex 4 (Table 26 to Table 35). We also provide more detailed information for mahi-mahi, striped marlin, silky shark, oceanic whitetip and loggerhead turtle, and provide effects plots for their catch rate models in Annex 3.

Table 3 Estimated annual longline catch ('000s individuals). Median catch (med), and lower (low) and upper (high) 95 % confidence intervals are provided for finfish (excluding billfish), billfish, sharks and rays, marine mammals and turtles.

	Finfish ('000s)			Billfish ('000s)			Sharks ('000s)			Turtles ('000s)			Marine mammals ('000s)		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	10,690.5	11,134.5	11,715.3	1,874.9	2,041.9	2,233.2	2,167.8	2,327.6	2,525.6	10.8	16.6	28.7	1.9	3.0	5.0
2004	9,734.4	10,150.7	10,725.8	1,648.1	1,790.7	1,949.9	2,465.7	2,656.4	2,896.3	12.0	17.5	25.3	1.7	2.6	4.0
2005	8,690.6	9,022.6	9,406.7	1,530.9	1,665.9	1,812.4	2,120.5	2,285.3	2,476.7	10.3	13.6	19.3	1.2	1.7	2.6
2006	8,610.0	8,926.2	9,264.1	1,440.5	1,581.5	1,751.2	1,996.3	2,157.4	2,355.6	10.3	14.3	21.5	1.1	1.7	2.5
2007	8,124.4	8,410.4	8,706.5	1,915.0	2,111.6	2,421.0	2,095.5	2,254.4	2,440.6	22.0	32.8	62.3	1.2	1.9	3.0
2008	7,578.3	7,848.6	8,137.3	1,564.2	1,726.0	1,911.0	1,985.9	2,140.9	2,325.5	23.7	36.1	70.1	1.3	2.0	3.2
2009	9,111.9	9,417.8	9,758.5	1,870.3	2,059.4	2,269.6	2,400.7	2,611.9	2,855.1	29.2	44.2	76.5	1.5	2.3	3.6
2010	11,038.2	11,471.4	11,923.2	1,836.6	2,030.3	2,235.3	2,581.1	2,821.0	3,123.3	19.7	29.2	53.6	1.6	2.4	3.5
2011	10,932.7	11,277.5	11,677.1	1,993.3	2,188.5	2,416.9	2,801.8	3,039.1	3,324.3	14.8	21.7	39.2	2.0	2.8	4.2
2012	10,632.7	11,036.1	11,456.7	1,716.3	1,859.5	2,053.7	2,373.2	2,588.4	2,910.8	15.7	24.2	43.1	2.2	3.2	5.1
2013	8,639.2	8,941.6	9,225.8	1,166.4	1,254.4	1,358.7	1,541.0	1,647.5	1,769.8	13.2	18.5	30.1	2.2	3.1	4.2
2014	8,276.4	8,579.7	8,870.4	1,148.5	1,246.3	1,359.8	1,558.6	1,670.8	1,804.4	15.5	21.6	32.1	2.4	3.4	4.9
2015	8,971.9	9,255.6	9,542.3	1,211.2	1,307.4	1,408.4	1,851.9	1,990.4	2,148.0	24.7	32.1	44.8	2.1	3.0	4.3
2016	8,118.8	8,359.9	8,631.9	1,077.2	1,166.3	1,262.2	1,825.7	1,957.8	2,097.3	18.3	24.1	35.4	2.0	2.8	4.2
2017	8,276.9	8,620.2	8,953.2	1,036.9	1,117.0	1,209.4	1,686.9	1,796.2	1,919.5	12.5	17.8	26.1	3.3	5.0	7.9

Note: turtle catch estimates are likely unreliable (see discussion in Section 9).

8.1. Finfish

Table 4 Median finfish catch estimates ('000 individuals) by species/species group. Species/species group accounting for less than < 2% of total finfish catch have been grouped in to 'others'.

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	2,444.8	2,547.3	1,871.4	589.3	544.8	505.4	513.0	407.5	252.3	213.8	1,207.0	11,096.5
2004	2,382.2	1,648.5	1,863.4	634.0	414.6	603.6	397.5	252.9	326.3	214.6	1,379.6	10,117.2
2005	2,247.3	1,499.2	1,581.3	561.6	440.3	554.2	421.3	243.9	254.4	186.0	1,001.9	8,991.4
2006	2,346.4	1,552.9	1,456.7	528.4	575.2	520.1	495.9	288.1	213.0	188.2	741.7	8,906.5
2007	2,036.3	1,772.9	1,367.7	548.7	531.2	530.3	421.9	260.4	190.1	151.9	582.2	8,393.5
2008	1,945.6	1,391.7	1,290.1	605.0	516.8	523.1	369.6	250.3	197.3	150.4	583.5	7,823.5
2009	2,509.7	1,630.3	1,384.4	846.0	649.4	556.5	404.2	334.0	192.3	170.2	723.3	9,400.2
2010	3,228.6	1,757.7	1,464.6	1,155.8	858.9	662.9	486.2	482.5	222.7	222.8	889.7	11,432.3
2011	2,939.4	1,698.9	1,493.7	1,257.1	791.8	791.6	443.3	499.2	310.7	223.4	807.8	11,256.9
2012	3,110.7	1,807.6	1,574.8	1,036.4	560.8	770.2	446.0	486.7	333.2	200.8	686.1	11,013.5
2013	2,581.2	1,449.1	1,307.5	720.7	447.5	641.6	435.2	368.3	272.2	179.0	520.2	8,922.5
2014	2,217.5	1,501.1	1,386.8	642.1	482.8	576.6	484.8	332.2	259.8	170.8	507.2	8,561.6
2015	2,293.0	1,867.3	1,506.1	654.9	536.7	439.4	512.4	361.4	257.9	159.3	653.6	9,242.3
2016	1,932.0	1,822.0	1,264.0	614.8	522.2	320.5	421.4	329.5	241.2	130.2	747.2	8,345.0
2017	1,658.9	2,299.6	1,268.8	645.7	502.0	323.6	437.5	316.8	263.7	137.2	743.2	8,597.0
Species total	**35,873.7**	**26,246.0**	**22,081.3**	**11,040.6**	**8,375.1**	**8,319.7**	**6,690.1**	**5,213.6**	**3,787.2**	**2,698.6**	**11,774.1**	**142,099.9**

Table 5 Median finfish catch estimates (tonnes) by species/species group.

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	36,444.2	72,662.2	68,192.3	3,655.7	1,827.4	3,230.9	5,365.8	2,009.7	438.6	6,686.3	19,573.1	220,086.4
2004	35,908.9	44,329.1	68,153.9	3,848.1	1,390.7	3,751.2	4,143.1	1,250.5	573.4	6,700.6	29,629.1	199,678.8
2005	34,021.6	40,354.3	57,120.1	3,370.7	1,477.0	3,378.1	4,398.2	1,209.0	450.3	5,805.0	21,805.6	173,389.9
2006	36,347.8	41,486.2	52,386.5	3,180.2	1,929.3	3,146.9	5,199.4	1,432.1	376.9	5,871.7	14,925.5	166,282.4
2007	31,300.4	49,875.1	50,149.0	3,455.6	1,781.7	3,161.5	4,425.7	1,280.9	332.2	4,736.0	12,013.5	162,511.7
2008	30,074.1	40,001.9	46,476.4	3,803.3	1,733.7	3,106.1	3,903.6	1,240.1	343.7	4,692.8	12,560.2	147,936.0
2009	38,481.8	47,686.9	50,488.2	5,651.2	2,178.3	3,393.6	4,282.0	1,642.7	326.9	5,325.9	13,892.8	173,350.2
2010	49,540.2	50,714.6	52,580.7	7,669.2	2,881.2	4,174.5	5,135.8	2,382.5	394.8	6,991.0	13,868.1	196,332.6
2011	45,289.6	48,053.5	53,762.4	8,057.5	2,656.0	4,907.2	4,657.5	2,458.6	566.1	6,984.0	14,613.3	192,005.7
2012	48,325.4	49,791.4	56,625.9	6,658.4	1,881.3	4,801.1	4,682.0	2,398.7	584.7	6,289.1	11,888.0	193,925.9
2013	40,331.6	39,236.7	46,164.5	4,567.9	1,501.1	4,041.1	4,576.3	1,828.6	473.7	5,610.0	7,523.1	155,854.6
2014	34,824.8	40,703.0	49,289.1	4,089.2	1,619.6	3,600.6	5,100.4	1,647.5	443.6	5,352.3	7,776.5	154,446.6
2015	35,757.0	50,907.5	54,059.9	4,029.9	1,800.4	2,698.0	5,342.7	1,782.5	453.8	4,995.7	13,436.0	175,263.4
2016	30,096.8	50,059.0	44,673.0	3,705.4	1,751.7	1,932.3	4,436.5	1,637.2	403.2	4,073.5	22,649.3	165,418.0
2017	25,933.1	63,548.4	44,142.7	4,025.3	1,683.9	2,018.5	4,642.6	1,583.4	436.1	4,301.0	21,184.8	173,500.0
Species total	**552,677.3**	**729,409.9**	**794,264.5**	**69,767.5**	**28,093.3**	**51,341.7**	**70,291.9**	**25,784.0**	**6,598.3**	**84,415.1**	**237,338.8**	**2,649,982**

8.1.1. Mahi mahi

Table 6 Median (med) and lower (low) and upper (high) 95% confidence intervals for mahi mahi catch ('000 individuals) by region.

	north temp			trop			south temp			Total		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2003	161.4	193.0	231.1	122.9	147.1	175.0	140.3	164.1	191.7	456.6	505.4	559.7
2004	217.5	263.8	311.0	141.4	167.2	196.4	148.7	171.4	197.5	546.3	603.6	661.2
2005	224.2	266.0	312.2	121.2	140.7	163.3	127.7	147.1	166.9	505.3	554.2	606.9
2006	210.4	249.2	292.4	117.5	137.9	161.2	116.4	131.8	149.6	473.0	520.1	569.2
2007	233.2	275.9	324.5	123.2	142.8	167.5	97.1	110.7	124.8	479.2	530.3	586.2
2008	225.4	268.4	321.2	121.1	141.5	164.6	99.4	112.1	126.4	474.1	523.1	582.7
2009	237.3	280.3	331.9	108.8	128.2	152.4	132.8	147.9	167.9	507.4	556.5	614.3
2010	230.2	275.0	329.1	142.5	168.6	200.8	190.1	217.3	247.2	603.9	662.9	729.8
2011	282.1	333.8	400.6	204.2	236.2	272.9	196.0	220.6	247.5	728.5	791.6	874.6
2012	266.1	312.4	369.7	196.7	230.6	272.7	200.4	225.9	253.9	701.8	770.2	846.5
2013	213.8	247.5	288.8	155.6	181.0	209.7	190.0	212.3	238.6	587.1	641.6	695.6
2014	203.4	240.1	282.7	124.6	145.0	168.6	168.7	191.3	213.4	532.2	576.6	626.7
2015	167.9	195.0	226.3	98.0	113.7	132.8	117.1	131.3	146.7	403.7	439.4	480.4
2016	136.7	159.8	187.1	60.0	70.4	82.6	79.3	89.4	101.3	292.4	320.5	351.2
2017	120.3	139.2	163.8	58.3	68.6	80.6	100.2	114.6	130.9	296.5	323.6	354.7

Table 7 Median (med) and lower (low) and upper (high) 95% confidence intervals for mahi mahi catch ('000 individuals) deep and shallow setting.

	shallow			deep			Total		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2003	115.3	132.7	153.2	339.4	372.7	408.2	456.6	505.4	559.7
2004	151.0	178.2	207.2	390.5	425.3	462.8	546.3	603.6	661.2
2005	135.9	160.9	189.3	363.7	393.0	422.3	505.3	554.2	606.9
2006	112.3	134.1	160.6	356.8	385.3	415.5	473.0	520.1	569.2
2007	170.2	200.2	235.4	305.7	329.7	356.6	479.2	530.3	586.2
2008	140.8	169.2	206.0	327.4	353.4	380.8	474.1	523.1	582.7
2009	186.2	217.4	255.3	316.2	339.3	364.5	507.4	556.5	614.3
2010	172.4	201.6	237.4	425.4	460.1	497.9	603.9	662.9	729.8
2011	205.4	239.8	287.2	514.4	551.2	593.4	728.5	791.6	874.6
2012	174.9	203.3	239.4	524.1	566.5	613.1	701.8	770.2	846.5
2013	106.2	123.8	143.6	478.3	517.7	554.0	587.1	641.6	695.6
2014	107.6	128.3	152.3	417.9	448.4	482.0	532.2	576.6	626.7
2015	80.7	95.7	114.1	320.8	344.4	370.2	403.7	439.4	480.4
2016	56.1	67.3	81.2	234.5	252.7	272.6	292.4	320.5	351.2
2017	40.6	48.3	58.3	254.0	275.2	298.3	296.5	323.6	354.7

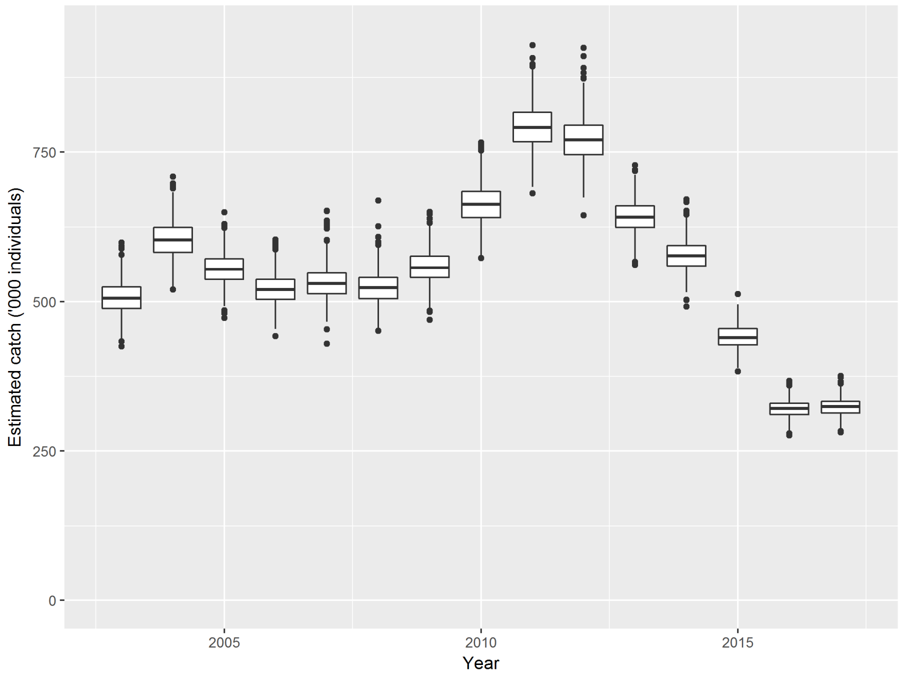


Figure 24 Total estimated mahi mahi catch by year.

8.2.Billfish

Table 8 Median billfish catch estimates ('000 individuals) by species/species.

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	838.7	314.2	434.8	198.0	131.3	101.9	7.6	2,026.7
2004	1,011.3	240.6	242.1	144.4	71.4	69.1	5.4	1,784.4
2005	1,016.8	203.5	197.2	118.2	56.3	62.3	4.7	1,659.0
2006	907.4	209.2	205.0	114.4	55.3	75.2	5.6	1,572.2
2007	1,348.2	272.4	186.2	101.4	90.6	99.5	4.6	2,102.9
2008	1,080.9	265.2	136.0	101.4	82.6	51.3	3.7	1,721.0
2009	1,258.6	353.0	154.7	111.1	143.3	30.7	4.1	2,055.4
2010	1,136.4	347.2	203.2	149.5	157.2	20.5	5.8	2,019.8
2011	1,253.9	332.8	267.0	188.8	108.4	20.8	9.3	2,181.1
2012	980.6	320.0	239.0	173.4	93.1	37.2	8.9	1,852.2
2013	633.5	236.0	148.5	123.5	74.8	29.3	6.9	1,252.4
2014	636.6	245.8	125.3	110.9	89.7	26.4	6.6	1,241.3
2015	627.3	250.8	123.4	129.0	120.7	43.7	6.8	1,301.7
2016	554.9	194.3	122.8	142.5	101.8	40.2	6.2	1,162.7
2017	540.6	182.0	127.1	141.2	86.6	29.9	6.6	1,113.9
Species total	**13,825.8**	**3,966.9**	**2,912.5**	**2,047.6**	**1,463.1**	**738.1**	**92.7**	**25,046.7**

Table 9 Median billfish catch estimates (tonnes) by species/species.

