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Billfish research plan 2023 - 2027

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Stephen Brouwer[1], Matthew Farthing[2] and Paul Hamer[3]

[1] Saggitus Limited

[2] Southern African Fisheries Ecology Research Lab (SAFER$_{LAB}$)

[3] Oceanic Fisheries Programme, The Pacific Community (SPC)

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Executive Summary

This document represents a proposal for the WCPFCs first billfish Research Plan (BRP) covering the years 2023-2027. The BRP was developed with input from an online Informal Working Group (BRP-IWG) comprised of Commission Members, Cooperating non-Members, and participating Territories (CCMs) and observers. This document includes a data review and a detailed list of stock assessment and biological metrics are also included in WCPFC-SC19-2023/SA-WP-16 suppl. In addition we collate research recommendations from recent stock assessment papers and have provided those as a list of project titles for the consideration of SC19. It is recommended that this be considered within an Informal Small Group at SC19 and a final project list be presented to SC19 with a research schedule for prioritisation.

The following recommendations are proposed for the SC to consider:

1. Given the 4 to 5-year assessment cycle for billfish the research plan is recommended to encompass two assessment cycles and as such the BRP should run over 2023-2030.
2. It is recommended that SC19 establish an Informal Small Group to evaluate the BRP (ISG-billfish), and maintain this as a standing ISG to evaluate progress against the BRP at subsequent SC meetings. When the ISG develops its terms of reference we suggest that it considers including the following:
    (a) The ISG-billfish rank the projects listed within Table 7 for prioritisation within the billfish research plan[1].
    (b) The ISG-billfish consider streamlining the projects and merge or remove projects where necessary.
    (c) The ISG-billfish schedule the projects listed in Table 7.
    (d) The ISG-billfish develop terms of reference for all projects including stock assessments intended to begin in 2024.
3. It is recommended that all assessments take Table 4 and Table 5 into account when considering metrics for reporting assessment results.
4. It is recommended that standardised CPUE analyses and fishery characterisations be undertaken for black marlin, sailfish and shortbill spearfish and that the SC19 ISG-billfish consider prioritisation and timing for this work, once completed if this work is informative, it should be repeated on a five-yearly schedule.
5. It is recommended that a stratified sampling program be designed to make biological sampling most efficient and useful.
6. It is also recommended that the SC discuss how to incorporate the SC17 recommendations on Limit Reference Points into the BRP and develop a process to make recommendations to the Commission on agreed LRPs for use within assessments.
7. Lastly, it is also recommended that on all longline logsheets vesslels record time as UTC and not ships time so that local time can be estimates.

[1]Note: projects from the BRP elevated to the SC workplan for prioritisation will get re-prioritised as per the agreed SC prioritisation process.

1 Introduction

The Western and Central Pacific Fisheries Commission (WCPFC) Billfish Research Plan (BRP) is being developed to design, plan and co-ordinate research relevant to the assessment and management of billfish in the Western and Central Pacific Ocean (WCPO). The 2023-2027 BRP is designed to be a living document that can change as the information needs of the WCPFC evolve. The plan will be assessed annually by the Scientific Committee usually through an Informal Small Group (ISG) and the following years' work will be recommended to the Scientific Committee for endorsement to be considered for funding through the WCPFC annual meeting. It is anticipated that this document will be finalised at SC19, as will the 2023 project list.

This plan falls within the umbrella of Articles 5(d) and 10.1(c) of the Convention which state that: "*. . . the members of the Commission shall assess the impacts of fishing, other human activities and environmental factors on target stocks, non-target species, and species belonging to the same ecosystem or dependent upon or associated with the target stocks. . .*" and "*. . . the functions of the Commission shall be to adopt, where necessary, conservation and management measures (CMMs) and recommendations for non-target species and species dependent on or associated with the target stocks, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened to this end.*"

This plan was developed with input from an online Informal Working Group (BRP-IWG). That included Commission Members, Cooperating non-Members, and participating Territories (CCMs), and WCPFC Observers. Seven CCMs, two WCPFC Observers, the WCPFC Secretariat, the WCPFC Science Service Provider and the authors of this document participated in the BRP-IWG (Table 1).

The focus of this plan are the six WCPFC billfish (black marlin; blue marlin; striped marlin; sailfish; shortbilled spearfish; and swordfish). As with its forerunners for other taxa, this plan could also support the efforts of the WCPFCs members to meet their obligations under other relevant international instruments. Importantly, the WCPFC budget may not be sufficient (nor is it expected) to complete all the recommended work for successful implementation of the plan. Member countries and other organisations are encouraged to undertake some of the work through funding external to the WCPFC. For each of the WCPFC Billfish, the plan will summarise the available data; the current stock status and present information sheets that summarise the biological parameters and assessment information for each species. In addition, the plan proposes guidelines for metrics to be included in assessments to ensure consistency in reporting and ease of comparison between species; finally we outline a proposal for the 2023-2027 BRP direction and project plan; and make some overall recommendations for the 2023-2027 period. The species considered in this document along with their scientific names and species codes are listed in Table 2.

Overall within the WCPO billfish form a relatively small but valuable part of the catch, which has increased in recent years. Most of the reported billfish catch consists of blue marlin and swordfish, with other species making up small proportions of the catch (Figure 1). Billfish are usually reported to species codes and rarely are generic codes such as BIL (billfish nei.) used (Figure 1).

2 WCPFC Billfish Data Holdings

For effective planning Commission Members and Participating Territories (CCMs) should be aware of the data available for analyses. To this end, a data compilation is presented here. This data compilation is not intended as a detailed analysis of trends, but rather a compendium of the data available to inform the research planning process. In order to assess what data are available for analysis, the data held by the Pacific Community (SPC) were extracted. This included longline and purse seine logsheet and observer data. These data were collated in R (R Core Team, 2020) and are presented for information. Finally, the stock structure of most billfish species is not completely understood, but both the striped marlin and swordfish are split into North Pacific (NP) and South-West Pacific Ocean (SWPO) stocks for assessment purposes. For assessments, the black marlin, sailfish and shortbill spearfish are considered as single WCPO stocks, whilst the blue marlin is assessed as a singular Pacific Ocean (PO) stock.

Stock specific data compilations are presented in Figure 2 to Figure 9. These data are stored in the SPC catch and effort data base as well as the Pacific Tissue Bank (`https://www.spc.int/ofp/PacificSpecimenBank`). For black marlin, few biological samples are stored in the Tissue Bank, but there are observed catch and length data spanning more than a decade, although the length sampling contains relatively few samples per year (Figure 2). Blue marlin have more biological samples, sex specific length data as well as observed and reported catch data (Figure 3). Striped marlin have few samples in the Tissue Bank, length samples span two decades but most are from the most recent few years, but there is relatively good catch information (Figure 4 and Figure 5). Shortbill spearfish and sailfish have few samples of any kind in the Tissue Bank and only a small number of length samples, while observed data span two decades there are few catch records within those (Figure 6 and Figure 7). Swordfish have few samples stored in the Tissue Bank but there are many sex specific length samples spanning from 2005 to 2022. Most of the sampling has occurred between 2010 and 2016 (Figure 8, and Figure 9).

The biological data are summarised in information cards for each species (Appendix 1), in addition, more extensive data are presented in the attached excel spreadsheet WCPFC-SC19-2023/SA-WP-16 suppl.. The data within these sheets have been compiled largely from working and information papers obtained from WCPFC SC meetings 1-18, including the assessment reports for each stock under the jurisdiction of the WCPFC. Where information was not available, a literature review was conducted to obtain the nearest and best available estimates from the Pacific Ocean outside of the WCPO; the Indian Ocean; Atlantic Ocean and the Mediterranean Sea (in order of priority).

It is strongly recommended that analysts planning and undertaking new work check for updated investigations before relying on the parameters referenced here, as work is ongoing worldwide. In addition, the parameters in these figures and those tabled in WCPFC-SC19-2023/SA-WP-16 suppl. are presented as a range, not necessarily the preferred value for specific work. Acknowledging that some geographical variability of biological parameters is likely, it is recommended that the SC develop an agreed suite of values (or upper and lower bounds - for application to assessment grids), as well as the agreed units (lower jaw fork length or eye fork length etc.) for these measurements to populate these sheets. Noting that using the best available estimate is preferable over a grid approach for assessment inputs, but the grid could be used, where appropriate, for sensitivity analysis.

The sheets should be updated by the SC (through the BRP-ISG) as new information comes to light. It is therefore recommended that WCPFC-SC19-2023/SA-WP-16 suppl. reviewed and updated as necessary updated annually by the billfish ISG at the SC.

2.1 Broadbill swordfish

Broadbill swordfish (*Xiphias gladius*) is well studied in the Pacific Ocean, and is currently separated into North Pacific and Southwest Pacific Ocean (SWPO) stocks in the WCPO. Sex specific age-growth and maturity information is available for swordfish from several studies of the north Pacific stock (Valeiras et al., 2008, DeMartini et al., 2007, Sun et al., 2002, Uchiyama, 1998, Kapur et al., 2017) and the SWPO stock (Young and Drake, 2004, Farley et al., 2016, Griggs et al., 2005, Ducharme-Barth et al., 2021). A range of length-weight conversions for combined sexes are available for both stocks (Sun et al., 2002, Kapur et al., 2017, Skillman and Yong, 1972, Campbell and Dowling, 2003, Ducharme-Barth et al., 2021, Davies et al., 2008, Kolody et al., 2006), and weight-at-age conversion factors are available for the north Pacific stock (Kapur et al., 2017). Investigations of swordfish movement have been conducted in the north Pacific (Abecassis et al., 2012, Patterson et al., 2021), the Central Pacific (Dewar et al., 2011), Japan (Takahashi et al., 2003) and Hawaii (Brill et al., 1993). For the SWPO stock, investigations of swordfish movement have been conducted in New Zealand (Holdsworth et al., 2007) and in the SWPO and southeast Pacific Ocean (SEPO) region (Evans et al., 2014). Genetic information on stock structure of swordfish is presented in several studies within the Pacific Ocean (Alvarado Bremer et al., 2006, Hinton and Alvarado Bremer, 2007, Chow et al., 1997, Chow and Takeyama, 2000, Kasapidis et al., 2008) and for the SWPO stock (Evans et al., 2021), however, stock structure in the Pacific Ocean remains uncertain. Natural mortality estimates are available for female swordfish in the north Pacific (DeMartini et al., 2007), for both sexes (Griggs et al., 2005) and combined sexes (Ducharme-Barth et al., 2021) in the SWPO. For the north Pacific stock, the latest quantitative assessment (ISCBWG, 2018) concluded that the stock was not overfished, and that overfishing was not taking place. For the SWPO stock, the latest quantitative assessment suggests that the stock is not overfished, and overfishing was not taking place (Ducharme-Barth et al., 2021).

There are CMMs in place for both the north Pacific (CMM2022-02) and the SWPO stock (CMM2009-03) with a revision currently under development (WCPFC19-2022-DP07). Research recommendations from the latest quantitative assessments for both stocks highlighted the need to develop sex disaggregated models to account for the significant differences in life history between the sexes. The bias associated with sex aggregated models (due to limited availability of sex-specific catch composition data) and relatively simple single region spatial structure represent key areas of uncertainty in both assessments.

2.2 Striped marlin

Like swordfish, striped marlin (*Kajikia audax*) are well studied in the Pacific Ocean, and are also separated into north Pacific and SWPO stocks in the WCPO. There is sex specific and combined-sex age and growth information available for both the north Pacific (Fitchett, 2019, Sun et al., 2011, Skillman and Yong, 1976a) and SWPO stocks (Kopf et al., 2011). Length-weight and weight-at-age conversion factors for combined sexes are available for the north Pacific stock (Kapur et al., 2017, ISCBWG, 2022, Skillman and

Yong, 1972) and the SWPO stock (ISCBWG, 2022, Ducharme-Barth et al., 2019, Davies et al., 2012). Some maturity information is also available for both the north Pacific stock (Kapur et al., 2017, Chang et al., 2018, Kopf et al., 2012, ISCBWG, 2022) and the SWPO stock (Kopf et al., 2011, Farley et al., 2021, Kopf et al., 2012, ISCBWG, 2022). Sex specific natural mortality estimates are available for both stocks (Skillman and Yong, 1976b, ISCBWG, 2022, Ducharme-Barth et al., 2019, Davies et al., 2012).

Assessments of genetic stock structure of striped marlin (McDowell and Graves, 2008) and of movement behaviour in the Pacific Ocean have been conducted (Graves and McDowell, 1994). For the north Pacific stock, the latest quantitative assessment ISCBWG (2022) concluded that the stock was overfished, and that overfishing was taking place. For the SWPO stock, the latest quantitative assessment suggests that stock is overfished, but that overfishing is not taking place (Ducharme-Barth et al., 2019). There are CMMs in place for both the north Pacific stock (CMM 2010-01) and the SWPO stock (CMM2006-04).

Research recommendations from the latest quantitative assessment in the SWPO stock highlight the need to improve estimates of life history parameters (growth, maturity and natural mortality), especially in smaller individuals, and to obtain better estimates of movement to facilitate the development of a spatially explicit model structure. Recommendations also called for improved weight-length and length-length conversion factors as well as growth estimates to improve assessment inputs.

2.3 Blue marlin

Blue marlin (*Makaira mazara*) are relatively well studied in the Pacific Ocean, and are currently assessed as a single Pacific Ocean stock. There is a range of information available from quantitative assessments (ISCBWG, 2021, ISCBWG, 2016, ISCBWG, 2013, Hinton, 2001) and studies of age-and-growth (Andrews et al., 2018, Hill, 1986, Chen, 2001, Dai, 2002, Skillman and Yong, 1976a) life history (Kapur et al., 2017, Brodziak, 2013), genetics (Williams et al., 2020, Finnerty and Block, 1992), and population and reproductive biology (Sun et al., 2009, Shimose et al., 2009). Evidence suggests that there has been difficulty obtaining reliable age and growth information due to trouble obtaining accurate age estimates from alternative hard structures. There is therefore no reliable age-at-maturity estimates available for the region, and the ensemble model approach was adopted for the latest quantitative assessment to reduce uncertainty surrounding the growth curve (ISCBWG, 2021). The latest assessment (ISCBWG, 2021) indicates that the Pacific Ocean stock is not overfished, and that overfishing is not taking place. There are no CMMs in place for the Pacific Ocean stock of blue marlin. Recommendations from the latest assessment include increasing biological sampling to improve life history parameter estimation.

2.4 Black marlin

Black marlin (*Istiompax indica*) are currently managed as a single stock in the Pacific Ocean. There is a range of sex-specific growth models presented by Sun et al. (2007) for the Pacific Ocean black marlin stock, along with length- and age-at-maturity for both sexes. Length-weight and weight-length conversion factors for combined sexes are available (Speare, 2003, Shimose et al., 2008), along with sex-specific conversion factors (Skillman and Yong, 1972). Maturity information for female black marlin is presented in

Sun et al. (2015). Several studies of black marlin movement in the Pacific Ocean have been conducted (Williams et al., 2017, Chiang et al., 2015, Domeier and Speare, 2012, Gunn et al., 2003). Genetic investigations of reproductive connectivity and stock structure have been conducted in Australia and Chinese Taipei (Williams et al., 2016), and in the Indo-Pacific Ocean region (Falterman, 1999). No quantitative assessments of the Pacific Ocean black marlin stock have been conducted, and there are no estimates of natural mortality or stock-recruitment-relationships available. An Ecological Risk Assessment (ERA) (Kirby and Hobday, 2007) which included information on black marlin suggests medium-low susceptibility and medium-low productivity. There are currently no CMMs in place for Pacific Ocean stock(s) of black marlin.

2.5 Sailfish

Sailfish (*Istiophorus platypterus*) are not well studied in the Pacific Ocean. A study by Chiang et al. (2004) presents growth models for both males and females, and a range of length-length and length-weight conversions for fish from Chinese Taipei. Studies from the Eastern Pacific present some age and growth information for combined sexes (Alvarado-Castillo and Felix-Uraga, 1998, De Guevara et al., 2011), and some maturity information from a reproductive study (Hernández and Mauricio, 1998). Estimates of natural mortality are available in a report by Chiang et al. (2009) which produced sex specific spawner biomass per recruit and yield per recruit assessments for sailfish caught in the longline fishery off Chinese Taipei. An ERA included sailfish in Kirby and Hobday (2007) which reports high susceptibility and medium productivity, but there has not yet been a quantitative assessment in the WCPO and there are no CMMs in place.

2.6 Shortbill spearfish

Shortbill spearfish (*Tetrapturus angustirostris*) is the most poorly understood billfish in the WCPO, and is currently considered to be a single Pacific Ocean stock. There is a paucity of life history information for this species, and no assessments have been conducted in the Pacific Ocean. There is a single, combined sexes length-weight conversion factor from a study in the Central Pacific Ocean (Skillman and Yong, 1972), and a single recent study of the movement behaviour of shortbill spearfish from Hawaii (Arostegui et al., 2019). There are no CMMs in place. An ERA by Kirby and Hobday (2007) included shortbill spearfish and indicated medium susceptibility and medium productivity.

2.7 Biological data

Length data are collected by observers on longline and purse seine vessels. For purse seine, the data are presented separately for associated and unassociated sets (Figure 10). There are no clear changes in length distributions for any of the billfish between 2008 and 2022. Black and striped marlin and sailfish are caught at about the same size in purse seine and longline sets, whereas larger blue marlin are caught in purse seine unassociated sets. Shortbill spearfish and swordfish are seldom caught in purse seine sets.

Within longline sets, there are both deep and shallow water sets. Hooks are numbered starting from one at the start of the lines to the middle and then in reverse to the end of the line, so that a lower hook number is closer to the surface, and the highest hook number will be the deepest. Blue and black marlin are caught on both shallow and deep hooks. Striped marlin and shortbill spearfish seem to have a bimodal catch by hook distribution. This could be a result of catch in clusters by number of hooks between floats across the longline fleet and should be explored in more depth in a fishery characterisation. Swordfish and to a lesser extent sailfish are caught in the shallowest hooks (Figure 11).

For most species, deep and shallow water sets catch the same sized fish, suggesting that there is not much size segregation by depth for these species (Figure 12).

The length data for black marlin show that length data were collected in low numbers at the start of the data collection and peaked in 2016. About three quarters of the samples are sex-specific, and most black marlin data are recorded as a single length code. Overall the length distribution is normally distributed but a higher proportion of small fish have have no assigned sex (Figure 13).

Blue marlin length data collections have been relatively consistent since 2012. Mean length in the longline sets has declined slightly since 2008 (Figure 14). Most are measured to the same length code. The length distribution from longline sets is normally distributed and few length measurements are not assigned to a length code.

Striped marlin length data have been collected since the mid-2000s, with data collection peaking in 2019 and declining slightly since then (Figure 15). Striped marlin are measured to two different length codes. The length distribution from longline sets is normally distributed and most measurements are assigned to sex. Overall the mean length has declined somewhat since the mid-2000s.

There are very few sailfish length samples but some trends are evident. Sampling has increased consistently since 2011 with some slight declines in mean length through this time (Figure 16). Sailfish are measured largely to a single code and lengths are most often associated with a sex record.

Shortbill spearfish length data have only been collected in any numbers since 2017 (Figure 17). Overall mean length has not changed substantially through time. About two thirds of the fish are measured to the same code (FL) with most others being measured as EO. Around 30% of the samples have no sex recorded.

Swordfish data collection has been relatively good since 2011, with no obvious changes in overall mean length (Figure 18). Swordfish are measured to two length codes (EO and LF). For small fish, most have undetermined sex, and for larger fish about 5-10% have no sex category, with most unclassified data occurring from 2018-2020.

2.8 Fate and condition

Almost all billfish landed on longline vessels are retained (Figure 19). There are no clear trends in billfish fate. However, black marlin are retained at higher rates since 2015. Swordfish have the lowest overall retention rate, although the retention rate is still very high at around 90%.

A high proportion of the billfish catch is dead upon capture, but the proportion varies among species. About 75% of sailfish and shortbilled spearfish are dead upon capture with only small proportions (5-20%) being alive and healthy (Figure 20). Black marlin fare a little better with 60-75% dead at capture, while most of those alive at capture are considered alive and healthy. Around 40% of swordfish are alive at capture but the condition of fish that are alive at capture is mostly reported as unknown. An estimated 45% of blue marlin are alive at capture and about half of those have an unknown health status. Striped marlin have the best survival rates at capture, with around 50% being alive, however, the condition of these live fish is mostly reported as unknown.

Most black marlin, sailfish and shortbill spearfish are dead when discarded, about 25% of blue marlin and swordfish are dead when discarded but with slightly higher rates of live discards for striped marlin (Figure 21).

3 Fisheries data

3.1 CPUE

Annual unstandardised CPUE trends from observer records are shown in Figure 22. These data are difficult to interpret due to the high variation among records within years. Interpreting these trends in relation to abundance without standardising the index to account for changes in fishery characteristics and observer effects should be done with caution, and a more rigorous analysis taking into account the gear characteristics and other factors is recommended as part of formal fishery characterisations. Figure 23 shows that CPUE data derived from the logsheet data are also available for analysis.

Seasonal CPUE data are available for analysis (Figure 24, Figure 25). However, as with the annual data, in order to assess seasonal trends one should also assess the CPUE spatially by fleet and targeting behaviour and with appropriate CPUE standardisation methods.

3.2 Set characteristics

Gaining an understanding of operational and gear characteristics can inform decisions about factors to use in CPUE standardisations. Here we describe the characteristics of the gear that account for catch of each of the WCPO billfish species.

Information is available on the number of baskets set (Figure 26); the distance between branchlines (Figure 27); the branchline length (Figure 28); floatline length (Figure 29); number of hooks between floats (Figure 30); the number of hooks set(Figure 31); and the use of lightsticks (Figure 32).

Sets for all species except swordfish have similar characteristics. The marlins, sailfish and shortbill spearfish are caught most frequently on sets with about 300-400 baskets, 20-29m long branchlines; 20-39m long float lines; 20-30 hooks between floats; and on lines with 2000-3000 hooks set. Swordfish on the other hand are caught in shallow water sets which have 200-300 baskets; 20-29m long branchlines; float lines shorter than 20m; less than 10 hooks between floats and total hooks set of 1000-1500.

Light stick information is difficult to interpret as most sets have no light sticks. However, in more recent years light stick use is becoming more frequently reported in gear catching blue marlin, striped marlin, sailfish, shortbill spearfish and swordfish.

The logsheet data also show that for all species except swordfish gear characteristics are similar. The logsheet data show that sets catching swordfish have fewer hooks between floats (Figure 33) and fewer hooks on the set (Figure 34).

Hook type can influence the catchability of a fish. Overall the observer data shows an increase in the prevalence of circle hooks (Figure 35), however, this could be related to an increase in observer rates in Fiji and French Polynesia. On vessels flagged to both these CCMs, the use of circle hooks has increased in the most recent years, while some Japanese flagged vessels use mostly Japanese hooks (Figure 36). Overall the trends in catch by species and hook type show few differences between species. While Japanese hooks and J-hooks make up a relatively low proportion of the hooks observed in the last decade, they account for about over 25% and 20% receptively of the overall catch of most billfish species (Figure 37). Hook type can also influence the survival of a fish. Generally for billfish, hook type does not appear to influence the condition at landing (Figure 38).

In addition to these characteristics, the effect of conducting a longline set during the day or night can influence the catchability of billfish. As a result the time of day at the start of the set should be taken into account. In doing this, it should be noted that some fleets record time as ships time, others at UTC and some as country capital time. Clarifying this at a fleet level will be needed before this analysis can be completed with any certainty.

3.3 Observer data collection bias

Observer data within the WCPO can have some biases as the observer effort is not always representative of the fishing effort in space, time and by vessel flag. Observer effort in some areas such as the Hawaiian EEZ is relatively high, while in other areas such as the high seas and some parts of the tropics, observer information is deficient (Figure 39). This has also changed over time with some CCMs like Fiji and Tonga increasing their observer coverage in the more recent years (Figure 40). In addition, different observer programs may have different practices and operate in different areas (Figure 41 and Figure 42). For billfish, generally the fate of fish is the same irrespective of the observer program collecting the information (Figure 43) or the vessel flag catching the fish (Figure 44).

While the billfish fate does not change much between flags and observer programs, the gear characteristics do change substantially. For example the observed hooks between floats varies between programs with fewer hooks between floats observed in the Australian, Hawaiian and New Zealand programs (Figure 45). While the hooks between floats has changed through time for French Polynesia, decreasing in the most recent years. Similarly, for floatline length, the observer programmes from Australia, Hawaii, New Zealand and New Caledonia report shorter floatline lengths and those for Fiji and Chinese Taipei have changed through time with Fiji floatlines becoming longer and Chinese Taipei becoming shorter (Figure 46). Both of these factors impact the depth of the hooks and will affect the catchability of billfish.

In this data summary we have not included analyses of detailed gear characteristics by flag, observer program and species. However, these should be included in fishery characterisations, at a species level, to evaluate implication of different data sources and observer coverage. These analyses will provide insights into the catchability of the different species and whether observer program and vessel flag will need to be taken into account when undertaking CPUE standardisations.

4 Current stock status

Five of the eight billfish stocks within the WCPO have had successful stock assessments undertaken. The results of these assessments are summarised by Hare et al. (2021) and presented in Figure 47. The most recent assessments indicate that blue marlin, and both north and southwest Pacific swordfish are not overfished and overfishing is not taking place; southwest Pacific striped marlin is overfished but overfishing is not taking place; while north pacific striped marlin is overfished and overfishing is taking place.

The biological and stock status information are summarised in stock specific information sheets (Appendix 1 Figure AI - 1 to Figure AI - 8). These sheets summarise the available life history information for each species, stock status information and WCPFC CMMs applicable to each stock.

4.1 Guidelines for assessment reporting metrics

Brouwer and Hamer (2021) reviewed the work done on establishing Limit Reference Points (LRPs) within the WCPFC and considered options for a LRP and relevant performance indicators for WCPFC billfish. They noted that in some settings, fishery managers have considered a more risk prone approach to LRPs for bycatch species, if the objectives for those stocks are different to those of target tuna species. However, the characterisation of species as bycatch, non-target and target species and the development of alternative objectives for each has not been considered by the WCPFC. They also note that where the underlying biology of target and bycatch stocks are comparable, there is no clear basis for setting the biological limits, defined by their LRPs, at different levels. In addition, the acceptable risk of falling below a LRP is a management decision, and should ideally be determined to support the achievement of fishery objectives for each stock.

Based on the work by Brouwer and Hamer (2021) SC17 concluded the following:

- The WCPFC should develop interim objectives for Southwest Pacific striped marlin to guide the appropriate levels for any agreed LRP and the associated maximum risk levels for breaching this LRP.
- While an LRP equivalent to 20% $SB/SB_{F=0}$ for Southwest Pacific striped marlin was supported by several CCMs (consistent with the logic behind the application to key tuna stocks), several other CCMs pointed out that the life-history of billfish are substantially different to key tuna species and therefore did not support this LRP. Several CCMs also noted that in adopting the tuna LRPs, in their view the Commission took into account factors such as the risk of greater fluctuations in recruitment and smaller fish sizes and values as biomass declined, and these factors may not be as applicable to setting LRPs for billfish.
- Several CCMs supported the development of billfish LRPs based on MSY criteria with appropriate risk choices.
- For WCPO billfish species the identification of appropriate LRPs should be guided by developing management objectives for different species divided into the following groups: target species (swordfish); data-rich bycatch species (striped and blue marlin); medium information bycatch species with levels of catch (black marlin); and data-poor, low-catch bycatch species (shortbilled spearfish and sailfish). Having

agreed objectives would help clarify which approach to use and inform selection of the acceptable risk of breaching the LRP.

- Each billfish species should initially be assessed against the potential LRPs listed in Table 4. The SC should also work towards developing a minimum list of metrics that should appear in any future billfish assessment reports and a preferred metric for each WCPO billfish stock. For example, several CCMs suggested the addition of F_{MSY} and SB_{MSY}-related values, as it is related to the spirit of the Convention in their view and is the reference point used by other RFMOs for billfish species. In the interim SC agreed to retain Table 4 as an interim list of candidate LRPs for billfish.
- The applicability of LRPs should be evaluated, whenever possible, at the stock level. Some CCMs noted that for some species, like the south Pacific swordfish, the adopted LRP for tropical tuna species ($20\%SB_{F=0}$) is significantly above SB_{MSY}.
- There was support for the proposed additions to the hierarchical approach, originally endorsed by WCPFC8 for key target species and SC10 for elasmobranchs, to cater for empirical and risk-based reference points of medium and low data stocks. The updated table is presented in Table 5.
- These decisions should be incorporated into the Billfish Research Plan that is scheduled to be developed in 2022 and focus that work on developing objectives, assessing LRPs for each species, and determining if a pathway to a higher level of information and knowledge should be developed. This plan should also consider a request that the SSP compile a table based on existing assessments of billfish and sharks that shows SB_{MSY}, SB_0 and $SB_{F=0}$ levels and the percentage of SB_{MSY} relative to the other two metrics, with associated uncertainty.
- The risk-based fishing mortality benchmarks should be defined as dependent variables in the two main assessment platforms used (Stock Synthesis and MFCL) so that statistical uncertainty of the estimates can be calculated.

While appropriate LRPs should be agreed and adopted for all billfish stocks, lack of adoption should not be seen as a precondition to undertaking stock assessments or developing sound management for these stocks. It is recommended that all assessments take Table 4 and Table 5 into account when considering metrics for reporting assessment results.

5 2023 - 2027 BRP Direction

Throughout the history of the WCPFC, a number of billfish stock assessments have been undertaken. In order to promote and guide improvements in future assessments research recommendations are typically included in assessment reports. These recommendations are included here for the latest quantitative assessments and the most recent ERA analyses that have included billfish stocks in the WCPO.

The following research recommendations have been made in recent SC assessment papers.

- **Swordfish (NP) - (ISCBWG, 2018)**

  - The lack of sex-specific size composition data and the simplified treatment of the spatial structure of swordfish population dynamics remained as two important sources of uncertainty for this benchmark assessment.

- **Swordfish (SWPO) - (Ducharme-Barth et al., 2021)**
  - Contingent on the collection of comprehensive sex-specific catch and size composition data, SC17 recommended to continue progress on developing a sex-disaggregated model to better account for the significant differences in life history between male and female swordfish. Implementation of a sex-disaggregated model applied to comprehensive sex-specific data could reduce bias in the model results. The Scientific Services Provider however did note that lack of sex specific size composition data was a major limitation to a sex disaggregate approach that would need to be improved.
  - The following three key research needs were identified in undertaking the assessment that should be investigated either internally or through directed research.
    * Directed longitudinal tagging of swordfish to reduce the uncertainty in movement rates, and a feasibility study to explore applying CKMR techniques to Southwest Pacific swordfish are the two most critical research items.
    * Development of a statistically robust sampling plan for the collection of fisheries dependent biological samples (by sex), including but not limited to age, catch, size frequency data, and genetic samples.
    * In order to improve quality of abundance indices there is a need to expand minimum reporting requirements for longline operational characteristics to include: a priori target species, light stick use, bait type, setting time (or fraction of night-time soak), and gear settings that influence fishing depth (e.g., hooks between floats, branch line length, float line length, and/or line setting speed).

- **Striped marlin (NP) - (ISCBWG, 2022)**
  - To improve the stock assessment, the WG recommends continuing model development work, to reduce data conflicts and modelling uncertainties, and re-evaluating and improving input assessment data.

- **Striped marlin (SWPO) - (Ducharme-Barth et al., 2019)**
  - Improved estimates of life history parameters including growth, maturity, and natural mortality. Verify the aging method used to derive the growth relationship in order to inform meta analyses for M and steepness specific to SWPO striped marlin. Additionally, efforts should be made to increase sampling of smaller individuals.
  - Better estimates of striped marlin movement (>180 days) are needed to characterize mixing rates across model region in order to develop spatially explicit model structure and improve upon "areas as fleets" approach.

- Improved estimates of conversion factors (such as weight-to-length and length-to-length) are needed, together with improved length-at-age estimates to better inform the data inputs used in the stock assessment.
- Conduct sensitivities analyses with respect to the uncertainties in conversion factors used in the stock assessment and assess whether this should be included as an axis in the structural uncertainty grid.
- Develop better estimates of historical catch (1950-1960) to resolve the potential issue of misidentification caused by merging the billfishes datasets.

- **Blue marlin (PO) - (ISCBWG, 2021)**
  - Uncertainty regarding the choice of BUM growth curve led to the ensemble model approach for this assessment. The BILLWG recognized that there is considerable uncertainty in input CPUE data in the recent years and life history parameters, especially growth. The BILLWG considered an extensive suite of model formulations and associated diagnostics for developing the assessment models. Overall, the BILLWG found issues with both the new growth and old growth model diagnostics and sensitivity runs that are consistent with the presence of data conflicts, but none of the model diagnostics show that the results of either model were invalid. It is recommended model development work to reduce data conflicts and modeling uncertainties continue and that input assessment data be reevaluated to improve the time series.
  - It is recommended that biological sampling to improve life history parameter estimates continue to be collected and ISC countries participate in the BILLWG International Biological Sampling program to improve those estimates.
- **Black marlin (WCPO); Shortbill spearfish (WCPO); Sailfish (WCPO) - (Kirby and Hobday, 2007)**
  - It is also anticipated that the SC will encourage further research into the fundamental biological characteristics of the more poorly understood target and non-target associated species, based on their risk ranking.

5.1 2023 - 2027 Schedule of work

The work required for billfish can be divided into a number of work streams 1) stock assessments and model improvements; 2) biological life-history information; and 3) observer data improvements.

5.1 Stock assessments

The stock assessment schedule for the two striped marlin stocks; blue marlin and two swordfish stocks are relatively well established and the assessment schedule has been included in the broader WCPFC assessment schedule (Table 6). Swordfish are assessed every four years with the marlin being assessed on a five-yearly schedule. Previous assessments for these species have been successfully undertaken by the SPC and ISC Table 7. Black marlin, sailfish and shortbill spearfish have not been assessed. Due to a lack of high quality data and reliable catch history information, undertaking data rich, quantitative assessments for these species is likely to be challenging and may not be possible (Level 4, Table 5). Alternative means to review trends in these stocks are possible and its is suggested that for these species fishery characterisations and standardised CPUE analyses be undertaken to assess trends in these stocks (Table 7), using CPUE_{t1-t2} or CPUE low as possible reference points (Brouwer and Hamer, 2021).

It is recommended that the current assessment schedule be maintained and the schedule be extended to 2030. It is also recommended that standardised CPUE analyses and fishery characterisations be undertaken for black marlin, sailfish and shortbill spearfish and that the SC19 ISG-billfish consider prioritisation and timing for this work, once completed if this work is informative, it should be repeated on a five-yearly schedule.

In addition to these assessments, previous work (outlined above) has indicated that assessments can be improved. This body of work has been developed into a series of project titles outlined in Table 7. It is recommended that the SC19 ISG-billfish consider prioritisation and timing for these projects.

5.1 Biology

A number of life-history data improvements are suggested in Table 7. All of these data can be collected in a single broad scale program. Broad scale observer based data collection can potentially be used to collect the samples required from multiple fleets and across a wide area through the WCPO, with the analysis taking place when enough data exist. If, however, specific stratifications or targeted areas for sampling are required for some species, a more considered stratified sampling approach may be required. This should be given consideration when designing the species specific sampling strategies.

Any genetic sampling work should begin with an initial scoping study to assess the most efficient spatio-temporal sampling strategy and the objectives of a sampling programme.

5.1 Observer data collection

Observer data collection should consider increasing sampling of sex-specific length data, as well as the collection of age and maturity samples. Samples should be sent to and stored at the SPC Tissue Bank who can co-ordinate and collate samples. Managing observer priorities on-board vessels is challenging. There is a risk that sampling could be excessive, as such, stratified sampling could make the sampling program more efficient (Table 7).

It is recommended that prior to large scale sampling of multiple species, an analysis be conducted to design a statistically robust and feasible sampling plan for the collection of fisheries dependent biological samples to make sampling most efficient. This will need to consider the purpose of the data and the spatio-temporal fishery and observer placement distribution.

6 Conclusions

While the assessment schedule for the two striped marlin stocks; blue marlin and two swordfish stocks is carefully considered, all other research work required is currently unplanned. This document has collated the work required. Five regular stock assessments are scheduled by the WCPFC and this plan has not altered that schedule. Additionally, low information fishery characterisations are suggested for black marlin, sailfish and shortbill spearfish (as a single project). Seventeen other projects are listed, these were derived from WCPO assessment recommendations as well as data gaps identified through this review. Some of these projects can be combined. It is suggested that the ISG-billfish consider and prioritise this list and then schedule the work over the lifetime of this plan. It is therefore suggested that when the ISG develops its terms of reference it considers including the following:

1. The ISG-billfish rank the projects listed within Table 7 for prioritisation within the billfish research plan[2].
2. The ISG-billfish consider streamlining the projects and merge or remove projects where necessary.
3. The ISG-billfish schedule the projects listed in Table 7.
4. The ISG-billfish develop terms of reference for all projects including stock assessments intended to begin in 2024.

It is also suggested that the BRP be extended to 2030 to encompass two assessment cycles and allow time to stagger this workload along with other competing research priorities within the WCPFC SC.

7 Recommendations

The following recommendations are proposed for the SC to consider:

1. Given the 4 to 5-year assessment cycle for billfish the research plan is recommended to encompass two assessment cycles and as such the BRP should run over 2023-2030.
2. It is recommended that SC19 establish an Informal Small Group to evaluate the BRP (ISG-billfish), and maintain this as a standing ISG to evaluate progress against the BRP at subsequent SC meetings. When the ISG develops its terms of reference we suggest that it considers including the following:
   (a) The ISG-billfish rank the projects listed within Table 7 for prioritisation within the billfish research plan[3].
   (b) The ISG-billfish consider streamlining the projects and merge or remove projects where necessary.
   (c) The ISG-billfish schedule the projects listed in Table 7.

[2] Note: projects from the BRP elevated to the SC workplan for prioritisation will get re-prioritised as per the agreed SC prioritisation process.

[3] Note: projects from the BRP elevated to the SC workplan for prioritisation will get re-prioritised as per the agreed SC prioritisation process.

(d) The ISG-billfish develop terms of reference for all projects including stock assessments intended to begin in 2024.

3. It is recommended that all assessments take Table 4 and Table 5 into account when considering metrics for reporting assessment results.
4. It is recommended that standardised CPUE analyses and fishery characterisations be undertaken for black marlin, sailfish and shortbill spearfish and that the SC19 ISG-billfish consider prioritisation and timing for this work, once completed if this work is informative, it should be repeated on a five-yearly schedule.
5. It is recommended that a stratified sampling program be designed to make biological sampling most efficient and useful.
6. It is also recommended that the SC discuss how to incorporate the SC17 recommendations on Limit Reference Points into the BRP and develop a process to make recommendations to the Commission on agreed LRPs for use within assessments.
7. Lastly, it is also recommended that on all longline logsheets vesslels record time as UTC and not ships time so that local time can be estimates.

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Tables

Table 1: The participant list from the online Informal Working Group.

Name	Affiliation
James Larcombe	AU
Don Bromhead	AU
Laura Tremblay-Boyer	AU
Michael Honeth	FFA
Adele Dutilloy	FFA
Jemel James	FM
Marko Jusup	JP
Hirobaka Ijima	JP
Beau Bigler	MH
John Annala	NZ
Leyla Knittweis	NZ
Michael Kinney	PIFSC
Matthew Farthing	SAFER LAB
Stephen Brouwer	Saggitus
Paul Hamer	SPC
Zi-Wei Yeh	TW
Michelle Sculley	USA
Jon Brodziak	USA
Nicholas Ducharme-Barth	USA
Sungkwon Soh	WCPFC

Table 2: The species list names and codes used in this report.

Code	English name	Scientific name
BIL	Billfish nei.	Istiophoriformes
BLM	Black marlin	*Istiompax indica*
BUM	Blue marlin	*Makaira mazara*
MLS	Striped marlin	*Kajikia audax*
SFA	Sailfish	*Istiophorus platypterus*
SSP	Shortbill spearfish	*Tetrapturus angustirostris*
SWO	Swordfish	*Xiphias gladius*

Table 3: The observer program code definitions.

Observer program code	Definition
ASOB	American Samoa
AUOB	Australia
CKOB	Cook Islands
CNOB	China
FJOB	Fiji
FMOB	Federated States of Micronesia
HWOB	Hawaii
JPOB	Japan
KIOB	Kiribati
KROB	Korea
MHOB	Marshall Islands
NCOB	New Caledonia
NZOB	New Zealand
PFOB	French Polynesia
PGOB	Papua New Guinea
PWOB	Palau
SBOB	Solomon Islands
TOOB	Tonga
TWOB	Chinese Taipei
VUOB	Vanuatu
WSOB	Samoa

Table 4: Proposed list of potential limit reference points for WCPFC billfish, categorized by SC17 as Target and Bycatch and by assessment type (WCPFC, 2021).

LRP	Group	Assessment type	Comments
x% F/FMSY	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
x% SB/SBF=0	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
x% SB0	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
SPR x% SBF=0	Bycatch	Medium data or data poor	Choose the level of x based on an evaluation.
x% CPUE 0	Target & Bycatch	Data rich or Medium data	Choose the start of a reliable CPUE series and the level of x.
SB/SBF=0 t1-t2	Target & Bycatch	Data rich	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
SB t1-t2	Target & Bycatch	Data rich	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
CPUE t1-t2	Target & Bycatch	Data rich or Medium data	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
SB/SBF=0 low	Target & Bycatch	Data rich	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
SB low	Target & Bycatch	Data rich	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
CPUE low	Target & Bycatch	Data rich or Medium data	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels. Note CPUE t1-t2 is more precautionary.
F/F lim >1	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be generated.
F/F crash >1	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be generated.

Table 5: The 5-level hierarchical approach agreed by SC17 for defining LRPs for bycatch species modified from that endorsed by WCPFC8 (WCPFC, 2021).

Level	Condition	LRP metrics
Level 1	A reliable estimate of steepness is available.	FMSY and BMSY
Level 2	Steepness is not known well, if at all, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated.	F x% SPRF=0 and either x% SB0 or x% SBF=0
Level 3	The key biological and fishery variables are not well estimated or understood.	x% SB0 or x% SBF=0
Level 4	Poor biological information, fishery data sparse or patchy with no ability to estimate parameters noted above, or other metrics considered important. But a reliable CPUE index is available.	CPUE t1-t2 or CPUE low
Level 5	The key biological variables (age, reproduction, intrinsic rate of increase and carrying capacity) are reliably estimated.	F/F crash >1 or F/F lim > 1

Table 6: The current billfish related assessment plan for the WCPFC as outlined in Table WP-02 of the SC18 summary report. Swordfish are assessed every 4 years with other billfish being assessed on a 5-yearly cycle. The comments are the authors perspective on the work planned.

Species	Stock	Last assessment	2022	2023	2024	2025	2026	Comments
Striped marlin	N Pacific	2019		X				Go ahead as planned
	SW Pacific	2019			X			
Swordfish	N Pacific	2018		X				
	SW Pacific	2021				X		
Blue marlin	Pacific	2021					X	
Black marlin	WCPO	Never						No quantitative assessment, ERA conducted in 2007, review trends through standardised CPUE analysis and fishery characterisations
Sailfish	WCPO	Never						
Shortbill spearfish	WCPO	Never						

Table 7: The billfish stock assessment project list for prioritisation by SC19.

1. Stock assessment				
Title	Priority	Start year	End year	Comments
1) North Pacific striped marlin stock assessment	TBD	2023	2023	Previous assessment successfully conducted by the ISC
2) Southwest Pacific striped marlin stock assessment	TBD	2024	2024	Previous assessment successfully conducted by the SPC
3) North Pacific swordfish stock assessment	TBD	2023	2023	Previous assessment successfully conducted by the ISC
4) Southwest Pacific swordfish stock assessment	TBD	2025	2025	Previous assessment successfully conducted by the SPC
5) Pacific blue marlin assessment	TBD	2026	2026	Previous assessment successfully conducted by the ISC
6) WCPO black marlin fishery characterisation and standardised CPUE analysis	TBD	2026	2026	These three projects could possibly be done as part of the same project
7) WCPO sailfish fishery characterisation and standardised CPUE analysis	TBD	2026	2026	
8) WCPO shortbill spearfish fishery characterisation and standardised CPUE analysis	TBD	2026	2026	

Table 7. Continued.

2. Projects recommended by WCPFC stock assessments				
Title	Priority	Start year	End year	Comments
1) Development of a statistically robust sampling plan for the collection of fisheries dependent biological samples (by sex), including but not limited to age, size frequency data, and genetic samples for WCPO swordfish (north and south).	TBD	2024	Ongoing	These data can be collected but will need to be prioritised by observer programs particularly in tropical and sub-tropical areas. Merge with observer project 1.
2) Develop sex-disaggregated assessment models for swordfish.	TBD	TBD	TBD	Undertake this work once enough data have been collected in the previous project. Review the possibility of undertaking this work as part of next assessment.
3) Investigated the application of swordfish length-weight relationship bias correction factors.	TBD	TBD	TBD	Consider as part of next assessment.
4) Undertake directed longitudinal tagging of southwest Pacific swordfish to reduce the uncertainty in movement rate.	TBD	TBD	TBD	The assessment authors considered this to be highly important research
5) Undertake a feasibility study to explore applying CKMR techniques to Southwest Pacific swordfish.	TBD	TBD	TBD	The assessment authors considered this to be highly important research
6) Expand minimum reporting requirements for longline operational characteristics to include: a priori target species, light stick use, bait type, setting time (or fraction of night-time soak).	TBD	TBD	TBD	This is required to improve quality of abundance indices for all billfish.
7) For north Pacific striped marlin continue model development work, to reduce data conflicts and modelling uncertainties, and re-evaluating and improving input assessment data.	TBD	TBD	TBD	Consider as part of next assessment.

Table 7. Continued

2. Projects recommended by WCPFC stock assessments				
Title	Priority	Start year	End year	Comments
8) Develop improved estimates of life history parameters of south Pacific striped marlin including growth, maturity, and natural mortality. Verify the aging method used to derive the growth relationship in order to inform meta analyses for M and steepness specific to SWPO striped marlin.	TBD	TBD	TBD	This work could be included as part of biology project number 1.
9) Undertake directed longitudinal tagging of south Pacific striped marlin to reduce the uncertainty in movement rate.	TBD	TBD	TBD	Note that some of this work could be undertaken using sport fisheries in Pacific Island States.
10) Develop spatially explicit model structure and improve upon "areas as fleets" approach.	TBD	TBD	TBD	This work will can only be undertaken after project 9 is completed. Consider with next assessments.
11) Develop improved estimates of conversion factors (such as weight-to-length and length-to-length) for south Pacific striped marlin.	TBD	TBD	TBD	This work could be included as part of biology project number 1.
12) Conduct sensitivities analyses with respect to the uncertainties in conversion factors used in south Pacific striped marlin stock assessments.	TBD	TBD	TBD	Consider as part of next assessment.
13) Develop better estimates of historical catch (1950-1960) to resolve the potential issue of misidentification caused by merging billfishes datasets.	TBD	TBD	TBD	SC to consider if 10 years of historical catch prior to 1960 will be informative.
14) Collect biological material for Pacific ocean blue marlin and undertake growth and maturity studies to get improved growth and maturity estimates.	TBD	TBD	TBD	This work could be included as part of biology project number 1.

Table 7. Continued.

3. Biology				
Title	Priority	Start year	End year	Comments
1) Biology of black marlin, shortbill spearfish and sailfish in the WCPO from longline fisheries.	TBD	2026	2028	Collect samples (fin spines and otoliths) and then undertake age growth and reproductive analyses to get growth and maturity parameters to inform productivity rates of this species. This is probably a low priority and sample collection could be opportunistic and the work undertaken when enough samples exist.
2) Release mortality of tropical billfish from longline and purse seine fisheries	TBD	NA	NA	This work is probably not necessary for longline catch as a very small proportion of billfish are released (~1%) and of those that are released back into the ocean most (~90%) are dead. Recommend not to explore this project for longline sets. For purse seine sets observers would need to collect more information on the fate of the billfish catch in purse seine sets prior to planning any release mortality work.

Table 7. Continued.

4. Observer data				
Title	Priority	Start year	End year	Comments
1) Design a statistically robust sampling plan for the collection of fisheries dependent biological samples to make biological sampling of billfish most efficient, and relevant to the billfish data requirements.	TBD	TBD	TBD	This work should preclude any specific increases in billfish sampling by observers.

Figures

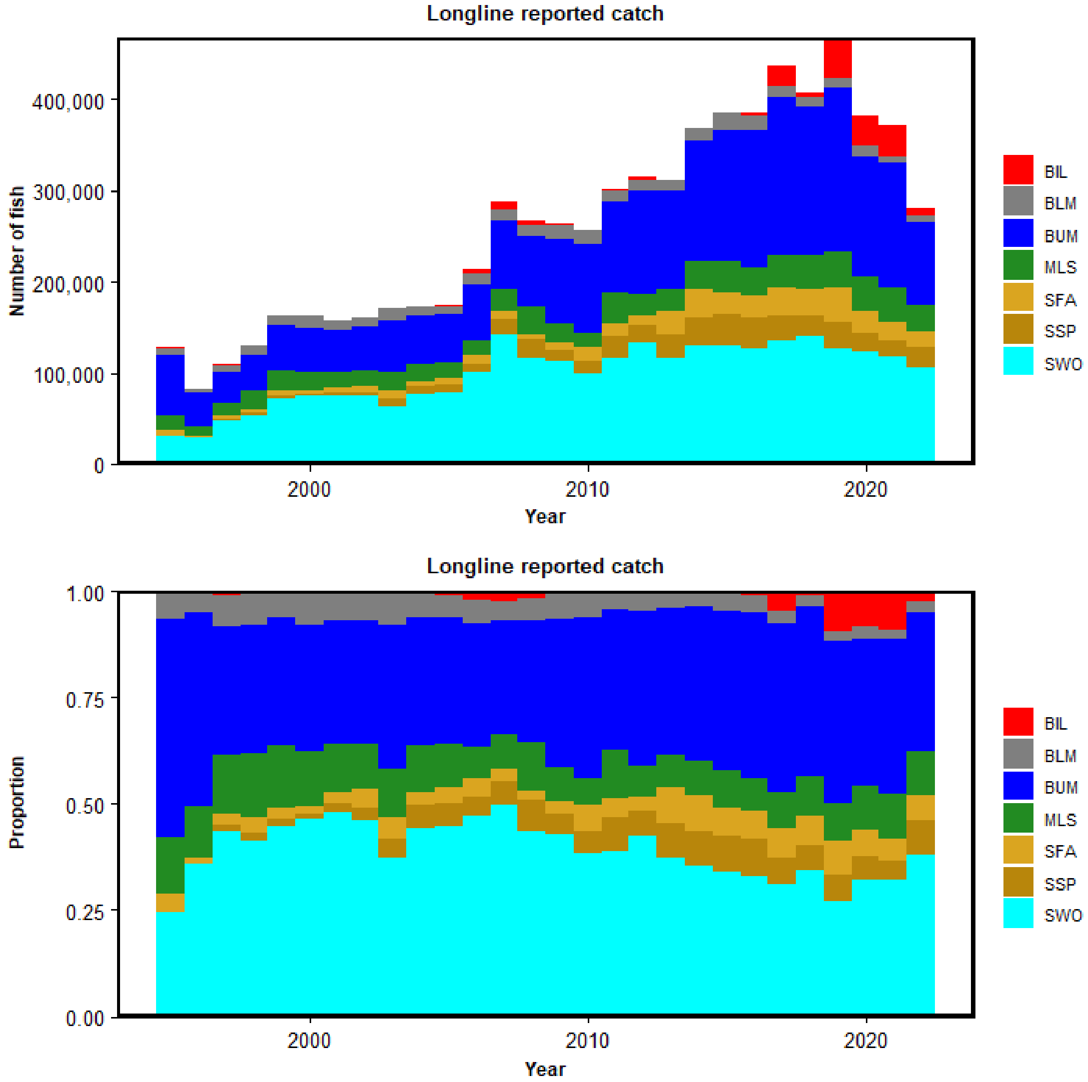


Figure 1: WCPFC reported longline billfish catch (top) and the catch proportion (bottom) of the billfish species caught in the WCPO.

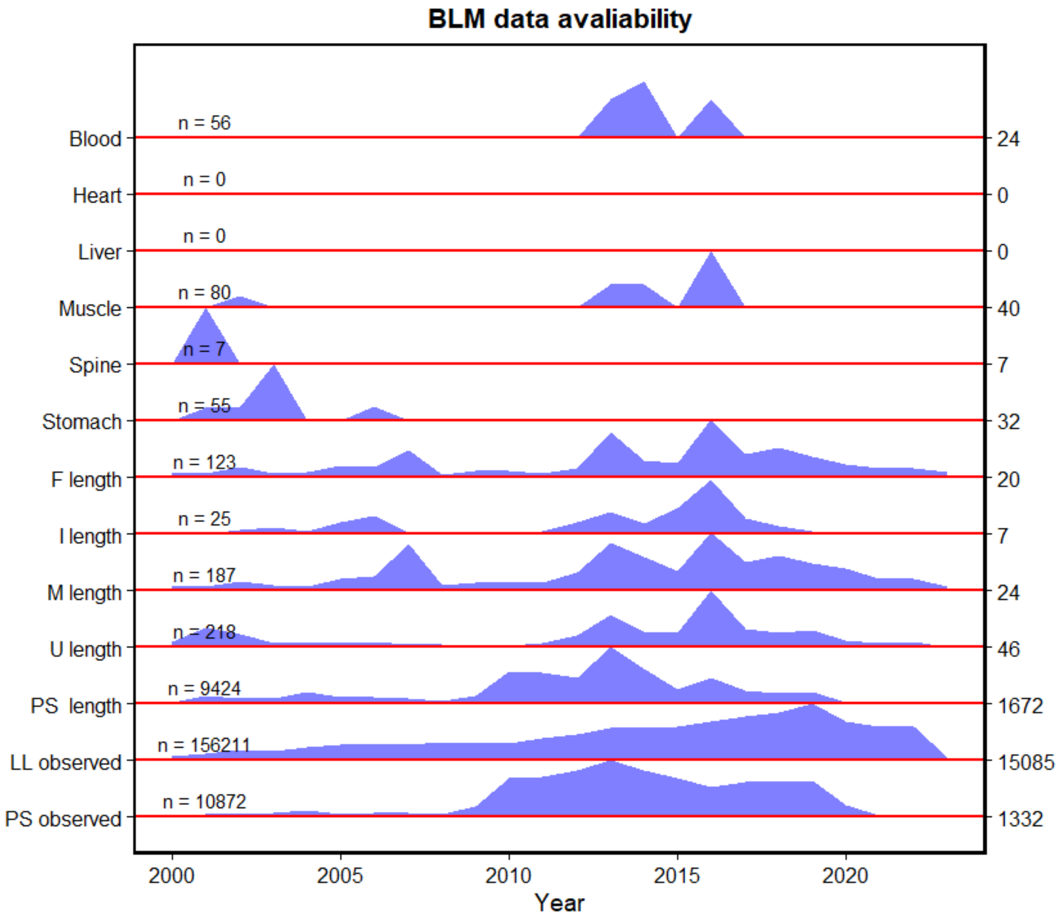


Figure 2: WCPFC data availability for black marlin from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

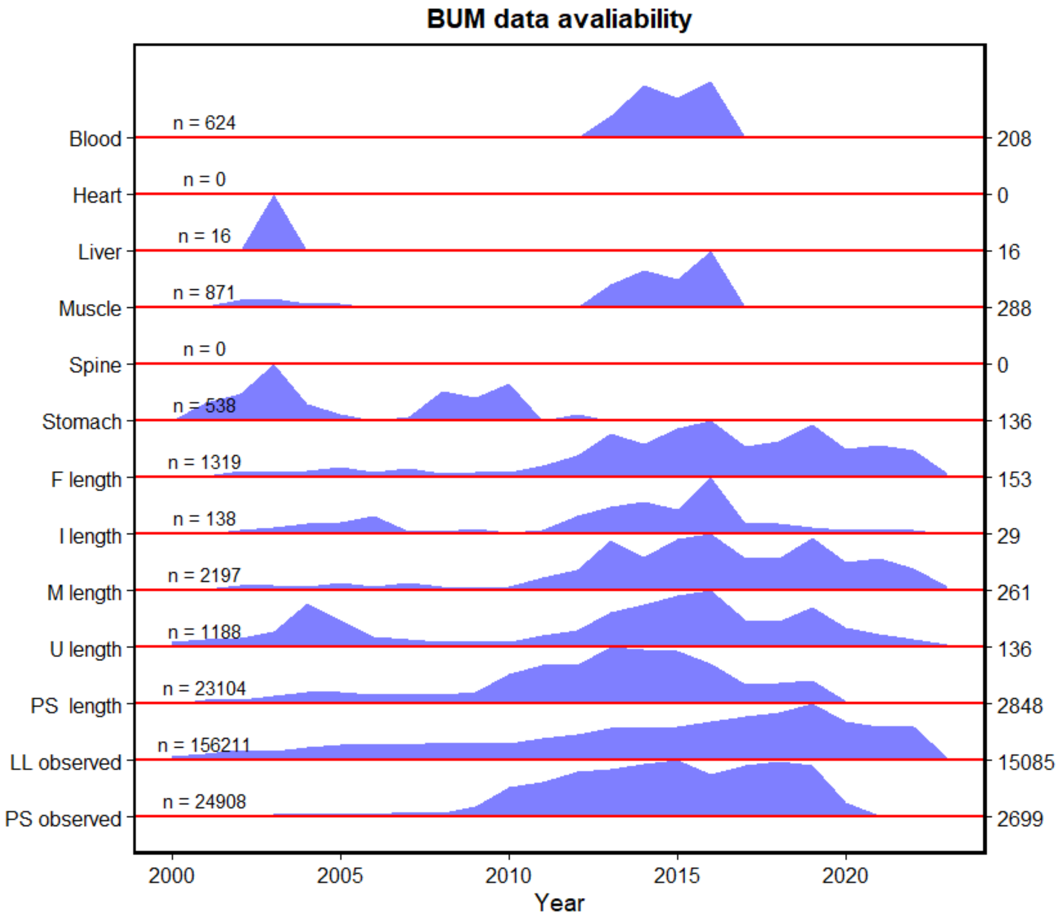


Figure 3: WCPFC data availability for blue marlin from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

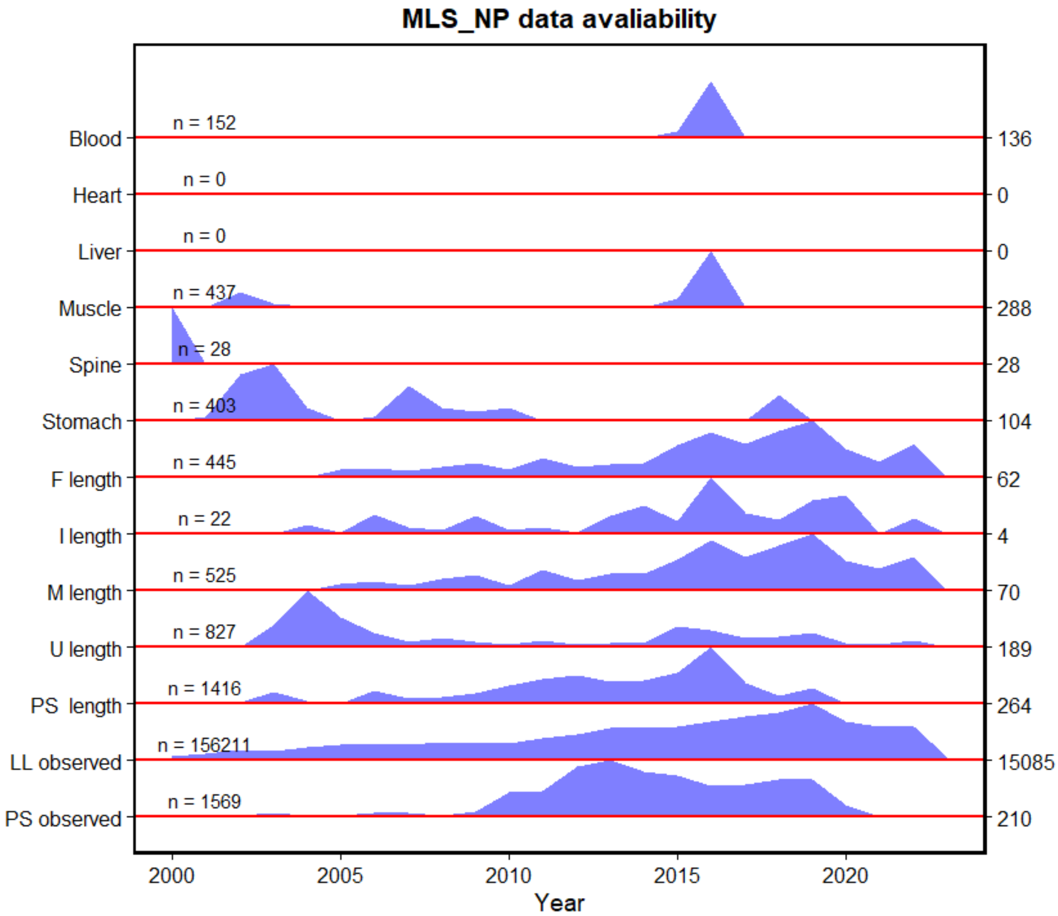


Figure 4: WCPFC data availability for striped marlin in the north Pacific from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (https://www.spc.int/ofp/PacificSpecimenBank).