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	47,733.9	19,407.1	23,778.4	4,388.8	4,674.9	6,438.7	318.9	106,740.6
2004	55,907.3	14,770.3	12,608.9	3,175.0	2,511.1	4,230.3	227.3	93,430.2
2005	55,236.7	12,458.3	10,011.1	2,563.1	1,961.2	3,846.1	196.5	86,273.0
2006	47,717.9	12,863.4	10,130.8	2,477.3	1,947.6	4,694.2	233.3	80,064.6
2007	67,770.0	16,889.6	9,212.7	2,190.5	3,278.1	6,209.7	192.8	105,743.4
2008	53,216.6	16,306.1	6,553.2	2,180.8	2,956.0	3,240.6	154.0	84,607.2
2009	64,418.0	22,003.9	7,788.0	2,438.4	5,205.4	1,936.9	172.3	103,962.8
2010	62,183.1	21,861.3	10,722.0	3,349.7	5,753.7	1,320.3	244.7	105,434.8
2011	65,679.0	20,817.6	13,820.2	4,191.1	3,950.6	1,321.0	392.0	110,171.5
2012	49,643.8	19,797.2	12,265.1	3,835.9	3,356.5	2,318.5	373.7	91,590.7
2013	33,189.9	14,522.6	7,688.8	2,734.8	2,658.4	1,813.6	290.4	62,898.5
2014	32,832.7	15,010.7	6,382.9	2,444.0	3,138.0	1,613.3	275.5	61,697.2
2015	31,998.5	15,203.5	6,188.4	2,805.3	4,166.6	2,617.7	283.4	63,263.5
2016	28,264.9	11,709.0	5,947.2	3,043.8	3,478.8	2,443.5	260.6	55,147.9
2017	28,586.9	11,023.6	6,419.1	3,072.3	2,999.8	1,860.3	275.8	54,237.8
Species total	**724,379.1**	**244,644.1**	**149,516.9**	**44,890.8**	**52,036.8**	**45,904.7**	**3,891.3**	**1,265,264**

8.2.1. Striped marlin

Table 10 Median (med) and lower (low) and upper (high) 95% confidence intervals for striped marlin catch ('000 individuals) by region.

	north temp			trop			south temp			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	148.4	179.3	220.3	125.9	152.6	185.0	84.4	100.8	121.3	391.4	434.8	489.1
2004	98.4	120.7	149.0	64.8	77.2	92.3	36.6	43.4	52.0	215.4	242.1	274.4
2005	92.7	110.8	135.9	42.3	50.2	59.7	30.0	35.4	40.9	174.6	197.2	224.1
2006	97.2	118.3	144.7	44.1	53.1	64.8	28.5	33.6	39.2	180.1	205.0	234.4
2007	89.6	110.1	136.0	43.3	51.7	61.2	19.9	23.5	28.1	162.9	186.2	212.0
2008	66.6	82.9	103.6	29.2	35.1	42.2	14.3	17.4	20.5	117.8	136.0	156.2
2009	70.9	87.3	106.4	35.6	42.7	51.4	20.4	24.1	28.4	136.8	154.7	176.9
2010	79.1	98.0	121.4	48.9	60.4	73.5	36.9	44.2	52.4	178.7	203.2	229.2
2011	106.3	133.1	165.9	69.8	83.7	101.5	41.8	49.3	58.4	235.8	267.0	306.5
2012	92.0	113.0	136.8	67.2	80.9	98.2	38.5	44.2	51.4	212.5	239.0	269.2
2013	56.2	67.1	80.3	39.9	47.1	56.1	29.4	33.7	39.3	134.2	148.5	165.1
2014	50.7	62.4	76.6	29.9	36.1	43.0	23.0	26.6	31.0	111.2	125.3	141.2
2015	51.7	62.2	76.0	31.2	37.4	44.5	19.9	23.1	26.8	110.4	123.4	139.3
2016	58.8	69.6	83.6	26.2	30.9	37.3	19.0	21.9	25.5	109.6	122.8	138.5
2017	52.2	62.1	75.3	26.9	33.3	40.9	26.2	31.1	37.0	114.0	127.1	141.3

Table 11 Median (med) and lower (low) and upper (high) 95% confidence intervals for striped marlin catch ('000 individuals) deep and shallow setting.

	shallow			deep			Total		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2003	135.9	154.8	177.8	253.9	279.4	311.2	391.4	434.8	489.1
2004	81.4	96.7	117.5	130.6	144.7	161.0	215.4	242.1	274.4
2005	63.9	77.0	94.1	108.7	119.8	132.8	174.6	197.2	224.1
2006	64.4	79.4	98.4	113.1	125.7	139.6	180.1	205.0	234.4
2007	80.1	96.8	117.0	80.9	89.2	97.1	162.9	186.2	212.0
2008	51.5	63.7	79.0	65.0	72.0	79.5	117.8	136.0	156.2
2009	68.2	81.3	97.9	66.7	73.3	80.4	136.8	154.7	176.9
2010	72.4	86.5	103.9	105.0	116.5	128.9	178.7	203.2	229.2
2011	93.9	113.6	138.6	138.8	153.6	170.3	235.8	267.0	306.5
2012	78.0	93.3	111.0	132.9	145.4	160.5	212.5	239.0	269.2
2013	38.0	44.6	52.9	95.3	103.9	113.5	134.2	148.5	165.1
2014	34.5	42.3	52.4	75.5	83.0	90.9	111.2	125.3	141.2
2015	31.2	38.3	47.6	77.2	84.9	92.9	110.4	123.4	139.3
2016	30.1	36.5	45.1	78.8	86.2	94.9	109.6	122.8	138.5
2017	24.1	28.8	35.0	89.0	98.1	108.3	114.0	127.1	141.3

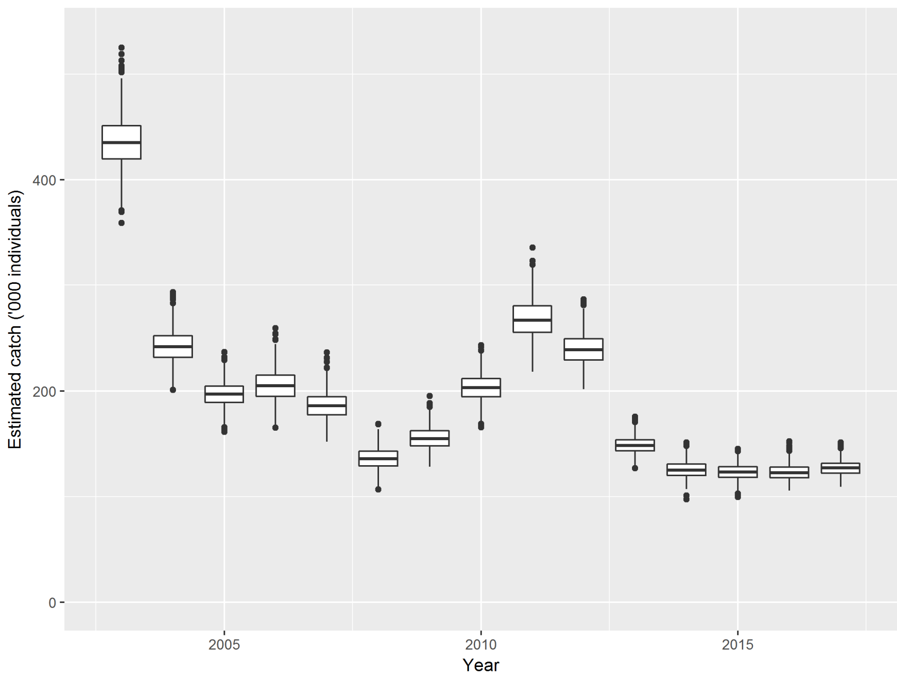


Figure 25 Total estimated striped marlin catch by year.

8.3. Sharks and rays

Table 12 Median shark catch estimates ('000 individuals) by species. Species/species group accounting for less than < 2% of total shark catch have been grouped in to 'others'.

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	1,166.6	235.2	264.0	144.2	180.9	47.7	64.2	141.0	70.3	2,314.1
2004	1,430.9	263.3	256.1	185.7	166.8	51.6	62.6	132.0	83.8	2,633.0
2005	1,212.5	243.0	228.6	176.1	130.0	56.0	58.2	110.4	50.9	2,265.6
2006	1,120.5	256.3	204.1	181.5	105.7	64.2	65.0	106.6	38.2	2,142.2
2007	1,154.8	334.7	159.8	184.6	111.9	67.2	72.5	111.4	42.5	2,239.5
2008	1,115.4	307.3	135.9	171.6	101.1	68.4	70.0	112.9	46.7	2,129.2
2009	1,330.2	380.6	232.2	198.3	113.0	72.6	55.3	150.9	56.3	2,589.5
2010	1,381.1	364.9	375.4	215.0	106.3	75.4	46.3	171.6	55.5	2,791.5
2011	1,522.0	417.7	383.7	210.2	112.2	105.6	46.1	170.8	50.3	3,018.6
2012	1,157.7	452.4	376.9	166.8	93.0	94.6	45.9	133.1	48.1	2,568.5
2013	805.2	188.2	258.8	125.3	55.0	59.4	22.8	81.6	40.9	1,637.2
2014	899.0	126.3	245.9	125.9	49.9	60.6	17.0	91.9	44.9	1,661.4
2015	1,010.8	196.7	300.5	114.6	61.8	70.7	29.5	150.0	49.2	1,983.7
2016	992.6	207.3	263.4	76.0	58.5	63.8	34.9	206.1	41.8	1,944.4
2017	975.3	139.5	249.6	38.6	41.3	40.1	21.0	247.7	36.1	1,789.4
Species total	**17,274.4**	**4,113.4**	**3,934.8**	**2,314.4**	**1,487.5**	**998.1**	**711.4**	**2,118.1**	**755.6**	**33,707.7**

Table 13 Median shark catch estimates (tonnes) by species.

Year	Blue shark	Silky shark	Pelagic stingray	Short finned	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	35,833.1	3,354.8	613.3	5,135.6	6,814.2	300.5	1,863.3	3,932.4	5,450.9	63,298.1
2004	43,194.0	3,652.1	568.0	6,536.9	6,159.7	317.2	1,471.3	3,585.9	7,064.7	72,549.8
2005	36,076.2	3,399.0	506.0	6,170.5	4,910.9	346.9	1,356.5	3,018.6	4,029.4	59,814.0
2006	33,053.3	3,646.0	458.2	6,213.4	4,035.7	397.5	1,648.2	2,918.5	2,446.1	54,817.0
2007	33,007.0	4,730.7	373.5	6,362.6	4,354.5	420.5	1,895.8	2,905.4	3,033.4	57,083.4
2008	32,124.4	4,376.4	320.4	5,864.9	3,920.8	425.7	1,905.7	2,980.7	3,322.2	55,241.1
2009	37,823.4	5,371.4	554.0	6,769.3	4,477.6	464.2	1,602.2	3,973.6	4,336.6	65,372.4
2010	40,932.0	5,333.7	922.0	7,293.4	4,310.4	489.2	1,442.2	4,784.3	4,366.4	69,873.6
2011	45,441.2	6,099.8	926.6	7,186.2	4,504.3	677.5	1,352.1	4,630.0	3,870.0	74,687.7
2012	35,387.3	6,477.4	896.6	5,665.2	3,600.5	595.0	1,374.4	3,581.8	3,868.8	61,446.9
2013	25,268.2	2,716.9	615.1	4,233.7	2,123.2	372.6	699.0	2,291.7	3,429.7	41,750.1
2014	27,355.8	1,769.4	565.8	4,232.2	1,923.0	378.8	504.4	2,559.2	3,574.3	42,862.9
2015	31,232.2	2,728.4	652.2	3,843.9	2,324.3	436.4	808.7	4,130.2	3,028.9	49,185.1
2016	30,551.6	2,984.0	602.8	2,563.5	2,215.6	388.3	1,098.4	5,803.8	2,038.5	48,246.5
2017	30,677.3	2,040.0	608.3	1,289.6	1,595.0	243.5	729.5	7,231.1	2,024.1	46,438.4
Species total	**517,956.7**	**58,680.0**	**9,182.9**	**79,361.0**	**57,269.7**	**6,253.7**	**19,751.7**	**58,327.2**	**55,884.1**	**862,667.1**

8.3.1. Silky shark

Table 14 Median (med) and lower (low) and upper (high) 95% confidence intervals for silky shark catch ('000 individuals) by region.

	north temp			trop			south temp			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	32.7	52.7	84.6	87.0	150.5	273.0	19.1	30.3	46.9	163.8	235.2	359.3
2004	20.1	34.3	58.6	115.9	203.6	360.3	18.1	25.7	38.3	174.8	263.3	425.0
2005	25.4	39.9	66.8	101.7	171.7	314.7	19.7	27.5	39.0	168.4	243.0	380.8
2006	27.2	43.8	72.2	107.4	174.6	309.0	24.7	34.6	48.4	179.6	256.3	389.5
2007	44.1	68.3	108.8	145.3	224.8	355.6	28.8	38.7	52.9	248.3	334.7	459.4
2008	49.9	81.7	128.8	119.0	187.5	312.9	27.8	36.5	50.2	232.3	307.3	447.2
2009	49.2	79.1	122.3	155.0	259.7	446.2	28.7	41.0	57.1	268.4	380.6	574.4
2010	46.4	73.2	117.5	118.8	224.4	474.3	37.5	60.5	98.4	240.5	364.9	622.3
2011	56.8	95.0	162.1	137.6	255.0	490.9	41.7	64.1	103.0	289.5	417.7	646.4
2012	45.2	72.6	120.3	191.3	316.6	608.2	39.6	59.5	91.3	311.7	452.4	738.8
2013	18.3	28.4	43.0	82.9	132.1	218.2	19.9	26.4	36.1	136.6	188.2	275.8
2014	15.3	24.9	41.7	54.8	86.2	146.7	9.8	13.3	18.5	90.9	126.3	186.0
2015	24.3	38.5	59.6	87.1	137.1	216.1	14.0	18.7	24.9	140.4	196.7	278.9
2016	36.5	53.9	83.8	78.1	124.3	200.4	20.6	27.1	36.5	154.1	207.3	287.4
2017	26.3	39.0	62.0	50.0	77.8	126.2	15.6	20.9	28.2	106.1	139.5	195.6

Table 15 Median (med) and lower (low) and upper (high) 95% confidence intervals for silky shark catch ('000 individuals) deep and shallow setting.

	shallow			deep			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High
2003	54.2	75.1	102.9	106.9	160.0	261.1	163.8	235.2	359.3
2004	33.1	44.2	58.7	138.9	219.8	368.7	174.8	263.3	425.0
2005	23.9	33.9	50.7	138.1	207.6	345.5	168.4	243.0	380.8
2006	28.7	40.0	56.8	147.8	215.0	343.0	179.6	256.3	389.5
2007	91.2	119.9	162.0	153.6	214.6	316.1	248.3	334.7	459.4
2008	78.1	106.0	146.4	144.4	201.2	310.7	232.3	307.3	447.2
2009	117.2	151.9	200.1	147.5	231.0	382.5	268.4	380.6	574.4
2010	103.8	140.2	197.7	135.3	222.0	423.0	240.5	364.9	622.3
2011	122.5	163.9	220.8	160.4	255.0	441.6	289.5	417.7	646.4
2012	121.4	159.2	220.6	188.2	292.1	523.5	311.7	452.4	738.8
2013	39.0	52.4	71.9	96.6	135.9	207.8	136.6	188.2	275.8
2014	21.2	30.2	43.6	67.2	96.0	147.5	90.9	126.3	186.0
2015	24.4	34.8	50.6	111.9	160.5	237.9	140.4	196.7	278.9
2016	27.2	37.2	53.7	123.8	169.5	242.7	154.1	207.3	287.4
2017	24.5	33.0	47.8	79.5	106.2	148.7	106.1	139.5	195.6

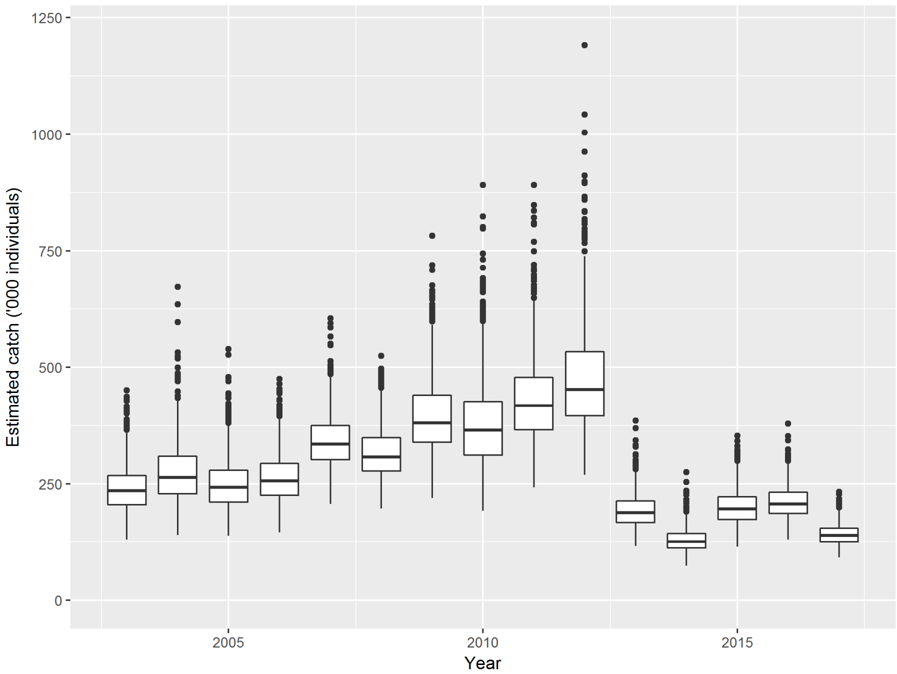


Figure 26 Total estimated silky shark catch by year.

8.3.1. Oceanic whitetip

Table 16 Median (med) and lower (low) and upper (high) 95% confidence intervals for oceanic whitetip catch ('000 individuals) by region.

	north temp			trop			south temp			Total		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2003	37.2	51.2	73.1	58.0	96.0	160.4	23.8	32.6	44.8	139.4	180.9	250.8
2004	36.9	51.0	71.7	52.9	87.9	158.9	19.6	25.8	34.4	128.4	166.8	239.0
2005	37.7	50.7	69.1	34.3	57.3	104.1	15.4	20.3	25.8	100.2	130.0	174.5
2006	28.9	41.5	59.0	27.0	45.3	82.1	13.8	18.3	23.8	83.1	105.7	144.8
2007	33.0	46.8	67.0	30.9	48.5	78.3	12.1	15.5	20.3	87.4	111.9	146.9
2008	32.5	46.2	64.8	24.2	39.4	65.1	10.9	14.4	18.7	78.0	101.1	132.8
2009	32.7	47.6	66.9	28.1	45.9	77.3	14.1	18.1	23.8	88.0	113.0	149.0
2010	25.3	38.1	55.4	25.4	41.5	73.8	17.6	25.2	36.5	81.3	106.3	142.3
2011	31.8	46.9	70.7	26.3	42.0	71.3	15.9	21.5	29.3	86.9	112.2	146.0
2012	20.1	29.7	43.8	26.8	44.6	76.6	12.5	17.2	23.9	70.3	93.0	125.9
2013	11.5	16.1	22.9	16.4	25.6	42.4	9.4	12.4	16.1	43.3	55.0	72.0
2014	12.8	18.2	26.4	13.6	21.0	34.9	8.0	10.1	12.7	39.4	49.9	66.3
2015	16.9	23.6	33.3	18.1	26.9	44.1	8.7	10.7	13.3	49.2	61.8	81.0
2016	17.6	25.0	35.3	14.3	21.5	35.0	9.0	11.1	14.1	47.0	58.5	74.7
2017	11.4	15.9	23.1	9.6	14.7	23.3	8.2	10.3	13.1	33.6	41.3	52.3

Table 17 Median (med) and lower (low) and upper (high) 95% confidence intervals for oceanic whitetip catch ('000 individuals) deep and shallow setting.

	shallow			deep			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High
2003	51.6	63.4	79.3	85.6	117.7	174.3	139.4	180.9	250.8
2004	42.1	52.4	65.8	80.8	112.8	180.0	128.4	166.8	239.0
2005	34.3	44.3	57.9	60.4	84.4	129.3	100.2	130.0	174.5
2006	27.5	36.9	48.9	51.1	68.8	104.4	83.1	105.7	144.8
2007	43.3	55.9	73.5	40.9	55.7	80.1	87.4	111.9	146.9
2008	35.8	47.2	62.8	38.7	53.0	77.1	78.0	101.1	132.8
2009	46.7	60.8	78.8	36.9	51.1	78.2	88.0	113.0	149.0
2010	38.4	49.9	64.8	40.5	55.8	83.0	81.3	106.3	142.3
2011	43.1	57.0	77.5	40.1	54.3	79.9	86.9	112.2	146.0
2012	29.3	39.4	50.7	38.9	53.4	78.6	70.3	93.0	125.9
2013	14.6	18.5	24.0	27.7	36.0	50.5	43.3	55.0	72.0
2014	13.1	17.4	23.6	24.8	32.1	45.4	39.4	49.9	66.3
2015	14.6	19.6	26.9	32.8	41.7	59.5	49.2	61.8	81.0
2016	12.8	17.9	24.6	32.4	40.3	53.6	47.0	58.5	74.7
2017	8.4	11.2	15.2	24.2	30.0	38.3	33.6	41.3	52.3

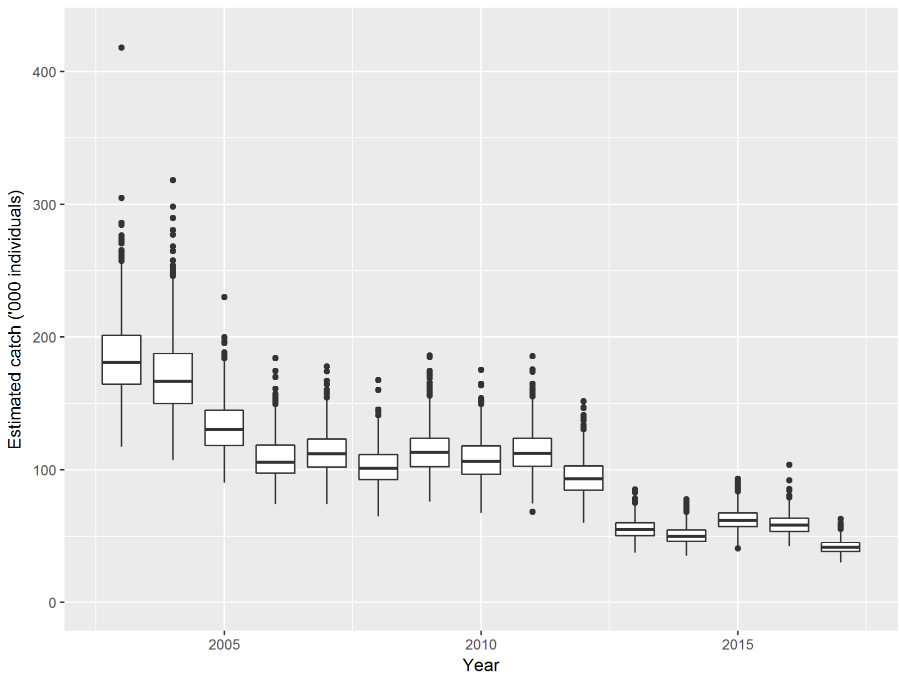


Figure 27 Total estimated oceanic whitetip catch by year.

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

Table 18 Median turtle catch estimates (individuals) by species/species.

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	9,670	2,166	91	1,399	788	1,434	15,548
2004	6,495	4,186	266	1,847	850	2,695	16,337
2005	4,294	2,662	1,286	1,996	638	2,018	12,894
2006	5,065	1,509	3,591	1,496	534	1,359	13,555
2007	19,635	5,393	3,273	1,583	979	1,046	31,908
2008	20,296	9,645	1,120	1,000	1,149	540	33,750
2009	29,393	9,356	964	1,424	1,535	249	42,921
2010	18,900	4,219	1,209	1,856	1,586	177	27,947
2011	13,030	2,796	1,376	1,992	1,355	148	20,697
2012	14,711	3,211	1,443	2,153	1,428	271	23,217
2013	9,588	3,254	1,797	1,808	969	378	17,795
2014	10,184	3,555	3,272	1,840	996	835	20,681
2015	14,591	3,990	5,208	1,865	1,598	3,622	30,874
2016	12,364	3,586	3,345	1,132	1,597	1,161	23,184
2017	8,507	5,769	1,163	617	901	22	16,979
Species total	**196,722**	**65,296**	**29,405**	**24,006**	**16,902**	**15,956**	**348,286**

Note: refer to Section 9 for discussion regarding of olive ridley catch estimates.

8.4.1. Loggerhead turtle

Table 19 Median (med) and lower (low) and upper (high) 95% confidence intervals for loggerhead turtle catch (individuals) by region.

	north temp			trop			south temp			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	2	34	501	1	15	236	1	11	148	16	91	714
2004	30	141	635	11	55	228	9	37	154	103	266	794
2005	286	753	1,976	103	259	701	81	200	505	673	1,286	2,670
2006	906	2,158	4,967	311	722	1,602	236	522	1,272	1,973	3,591	6,507
2007	937	2,117	5,139	252	707	1,769	144	334	730	1,855	3,273	6,351
2008	231	753	2,236	54	180	631	42	106	325	521	1,120	2,614
2009	204	553	1,592	83	237	725	40	102	263	479	964	2,010
2010	222	616	1,679	117	329	978	82	189	476	660	1,209	2,346
2011	288	787	2,018	127	332	990	71	180	427	726	1,376	2,667
2012	247	666	1,807	155	487	1,449	70	187	526	712	1,443	3,015
2013	322	804	1,987	236	587	1,699	129	288	650	1,018	1,797	3,407
2014	765	1,785	4,168	391	852	2,115	220	469	981	1,890	3,272	5,980
2015	1,220	2,636	5,899	798	1,642	3,897	348	699	1,502	3,254	5,208	8,776
2016	819	1,905	4,398	381	793	1,805	250	521	1,104	1,981	3,345	5,822
2017	140	555	2,178	70	257	923	59	220	822	522	1,163	2,927

Table 20 Median (med) and lower (low) and upper (high) 95% confidence intervals for loggerhead catch (individuals) deep and shallow setting.

	shallow			deep			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High
2003	6	40	377	8	46	296	16	91	714
2004	36	123	479	56	137	344	103	266	794
2005	274	617	1,526	351	646	1,190	673	1,286	2,670
2006	756	1,690	3,760	1,094	1,838	2,935	1,973	3,591	6,507
2007	1,123	2,182	4,756	631	1,079	1,772	1,855	3,273	6,351
2008	238	652	1,810	239	448	889	521	1,120	2,614
2009	255	586	1,429	197	367	667	479	964	2,010
2010	287	635	1,456	336	572	1,060	660	1,209	2,346
2011	331	771	1,719	348	600	1,053	726	1,376	2,667
2012	301	684	1,662	407	751	1,397	712	1,443	3,015
2013	367	737	1,608	630	1,043	1,877	1,018	1,797	3,407
2014	779	1,550	3,292	1,059	1,698	2,810	1,890	3,272	5,980
2015	946	1,867	3,992	2,095	3,291	5,525	3,254	5,208	8,776
2016	610	1,352	3,039	1,260	1,981	3,101	1,981	3,345	5,822
2017	150	408	1,396	347	740	1,630	522	1,163	2,927

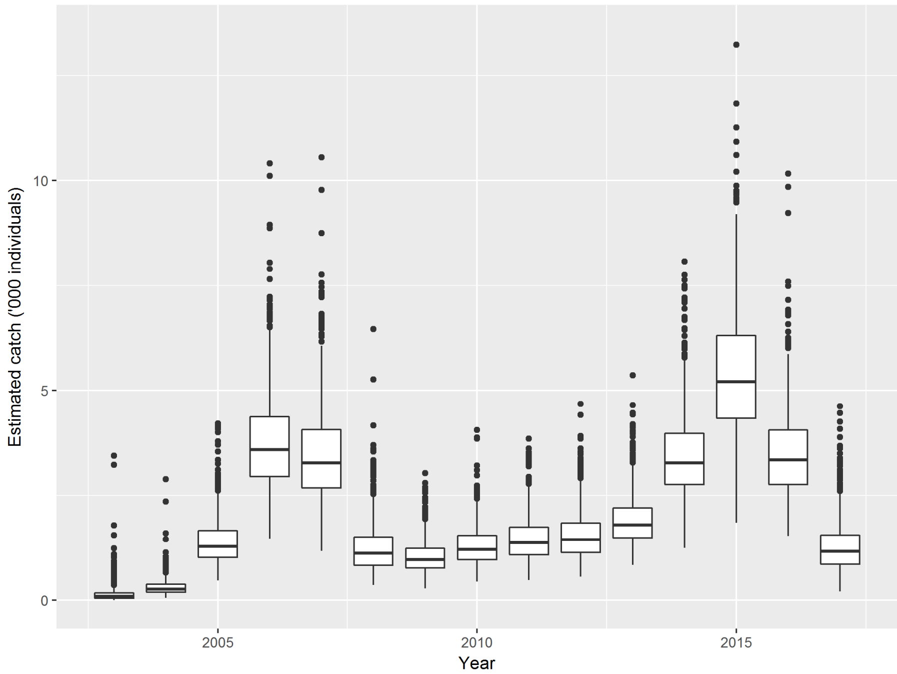


Figure 28 Total estimated loggerhead turtle catch by year.

9. Discussion

In this report we have attempted to estimate longline catches across the full range of finfish, sharks and rays, sea turtles and marine mammals that are caught in WCPFC-CA longline fisheries. The analysis was complicated by the coverage of available observer data, and for some years the coverage of HBF-specific aggregate data. The catch estimates presented here must be viewed in the context of the limitations of the dataset, and the methodology used to obtain the estimates.

Observer coverage for some key longline fleets has been limited for the time period considered in this report. Excluding west-tropical domestic fleets, the four fleets with the highest expended effort in the WCPFC Convention Area accounted for 70% of total effort from 2003 to 2017, with an overall average observer coverage of < 1%. The issue is particularly pronounced in the north temperate region, where the two fleets with the highest expended effort accounted for 80% of the effort in the region with an average observer coverage of < 0.3%. The observer coverages presented here are based on SPC data holdings, and so may not reflect all observer data available in the region, and observer coverage rates throughout the WCPFC CA has generally increased through time. Regardless, it would appear likely that the region-wide catch estimates for the north temperate region (and their associated uncertainty) are unlikely to be robust.