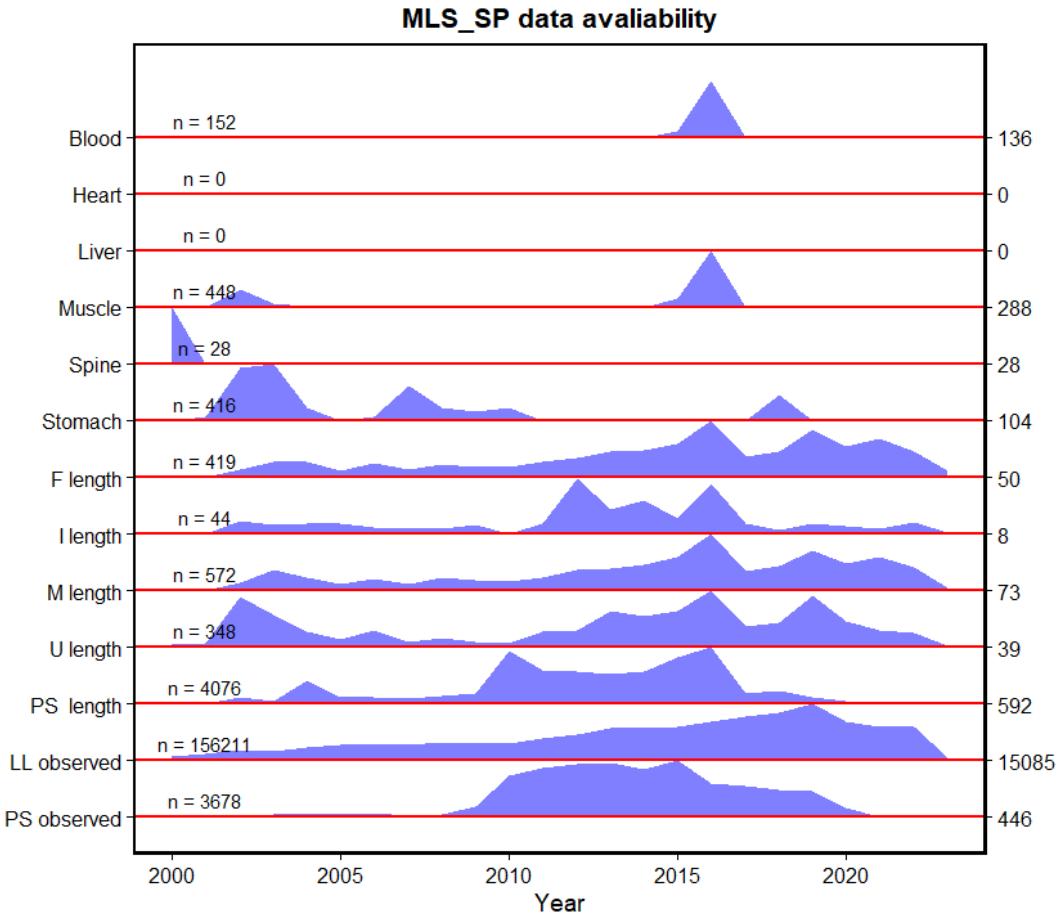


Figure 5: WCPFC data availability for striped marlin in the south Pacific from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (https://www.spc.int/ofp/PacificSpecimenBank).

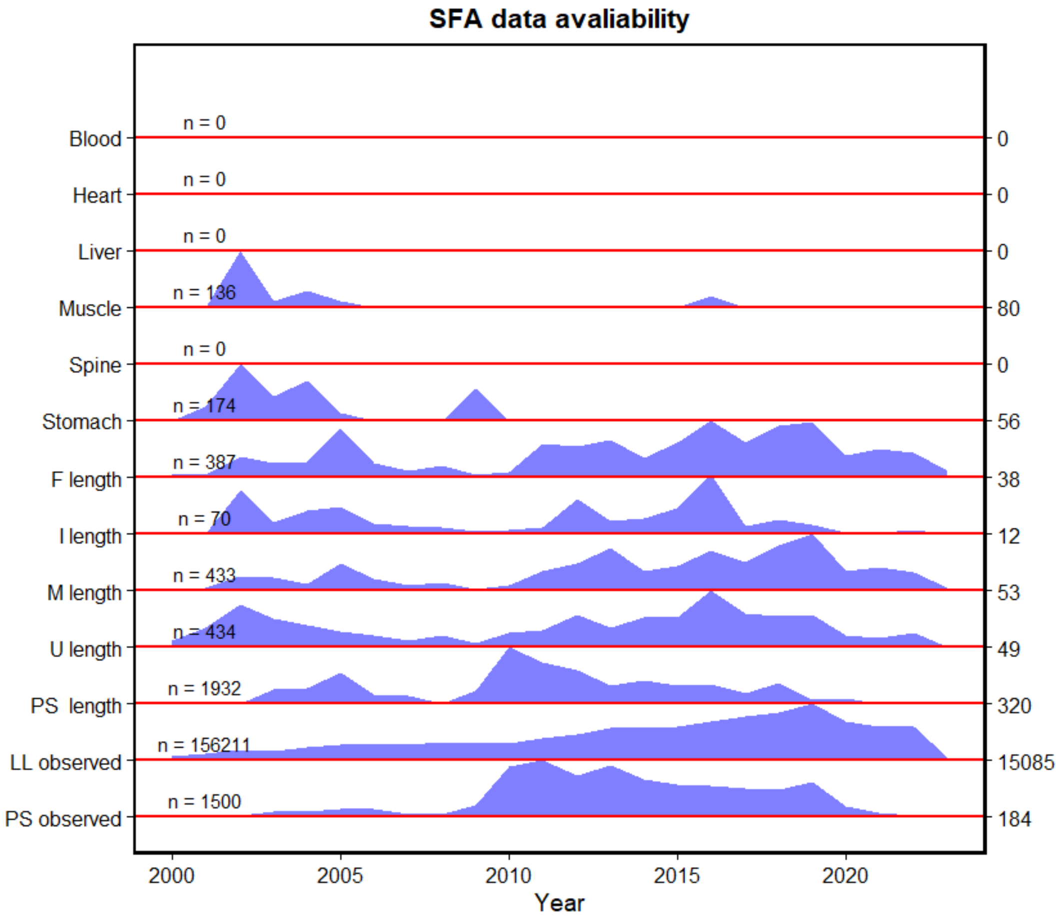


Figure 6: WCPFC data availability for sailfish from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

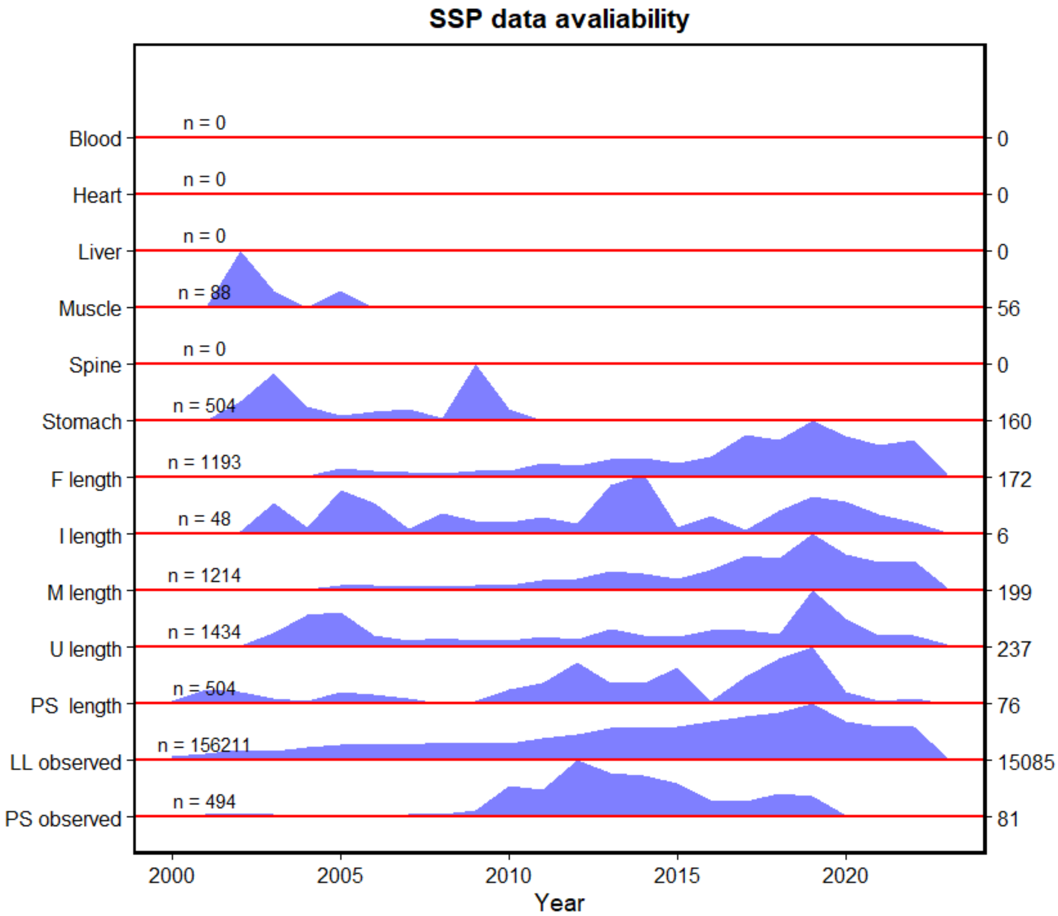


Figure 7: WCPFC data availability for shortbilled spearfish from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

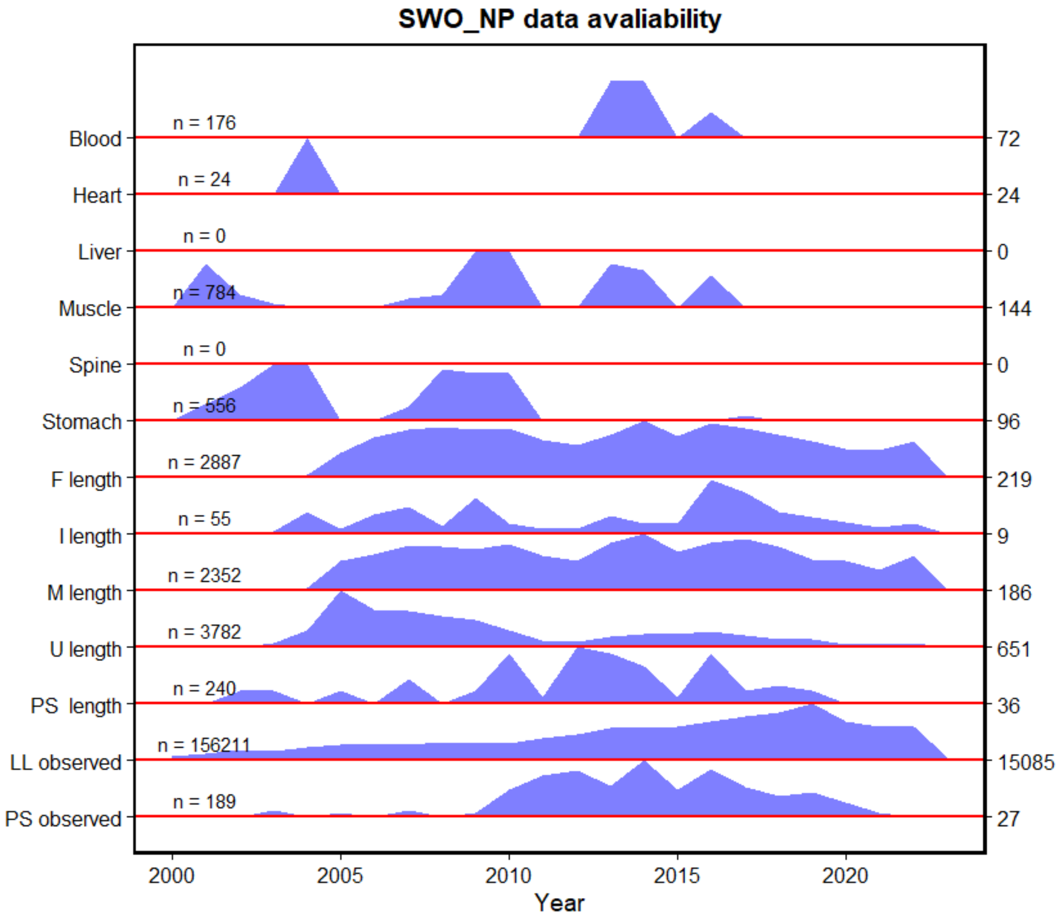


Figure 8: WCPFC data availability for swordfish in the north Pacific from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

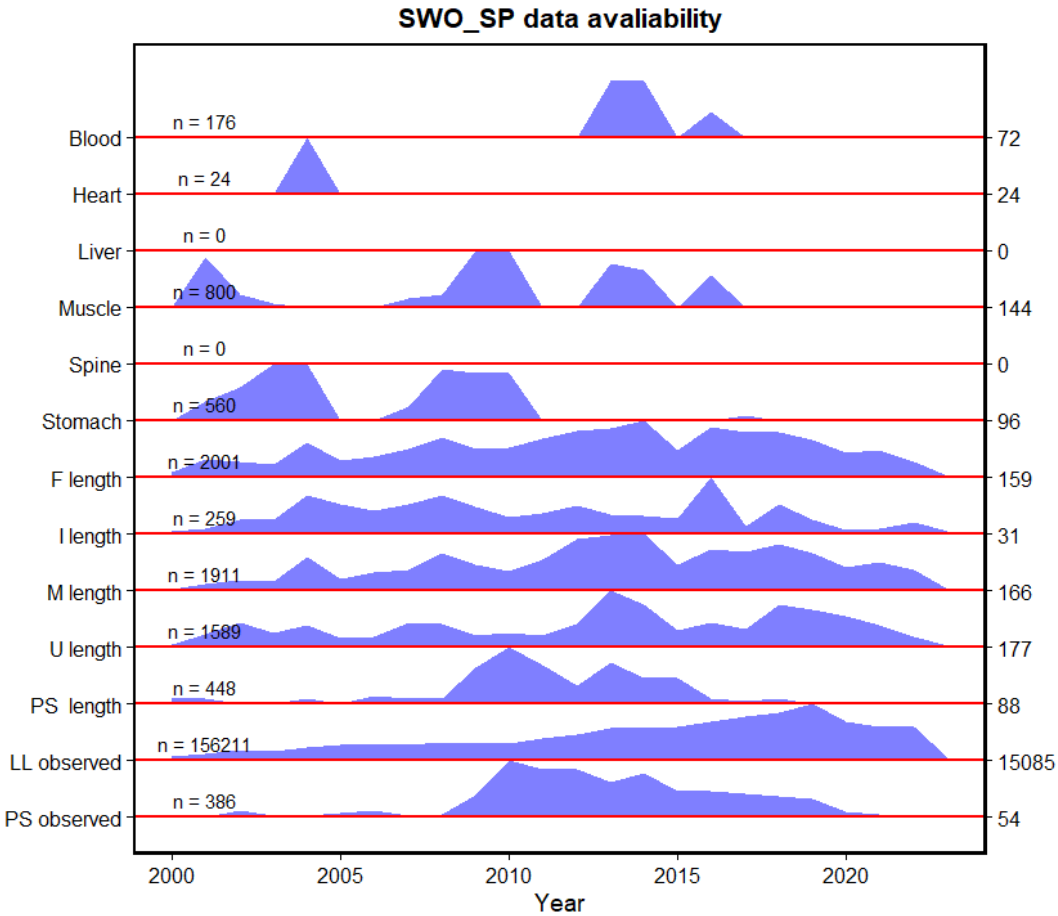


Figure 9: WCPFC data availability for swordfish in the south Pacific from 2000-2020 showing the data type, and the maximum number of annual samples collected, the width of the line represents the amount of data available relative to the biggest annual sample (number to the right). LL and PS observed number of observed individuals from the longline and purse seine fisheries respectively; blood, heart, muscle, liver, spine and stomach are the number of samples housed in the WCPFC tissue bank (`https://www.spc.int/ofp/PacificSpecimenBank`).

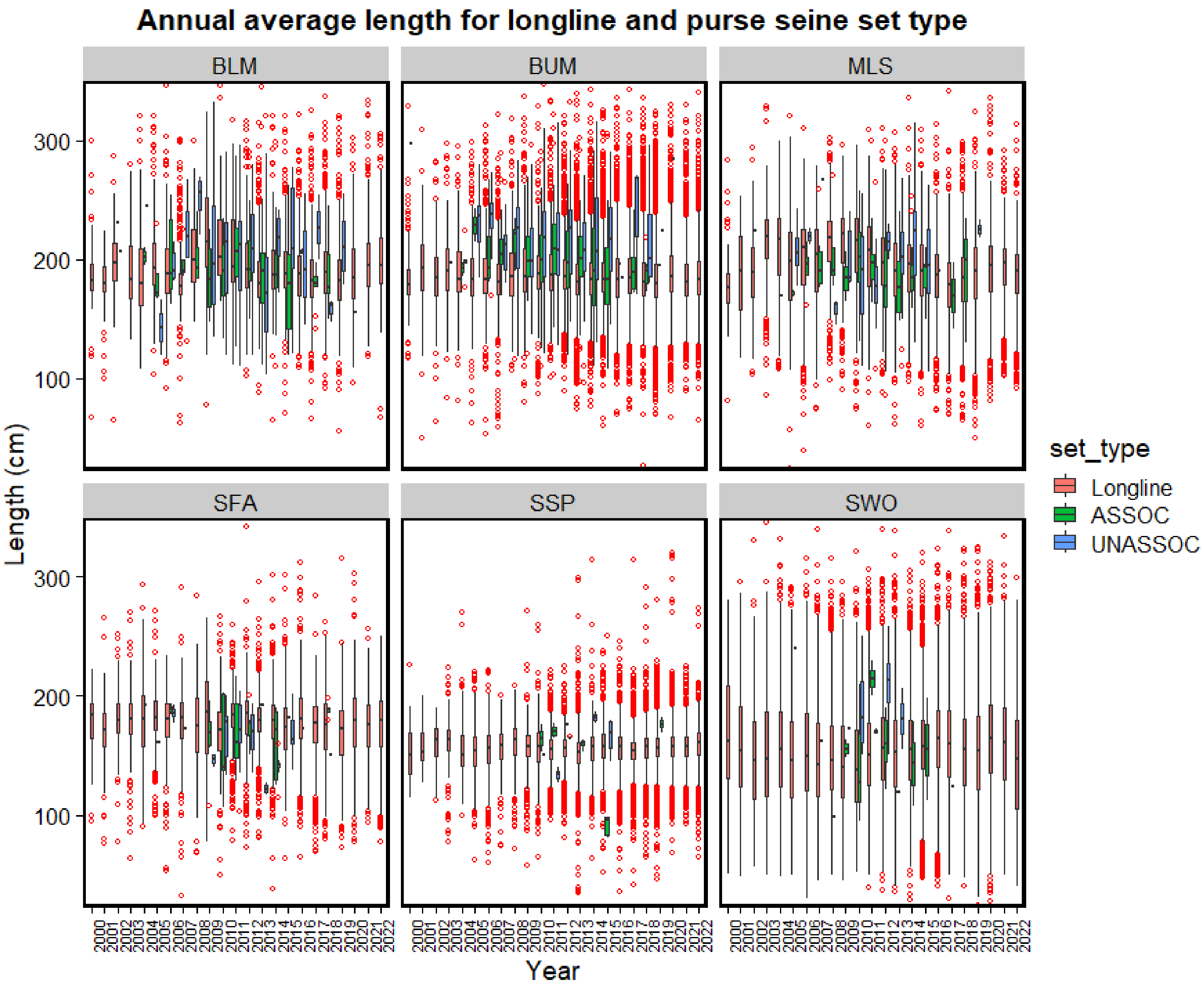


Figure 10: WCPFC observed billfish length by year for observed catch in the longline and purse seine FAD associated (ASSOC) and unassociated (UNASSOC) sets.

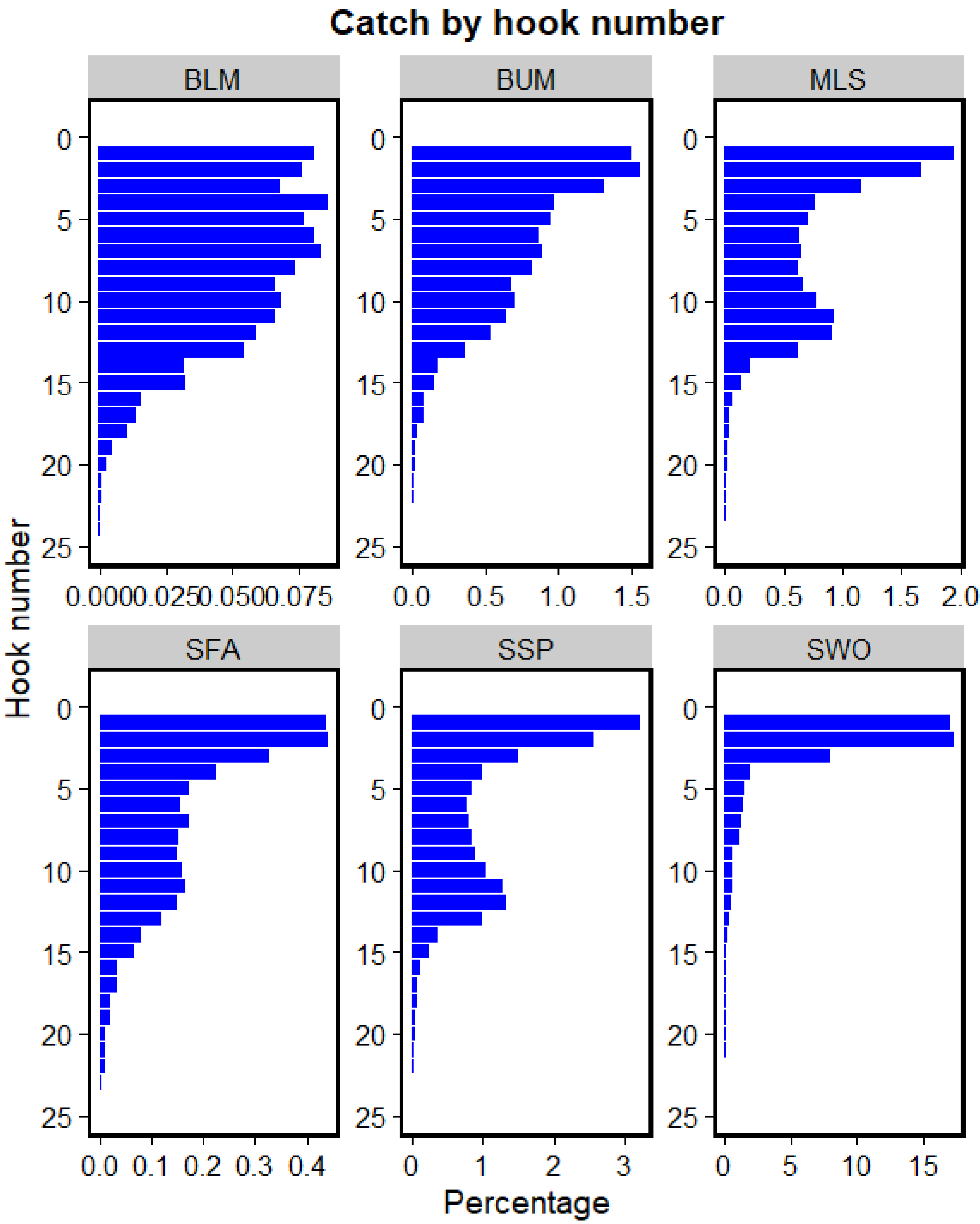


Figure 11: WCPFC observed longline billfish catch proportions by hook number in the longline set.

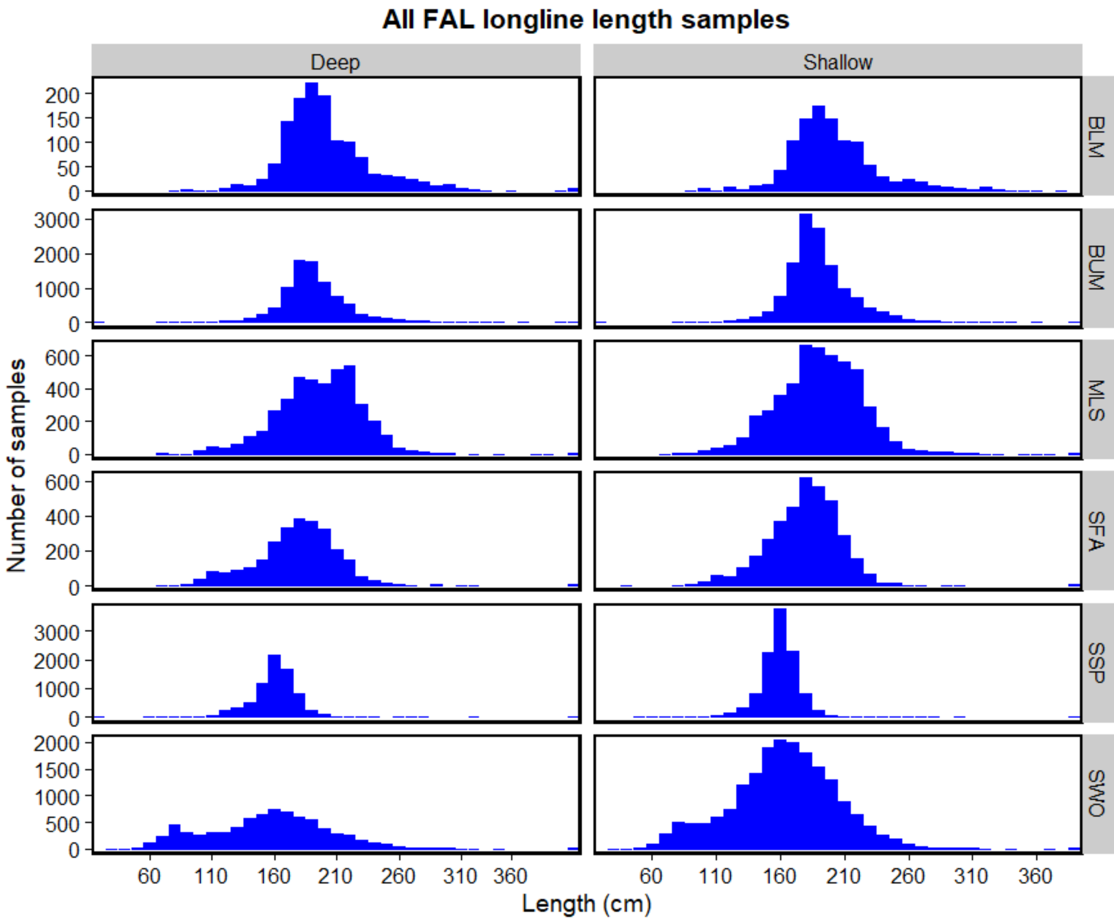


Figure 12: WCPFC observed billfish length distribution by depth of capture for observed catch in the longline fisheries. Estimated from the hook number where fish caught on hooks 7 and above were considered deep and those on hooks 6 or less shallow.

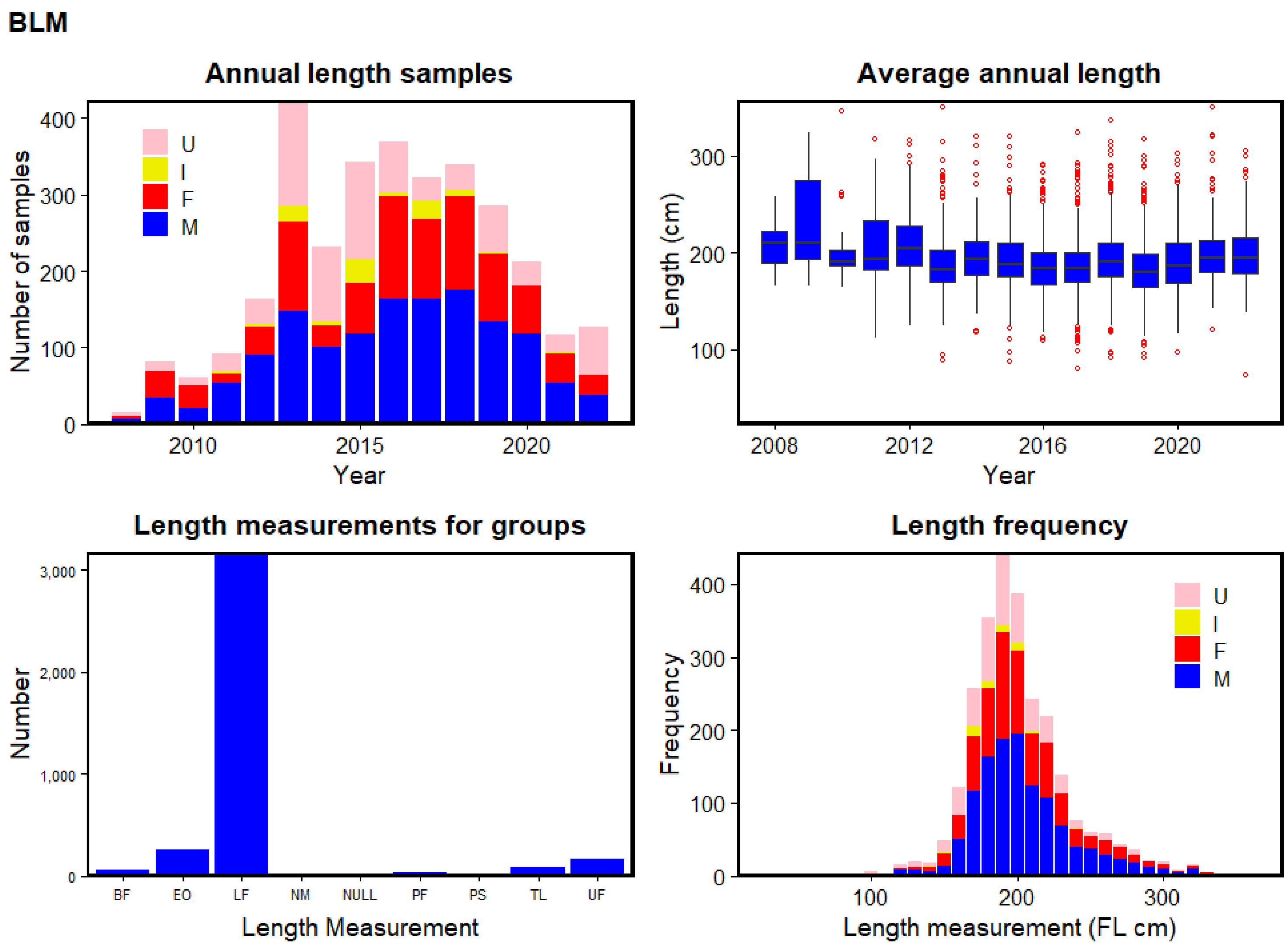


Figure 13: WCPFC observed black marlin length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

BUM

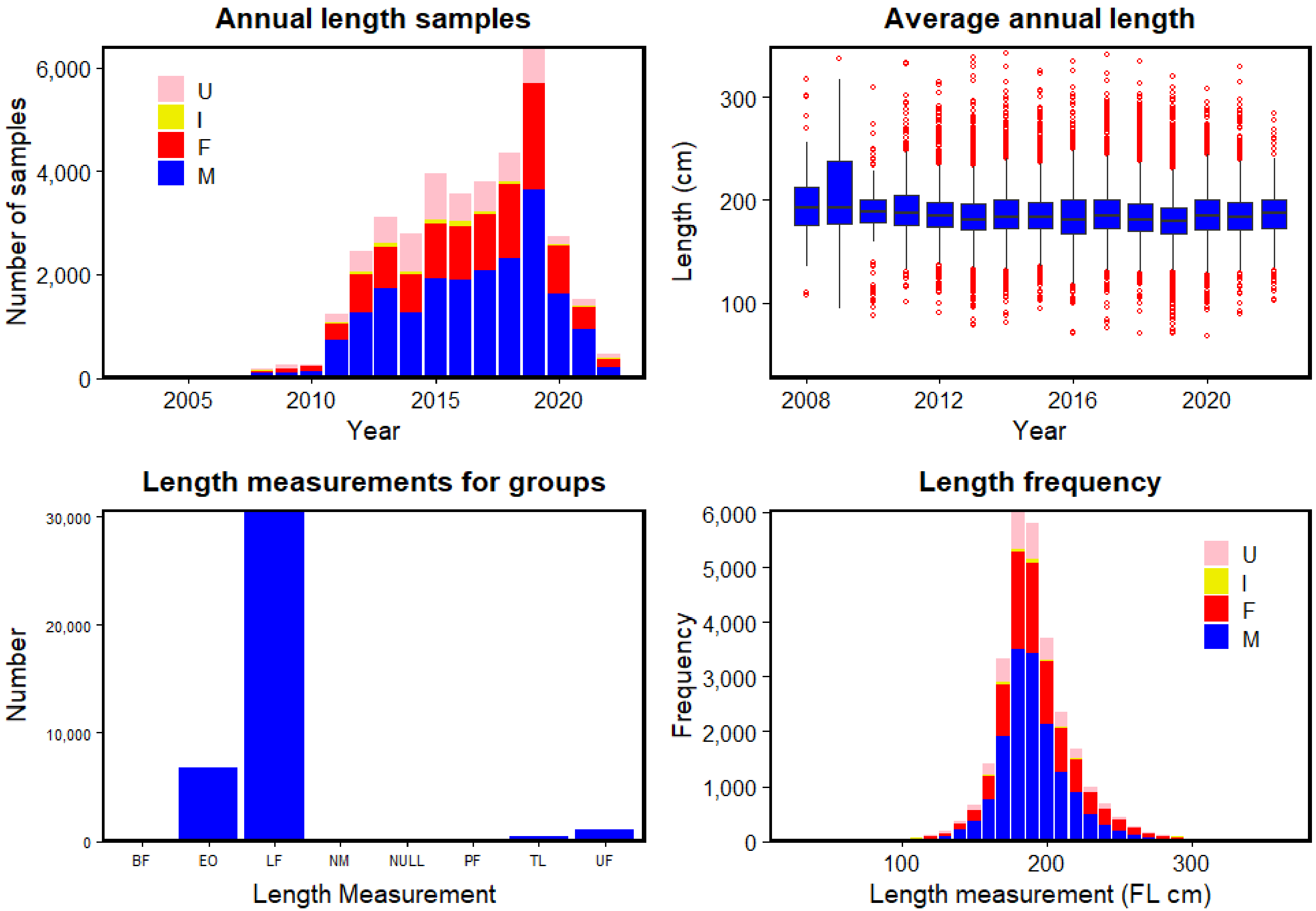


Figure 14: WCPFC observed blue marlin length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

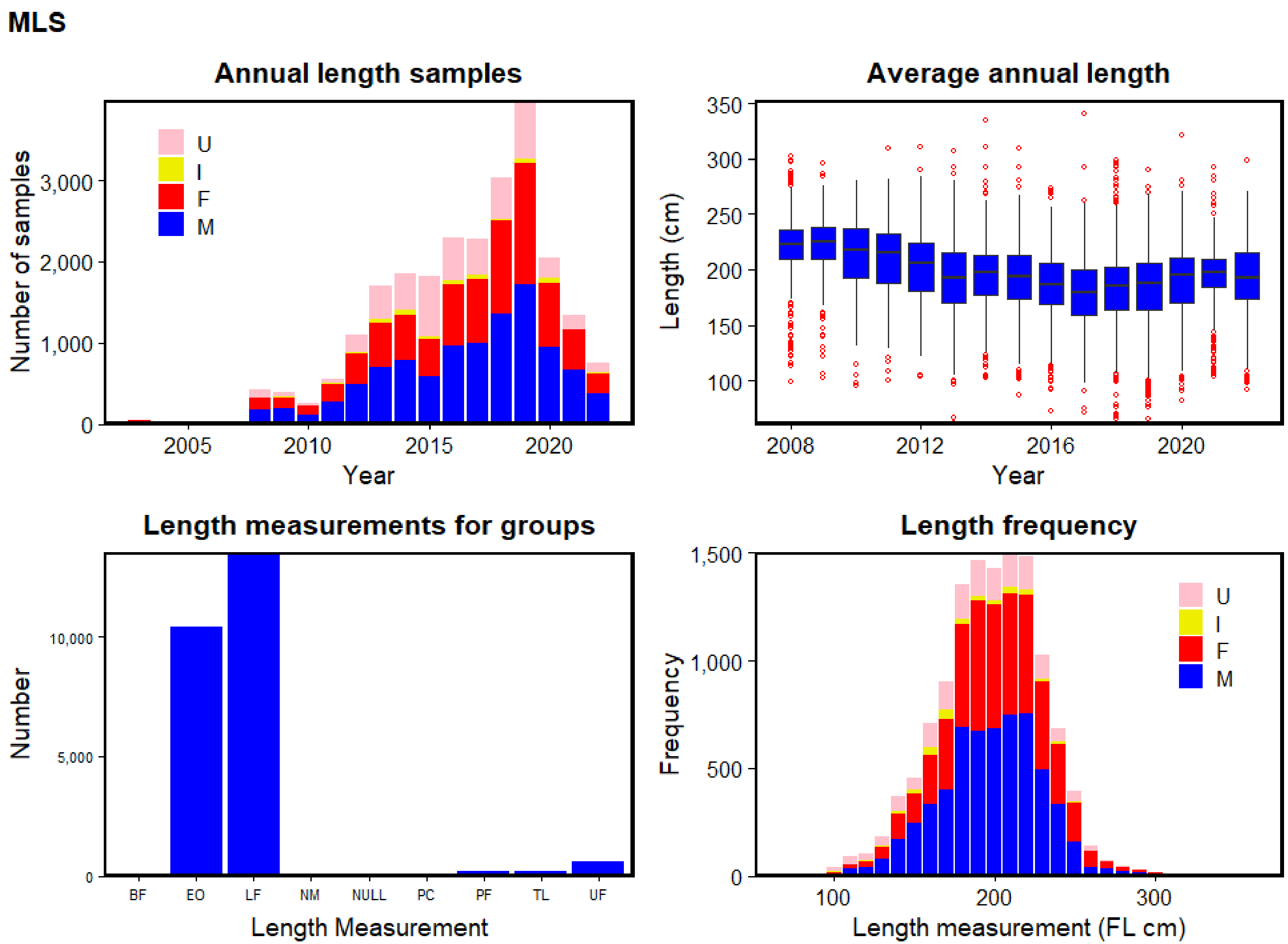


Figure 15: WCPFC observed striped marlin length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

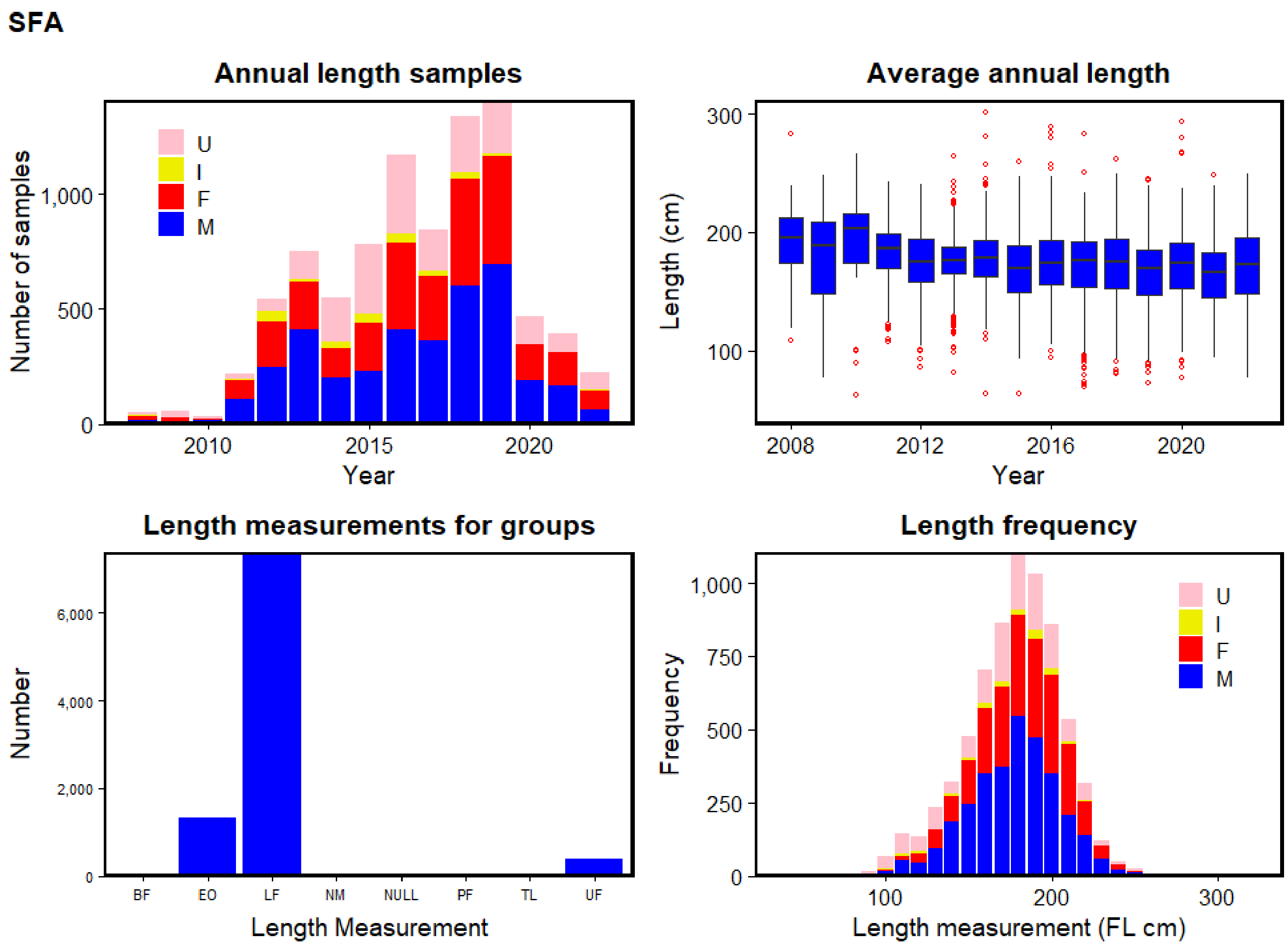


Figure 16: WCPFC observed sailfish length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

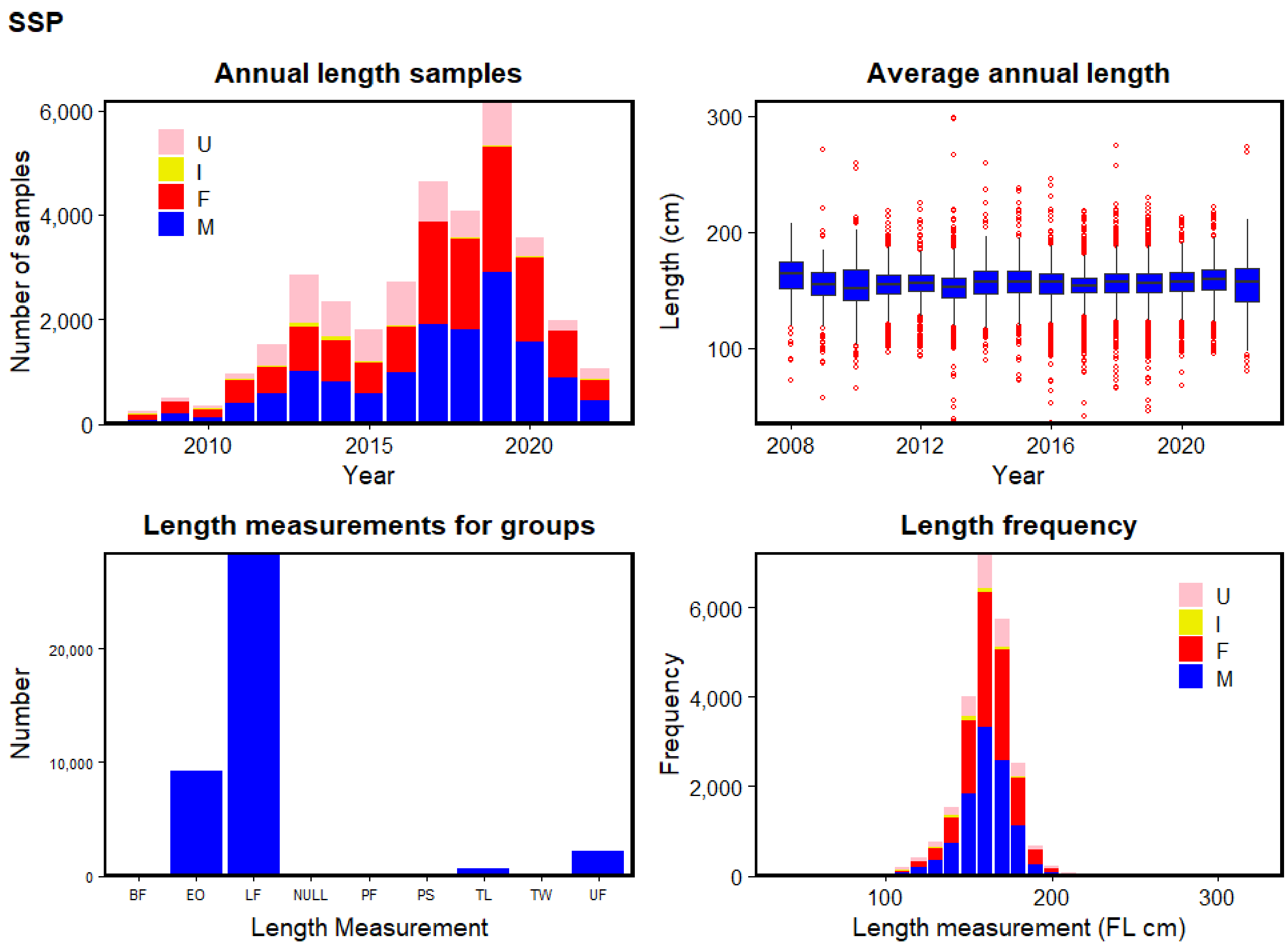


Figure 17: WCPFC observed shortbill spearfish length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

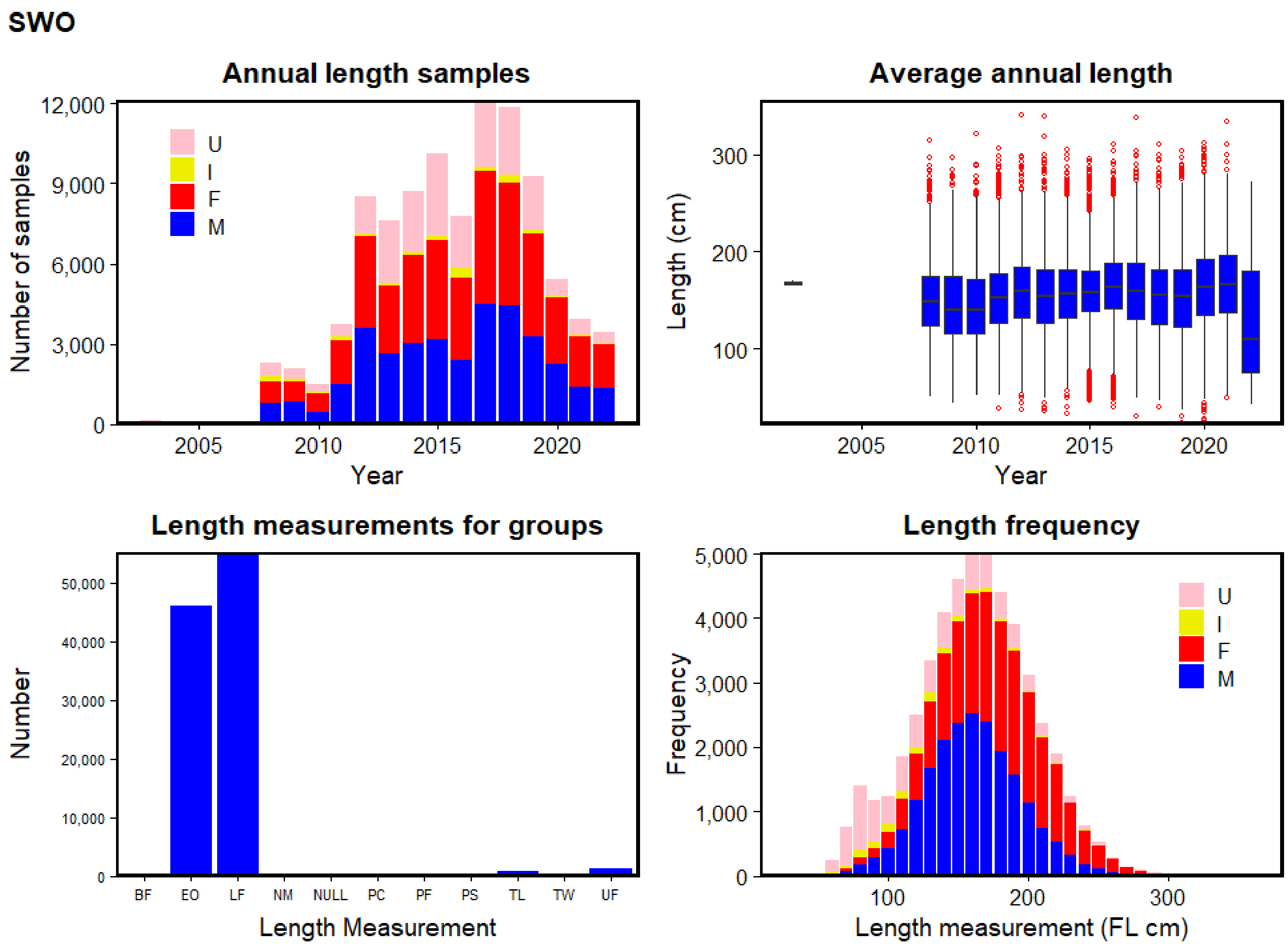


Figure 18: WCPFC observed swordfish length samples by year (top left); mean length by year (top right); length measurement type (bottom left); and length frequency distribution by sex (bottom right)from longline vessels.

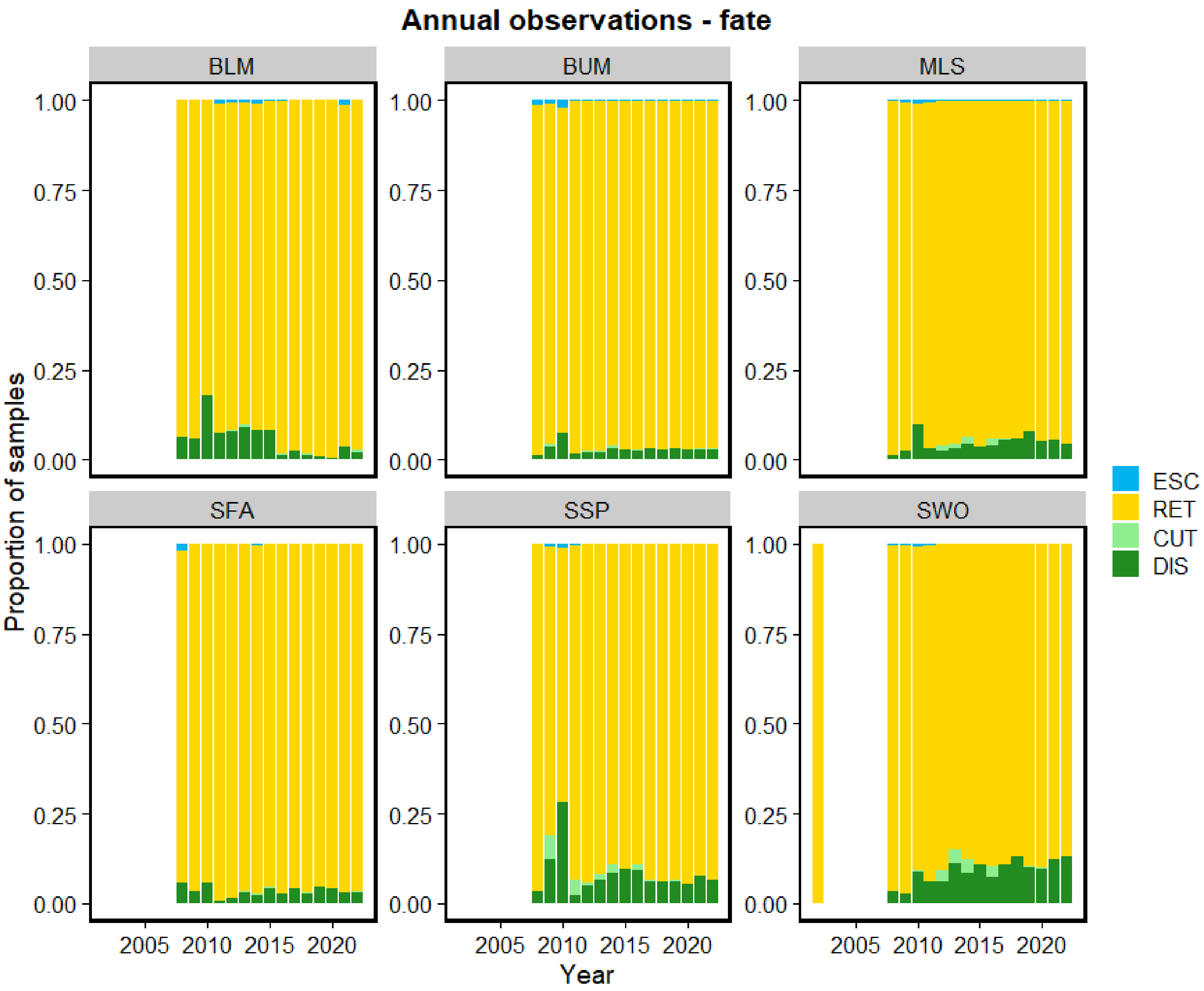


Figure 19: The fate of billfish caught in longline sets within the WCPO. Species code names can be found in Table 2, ESC = escaped, RET = retained, CUT = cut-free, DIS = discarded.

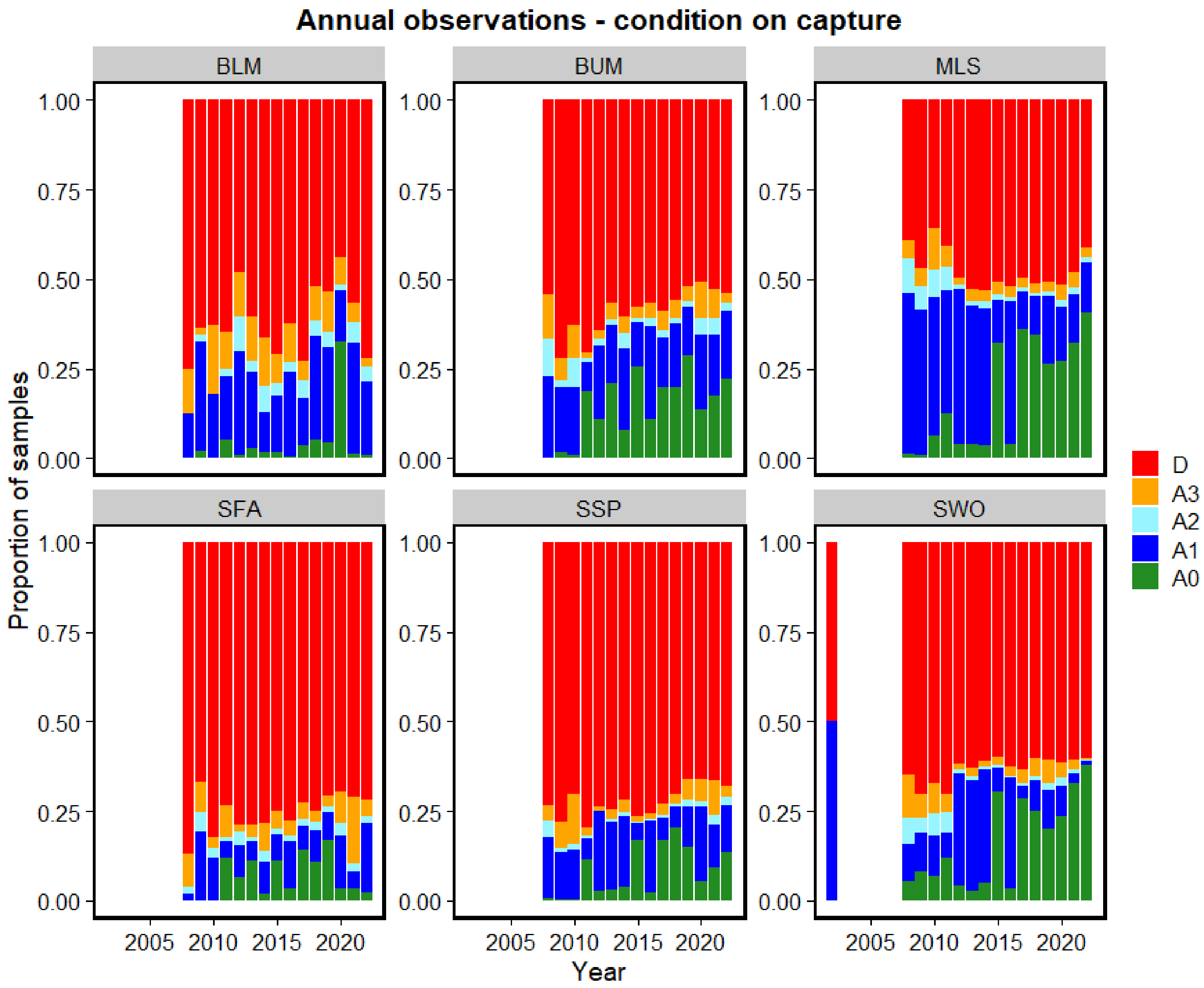


Figure 20: The condition on capture of billfish caught in longline sets within the WCPO. Species code names can be found in Table 2, D = dead, A3 = alive and severely injured, A2 = alive and injured, A1 = alive and healthy, A0 = alive health status unknown.