Former shark fisheries in the EEZs of Papua New Guinea and the Solomon Islands are not included in longline aggregate data held by SPC, and as a result the longline catch estimates presented do not cover these fisheries. This is particularly an issue for catch estimates of silky sharks in the tropical region which will be underestimated prior to the ban on silky shark retention as of 1st July 2014, along with other species associated with shallow sets in the area.

The uncertainty of our catch estimates only incorporates uncertainty in catch rates, and specifically does not include uncertainty in the estimated proportions of effort by HBF. The depth of fishing gear has a large impact on the catch rates for a wide range of the species considered here. As such, we likely underestimate the uncertainty in catch estimates from 2003 to 2009, i.e. those years with less L_BEST_HBF effort coverage (Figure 5). Additionally, catch estimates may be biased if available L_BEST_HBF data are not representative. Comparisons of L_BEST_HBF coverage of swordfish catch and effort did suggest that available L_BEST_HBF may not be representative for all fleets, i.e. the coverage of swordfish catch did not scale linearly with coverage of effort.

The SPC/FFA Gen-II form was introduced in 2003. Observers were instructed to record catch events of species of special interest (SSIs) on both the LL-4 form and the Gen-II form, with the GEN-II form intended to provide additional information on the event. A comparison of LL-4 and Gen-II data indicates that some observers did not record all SSI catch events on the LL-4 form. Review of available data indicated that there are a small number of additional GEN-II catch records (representing ~ 60 individuals) from 2003 to 2010 that had not been successfully migrated to SPC's existing master observer data. Work is currently ongoing to ensure that these additional records are captured in the master observer database. The 2016 revision of the GEN-II form will prevent these issues from occurring in the future.

Olive ridley catch estimates had a peak of ~ 30,000 individuals in 2009, and represented 62 % of total estimated catches of olive ridley, green, loggerhead and leatherback turtles. This is almost double the estimate of 35 %, obtained from a recent sea turtle-specific initiative focussing on sea turtle mitigation effectiveness (Common Oceans, 2017). It would appear likely that our olive ridley catches are overestimates, as the estimates of 35 % were obtained using a simulation model that accounted for estimates of sea turtle distributions, and benefited from additional observer data provided by countries specifically for the workshops. This also suggests that the estimates of overall sea turtle catches are likely overestimated.

The estimates of WCPFC-CA wide silky shark catch presented here are broadly consistent with those from Rice (2012). Both sets of estimates displayed a general increasing trend in catches from 2003 to 2009, with catches in the region of 150,000 to 400,000 individuals. These catch estimates are somewhat higher than estimates by Lawson (2011), which were in the region of 100,000 to 200,000 individuals. The estimates of WCPFC-CA wide oceanic whitetip presented here are somewhat higher than those by Lawson (2011) and Rice (2012), though the declining trend from 2003 to 2006 and then plateau from 2007 to 2009 is consistent with the trend in estimates of Lawson (2011). It is not immediately clear why our estimates for silky shark are more consistent with those of Rice (2012), and our estimates for silky shark are more consistent with those of Lawson (2011). We do note that strong declines in oceanic whitetip catch rates in the WCPFC CA have been were detected in other studies of longline observer data in the WCPFC-CA (e.g. Clarke et al., 2013), and so we might expect catches to demonstrate a similar trend.

Residual diagnostics indicated a lack of fit for log-normal components of catch rate models for target species, which suggests that targeting behaviour was not adequately captured by the use of L_BEST species compositions clusters. This is not necessarily surprising, as the L_BEST data does not differentiate between deep and shallow sets, and there may be different targeting behaviour within an L_BEST strata for the same fleet. Replacing aggregate species composition clusters with a flag effect is one option to address this, though it would not necessarily address the issue of within-flag variation in targeting behaviour. The use of L_BEST_HBF species compositions may also be helpful, though it would require other changes to the parameterisation of the model to avoid severe multi-collinearity, and would introduce difficulties in achieving 'raised' estimates of catches given the incomplete coverage of L_BEST_HBF data.

It is clear that our catch estimation approach underestimated catches of albacore, yellowfin and bigeye, and over-estimated catches of swordfish, based on comparisons with aggregate catch data. The overestimation of swordfish catches was mainly driven by estimates for the 'north temperate' region (i.e. north of 10°N), and was particularly severe for 2007 to 2012. We note that the estimates of shallow effort in the north temperate region from 2007 to 2012 appear to be erroneously high (Table 2). One cause for the differences in estimated and reported catches is the apparent inability of the models to capture targeting behaviour. However, it is also likely that the available levels of coverage in observer data, and 'L_BEST_HBF', also contributed to this. Comparisons of estimated catches with logsheet data of the deep-set Hawaiian longline fishery indicated that the catch estimates were more accurate for fisheries with consistently high observer coverage (20 % of trips in this case).

Catch indices do not necessarily provide an accurate proxy for trends and/or absolute levels of mortalities resulting from the catch and release of individuals. We have not attempted here to estimate mortalities, though this has been previously been explored for some species, e.g. oceanic white tip and silky sharks (Harley et al., 2015) and sea turtles (Common Oceans, 2017). We note that the time series of catches may be particularly misleading for species with no-retention policies either through domestic or regional measures. This includes oceanic whitetip and silky shark, for which no-retention measures were introduced on 1st January 2013 (WCPFC CMM 2011-04) and 1st July 2014 (WCPFC CMM 2013-08) respectively.

Hooks between floats was an important predictor for a wide range of our catch rate models. However it is important to note that HBF is likely correlated with a wide range of (un-modelled) variables that have been demonstrated to influence catch rates in longline fisheries, e.g. time of setting, hook geometry and size, bait types etc. As such, the HBF term in the model is likely to reflect the influence of more than just the (proxy of) depth of the gear. We note that the use of HBF is convenient as it is almost always available in observer data, and HBF-specific effort data are available (i.e. L_BEST_HBF).

10. Recommendations

We recommend that:

- The Scientific Committee note the difficulties in robust estimation of longline catches from observer data, given the very low levels of observer coverage, and for some years (2003-2008) the coverage of L_BEST_HBF data
- The Scientific Committee note that observer coverage levels in the region are generally less than 5%, though acknowledging that observer coverage can be expressed in a variety of units (e.g. trips with observers on board, hooks with observer onboard, hooks observed)
- The Scientific Committee take note of the regions of the WCPFC-CA with substantial fishing effort and low levels of available observer coverage, and the implications this has on (by)catch estimation at a regional level
- The Scientific Committee consider whether historic L_BEST_HBF aggregate data can be derived by members (where necessary), to support future analysis of longline observer data
- The Scientific Committee decide on whether these preliminary estimates of longline bycatch are suitable for public release in the context of the associated uncertainties, and
- The Scientific Committee consider the utility of the work presented here, and whether periodic future updates would be helpful.

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ANNEX 1

Table 21 Percentage of sets with recorded catches of the different species / species groupings by region and strategy. The table rows are ordered by species group (BIL – billfish, MAM – marine mammals, SHK – sharks and rays, TEL – finfish, and TTX – sea turtles) and then by total sets where catches were observed.

			n.temp		s.temp		trop		
Species/species group	Scientific name	Group	deep	shallow	deep	shallow	deep	shallow	Total
Swordfish	Xiphias gladius	BIL	28.7%	98.6%	20.9%	45.9%	28.3%	48.6%	36.1%
Short-billed spearfish	Tetrapturus angustirostris	BIL	42.1%	7.5%	18.8%	6.0%	10.3%	3.6%	24.2%
Striped marlin	Tetrapturus audax	BIL	38.3%	20.6%	12.9%	18.9%	10.7%	14.2%	23.7%
Blue marlin	Makaira nigricans	BIL	18.0%	6.1%	19.2%	5.0%	32.2%	40.6%	18.5%
Sailfish (indo-pacific)	Istiophorus platypterus	BIL	2.2%	0.1%	6.9%	2.4%	11.0%	39.1%	5.1%
Black marlin	Makaira indica	BIL	0.2%	0.0%	3.2%	3.2%	5.3%	8.1%	2.1%
Billfishes nei	Billfishes nei	BIL	1.6%	0.6%	0.4%	0.2%	0.4%	0.0%	0.9%
Marine mammal	Mammalia	MAM	0.2%	0.6%	0.5%	3.0%	0.4%	0.9%	0.6%
Blue shark	Prionace glauca	SHK	86.2%	96.3%	39.3%	51.6%	26.7%	19.3%	62.8%
Pelagic stingray	Dasyatis violacea	SHK	15.5%	8.1%	29.8%	3.9%	26.5%	13.1%	19.4%
Short finned mako	Isurus oxyrhinchus	SHK	12.2%	38.7%	12.9%	27.5%	3.0%	4.2%	15.0%
Elasmobranchs nei	Elasmobranchii nei	SHK	15.4%	9.8%	7.3%	30.2%	10.0%	24.5%	12.8%
Bigeye thresher	Alopias superciliosus	SHK	19.4%	3.3%	2.4%	2.3%	8.7%	12.1%	10.1%
Silky shark	Carcharhinus falciformis	SHK	3.3%	0.4%	11.2%	4.7%	29.5%	73.0%	10.1%
Oceanic whitetip shark	Carcharhinus longimanus	SHK	6.2%	3.7%	7.6%	5.3%	10.2%	21.1%	7.0%
Thresher sharks nei	Alopiidae nei	SHK	3.6%	0.8%	1.7%	6.9%	5.2%	7.2%	3.2%
Porbeagle shark	Lamna nasus	SHK	0.0%	0.0%	3.4%	19.8%	0.0%	0.0%	2.2%
Long finned mako	Isurus paucus	SHK	0.8%	0.2%	2.1%	0.6%	3.7%	2.3%	1.5%
Hammerhead sharks	Sphyrnidae	SHK	0.5%	0.2%	0.9%	3.0%	0.8%	18.3%	1.1%
Mantas & mobulids	Mobulidae	SHK	0.3%	0.4%	0.7%	1.6%	2.5%	5.2%	0.9%
Mako sharks nei	Isurus spp nei	SHK	0.4%	0.7%	0.1%	0.1%	0.1%	0.0%	0.3%
Whale shark	Rhincodon typus	SHK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bigeye	Thunnus obesus	TEL	92.7%	40.9%	56.6%	35.2%	78.8%	31.2%	70.1%
Escolars	Gempylidae	TEL	84.5%	66.1%	53.8%	37.5%	38.3%	30.9%	63.5%
Longsnouted lancetfish	Alepisaurus ferox	TEL	89.6%	63.5%	40.0%	22.7%	13.5%	1.3%	56.5%
Yellowfin	Thunnus albacares	TEL	46.0%	15.1%	65.6%	54.3%	70.9%	72.3%	52.2%
Mahi mahi	Coryphaena hippurus	TEL	70.6%	46.1%	41.7%	29.2%	16.4%	32.1%	48.9%
Albacore	Thunnus alalunga	TEL	25.5%	31.3%	84.5%	66.5%	32.0%	2.5%	45.6%
Pomfrets	Bramidae	TEL	75.0%	12.6%	18.5%	36.5%	19.2%	2.1%	40.6%
Wahoo	Acanthocybium solandri	TEL	45.8%	3.9%	54.2%	7.6%	34.6%	8.2%	38.7%
Skipjack	Katsuwonus pelamis	TEL	47.2%	4.5%	42.7%	11.5%	25.9%	6.1%	35.0%
Opah	Lampris guttatus	TEL	46.3%	10.5%	21.9%	13.3%	5.6%	0.4%	26.8%
Great barracuda	Sphyraena barracuda	TEL	7.4%	0.1%	25.0%	4.5%	9.4%	48.9%	12.2%
Marine fishes nei	Teleosts nei	TEL	14.9%	5.7%	10.4%	22.6%	8.5%	11.1%	12.1%
Scombrids nei	Scombridae nei	TEL	10.2%	10.1%	6.3%	38.8%	1.6%	1.6%	9.5%
Slender sunfish	Ranzania laevis	TEL	4.8%	0.0%	6.5%	0.3%	1.5%	0.1%	3.9%
Lampriformes nei	Lampriformes nei	TEL	2.4%	0.7%	2.9%	15.0%	0.4%	0.0%	2.8%
Sunfish nei	Molidae nei	TEL	1.0%	2.6%	3.9%	13.0%	1.3%	1.0%	2.8%
Lancetfishes nei	Alepisauridae nei	TEL	0.3%	0.0%	5.0%	4.1%	5.9%	2.2%	2.6%
Barracudas nei	Sphyraenidae nei	TEL	0.0%	0.0%	2.7%	1.4%	2.8%	17.4%	1.5%
Olive ridley turtle	Lepidochelys olivacea	TTX	0.2%	0.0%	0.2%	0.2%	1.7%	7.3%	0.5%
Green turtle	Chelonia mydas	TTX	0.0%	0.1%	0.3%	0.3%	0.6%	2.3%	0.2%
Loggerhead turtle	Caretta caretta	TTX	0.1%	0.8%	0.2%	0.1%	0.2%	0.5%	0.2%
Leatherback turtle	Dermochelys coriacea	TTX	0.0%	0.5%	0.1%	0.4%	0.3%	0.4%	0.2%
Hawksbill turtle	Eretmochelys imbricata	TTX	0.0%	0.0%	0.1%	0.0%	0.2%	0.6%	0.1%
Marine turtles nei	Chelonioidea nei	TTX	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%

ANNEX 2

Table 22 Alternative strata used to estimate HBF-specific effort proportions.

Strata
flag, year, month, 5° lat, 5° lon
flag, year, quarter, 5° lat, 5° lon
flag, year, month, 10° lat, 10° lon
flag, 5 year bin, month, 5° lat, 5° lon
flag, year, quarter, 10° lat, 10° lon
flag, 5 year bin, quarter, 5° lat, 5° lon
flag, 5 year bin, month, 10° lat, 10° lon
flag, month, 5° lat, 5° lon
flag, 5 year bin, quarter, 10° lat, 10° lon
flag, quarter, 5° lat, 5° lon
flag, year, month, 10° lat
flag, month, 10° lat, 10° lon
flag, quarter, 10° lat, 10° lon
flag, 5 year bin, quarter, 10° lat
flag, year, region
flag, 5 year bin, region
flag, quarter, 10° lat
flag, region

Table 23 Correlation structures by species/species group for poisson (left) and delta-lognormal (right) models.

Species / species group	Correlation structure
Lancetfishes nei	exchangeable
Barracudas nei	exchangeable
Billfishes nei	exchangeable
Black marlin	independence
Leatherback turtle	exchangeable
Great barracuda	exchangeable
Opah	exchangeable
Olive ridley turtle	exchangeable
Long finned mako	exchangeable
Lampriformes nei	exchangeable
Mako sharks nei	exchangeable
Marine mammal	exchangeable
Mantas & mobulids	exchangeable
Striped marlin	exchangeable
Sunfish nei	exchangeable
Sailfish (indo-pacific)	exchangeable
Short finned mako	exchangeable
Short-billed spearfish	exchangeable
Hawksbill turtle	exchangeable
Loggerhead turtle	exchangeable
Marine turtles nei	exchangeable
Green turtle	exchangeable
Wahoo	exchangeable

Species / species group	Delta correlation structure	Lognormal correlation structure
Albacore	exchangeable	exchangeable
Longsnouted lancetfish	independence	exchangeable
Bigeye	exchangeable	exchangeable
Pomfrets	exchangeable	exchangeable
Blue shark	exchangeable	exchangeable
Bigeye thresher	exchangeable	independence
Blue marlin	exchangeable	independence
Mahi mahi	exchangeable	exchangeable
Silky shark	exchangeable	independence
Escolars	exchangeable	exchangeable
Oceanic whitetip shark	exchangeable	independence
Pelagic stingray	exchangeable	independence
Porbeagle shark	independence	exchangeable
Slender sunfish	exchangeable	independence
Elasmobranchs nei	exchangeable	independence
Skipjack	exchangeable	exchangeable
Hammerhead sharks	exchangeable	independence
Swordfish	exchangeable	independence
Marine fishes nei	exchangeable	independence
Thresher sharks nei	exchangeable	independence
Scombrids nei	exchangeable	exchangeable
Yellowfin	exchangeable	exchangeable

Table 24 Average weights (kg) used to raise from catch numbers to weight for finfish, billfish, sharks and rays.

	n.temp		trop		s.temp	
Species / species group	**deep**	**shallow**	**deep**	**shallow**	**deep**	**shallow**
Albacore	17.72	11.07	15.13	17.15	15.36	10.87
Bigeye	33.00	38.91	38.92	48.82	28.64	39.39
Scombrids nei	59.48	59.48	27.85	59.48	51.01	62.95
Skipjack	5.44	4.53	4.65	3.83	5.03	5.02
Wahoo	11.43	12.30	9.55	9.62	10.86	12.51
Yellowfin	24.92	40.82	25.02	29.58	24.71	28.72
Barracudas nei	5.65	5.65	5.23	5.94	5.81	6.99
Escolars	3.43	8.07	4.70	8.07	9.29	7.03
Great barracuda	6.74	4.73	4.57	4.74	4.53	5.12
Lampriformes nei	8.86	8.86	8.86	8.86	8.86	9.01
Lancetfishes nei	1.66	1.66	1.66	1.66	1.73	1.66
Longsnouted lancetfish	3.35	3.35	3.35	3.35	3.36	3.35
Mahi mahi	4.87	4.97	6.15	7.36	7.81	9.22
Marine fishes nei	9.68	9.68	10.35	20.90	10.08	8.19
Opah	30.88	30.88	30.88	30.88	32.08	30.88
Pomfrets	1.21	1.21	2.53	1.21	1.32	1.19
Slender sunfish	3.00	3.00	3.00	3.00	3.00	3.00
Sunfish nei	75.02	75.02	202.01	75.02	61.33	76.88
Billfishes nei	41.96	41.96	41.96	41.96	41.96	41.96
Black marlin	51.44	67.26	55.64	63.61	76.50	84.49
Blue marlin	50.27	61.59	60.35	64.68	65.45	88.31
Sailfish (indo-pacific)	22.25	36.25	33.90	38.17	38.84	46.24
Short-billed spearfish	17.10	20.32	23.59	23.97	25.27	30.57
Striped marlin	32.04	42.05	55.07	61.16	72.21	107.54
Swordfish	26.16	45.64	50.74	44.79	91.30	147.25
Bigeye thresher	4.71	6.78	5.50	5.84	9.65	22.52
Blue shark	38.05	22.90	43.39	39.13	24.87	17.56
Hammerhead sharks	46.68	46.68	48.06	36.88	64.50	58.76
Long finned mako	66.29	78.44	48.59	93.64	100.40	128.32
Mako sharks nei	66.54	66.54	66.54	66.54	66.54	66.54
Mantas & mobulids	164.70	164.70	102.98	164.70	164.70	164.70
Oceanic whitetip shark	26.96	43.38	30.28	37.71	52.03	60.33
Porbeagle shark	15.28	15.28	15.28	15.28	14.00	16.77
Short finned mako	34.16	34.16	34.16	34.16	29.44	46.55
Silky shark	15.56	13.95	12.63	13.29	21.61	21.17
Thresher sharks nei	43.19	43.19	5.62	43.19	84.59	27.93
Elasmobranchs nei	24.98	24.98	22.09	18.16	49.29	35.15
Pelagic stingray	2.98	2.98	1.52	2.98	3.20	3.71

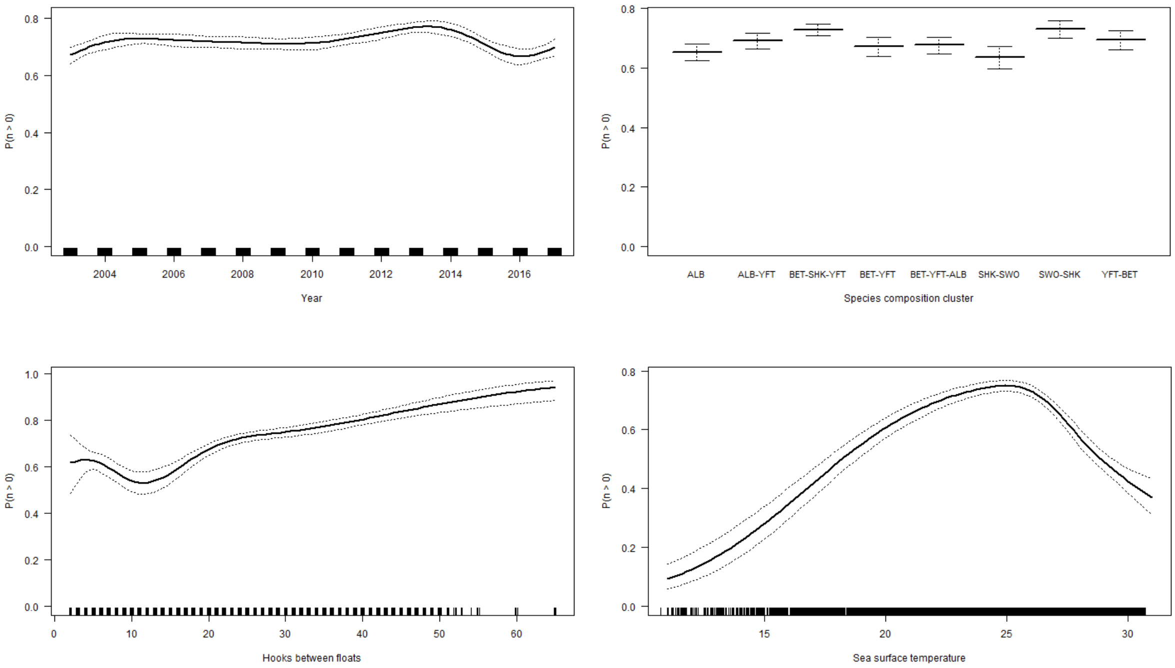
Table 25 Median CVs for finish and billfish catch rate estimates (left) and shark and rays, turtles and marine mammals (right).

Species / species group	CV
Barracudas nei	67.6%
Slender sunfish	65.9%
Lancetfishes nei	38.8%
Sunfish nei	27.7%
Lampriformes nei	27.3%
Great barracuda	22.8%
Scombrids nei	17.9%
Marine fishes nei	16.4%
Opah	12.4%
Longsnouted lancetfish	11.2%
Skipjack	9.7%
Wahoo	9.4%
Albacore	9.3%
Pomfrets	9.2%
Yellowfin	7.8%
Mahi mahi	7.7%
Bigeye	6.9%
Escolars	6.9%
Black marlin	64.1%
Billfishes nei	42.8%
Sailfish (indo-pacific)	26.6%
Blue marlin	13.5%
Short-billed spearfish	11.0%
Striped marlin	9.4%
Swordfish	9.3%

Species / species group	CV
Mako sharks nei	89.1%
Porbeagle shark	45.7%
Long finned mako	38.9%
Mantas & mobulids	37.0%
Hammerhead sharks	33.3%
Silky shark	26.4%
Oceanic whitetip shark	20.0%
Thresher sharks nei	19.8%
Bigeye thresher	18.1%
Pelagic stingray	15.2%
Elasmobranchs nei	14.2%
Short finned mako	12.2%
Blue shark	6.8%
Hawksbill turtle	349.7%
Marine turtles nei	175.2%
Green turtle	85.5%
Olive ridley turtle	83.6%
Loggerhead turtle	64.2%
Leatherback turtle	58.3%
Marine mammal	37.6%

ANNEX 3 Effect plots

(a) delta



(b) lognormal

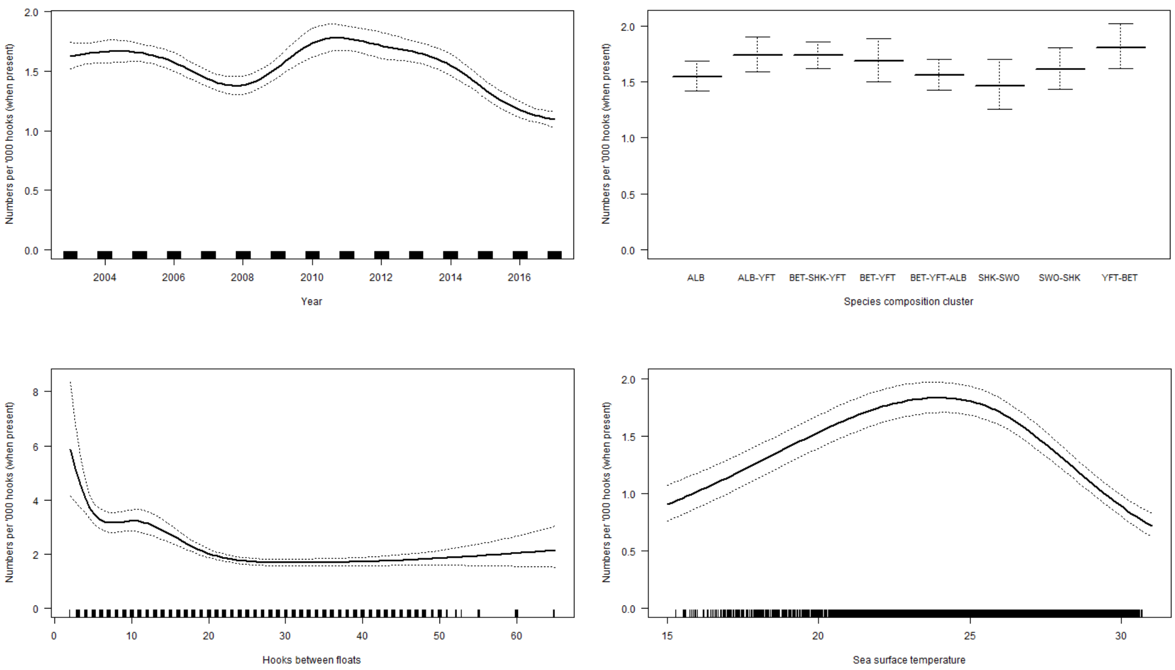


Figure 29 Effects plots for the delta component (a) and log-normal component (b) of the mahi mahi catch rate model: year (top left), aggregate catch composition cluster (top right), HBF (bottom left) and sea surface temperature (bottom right). Reference levels for explanatory variables for the delta effect plots were: year = 2011, cluster = 'BET-SHK-YFT', hbf = 25, sst = 26.1°C. Reference levels for explanatory variables for the lognormal effect plots were: year = 2010, cluster = 'BET-SHK-YFT', hbf = 25, sst = 25.8°C. Note that the uncertainty in mean response incorporates uncertainty from all model parameters.

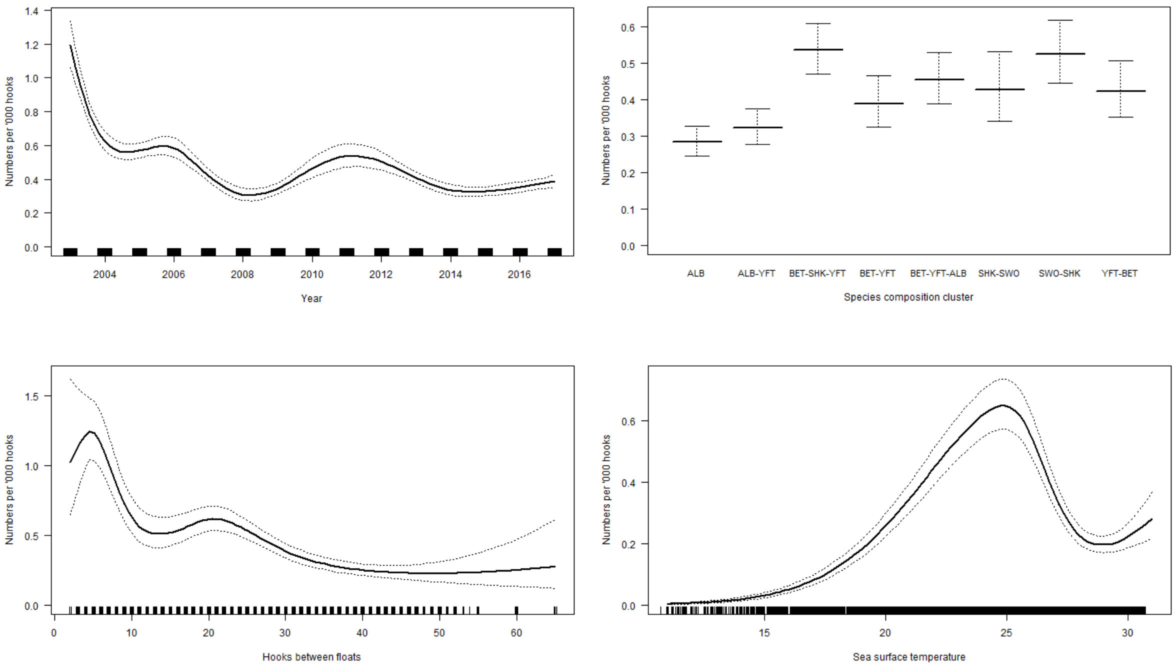


Figure 30 Effects plots for the striped marlin catch rate model: year (top left), aggregate catch composition cluster (top right), HBF (bottom left) and sea surface temperature (bottom right). Reference levels for explanatory variables were: year = 2011, cluster = 'BET-SHK-YFT', hbf = 25, sst = 26.1°C. Note that the uncertainty in mean response incorporates uncertainty from all model parameters.

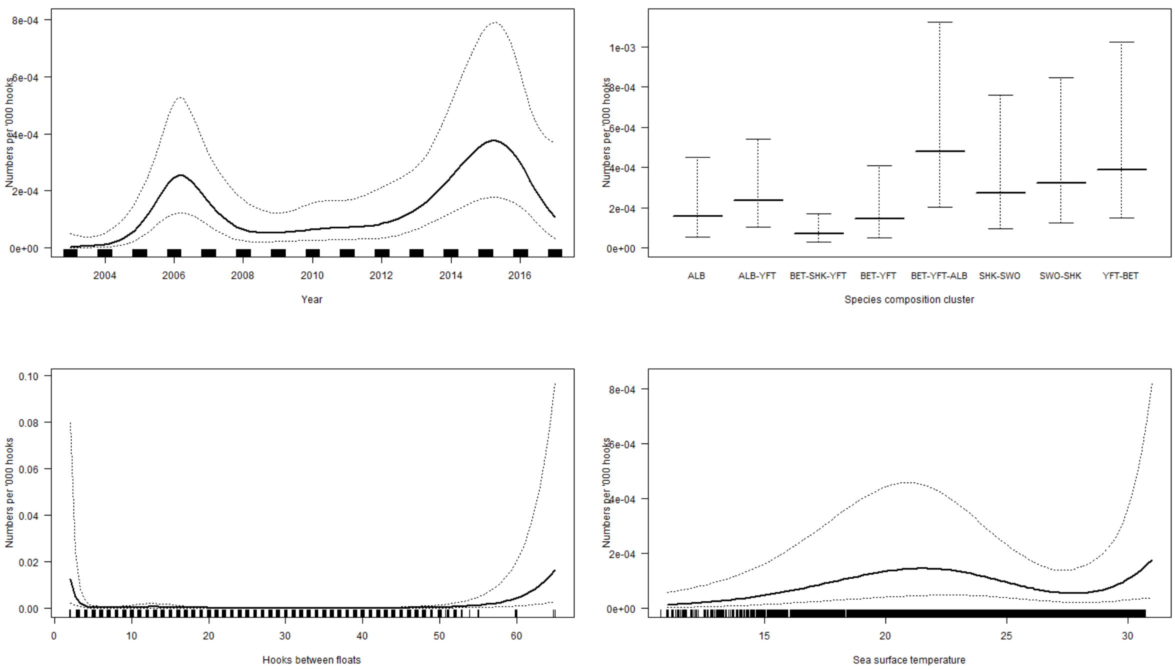


Figure 31 Effects plots for the loggerhead turtle catch rate model: year (top left), aggregate catch composition cluster (top right), HBF (bottom left) and sea surface temperature (bottom right). Reference levels for explanatory variables were: year = 2011, cluster = 'BET-SHK-YFT', hbf = 25, sst = 26.1°C. Note that the uncertainty in mean response incorporates uncertainty from all model parameters.