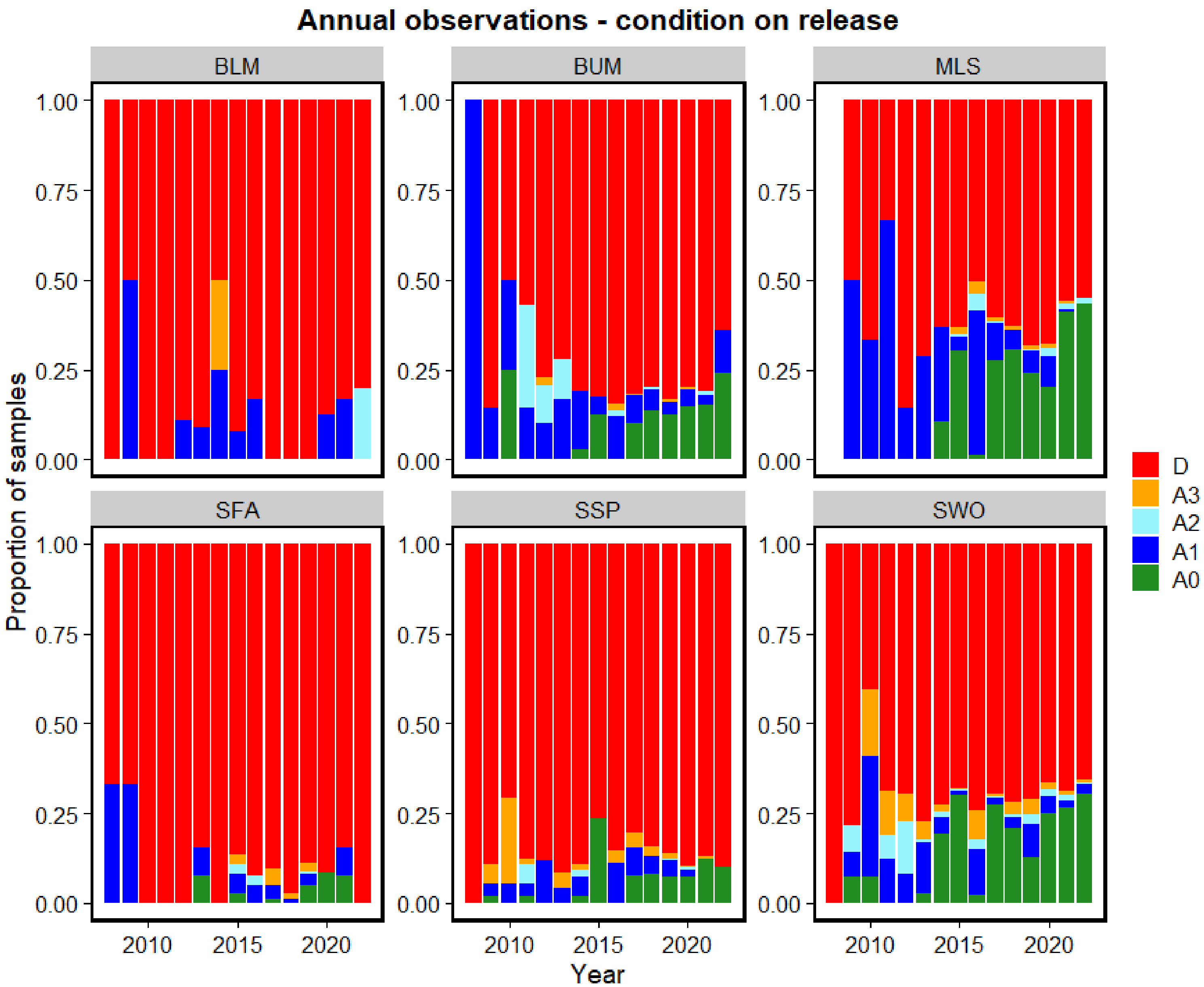


Figure 21: The condition on release of billfish caught in longline sets within the WCPO. Species code names can be found in Table 2, D = dead, A3 = alive and severely injured, A2 = alive and injured, A1 = alive and healthy, A0 = alive health status unknown.

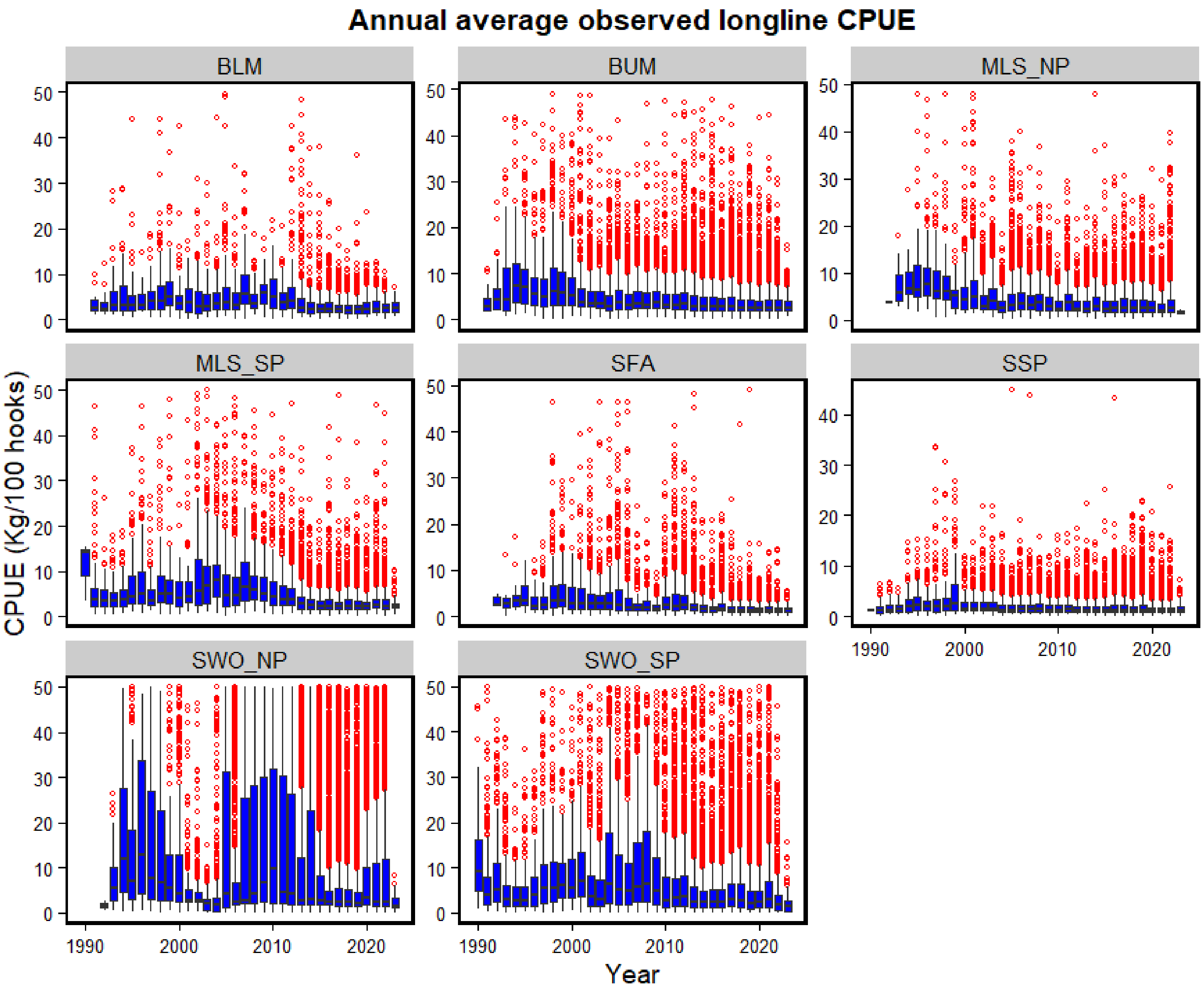


Figure 22: WCPFC observed longline billfish CPUE by year.

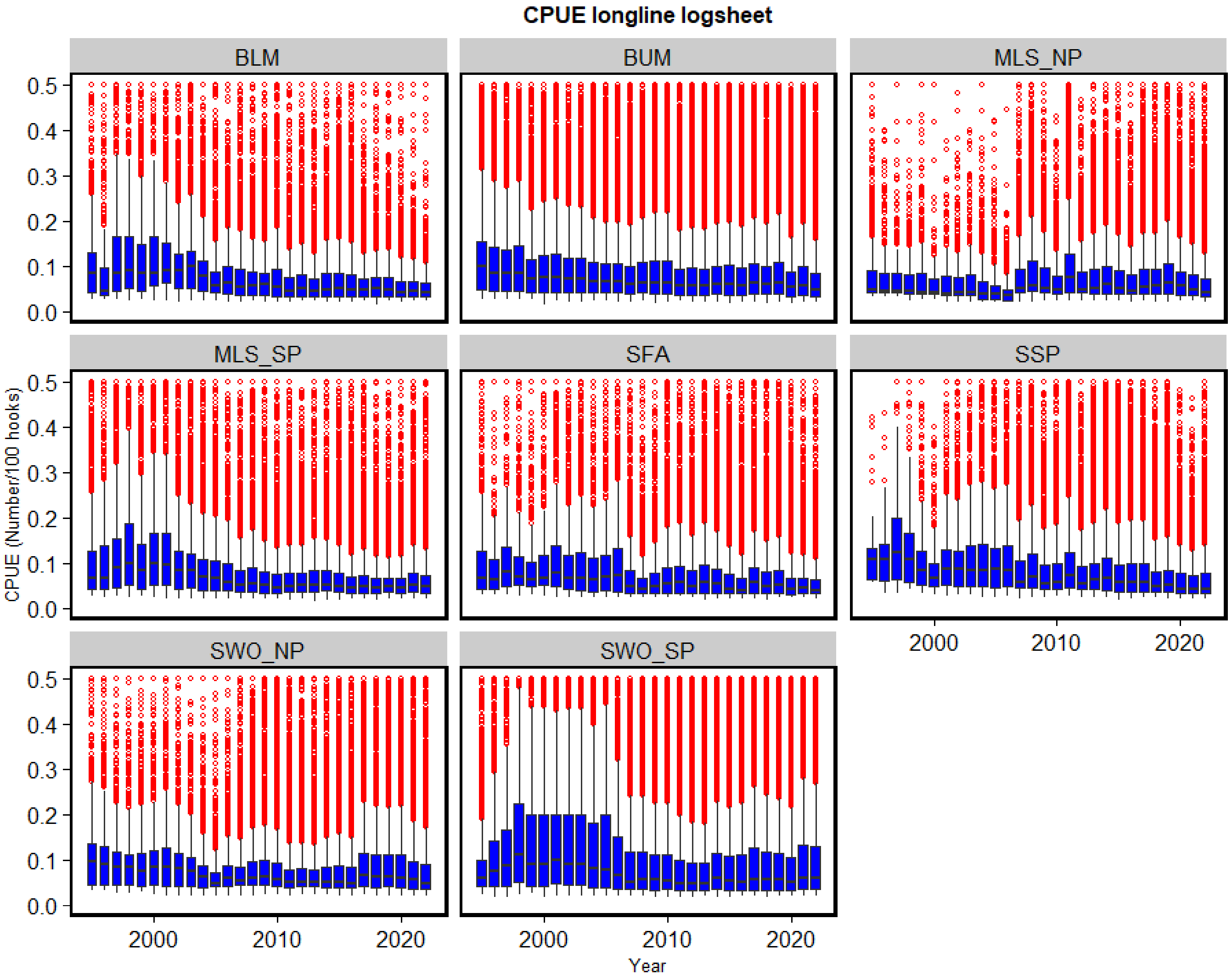


Figure 23: WCPFC longline logsheet billfish CPUE by year.

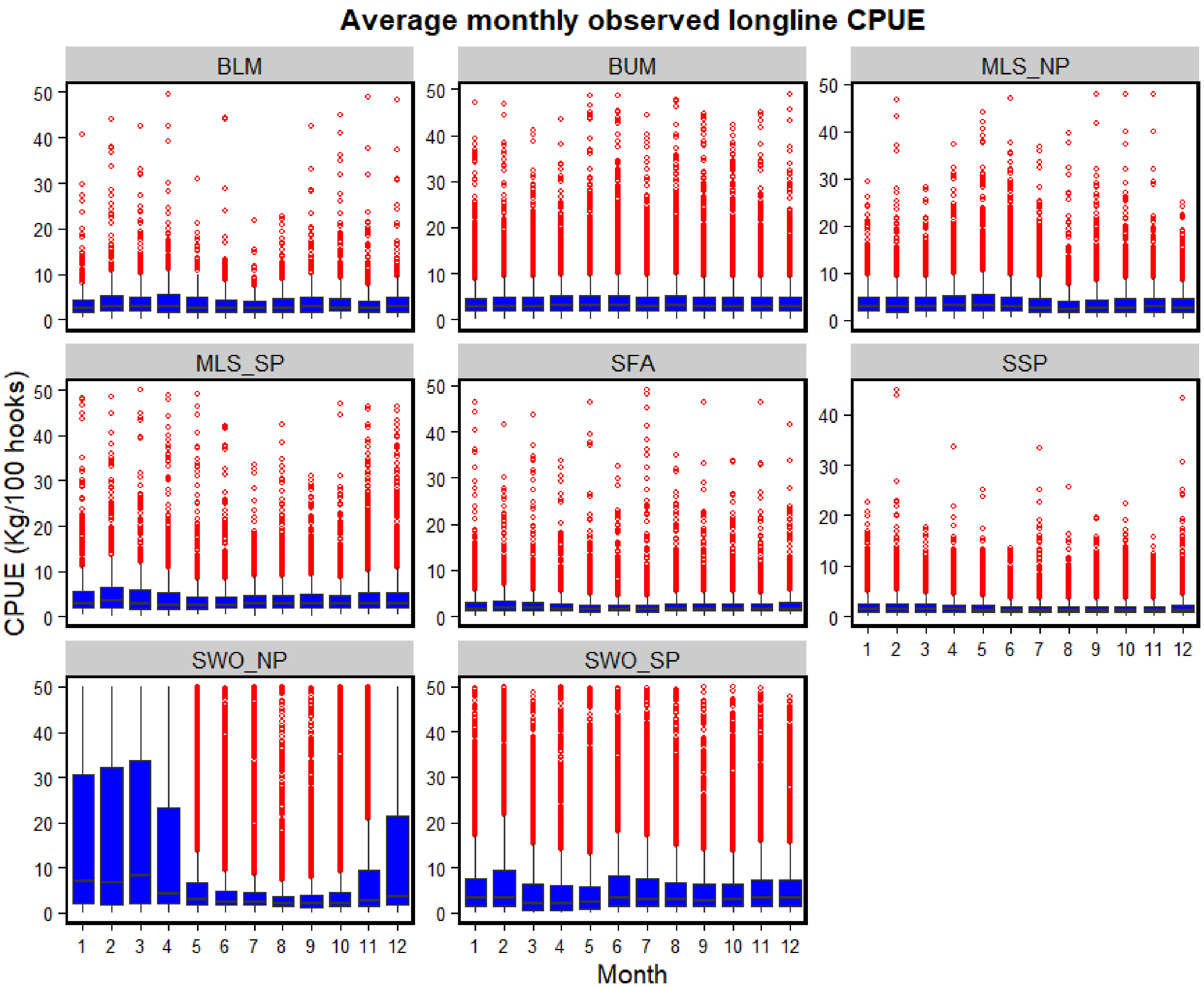


Figure 24: WCPFC observed longline billfish CPUE by month of the year.

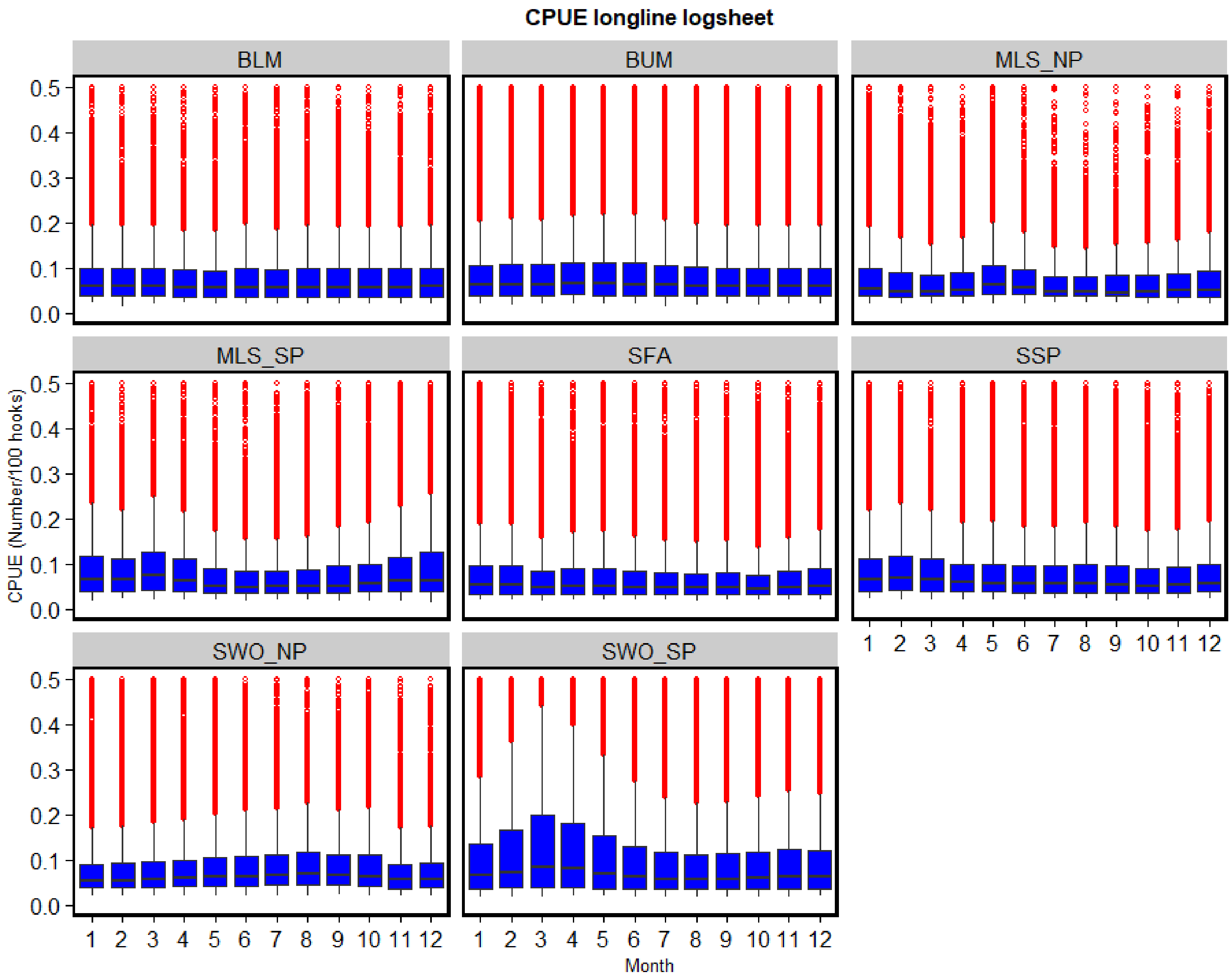


Figure 25: WCPFC longline logsheet billfish CPUE by month of the year.

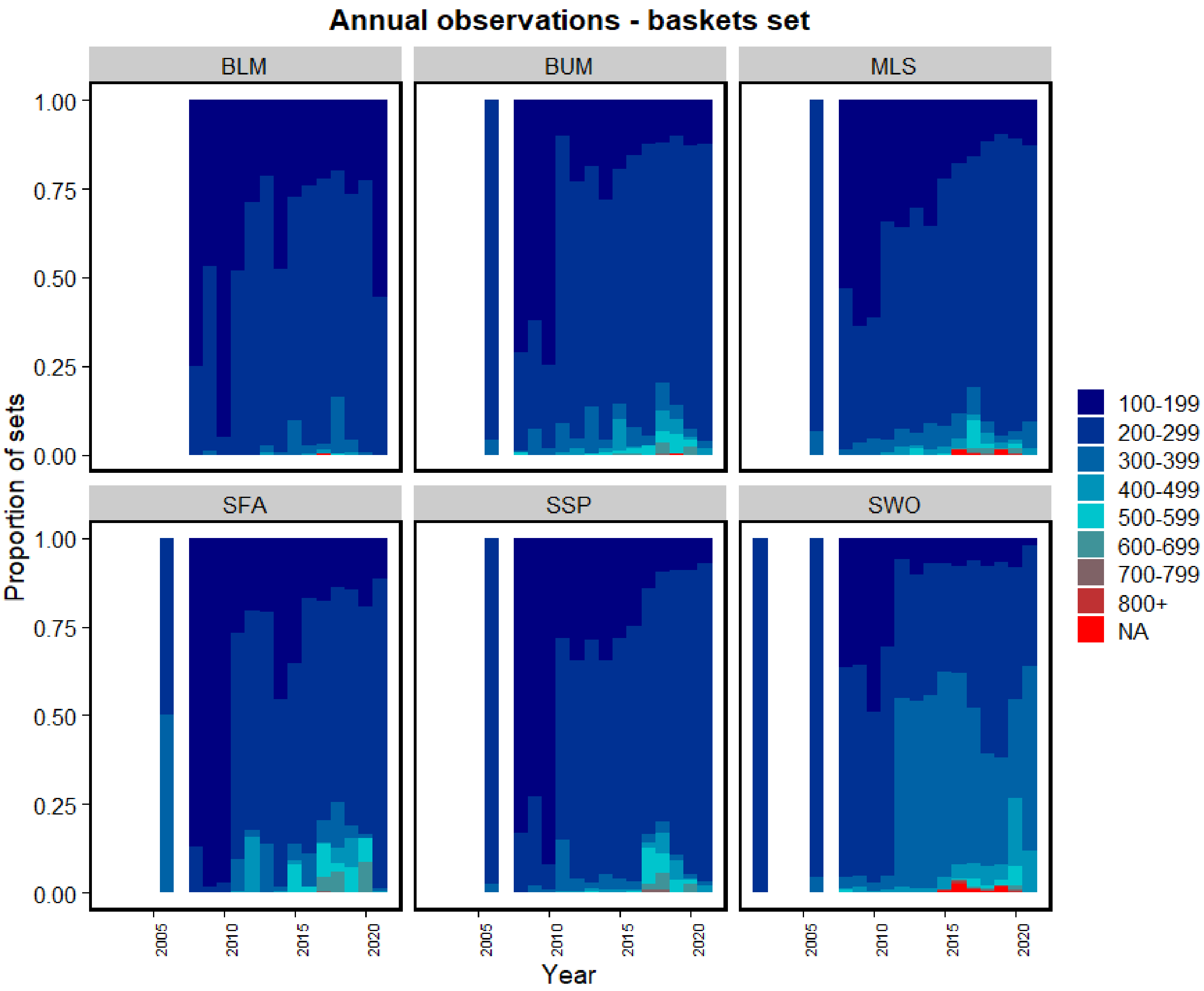


Figure 26: WCPFC proportions of sets with different numbers of baskets that accounted for observed billfish catches.

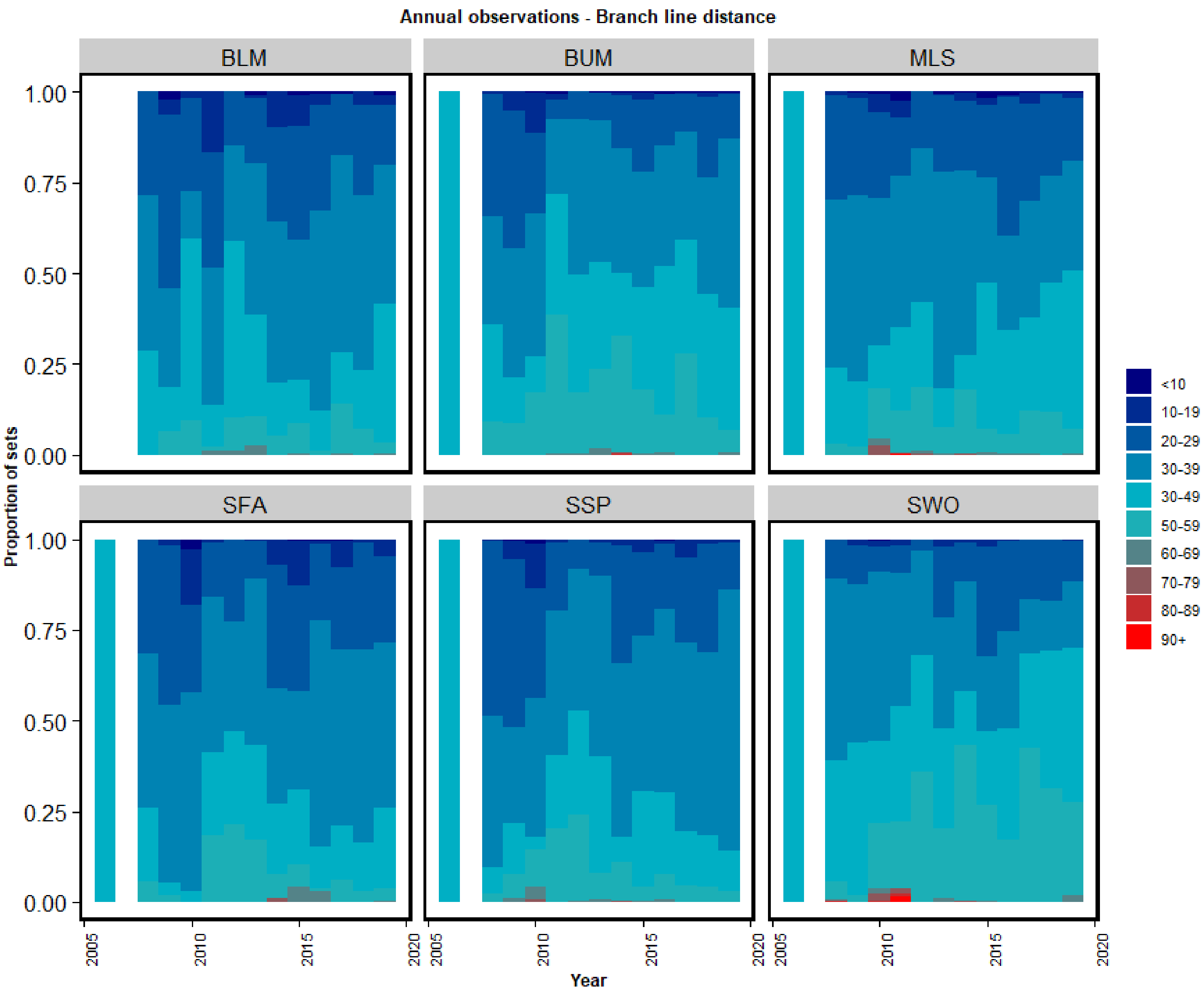


Figure 27: WCPFC proportions of sets with different branchline distance that accounted for observed billfish catches.

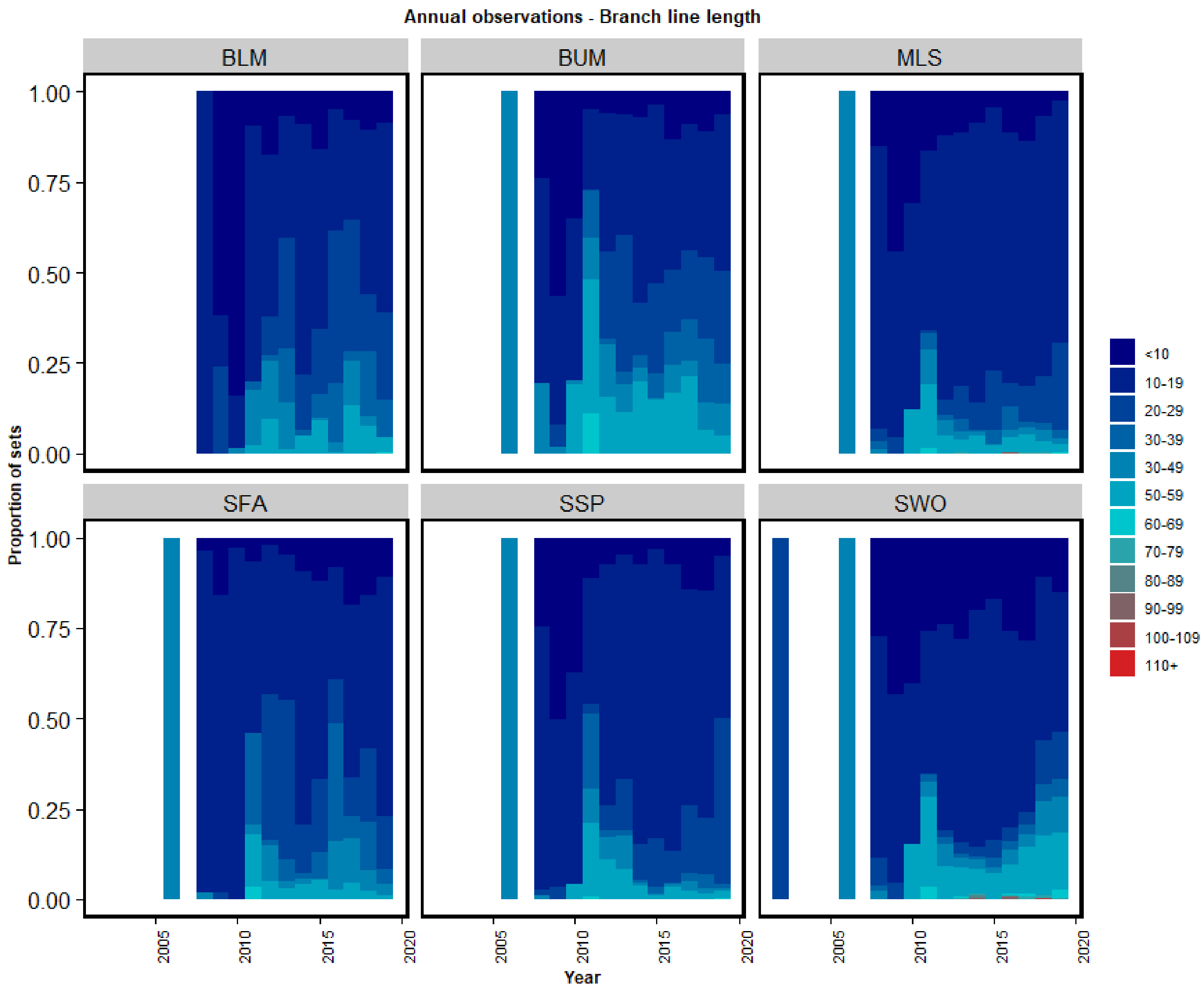


Figure 28: WCPFC proportions of sets with different branchline lengths that accounted for observed billfish catches.

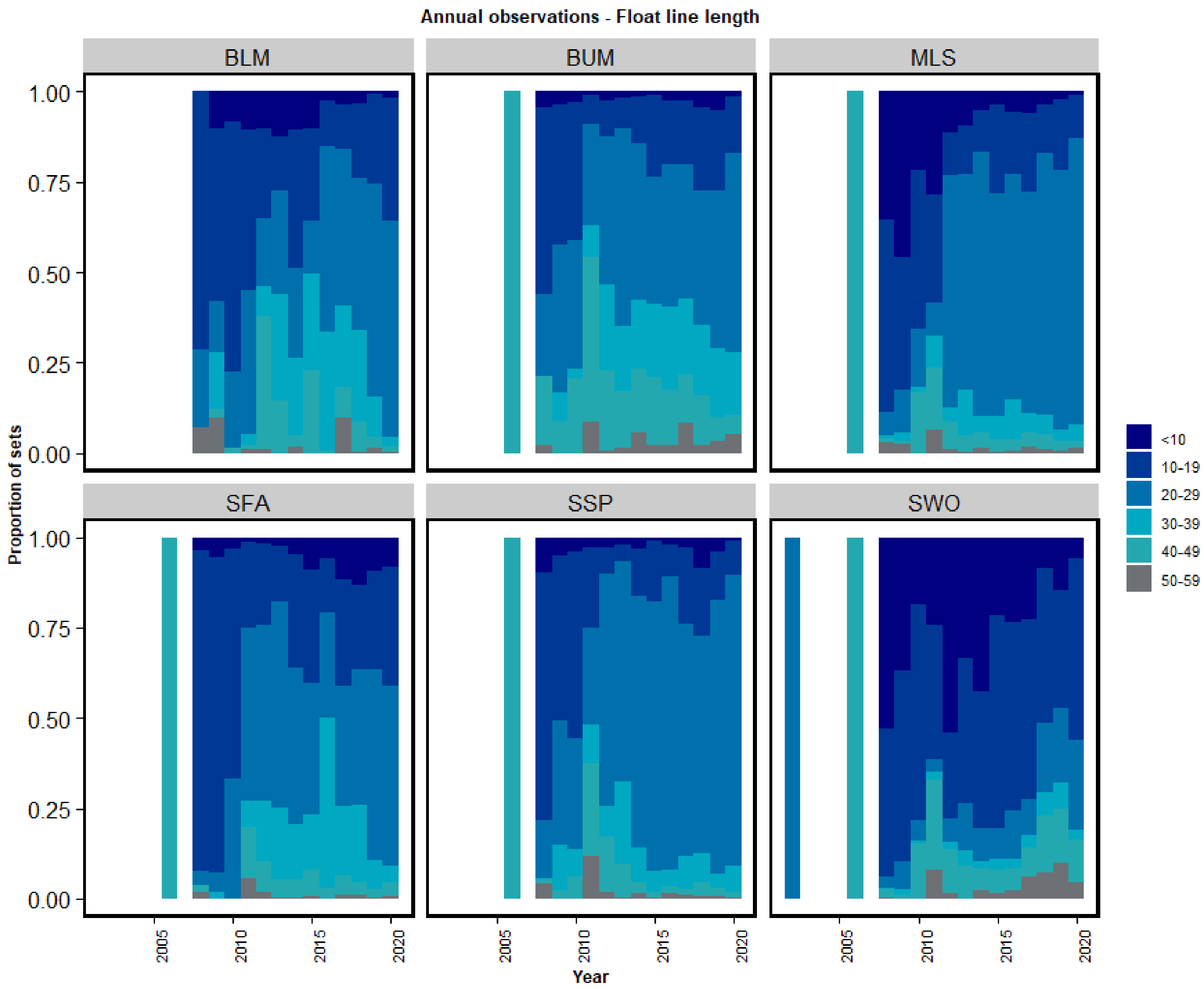


Figure 29: WCPFC proportions of sets with different floatline lengths that accounted for observed billfish catches.

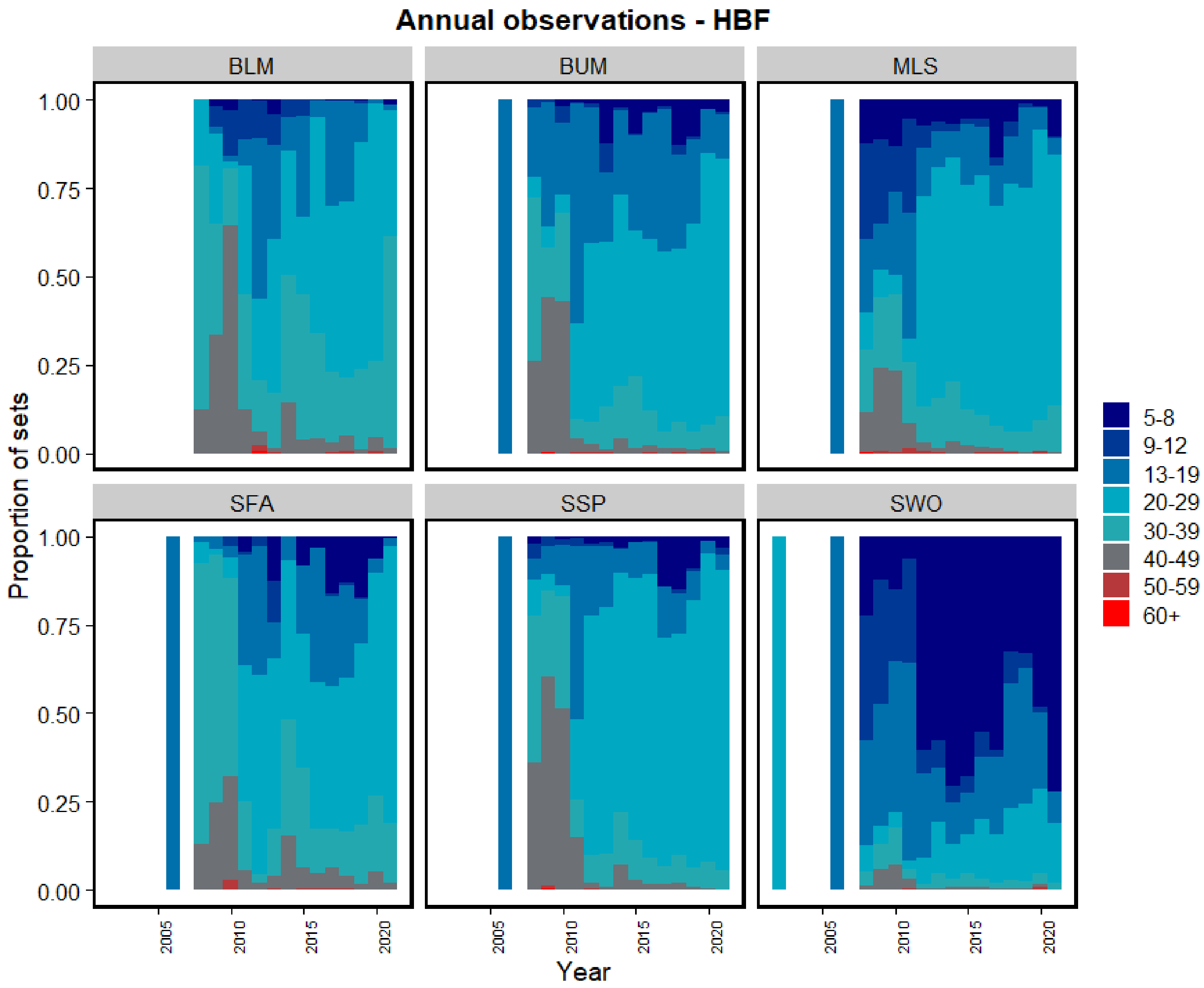


Figure 30: WCPFC proportions of sets with different numbers of hooks between floats that accounted for observed billfish catches.

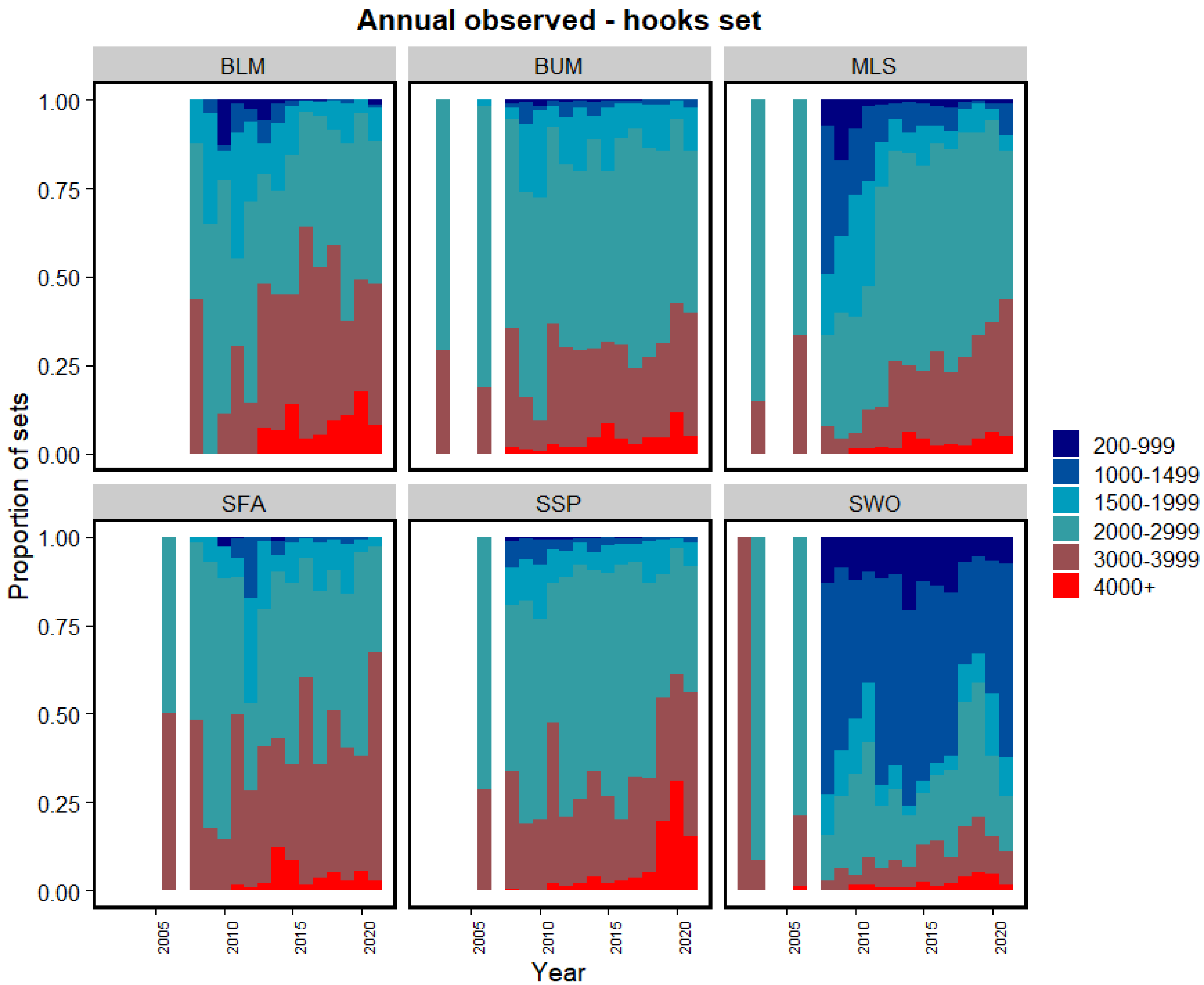


Figure 31: WCPFC proportions of sets with different numbers total hooks set that accounted for observed billfish catches.

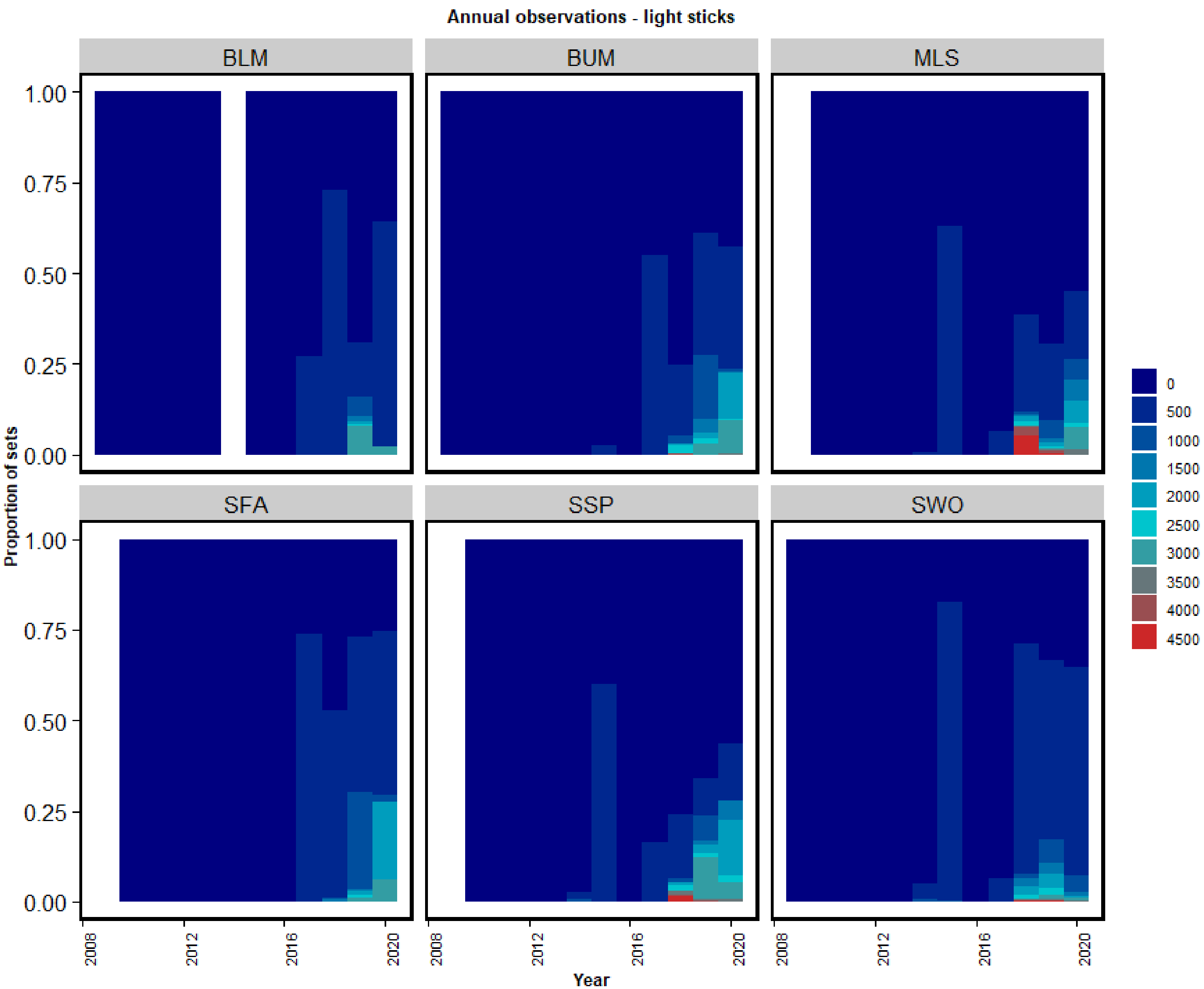


Figure 32: WCPFC proportions of sets with different numbers of lightsticks set that accounted for observed billfish catches.

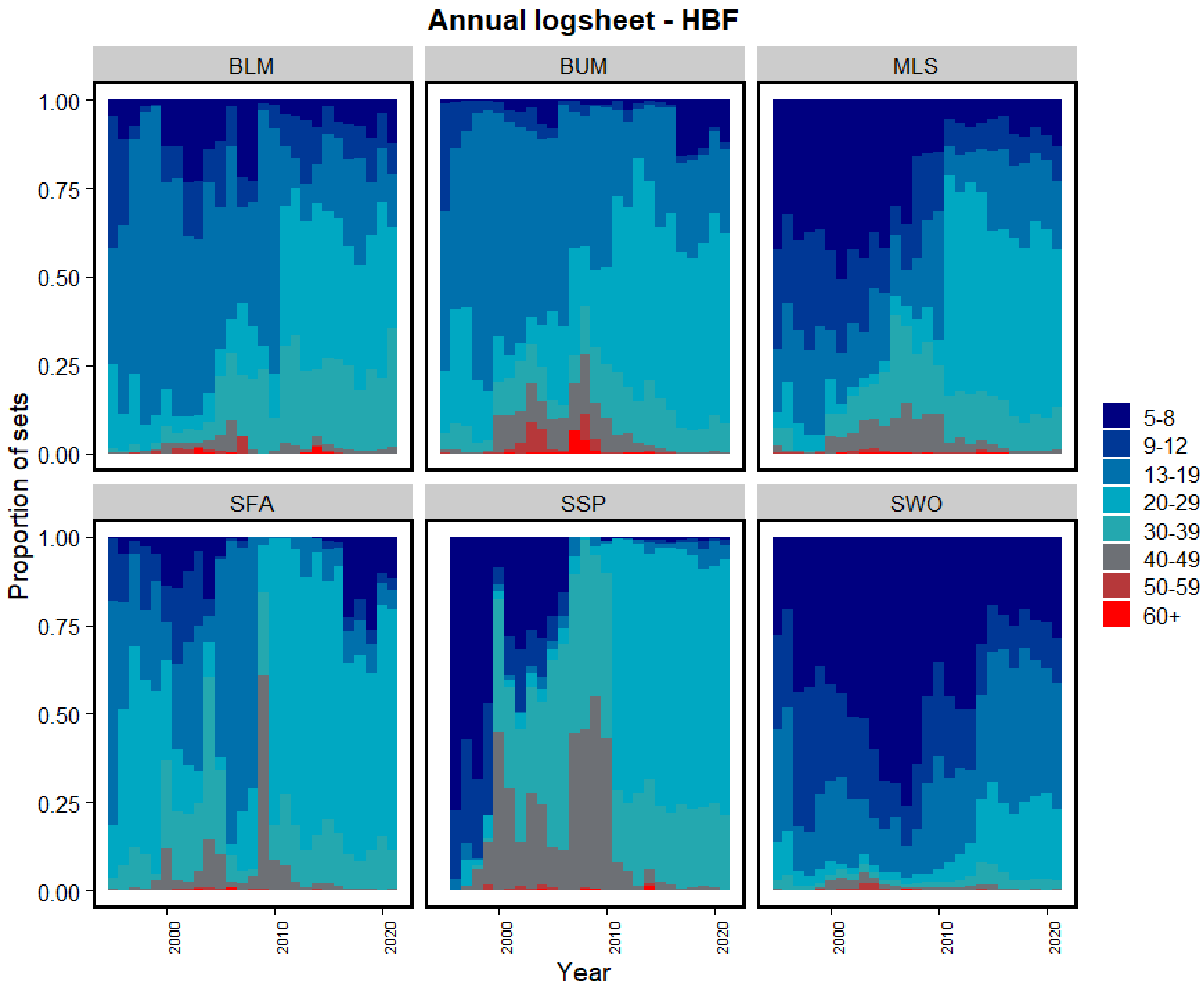


Figure 33: WCPFC logsheet recorded hook between floats by WCPFC observer program.

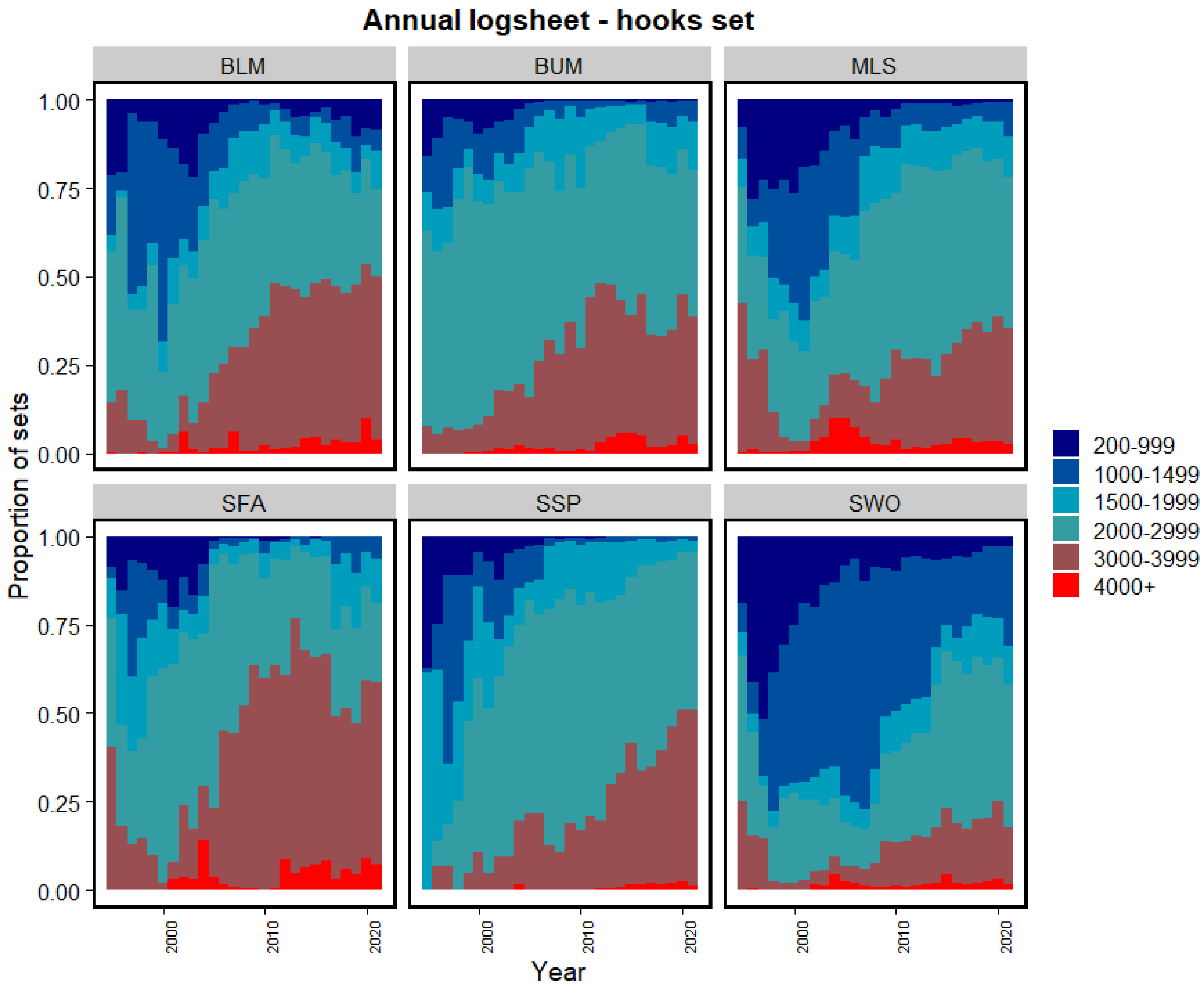


Figure 34: WCPFC logsheet recorded proportions of sets with different numbers total hooks set that accounted for billfish catch.

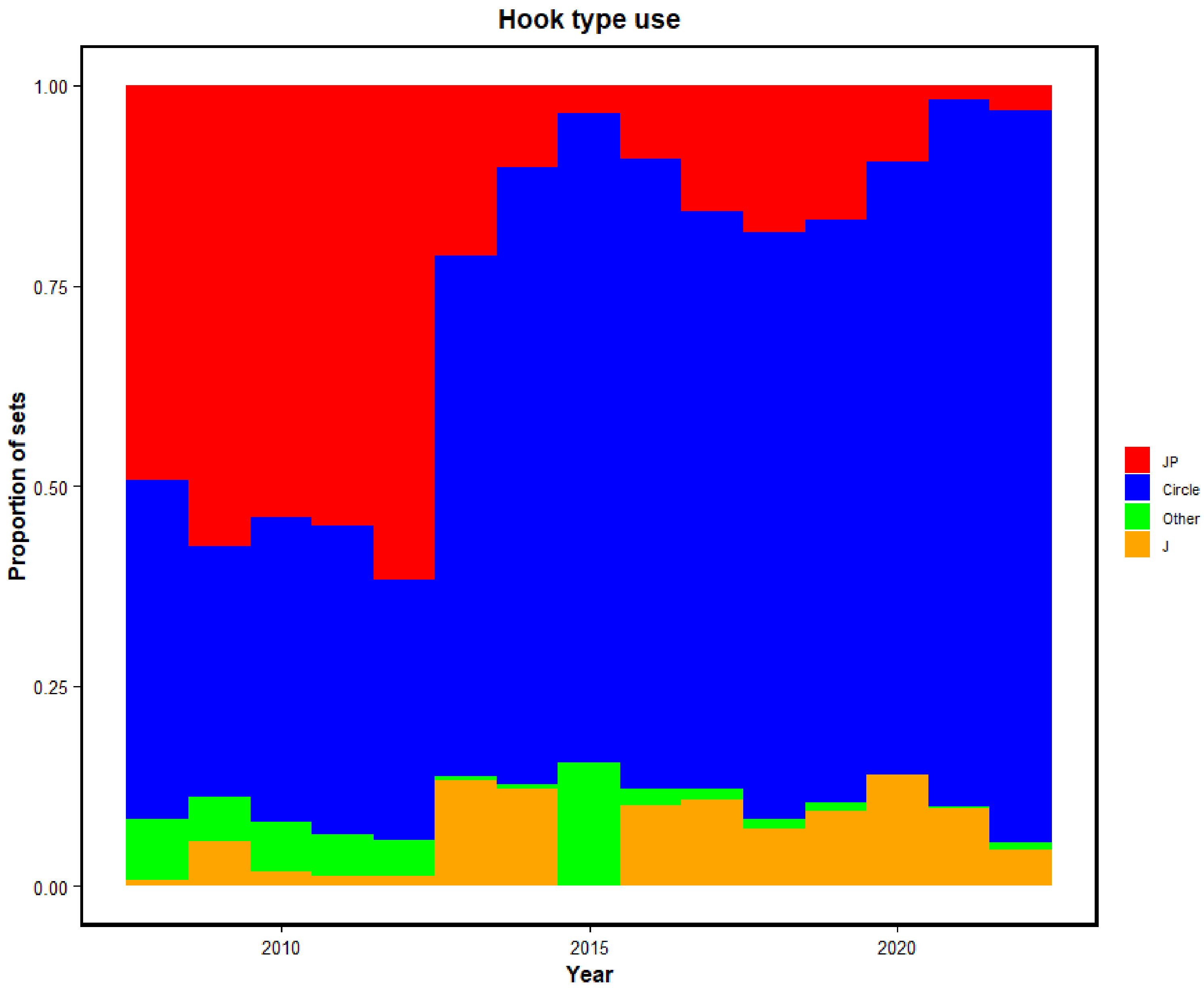


Figure 35: WCPFC observer recorded hook type on all sets.