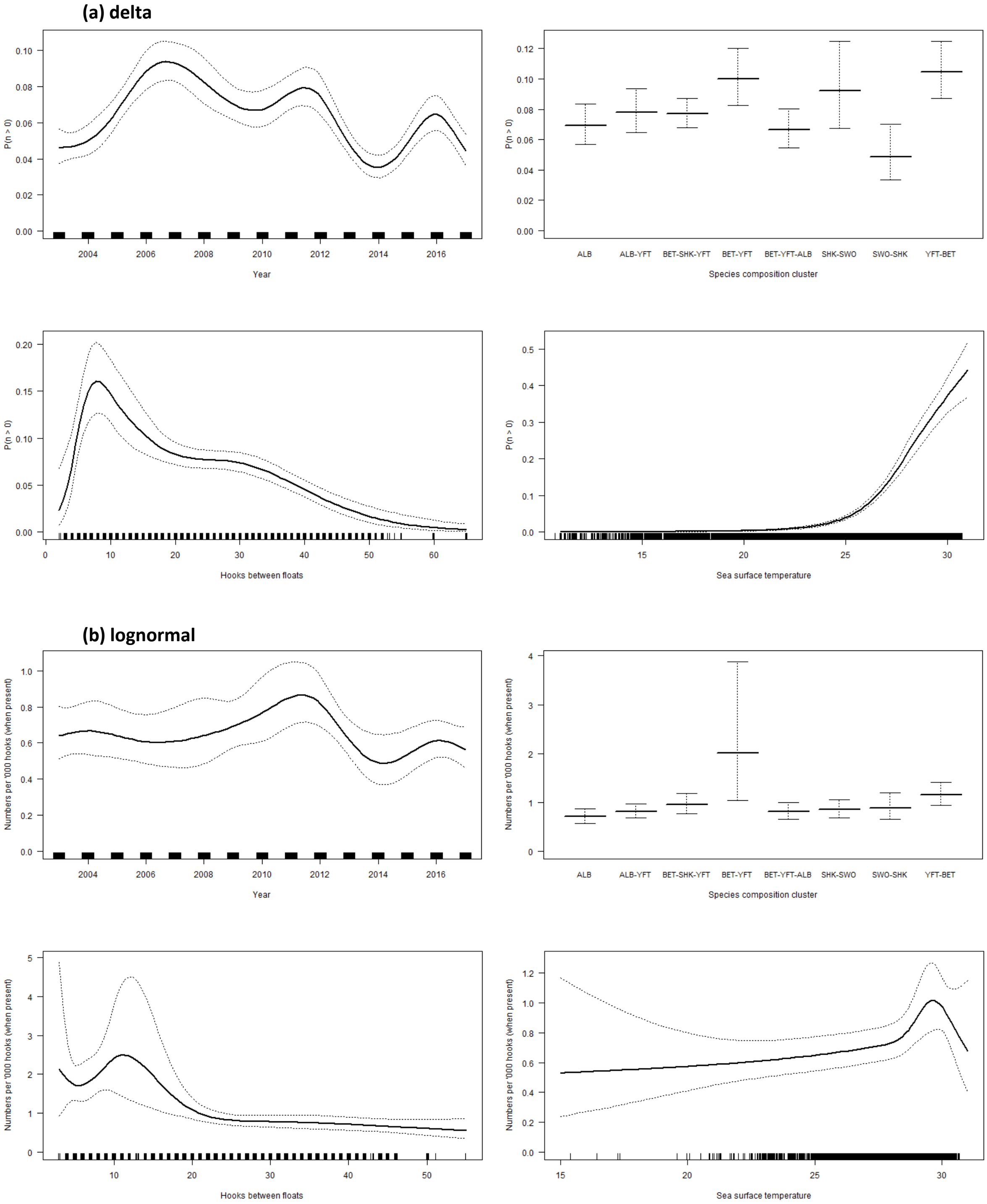
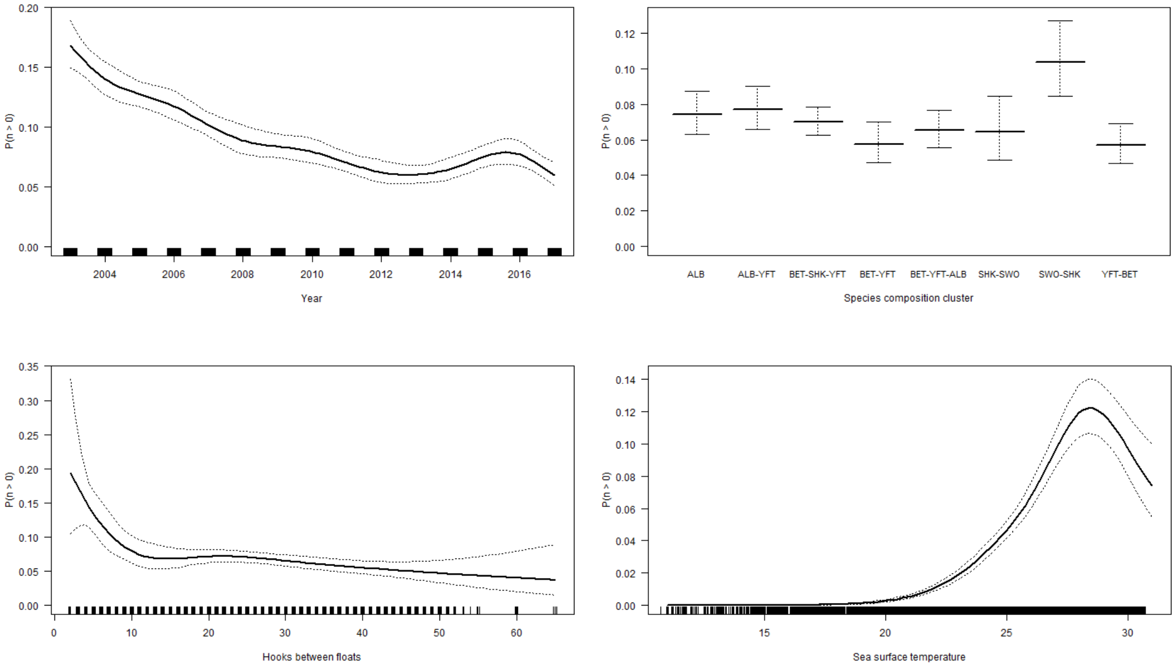


Figure 32 Effects plots for the delta component (a) and log-normal component (b) of the silky shark catch rate model: year (top left), aggregate catch composition cluster (top right), HBF (bottom left) and sea surface temperature (bottom right). Reference levels for explanatory variables for the delta effect plots were: year = 2011, cluster = 'BET-SHK-YFT', hbf = 25, sst = 26.1°C. Reference levels for explanatory variables for the lognormal effect plots were: year = 2012, cluster = 'ALB-YFT', hbf = 25, sst = 28.7°C. Note that the uncertainty in mean response incorporates uncertainty from all model parameters.

(a) delta



(b) lognormal

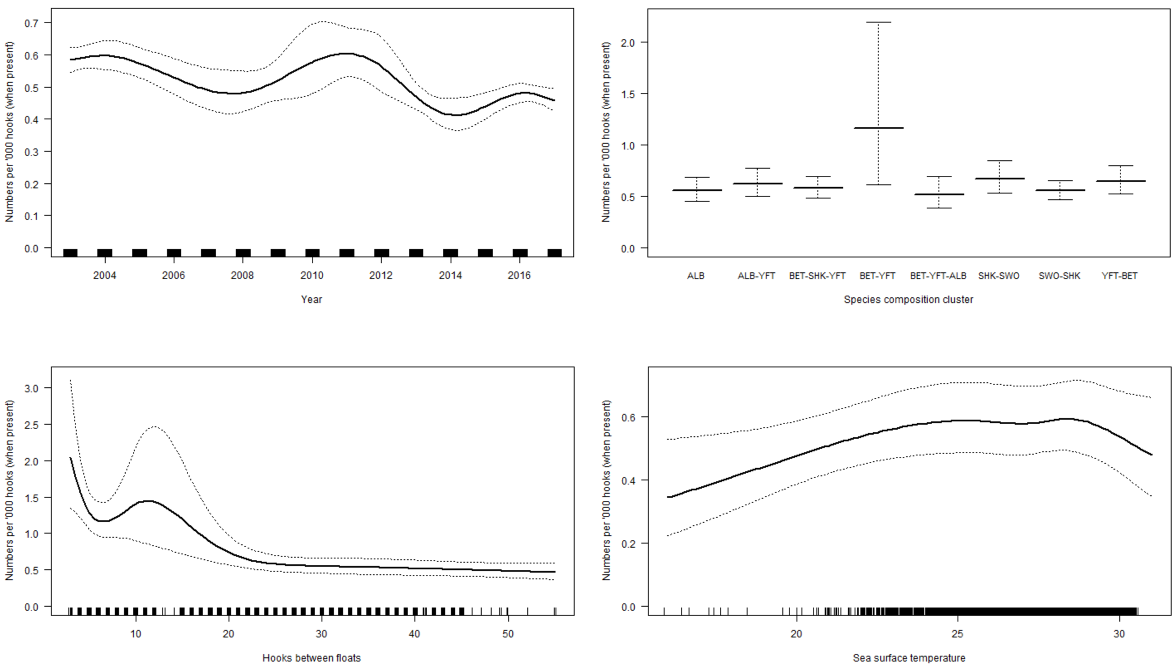


Figure 33 Effects plots for the delta component (a) and log-normal component (b) of the oceanic whitetip catch rate models: year (top left), aggregate catch composition cluster (top right), HBF (bottom left) and sea surface temperature (bottom right). Reference levels for explanatory variables for the delta effect plots were: year = 2011, cluster = 'BET-SHK-YFT', hbf = 25, sst = 26.1°C. Reference levels for explanatory variables for the lognormal effect plots were: year = 2010, cluster = 'BET-SHK-YFT', hbf = 25, sst = 27.1°C. Note that the uncertainty in mean response incorporates uncertainty from all model parameters.

ANNEX 4 Supplementary tables of catch estimates

Table 26 Median finfish catch estimates ('000 individuals) by species/species group and region.

a) North of 10N

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	581.1	762.6	470.6	216.2	237.3	193.0	106.4	110.1	83.0	80.4	314.9	3,155.6
2004	761.0	366.2	441.9	270.4	211.2	263.8	81.7	70.9	111.5	93.6	395.8	3,068.2
2005	707.6	359.0	413.0	268.9	233.5	266.0	91.7	71.1	97.6	85.1	316.8	2,910.3
2006	768.2	375.9	388.3	256.9	302.9	249.2	106.1	87.4	82.0	90.5	253.8	2,961.0
2007	701.5	441.1	378.5	281.7	293.4	275.9	91.3	79.8	77.0	75.2	205.8	2,901.3
2008	682.0	449.9	376.1	316.2	273.6	268.4	85.0	79.4	78.9	73.1	220.9	2,903.8
2009	730.2	467.3	324.0	399.8	318.7	280.3	78.6	92.8	74.5	74.7	248.7	3,089.6
2010	800.8	491.7	308.6	453.4	326.0	275.0	84.9	115.9	69.0	80.0	252.6	3,258.0
2011	896.0	427.5	337.1	521.3	324.1	333.8	83.5	130.3	98.5	89.7	255.8	3,497.6
2012	820.7	355.1	330.5	407.5	243.9	312.4	78.2	113.4	112.6	80.0	195.4	3,049.6
2013	681.9	307.4	299.2	271.4	191.9	247.5	77.0	85.2	92.0	73.0	136.2	2,462.7
2014	632.8	338.0	321.4	266.1	209.2	240.1	92.2	79.7	97.1	70.1	154.7	2,501.5
2015	629.8	468.1	339.8	278.7	230.2	195.0	102.8	88.5	97.1	62.9	221.6	2,714.6
2016	606.3	578.2	370.8	298.7	261.7	159.8	105.1	99.2	109.9	60.5	318.1	2,968.4
2017	420.3	779.2	381.2	272.5	216.5	139.2	100.7	85.5	111.9	56.6	284.6	2,848.3
Species total	**10,420.1**	**6,967.5**	**5,481.1**	**4,779.7**	**3,874.0**	**3,699.5**	**1,365.4**	**1,389.2**	**1,392.8**	**1,145.5**	**3,775.5**	**44,290.3**

b) 10S to 10N

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	302.3	1,060.2	1,013.3	194.1	99.8	147.1	228.5	149.7	103.0	41.4	400.5	3,740.1
2004	253.1	779.4	1,112.0	201.6	72.1	167.2	190.4	97.3	136.8	42.9	511.9	3,564.8
2005	274.6	697.8	892.4	151.9	77.5	140.7	195.0	91.3	105.9	37.4	348.3	3,012.8
2006	241.4	690.1	798.1	146.2	109.7	137.9	212.0	99.6	89.7	37.1	226.2	2,788.1
2007	227.6	903.0	754.0	159.3	102.8	142.8	182.1	94.6	78.1	32.8	188.6	2,865.7
2008	182.0	582.1	659.2	165.6	101.2	141.5	137.9	76.2	80.6	33.2	173.2	2,332.7
2009	221.3	766.6	762.1	235.2	104.2	128.2	140.6	98.5	73.2	30.6	204.1	2,764.5
2010	335.2	720.0	770.4	340.3	170.7	168.6	168.9	141.9	94.9	45.4	257.1	3,213.3
2011	404.1	744.3	812.6	413.8	200.6	236.2	177.4	170.1	143.2	55.4	248.8	3,606.4
2012	471.0	963.7	866.1	344.4	99.4	230.6	170.0	159.5	139.2	43.7	218.5	3,706.2
2013	347.6	716.5	653.6	216.8	72.3	181.0	152.8	112.3	106.5	33.7	158.9	2,752.0
2014	244.6	716.2	729.4	179.2	71.4	145.0	177.6	107.2	94.4	30.4	147.8	2,643.3
2015	419.8	946.8	862.9	202.6	103.4	113.7	226.4	142.7	104.0	32.6	196.8	3,351.7
2016	316.0	767.7	625.5	160.3	92.7	70.4	163.8	114.8	81.1	23.6	160.5	2,576.4
2017	150.7	812.5	552.1	158.2	75.4	68.6	134.2	86.5	84.3	20.5	140.0	2,283.1
Species total	**4,391.5**	**11,866.7**	**11,863.7**	**3,269.5**	**1,553.3**	**2,219.5**	**2,657.6**	**1,742.2**	**1,514.7**	**540.9**	**3,581.2**	**45,201.0**

c) South of 10S

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	1,552.7	725.5	385.3	178.3	203.8	164.1	176.4	147.4	64.7	90.9	434.2	4,123.4
2004	1,359.8	501.1	308.6	160.5	129.1	171.4	124.5	84.3	76.0	76.5	446.0	3,437.7
2005	1,263.9	441.2	275.5	139.1	126.8	147.1	133.5	80.6	49.9	62.8	316.7	3,037.0
2006	1,335.0	482.0	266.2	125.0	159.4	131.8	176.5	100.5	40.8	60.0	246.6	3,123.8
2007	1,106.2	424.9	234.0	106.2	133.0	110.7	146.7	85.6	33.9	43.0	176.1	2,600.1
2008	1,074.8	361.5	251.4	122.6	140.5	112.1	145.6	93.9	37.2	43.3	180.4	2,563.2
2009	1,553.2	394.7	295.6	209.2	224.6	147.9	183.0	142.1	44.1	64.0	255.8	3,514.2
2010	2,090.6	546.4	385.4	360.0	356.0	217.3	230.4	223.9	58.5	96.6	358.2	4,923.5
2011	1,629.3	525.9	343.0	320.5	267.1	220.6	182.2	198.9	67.7	77.7	287.1	4,120.2
2012	1,805.6	486.6	376.6	283.4	213.9	225.9	197.3	212.3	79.9	76.6	260.7	4,218.9
2013	1,549.5	425.5	351.9	231.0	181.8	212.3	204.0	170.6	73.1	71.4	218.4	3,689.5
2014	1,334.5	443.7	333.7	194.8	200.4	191.3	214.6	144.7	67.6	69.7	196.7	3,391.7
2015	1,240.8	451.1	300.9	172.9	201.2	131.3	182.3	129.6	56.5	63.3	227.1	3,156.8
2016	1,009.1	473.2	265.7	155.6	166.8	89.4	152.5	116.1	49.5	46.0	257.6	2,781.4
2017	1,087.3	703.9	333.2	215.2	206.5	114.6	201.5	144.0	67.2	59.5	304.7	3,437.6
Species total	**20,992.1**	**7,387.3**	**4,707.0**	**2,974.3**	**2,910.8**	**2,387.8**	**2,650.9**	**2,074.4**	**866.7**	**1,001.3**	**4,166.5**	**52,119.2**

Table 27 Median finfish catch estimates ('000 individuals) by species/species group, disaggregated by shallow and deep setting.

a) Shallow setting

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	524.6	870.7	251.0	161.8	67.6	132.7	34.0	49.2	29.1	21.5	258.8	2,400.9
2004	501.4	368.5	170.8	182.8	60.0	178.2	26.2	26.0	42.8	20.7	263.9	1,841.5
2005	418.2	283.0	117.2	154.6	64.1	160.9	23.7	22.0	24.7	15.9	168.4	1,452.8
2006	283.7	263.2	97.3	133.8	72.4	134.1	27.0	23.2	20.2	9.4	105.3	1,169.5
2007	310.7	638.4	195.1	202.4	99.4	200.2	37.1	34.6	26.6	8.8	120.3	1,873.7
2008	257.2	471.6	145.8	200.9	83.8	169.2	29.3	29.4	25.9	7.3	109.5	1,529.8
2009	363.3	732.1	192.4	323.6	115.1	217.4	40.1	50.6	31.6	9.1	168.5	2,243.8
2010	408.7	691.6	163.2	344.4	105.8	201.6	38.7	59.0	26.6	9.8	172.1	2,221.3
2011	407.6	623.8	141.9	376.7	92.8	239.8	35.5	60.5	35.3	9.6	165.6	2,189.1
2012	308.9	616.1	134.7	269.8	54.8	203.3	26.7	44.3	37.0	7.6	119.2	1,822.5
2013	189.4	373.0	82.0	131.8	26.2	123.8	17.1	21.9	20.5	5.6	71.7	1,063.0
2014	139.0	308.0	85.2	134.5	35.6	128.3	21.1	20.2	23.0	5.4	73.0	973.2
2015	156.7	344.9	75.7	129.9	43.3	95.7	20.5	21.5	19.9	4.7	93.9	1,006.6
2016	167.5	355.4	60.2	121.1	42.0	67.3	16.4	20.3	17.7	4.2	118.0	990.2
2017	106.7	515.1	62.6	93.3	23.2	48.3	13.8	15.9	14.0	3.7	103.1	999.8
Species total	**4,543.7**	**7,455.1**	**1,975.2**	**2,961.4**	**986.0**	**2,300.8**	**407.4**	**498.7**	**395.0**	**143.3**	**2,111.2**	**23,777.7**

b) Deep setting

Year	Albacore	Yellowfin	Bigeye	Escolars	Longsnouted lancetfish	Mahi mahi	Wahoo	Skipjack	Pomfrets	Opah	Others	Annual total
2003	1,919.9	1,679.2	1,620.1	427.5	477.3	372.7	478.8	358.3	223.2	192.2	942.3	8,691.4
2004	1,880.9	1,281.6	1,691.0	451.4	354.4	425.3	371.3	226.6	283.1	193.4	1,111.8	8,270.9
2005	1,831.1	1,216.3	1,462.9	406.7	375.8	393.0	397.3	221.7	229.1	170.2	829.4	7,533.5
2006	2,061.9	1,287.9	1,358.1	394.0	501.4	385.3	468.6	264.8	192.4	178.8	634.7	7,728.0
2007	1,725.1	1,134.9	1,171.7	346.0	431.3	329.7	384.6	225.8	163.3	143.1	460.8	6,516.4
2008	1,685.6	919.9	1,142.2	404.1	433.9	353.4	340.2	220.6	171.2	143.2	472.8	6,287.1
2009	2,147.5	897.2	1,192.6	522.0	534.6	339.3	363.6	282.8	160.8	161.1	552.6	7,154.1
2010	2,819.2	1,067.0	1,303.7	812.3	753.0	460.1	446.4	423.2	195.8	213.1	715.3	9,209.2
2011	2,528.0	1,075.4	1,352.1	879.2	700.1	551.2	407.6	439.3	275.3	213.7	640.7	9,062.6
2012	2,802.6	1,192.4	1,440.5	766.4	505.8	566.5	419.4	441.7	295.6	193.3	566.0	9,190.3
2013	2,392.3	1,075.0	1,225.2	588.5	421.3	517.7	417.8	346.0	251.7	173.4	448.3	7,857.3
2014	2,078.3	1,192.4	1,301.9	507.5	446.8	448.4	463.4	311.7	236.8	165.3	433.3	7,585.9
2015	2,134.6	1,522.1	1,431.1	525.2	493.2	344.4	491.9	339.4	238.3	154.7	558.6	8,233.6
2016	1,762.8	1,465.8	1,203.8	493.4	480.4	252.7	405.2	309.5	223.3	126.0	628.1	7,350.9
2017	1,553.7	1,786.5	1,206.7	552.7	478.7	275.2	423.5	300.7	249.6	133.5	638.0	7,598.8
Species total	**31,323.7**	**18,793.7**	**20,103.5**	**8,077.1**	**7,388.0**	**6,015.0**	**6,279.6**	**4,712.2**	**3,389.6**	**2,554.9**	**9,632.6**	**118,270.0**

Table 28 Median billfish catch estimates ('000 individuals) by species/species group and region.

a) North of 10N

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	461.2	91.0	179.3	71.2	50.0	22.5	2.7	877.9
2004	669.5	65.9	120.7	59.7	15.1	9.0	2.7	942.5
2005	770.2	72.1	110.8	54.0	14.1	8.7	2.7	1,032.6
2006	680.4	75.4	118.3	52.9	14.1	9.5	3.2	953.8
2007	1,022.1	105.0	110.1	48.6	24.1	11.3	2.8	1,323.9
2008	829.6	119.3	82.9	49.5	31.7	10.6	2.2	1,125.9
2009	877.5	131.9	87.3	50.6	41.7	4.7	2.4	1,196.2
2010	718.2	113.8	98.0	54.3	47.1	3.9	2.5	1,037.9
2011	865.7	127.0	133.1	71.5	31.6	3.4	4.7	1,236.9
2012	584.8	89.7	113.0	65.6	18.0	4.4	4.5	879.9
2013	359.3	61.5	67.1	44.7	14.8	4.7	3.1	555.1
2014	426.3	82.8	62.4	43.9	24.6	4.9	3.6	648.5
2015	435.6	80.5	62.2	54.4	33.7	8.5	3.6	678.5
2016	410.4	74.3	69.6	68.3	34.3	10.3	3.6	670.8
2017	358.0	63.7	62.1	58.1	31.1	8.9	3.1	585.0
Species total	**9,468.9**	**1,353.8**	**1,477.1**	**847.1**	**426.1**	**125.1**	**47.4**	**13,745.5**

b) 10S to 10N

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	246.2	173.4	152.6	69.6	61.8	51.2	2.5	757.4
2004	200.2	144.1	77.2	51.9	43.7	44.1	1.5	562.8
2005	121.1	101.2	50.2	37.0	30.3	38.3	1.1	379.2
2006	123.0	99.0	53.1	35.0	27.8	40.9	1.2	380.0
2007	233.7	132.0	51.7	32.0	52.6	57.9	1.1	561.0
2008	181.6	108.1	35.1	29.2	36.7	26.2	0.8	417.9
2009	268.7	168.1	42.7	29.4	80.0	19.5	0.9	609.5
2010	261.0	157.0	60.4	45.4	77.0	10.8	1.8	613.4
2011	258.7	148.3	83.7	65.2	54.5	11.8	2.9	625.1
2012	304.7	173.9	80.9	55.6	60.3	25.4	2.7	703.5
2013	192.5	123.1	47.1	35.4	46.6	18.4	2.1	465.3
2014	139.5	122.3	36.1	29.8	50.7	16.4	1.4	396.2
2015	125.5	134.0	37.4	39.0	70.7	28.6	1.6	436.8
2016	81.1	87.2	30.9	36.6	50.2	21.5	1.2	308.8
2017	96.8	77.6	33.3	32.7	39.7	14.3	1.7	296.1
Species total	**2,834.3**	**1,949.3**	**872.6**	**623.8**	**782.8**	**425.4**	**24.6**	**7,512.8**

c) South of 10S

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	131.1	48.0	100.8	55.9	18.7	20.4	1.9	376.8
2004	135.8	30.4	43.4	33.0	11.5	12.8	1.0	267.8
2005	123.7	30.0	35.4	26.9	11.1	13.3	0.8	241.1
2006	99.7	34.4	33.6	26.2	12.5	18.4	0.9	225.6
2007	93.8	35.0	23.5	20.3	12.5	18.9	0.7	204.7
2008	69.5	37.3	17.4	22.1	12.9	10.0	0.5	169.8
2009	106.0	51.8	24.1	30.8	19.2	5.1	0.6	237.6
2010	152.9	74.4	44.2	49.2	31.5	4.6	1.3	358.1
2011	125.4	57.2	49.3	51.1	20.9	4.4	1.5	309.7
2012	86.9	54.9	44.2	52.0	14.1	5.9	1.5	259.5
2013	78.9	50.0	33.7	42.7	12.8	5.5	1.6	225.2
2014	68.5	41.5	26.6	36.9	13.2	4.1	1.3	192.1
2015	64.3	36.1	23.1	35.3	15.6	5.6	1.2	181.2
2016	61.7	32.6	21.9	37.1	15.9	6.6	1.1	177.0
2017	84.6	39.5	31.1	49.6	14.4	5.2	1.6	226.0
Species total	**1,482.8**	**653.0**	**552.5**	**569.0**	**236.9**	**140.7**	**17.3**	**3,652.1**

Table 29 Median billfish catch estimates ('000 individuals) by species/species group, disaggregated by shallow and deep setting.

a) Shallow setting

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	633.3	121.9	154.8	30.6	67.4	30.3	2.3	1,040.5
2004	737.7	74.0	96.7	28.8	21.6	11.7	2.2	972.7
2005	775.3	62.0	77.0	22.1	13.4	8.1	2.0	959.9
2006	672.3	68.8	79.4	22.0	15.6	9.7	2.4	870.2
2007	1,145.4	139.4	96.8	27.0	51.5	33.7	2.4	1,496.3
2008	863.5	130.7	63.7	24.2	45.2	15.9	1.8	1,145.0
2009	1,041.7	186.2	81.3	32.1	88.4	12.7	2.2	1,444.7
2010	873.3	161.2	86.5	30.4	91.0	8.1	2.2	1,252.8
2011	993.5	166.1	113.6	39.4	61.4	7.9	4.0	1,385.8
2012	734.2	136.4	93.3	30.9	48.8	12.8	3.4	1,059.8
2013	429.1	80.2	44.6	14.9	33.2	8.2	1.9	612.2
2014	454.1	81.5	42.3	16.6	33.3	6.3	2.5	636.5
2015	435.9	66.2	38.3	18.5	34.4	8.3	2.2	603.6
2016	379.4	52.2	36.5	19.5	30.0	8.3	1.9	527.9
2017	324.4	48.1	28.8	12.6	34.2	9.5	1.3	458.9
Species total	**10,493.2**	**1,574.8**	**1,133.8**	**369.5**	**669.2**	**191.5**	**34.6**	**14,466.7**

b) Deep setting

Year	Swordfish	Blue marlin	Striped marlin	Short-billed spearfish	Sailfish (indo-pacific)	Black marlin	Billfishes nei	Annual total
2003	206.7	192.4	279.4	167.3	64.3	71.1	5.3	986.3
2004	270.9	166.9	144.7	115.8	49.7	56.5	3.2	807.7
2005	241.2	141.0	119.8	96.3	42.4	53.6	2.7	697.0
2006	232.8	140.1	125.7	92.5	39.3	64.4	3.1	697.9
2007	204.3	133.2	89.2	74.2	38.8	65.5	2.2	607.4
2008	217.0	134.5	72.0	77.0	37.2	35.6	1.9	575.1
2009	214.0	166.1	73.3	79.2	54.5	17.9	1.9	607.0
2010	264.0	185.4	116.5	119.0	66.8	12.4	3.6	767.8
2011	261.6	166.9	153.6	149.1	46.5	12.9	5.3	795.9
2012	243.9	183.3	145.4	142.3	44.3	24.7	5.4	789.4
2013	202.7	155.5	103.9	108.4	41.7	21.1	5.0	638.3
2014	181.0	164.6	83.0	94.1	56.2	20.1	4.1	603.0
2015	191.3	184.5	84.9	110.4	85.9	35.1	4.5	696.4
2016	174.3	142.0	86.2	122.8	71.0	31.7	4.2	632.3
2017	216.4	133.6	98.1	128.3	52.0	20.3	5.3	654.0
Species total	**3,322.1**	**2,390.1**	**1,775.8**	**1,676.7**	**790.5**	**542.8**	**57.6**	**10,555.6**

Table 30 Median shark and ray catch estimates ('000 individuals) by species/species group and region.