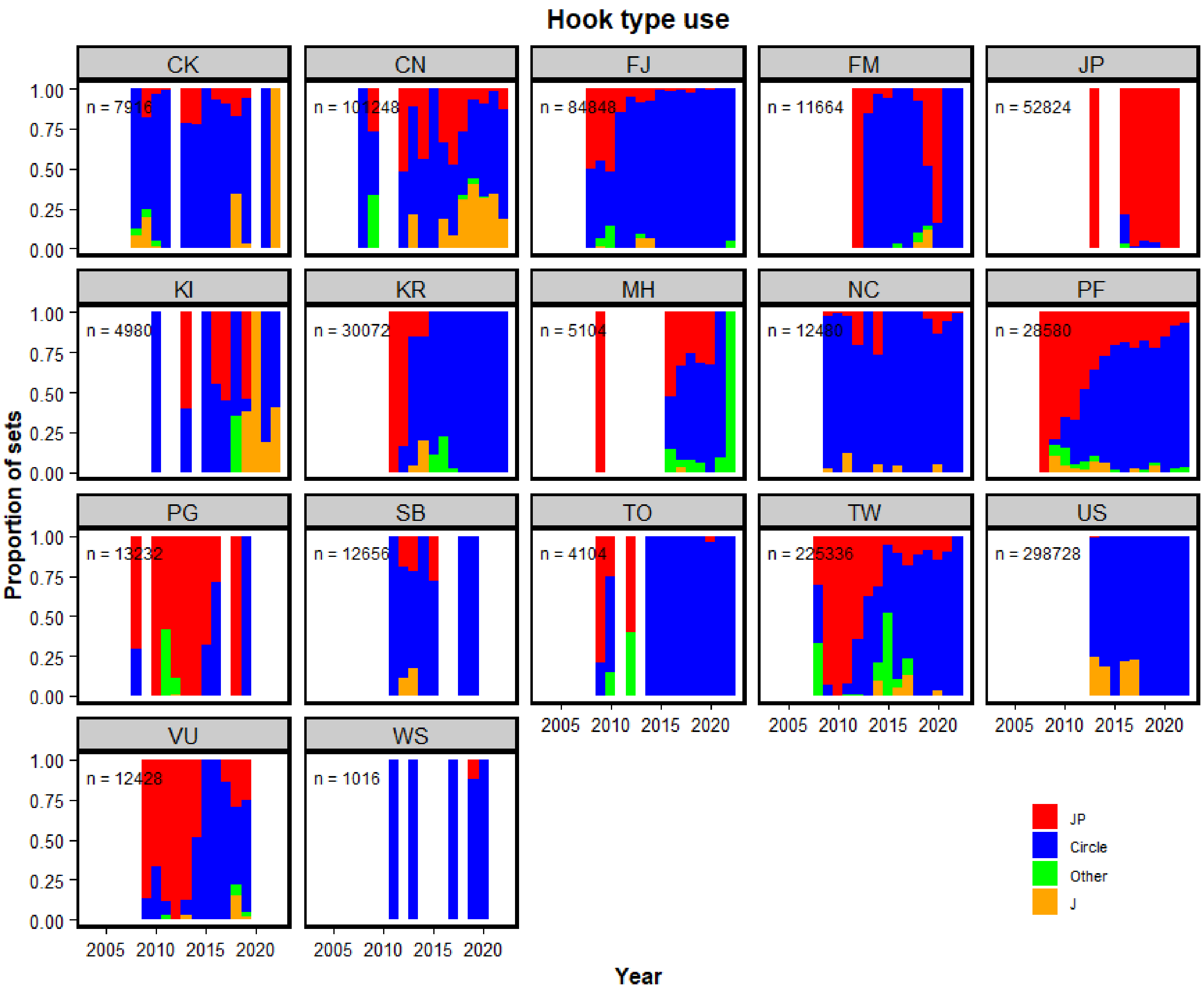


Figure 36: WCPFC observer recorded hook type by flag on all sets.

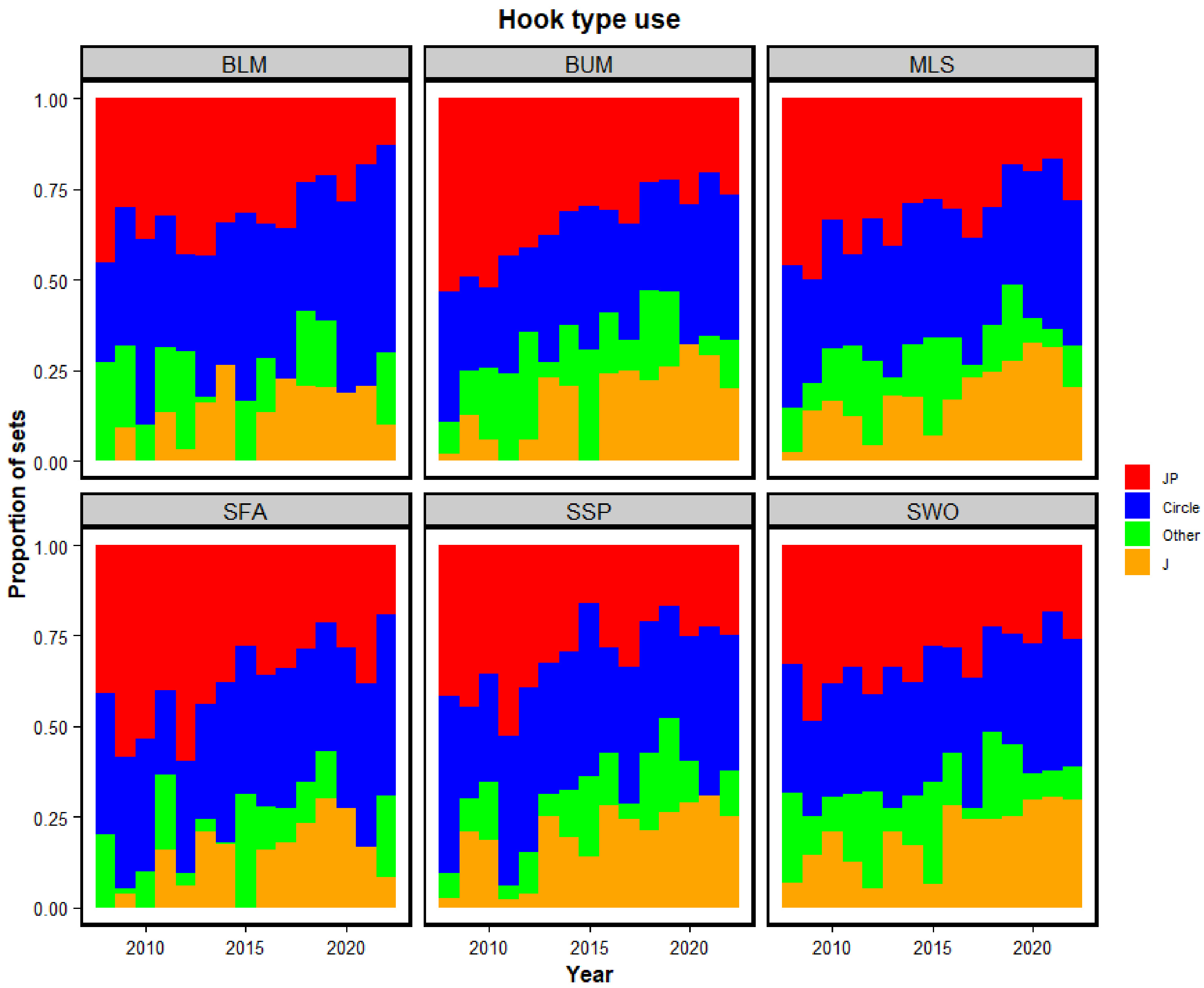


Figure 37: WCPFC observer recorded hook type set that accounted for billfish catch.

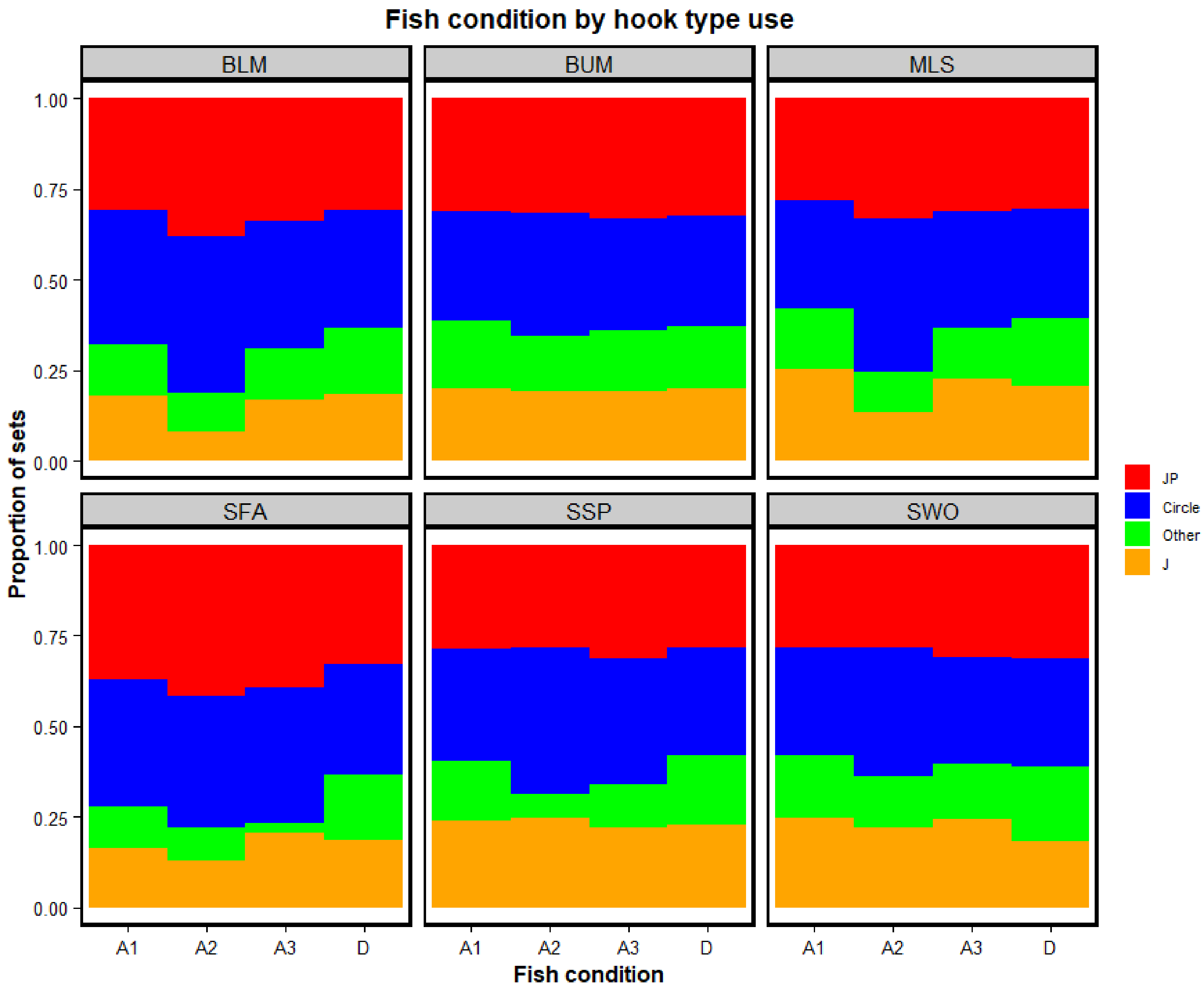


Figure 38: WCPFC observer recorded fish condition by hook type.

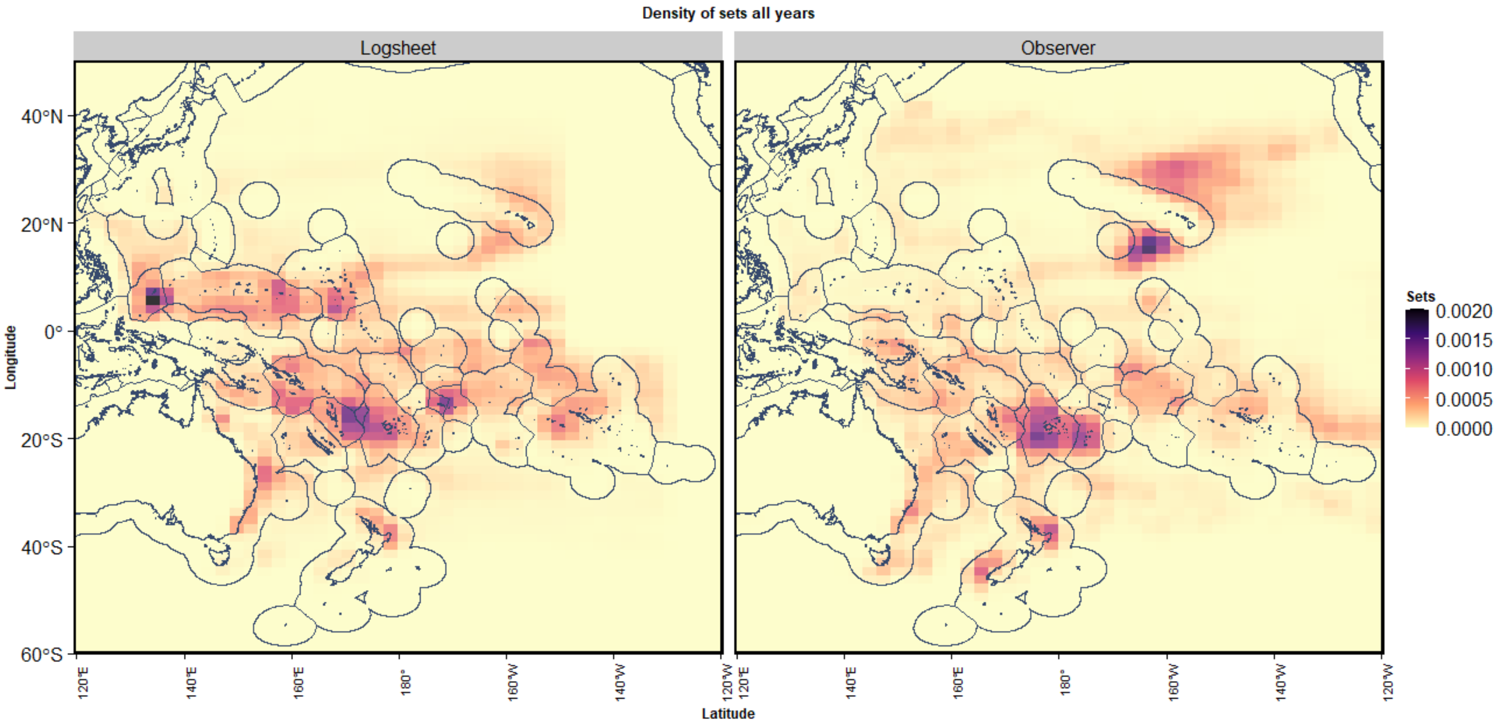


Figure 39: WCPFC percentage of logsheet sets and observed sets per 5x5 cell from 2002-2022.

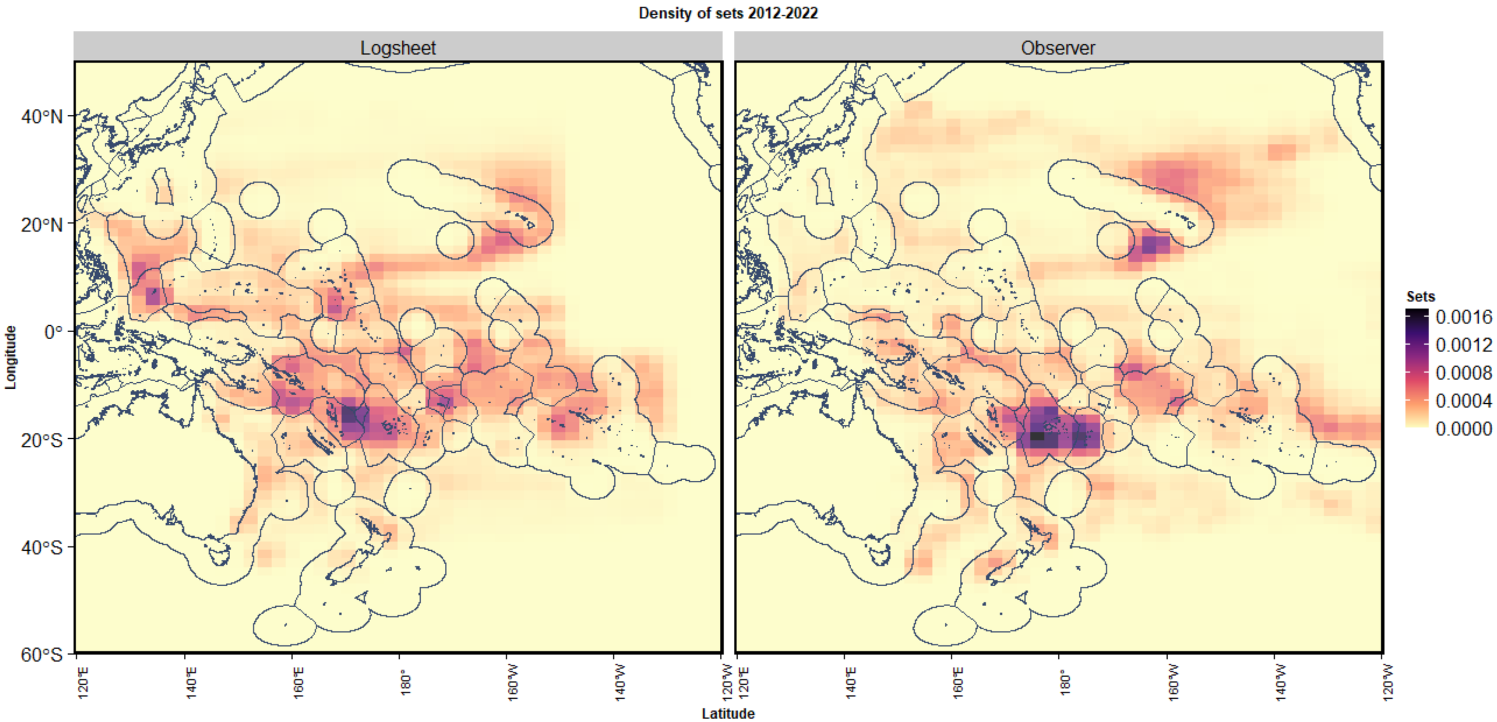


Figure 40: WCPFC percentage of logsheet sets and observed sets per 5x5 cell from 2012-2022.

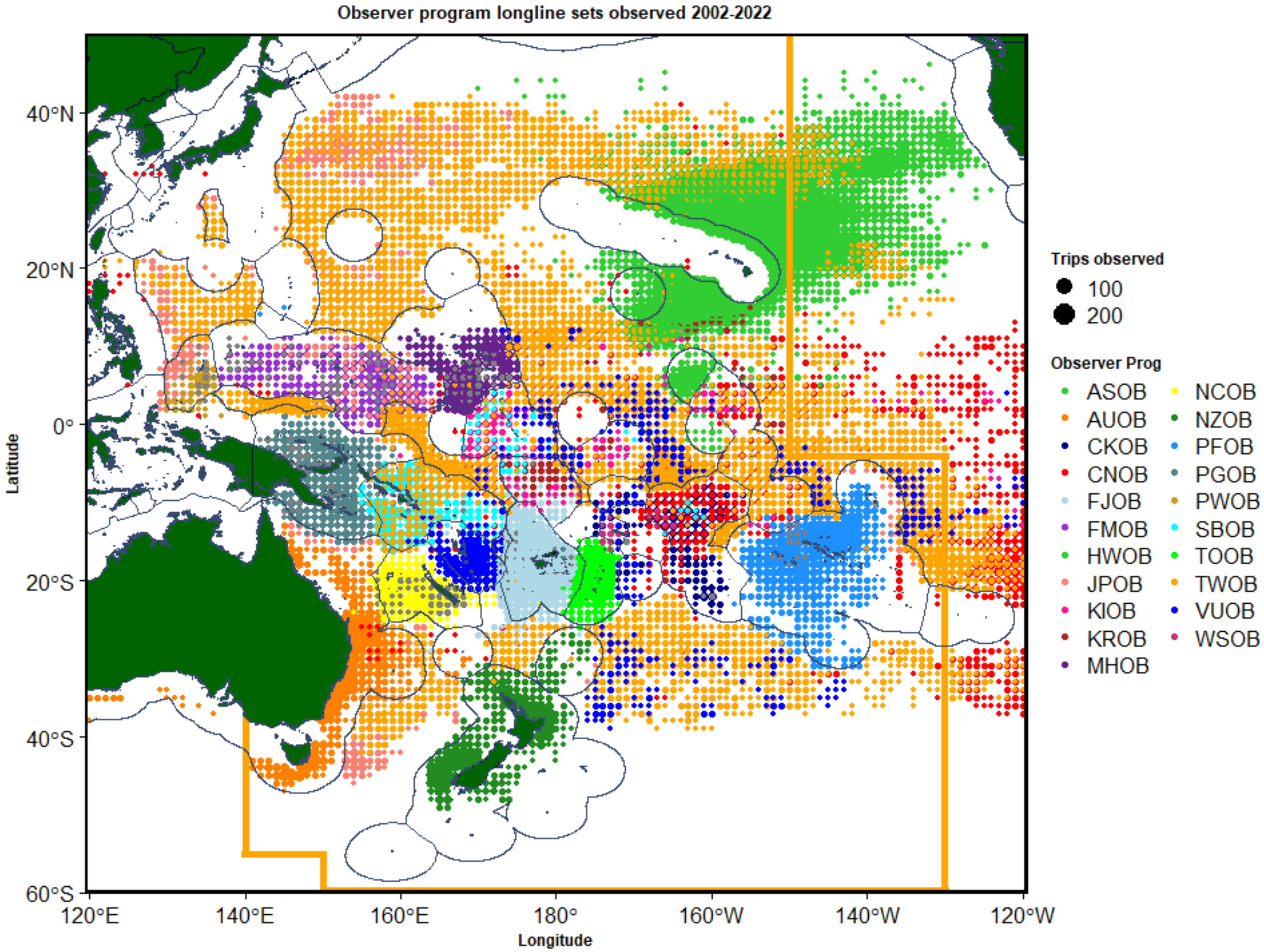


Figure 41: WCPFC observed longline effort distribution by observer program, showing the number of observed trips per 1x1 cell all data from 2002-2022 pooled. Note these data represent observed trips per cell, if a trip crosses into an adjacent cell it will appear in both cells. Observer program codes can be found in Table 3.

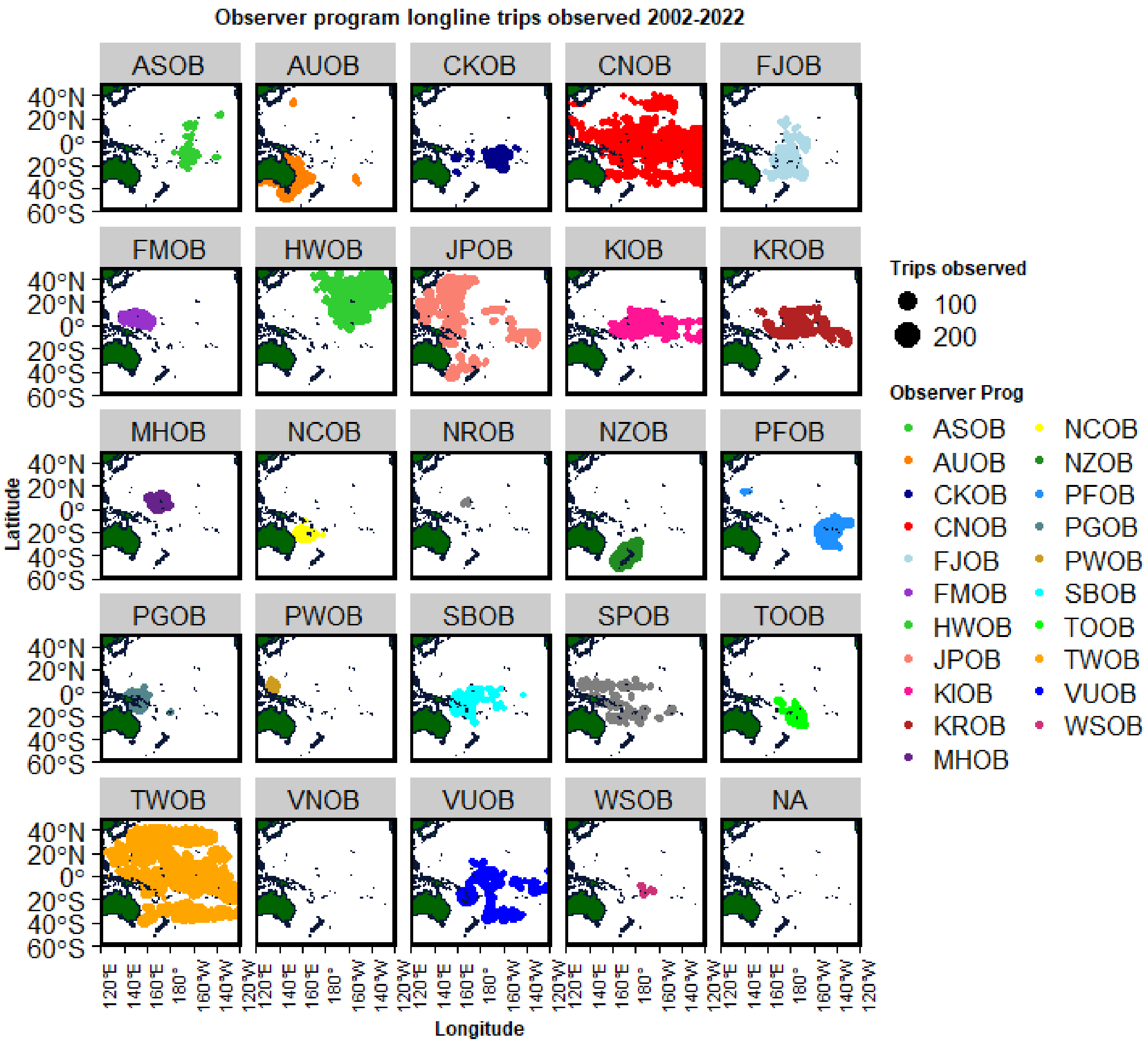


Figure 42: WCPFC observed longline effort distribution by observer program, showing the number of observed trips per 1x1 cell all data 2002-2022 pooled. Note these data represent observed trips per cell, if a trip crosses into an adjacent cell it will appear in both cells. Observer program codes can be found in Table 3.

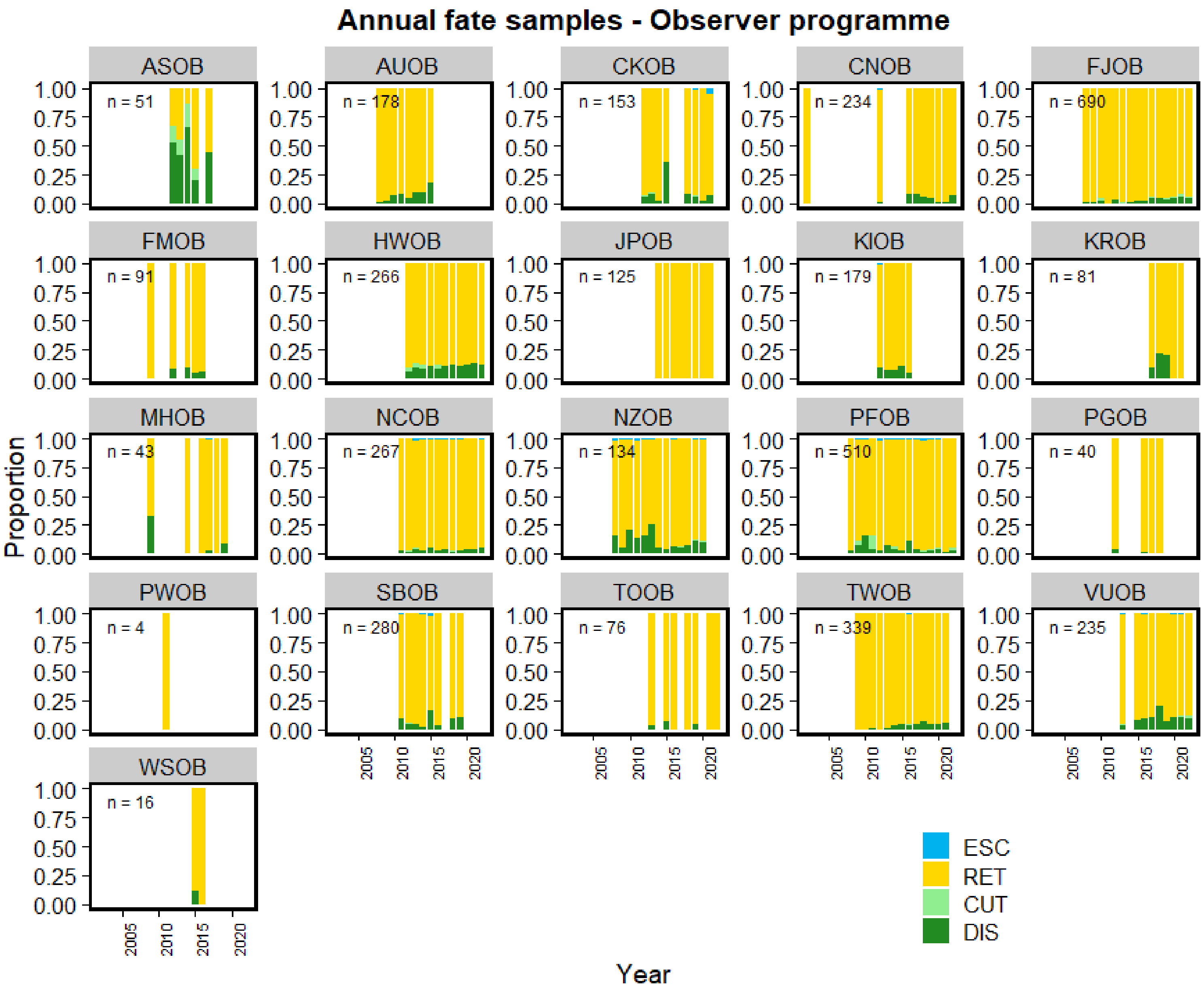


Figure 43: WCPFC observed fate (all billfish species combined) recorded by observer program. Observer program codes can be found in Table 3. ESC = escaped, RET = retained, CUT = cut-free, DIS = discarded.