a) North of 10N

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	539.7	52.7	48.4	64.2	51.2	13.1	13.3	43.3	15.7	841.6
2004	767.0	34.3	42.1	100.0	51.0	18.9	12.0	41.3	15.3	1,082.0
2005	745.9	39.9	39.1	101.1	50.7	24.6	11.7	41.5	10.7	1,065.2
2006	726.2	43.8	33.9	111.5	41.5	30.0	14.3	43.0	7.3	1,051.6
2007	801.1	68.3	29.5	128.0	46.8	31.6	15.4	45.6	9.6	1,175.9
2008	774.8	81.7	28.3	120.1	46.2	33.0	16.7	52.6	12.7	1,166.1
2009	879.3	79.1	39.3	129.6	47.6	37.6	11.5	66.3	14.8	1,305.1
2010	762.7	73.2	63.1	118.5	38.1	32.2	8.9	63.9	14.3	1,174.9
2011	916.3	95.0	73.6	129.5	46.9	48.3	9.9	70.5	12.9	1,402.9
2012	647.7	72.6	58.2	98.0	29.7	41.3	8.7	47.9	9.8	1,013.8
2013	401.2	28.4	42.6	66.7	16.1	22.2	4.2	25.9	8.1	615.5
2014	520.4	24.9	42.1	72.4	18.2	29.0	4.0	35.0	9.5	755.4
2015	587.2	38.5	48.0	64.4	23.6	33.6	7.1	57.9	9.1	869.3
2016	622.2	53.9	54.0	46.9	25.0	33.8	10.7	91.4	7.1	944.9
2017	517.9	39.0	53.6	20.4	15.9	19.3	6.9	99.5	6.5	779.0
Species total	**10,209.6**	**825.3**	**695.8**	**1,371.3**	**548.5**	**448.4**	**155.2**	**825.6**	**163.4**	**15,243.2**

b) 10S to 10N

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	309.6	150.5	145.1	13.1	96.0	28.1	36.8	62.9	20.4	862.5
2004	335.2	203.6	152.2	14.5	87.9	28.3	40.3	63.7	31.1	956.7
2005	234.1	171.7	133.5	13.1	57.3	26.5	36.8	47.3	17.7	738.0
2006	203.3	174.6	115.3	14.1	45.3	29.5	39.8	43.6	11.9	677.5
2007	208.7	224.8	87.7	16.8	48.5	31.3	45.6	48.4	16.2	728.0
2008	200.0	187.5	69.8	16.2	39.4	30.1	41.9	44.0	15.8	644.6
2009	243.0	259.7	123.4	17.3	45.9	29.4	33.8	61.3	20.5	834.4
2010	321.1	224.4	182.0	23.4	41.5	34.5	26.7	69.2	18.0	940.8
2011	366.9	255.0	190.5	26.4	42.0	46.8	26.8	67.9	17.6	1,039.9
2012	295.5	316.6	202.2	22.1	44.6	44.2	28.3	62.1	21.5	1,037.1
2013	206.6	132.1	132.5	15.3	25.6	29.3	13.4	38.3	17.3	610.4
2014	181.0	86.2	132.3	11.9	21.0	24.9	9.8	38.7	17.4	523.4
2015	220.6	137.1	181.9	11.6	26.9	30.3	17.4	65.5	15.4	706.6
2016	181.2	124.3	137.6	6.4	21.5	23.8	17.4	75.0	7.9	595.1
2017	193.5	77.8	110.8	3.1	14.7	15.7	9.4	87.9	6.2	519.0
Species total	**3,700.1**	**2,725.9**	**2,096.7**	**225.3**	**658.1**	**452.8**	**424.2**	**875.9**	**255.0**	**11,414.0**

c) South of 10S

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	311.5	30.3	70.1	65.9	32.6	6.1	13.7	33.0	31.8	594.9
2004	323.1	25.7	60.4	70.6	25.8	3.8	9.7	26.2	35.2	580.5
2005	231.4	27.5	55.2	61.3	20.3	4.0	8.9	20.2	21.3	450.1
2006	191.7	34.6	54.0	55.2	18.3	4.2	10.5	18.8	18.0	405.4
2007	143.5	38.7	42.3	39.8	15.5	4.0	11.0	15.8	15.6	326.1
2008	139.3	36.5	37.1	34.8	14.4	4.3	10.6	14.9	16.7	308.4
2009	208.3	41.0	68.0	51.3	18.1	5.0	9.5	22.0	19.1	442.3
2010	297.4	60.5	126.5	72.3	25.2	7.7	10.0	35.4	21.1	656.1
2011	241.5	64.1	116.0	53.4	21.5	9.0	8.5	30.0	18.3	562.3
2012	211.6	59.5	114.0	46.5	17.2	8.4	8.5	21.9	15.4	503.0
2013	196.8	26.4	83.0	42.9	12.4	7.3	5.0	17.1	14.3	405.3
2014	197.0	13.3	69.5	41.0	10.1	6.3	3.3	17.6	16.6	374.6
2015	201.1	18.7	69.1	37.6	10.7	6.5	4.8	25.6	23.7	397.8
2016	191.1	27.1	70.0	22.1	11.1	5.8	6.4	37.4	26.3	397.3
2017	261.8	20.9	83.8	14.8	10.3	4.7	4.5	57.6	22.6	481.1
Species total	**3,347.2**	**524.6**	**1,119.0**	**709.7**	**263.5**	**87.2**	**124.8**	**393.4**	**315.8**	**6,885.1**

Table 31 Median shark and ray catch estimates ('000 individuals) by species/species group, disaggregated by shallow and deep setting.

a) Shallow setting

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	520.4	75.1	34.3	64.6	63.4	11.5	10.0	46.1	30.7	856.1
2004	680.3	44.2	24.9	80.2	52.4	13.9	6.8	38.0	29.5	970.2
2005	593.8	33.9	18.9	76.4	44.3	16.6	5.4	31.7	15.2	836.2
2006	572.6	40.0	14.8	70.1	36.9	21.5	5.5	31.9	9.9	803.2
2007	729.1	119.9	24.2	98.1	55.9	28.1	10.9	48.5	17.9	1,132.7
2008	670.0	106.0	17.9	85.9	47.2	29.2	9.9	48.3	17.6	1,031.9
2009	830.6	151.9	37.3	101.3	60.8	37.7	10.6	75.8	26.6	1,332.6
2010	705.8	140.2	59.7	88.0	49.9	31.0	8.1	73.0	23.8	1,179.6
2011	817.4	163.9	59.5	92.5	57.0	44.4	7.4	74.7	21.7	1,338.7
2012	557.9	159.2	44.9	66.9	39.4	38.3	6.5	53.7	17.9	984.7
2013	297.3	52.4	22.9	36.0	18.5	16.6	2.1	24.1	12.3	482.4
2014	380.8	30.2	19.8	40.4	17.4	19.9	1.8	28.3	12.3	550.9
2015	404.7	34.8	17.8	35.0	19.6	21.2	2.9	41.0	12.3	589.3
2016	392.8	37.2	15.2	25.4	17.9	18.3	3.5	56.5	11.1	577.7
2017	282.9	33.0	16.6	9.5	11.2	8.0	2.1	58.6	11.2	433.1
Species total	**8,436.4**	**1,221.9**	**428.8**	**970.4**	**591.8**	**356.4**	**93.6**	**730.1**	**269.9**	**13,099.4**

b) Deep setting

Year	Blue shark	Silky shark	Pelagic stingray	Short finned mako	Oceanic whitetip	Bigeye thresher	Thresher sharks nei	Elasmobranchs nei	Others	Annual total
2003	645.3	160.0	230.0	79.3	117.7	36.1	54.2	94.1	39.1	1,455.9
2004	746.6	219.8	231.3	105.3	112.8	37.5	55.8	94.0	53.8	1,656.9
2005	618.3	207.6	209.6	99.8	84.4	38.7	52.7	77.9	35.4	1,424.4
2006	548.4	215.0	189.5	111.3	68.8	42.4	59.7	74.1	27.9	1,337.1
2007	425.0	214.6	135.4	86.7	55.7	39.2	61.3	62.1	24.4	1,104.3
2008	445.2	201.2	118.2	85.7	53.0	38.8	59.9	64.2	28.6	1,094.7
2009	500.2	231.0	194.8	97.2	51.1	34.3	44.5	74.6	29.5	1,257.2
2010	677.7	222.0	316.5	127.1	55.8	43.9	38.2	98.0	31.4	1,610.7
2011	708.6	255.0	322.6	117.7	54.3	60.3	38.5	95.0	28.3	1,680.4
2012	598.8	292.1	332.5	99.8	53.4	55.9	39.4	79.1	30.0	1,581.0
2013	508.4	135.9	235.5	89.2	36.0	42.9	20.6	57.6	28.5	1,154.7
2014	518.9	96.0	225.4	85.1	32.1	40.6	15.3	63.3	32.3	1,109.0
2015	604.9	160.5	282.1	79.4	41.7	49.3	26.5	108.7	36.5	1,389.6
2016	601.2	169.5	248.0	50.4	40.3	45.2	31.4	149.1	30.6	1,365.7
2017	692.1	106.2	232.9	29.1	30.0	31.9	18.9	188.5	24.7	1,354.3
Species total	**8,839.5**	**2,886.6**	**3,504.3**	**1,343.2**	**887.2**	**637.1**	**616.8**	**1,380.3**	**480.8**	**20,575.8**

Table 32 Median sea turtle catch estimates (individuals) by species/species group and region. See Section 9 for discussion regarding reliability of olive ridley bycatch.

a) North of 10N

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	4,183	848	34	558	148	437	6,209
2004	1,374	1,196	141	697	136	896	4,439
2005	1,330	852	753	884	106	681	4,605
2006	1,293	470	2,158	617	106	481	5,125
2007	4,568	1,672	2,117	669	179	366	9,571
2008	6,840	3,750	753	493	299	242	12,377
2009	6,820	3,240	553	617	328	69	11,628
2010	5,606	1,327	616	814	323	28	8,715
2011	3,570	960	787	809	286	45	6,457
2012	1,922	682	666	629	257	76	4,232
2013	1,535	720	804	578	193	134	3,964
2014	2,976	1,092	1,785	757	253	279	7,142
2015	4,824	1,378	2,636	891	324	1,076	11,129
2016	4,767	1,481	1,905	611	445	406	9,615
2017	3,561	2,421	555	299	220	4	7,061
Species total	**55,169**	**22,090**	**16,263**	**9,924**	**3,605**	**5,220**	**112,271**

b) 10S to 10N

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	4,482	669	15	414	267	542	6,389
2004	4,371	1,884	55	573	371	995	8,249
2005	2,317	1,085	259	487	273	826	5,247
2006	2,949	554	722	430	204	505	5,364
2007	12,606	2,546	707	601	450	405	17,314
2008	11,469	3,290	180	311	415	156	15,822
2009	19,670	4,240	237	554	728	80	25,509
2010	11,015	1,750	329	592	632	38	14,355
2011	8,013	1,167	332	697	570	42	10,820
2012	11,658	1,877	487	1,123	689	123	15,957
2013	7,229	1,807	587	845	493	141	11,102
2014	6,314	1,735	852	659	482	342	10,384
2015	8,683	1,928	1,642	627	905	1,785	15,570
2016	6,324	1,372	793	290	752	454	9,984
2017	4,193	2,045	257	159	392	4	7,050
Species total	**121,292**	**27,949**	**7,453**	**8,362**	**7,622**	**6,437**	**179,116**

c) South of 10S

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	440	291	11	301	161	253	1,457
2004	403	772	37	439	186	365	2,202
2005	390	560	200	486	147	328	2,111
2006	434	371	522	355	131	191	2,003
2007	691	739	334	204	176	132	2,275
2008	855	1,415	106	120	213	72	2,779
2009	913	1,111	102	174	211	27	2,537
2010	1,165	789	189	335	291	19	2,788
2011	877	470	180	333	260	18	2,138
2012	531	441	187	279	200	39	1,678
2013	401	517	288	288	146	65	1,705
2014	394	498	469	302	117	132	1,911
2015	617	505	699	271	200	479	2,770
2016	741	551	521	182	223	196	2,413
2017	392	929	220	102	119	3	1,765
Species total	**9,244**	**9,957**	**4,063**	**4,171**	**2,780**	**2,318**	**32,534**

Table 33 Median sea turtle catch catch estimates (individuals) by species/species group, disaggregated by shallow and deep setting. See Section 9 for discussion regarding reliability of olive ridley bycatch.

a) Shallow setting

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	7,316	1,163	40	884	249	201	9,853
2004	3,361	1,458	123	933	216	321	6,411
2005	1,495	868	617	985	119	240	4,324
2006	2,054	495	1,690	625	124	141	5,129
2007	15,794	3,259	2,182	1,073	432	227	22,966
2008	15,288	5,085	652	615	451	100	22,190
2009	23,537	6,105	586	1,047	774	47	32,095
2010	14,886	2,594	635	1,257	807	28	20,208
2011	9,902	1,721	771	1,293	635	26	14,349
2012	11,189	1,823	684	1,387	585	36	15,703
2013	6,728	1,568	737	1,009	347	41	10,431
2014	6,095	1,530	1,550	962	337	105	10,578
2015	6,645	1,400	1,867	932	341	259	11,445
2016	5,915	1,277	1,352	580	414	100	9,638
2017	5,463	2,546	408	331	320	2	9,069
Species total	**135,666**	**32,893**	**13,892**	**13,912**	**6,151**	**1,875**	**204,389**

b) Deep setting

Year	Olive ridley	Green turtle	Loggerhead turtle	Leatherback turtle	Hawksbill turtle	Marine turtles nei	Annual total
2003	2,208	925	46	508	529	1,219	5,434
2004	3,050	2,647	137	891	614	2,351	9,689
2005	2,635	1,731	646	985	486	1,755	8,237
2006	2,788	968	1,838	857	391	1,216	8,058
2007	3,840	2,032	1,079	498	531	806	8,786
2008	4,978	4,324	448	370	661	434	11,215
2009	5,739	3,007	367	369	754	196	10,433
2010	4,073	1,616	572	587	781	147	7,776
2011	3,148	1,066	600	668	699	122	6,304
2012	3,482	1,388	751	762	808	234	7,425
2013	2,847	1,662	1,043	792	622	336	7,302
2014	3,961	1,970	1,698	847	648	720	9,844
2015	7,686	2,529	3,291	903	1,222	3,353	18,984
2016	6,160	2,256	1,981	548	1,162	1,054	13,162
2017	2,933	3,168	740	276	573	20	7,709
Species total	**59,527**	**31,289**	**15,238**	**9,860**	**10,480**	**13,963**	**140,357**

Table 34 Median (med) and lower and upper (low and high) 95 % confidence intervals for marine mammal catch estimates (individuals) by region.

	north temp			trop			south temp			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
2003	446	996	2,314	282	676	1,514	584	1,216	2,508	1,853	3,035	5,009
2004	450	963	2,194	242	552	1,244	497	960	1,899	1,706	2,614	4,047
2005	371	740	1,441	200	391	753	307	538	937	1,205	1,710	2,609
2006	399	755	1,556	176	349	718	287	502	884	1,133	1,668	2,537
2007	469	932	2,017	205	428	860	259	446	733	1,237	1,856	2,973
2008	509	1,053	2,285	212	427	902	266	473	871	1,326	2,019	3,232
2009	575	1,118	2,196	241	481	980	361	601	1,049	1,496	2,295	3,551
2010	500	964	2,006	280	568	1,101	429	749	1,292	1,623	2,360	3,492
2011	673	1,351	2,658	380	694	1,330	438	731	1,218	2,006	2,821	4,203
2012	677	1,308	2,926	465	893	1,740	529	918	1,601	2,191	3,234	5,099
2013	652	1,156	2,138	449	819	1,489	631	991	1,647	2,191	3,052	4,213
2014	771	1,433	2,891	414	791	1,551	672	1,044	1,661	2,354	3,388	4,937
2015	666	1,235	2,475	459	861	1,563	528	828	1,338	2,140	3,013	4,339
2016	689	1,332	2,519	353	637	1,218	490	776	1,297	1,952	2,817	4,168
2017	1,101	2,203	4,659	473	998	2,044	901	1,680	3,194	3,325	5,034	7,911

Table 35 Median (med) and lower and upper (low and high) 95 % confidence intervals for marine mammal catch estimates (individuals) by strategy.

	shallow			deep			Total		
Year	Low	Med	High	Low	Med	High	Low	Med	High
2003	529	978	1,847	1,322	2,050	3,249	1,853	3,035	5,009
2004	475	823	1,480	1,188	1,782	2,652	1,706	2,614	4,047
2005	303	499	887	885	1,218	1,757	1,205	1,710	2,609
2006	264	453	905	836	1,206	1,704	1,133	1,668	2,537
2007	415	735	1,489	791	1,120	1,571	1,237	1,856	2,973
2008	422	772	1,586	854	1,228	1,761	1,326	2,019	3,232
2009	537	925	1,726	934	1,341	1,893	1,496	2,295	3,551
2010	484	783	1,470	1,106	1,554	2,206	1,623	2,360	3,492
2011	595	1,014	1,864	1,357	1,810	2,477	2,006	2,821	4,203
2012	574	978	1,919	1,585	2,227	3,235	2,191	3,234	5,099
2013	442	691	1,182	1,734	2,347	3,119	2,191	3,052	4,213
2014	498	813	1,549	1,829	2,565	3,539	2,354	3,388	4,937
2015	354	604	1,242	1,743	2,395	3,235	2,140	3,013	4,339
2016	327	611	1,206	1,593	2,209	3,047	1,952	2,817	4,168
2017	518	923	1,821	2,793	4,116	6,286	3,325	5,034	7,911