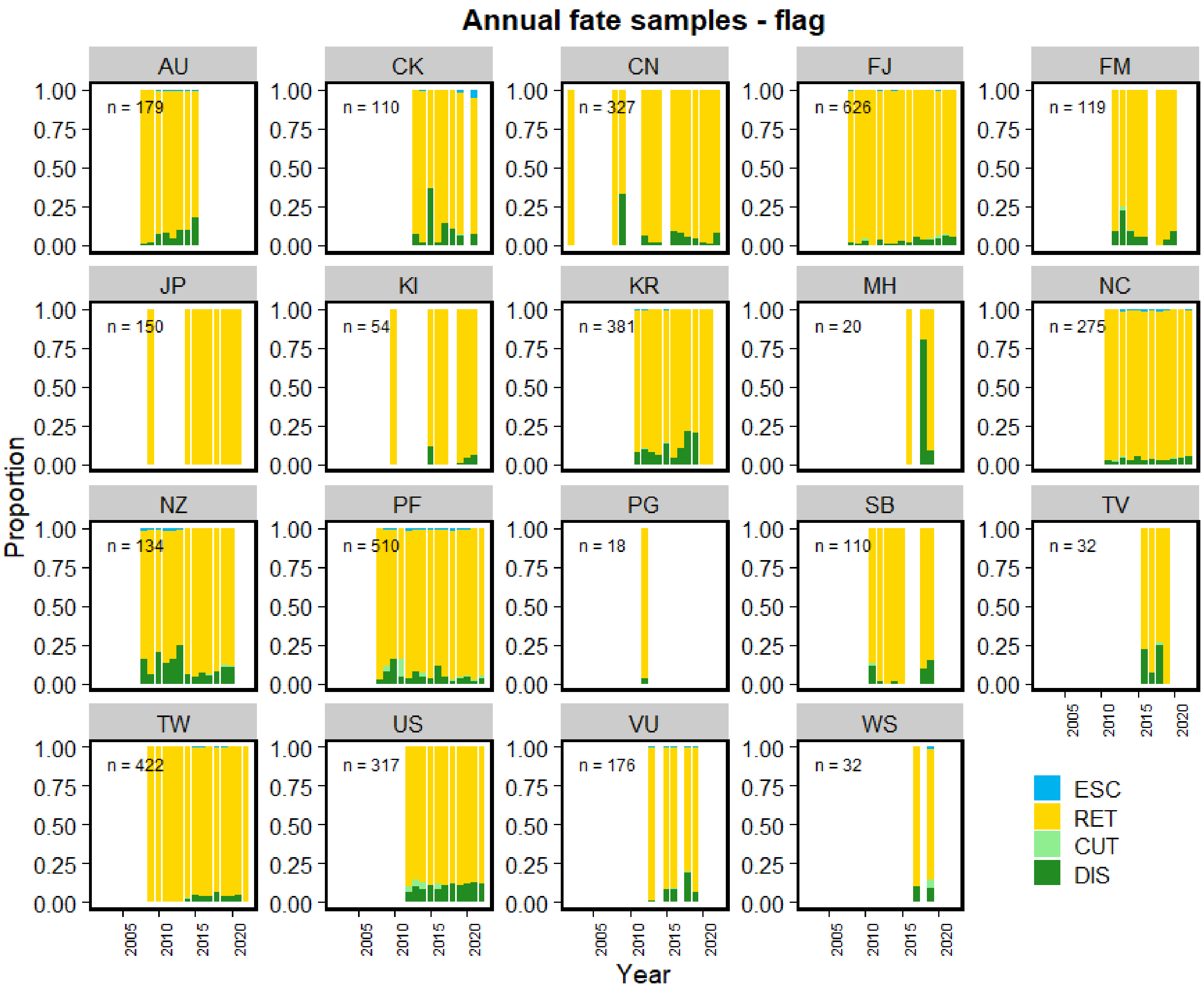


Figure 44: WCPFC observed fate (all billfish species combined) recorded by fishing vessel flag. ESC = escaped, RET = retained, CUT = cut-free, DIS = discarded.

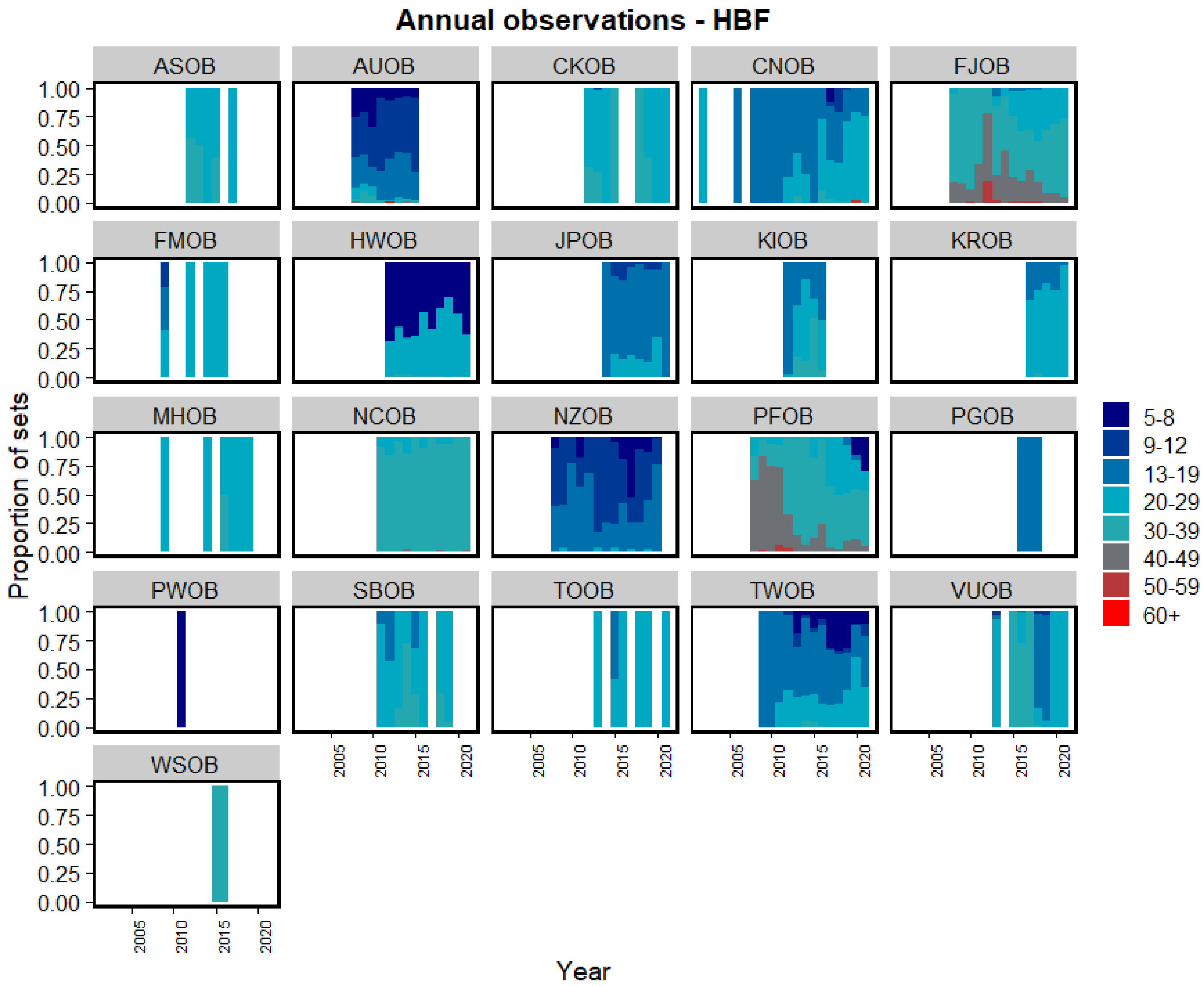


Figure 45: WCPFC observed hook between floats by WCPFC observer program. Observer program codes can be found in Table 3.

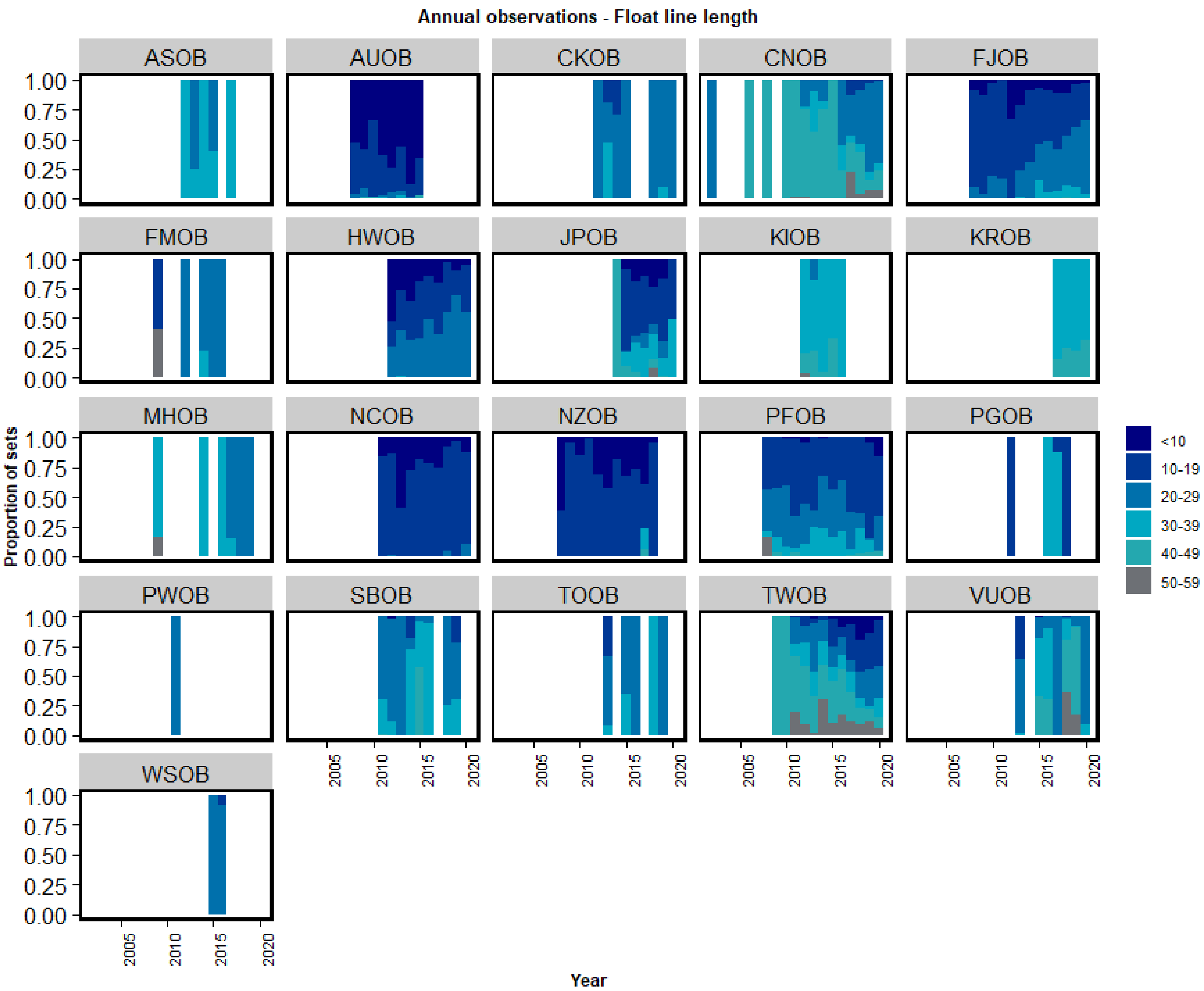


Figure 46: WCPFC observed floatline length by WCPFC observer program. Observer program codes can be found in Table 3.

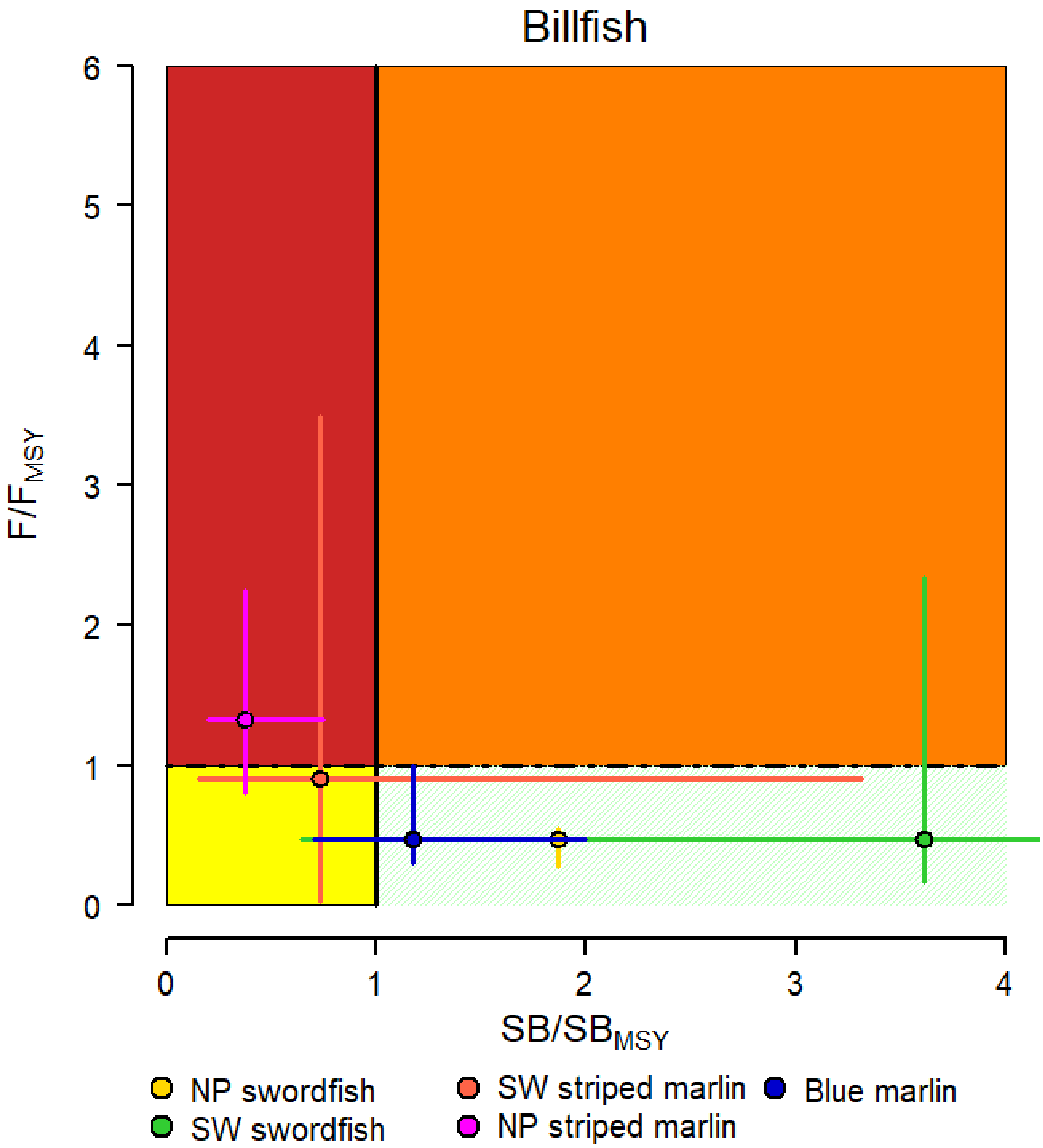
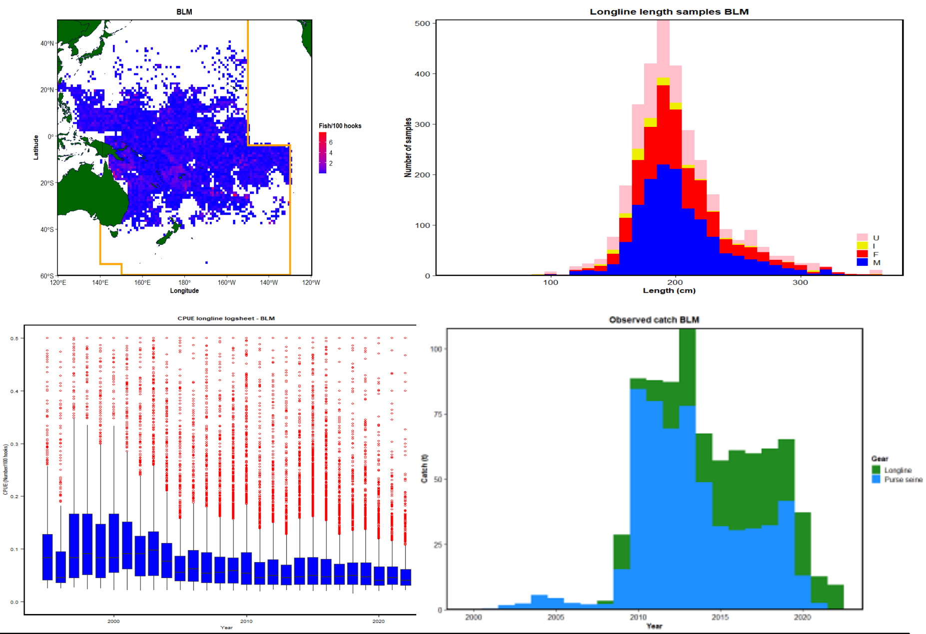


Figure 47: Kobe plot stock status summary for WCPO billfish assessed for which stock status has been determined. The WCPFC has not yet adopted LRPs for elasmobranchs and therefore MSY-based reference points are used as a default by the WCPFC. This figure has been produced by the SPC (Hare et al., 2021).

Appendix 1 - Information sheets

A summary of selected biological parameters and stock status for the billfish species considered in this plan. Note that units may vary between species and for more details please see the accompanying excel spreadsheet WCPFC-SC19-2023/EB-WP-xx supplementary material.

Black marlin − WCPO



Assessment Results	
Assessment Type	Stock Status
ERA − 2007	Susceptibility − Medium−Low; Productivity − Medium−Low

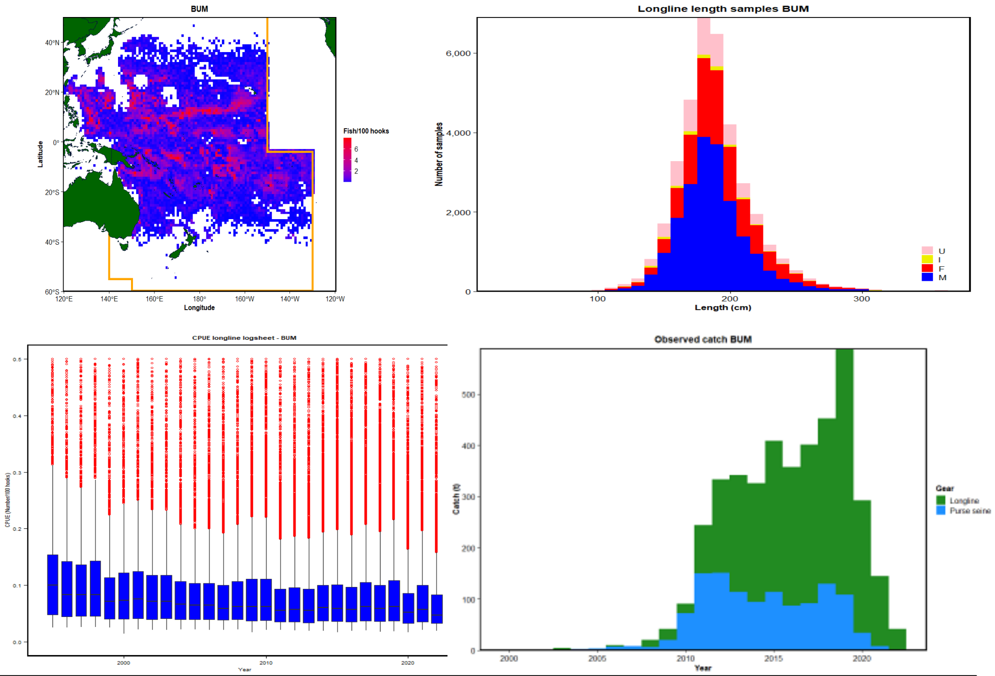
Life History							
L max	261.5−368.2	Max age	5−11	Length Max	261.5−368.2	Natural mortality	Unknown
k	0.03−0.125	t0	-9.2662 − −1.825	M	Unknown	r	Unknown
L inf	301.889−791.57	Age mat	5.4	Len mat	195	Conv factors	Yes

Sex specific parameters	Yes	Steepness	Unknown
Stock delineation	WCPO	Release mortality (%)	Unknown

WCPFC CMMs
None

Figure AI - 1: WCPFC research information summary sheet for black marlin (*Istiompax indica*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Blue marlin − PO



Assessment Results	
Assessment Type	Stock Status
Quantitative assessment − 2021	Not overfished, No overfishing

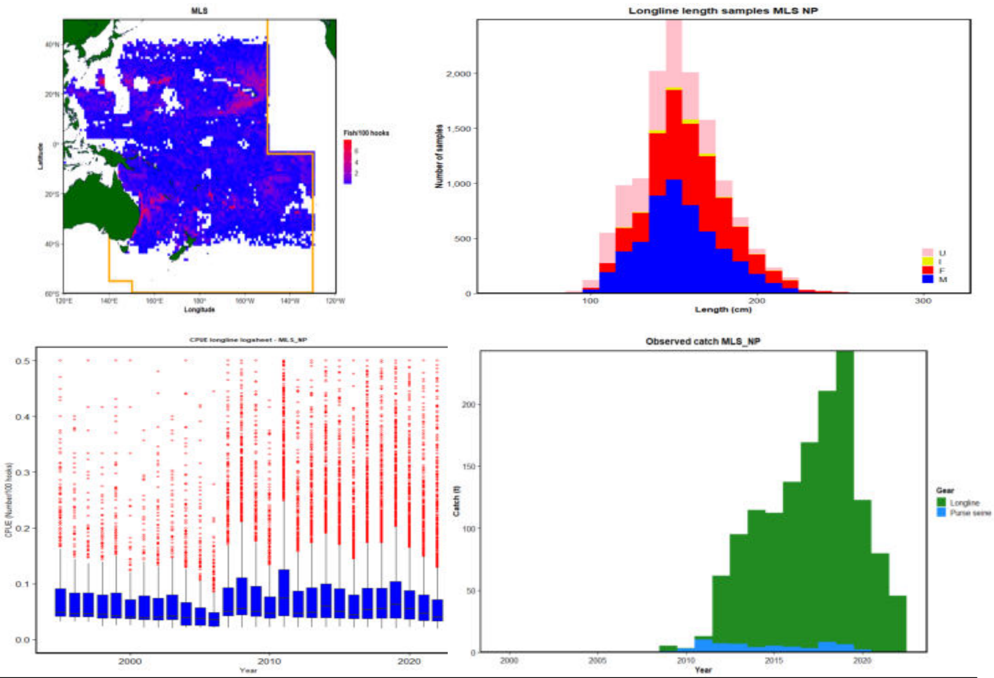
Life History							
L max	222−398.8	Max age	18−26	Length Max	222−398.8	Natural mortality	0.08−0.81
k	0.107−0.211	t0	−10.42 − −1.76	M	0.08−0.81	r	Unknown
L inf	215−501.8	Age mat	Unknown	Len mat	130−179.6	Conv factors	Yes

Sex specific parameters	Yes	Steepness	0.87
Stock delineation	PO	Release mortality (%)	Unknown

WCPFC CMMs
None

Figure AI - 2: **WCPFC research information summary sheet for blue marlin (*Makaira mazara*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.**

Striped marlin – NP



Assessment Results	
Assessment Type	Stock Status
Quantitative assessment – 2019	Overfished and Overfishing taking place

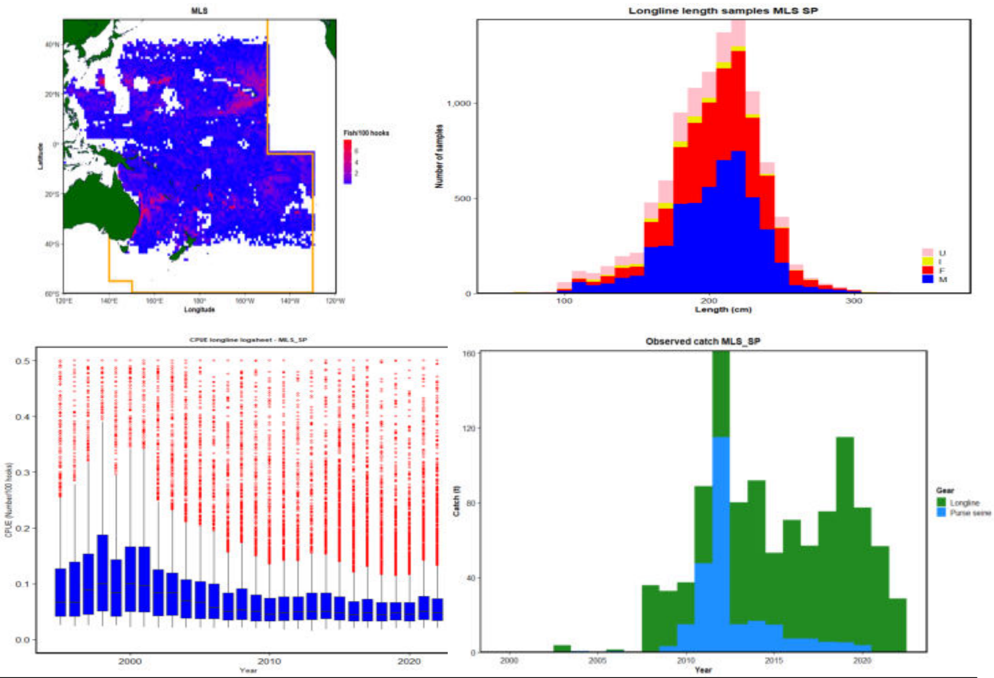
Life History							
L max	296–310	Max age	6–15	Length Max	296–310	Natural mortality	0.38
k	0.53–0.98	t0	−2.62 – −0.4	M	0.38	r	Unknown
L inf	174.19–188.04	Age mat	2.3–4.8	Len mat	152.2–181	Conv factors	Yes

Sex specific parameters	Yes	Steepness	0.87
Stock delineation	NP	Release mortality (%)	Unknown

WCPFC CMMs
CMM 2010–01

Figure AI - 3: WCPFC research information summary sheet for North Pacific striped marlin (*Kajikia audax*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Striped marlin – SP



Assessment Results	
Assessment Type	Stock Status
Quantitative assessment – 2019	Overfished, No overfishing

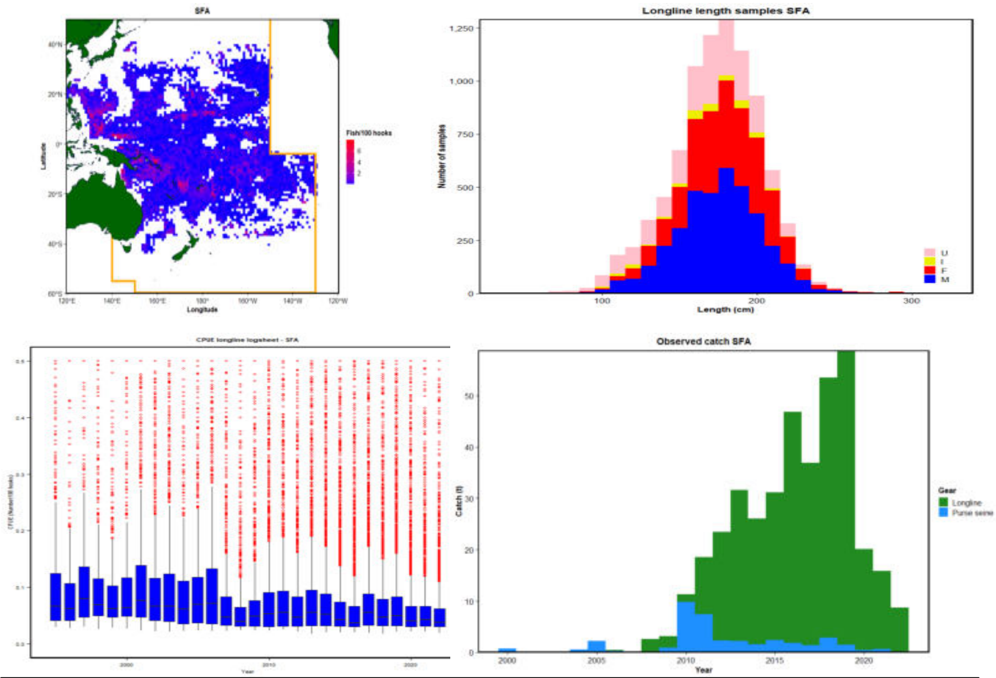
Life History							
L max	254–287.2	Max age	7–15	Length Max	254–287.2	Natural mortality	0.38–1.33
k	0.22–0.87	t0	−0.72 – −0.04	M	0.38–1.33	r	Unknown
L inf	237.46–256.5	Age mat	2–3	Len mat	166.8–214	Conv factors	Yes

Sex specific parameters	Yes	Steepness	0.8–0.87
Stock delineation	SP	Release mortality (%)	Unknown

WCPFC CMMs
CMM2006–04

Figure AI - 4: WCPFC research information summary sheet for South Pacific striped marlin (*Kajikia audax*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Sailfish – WCPO



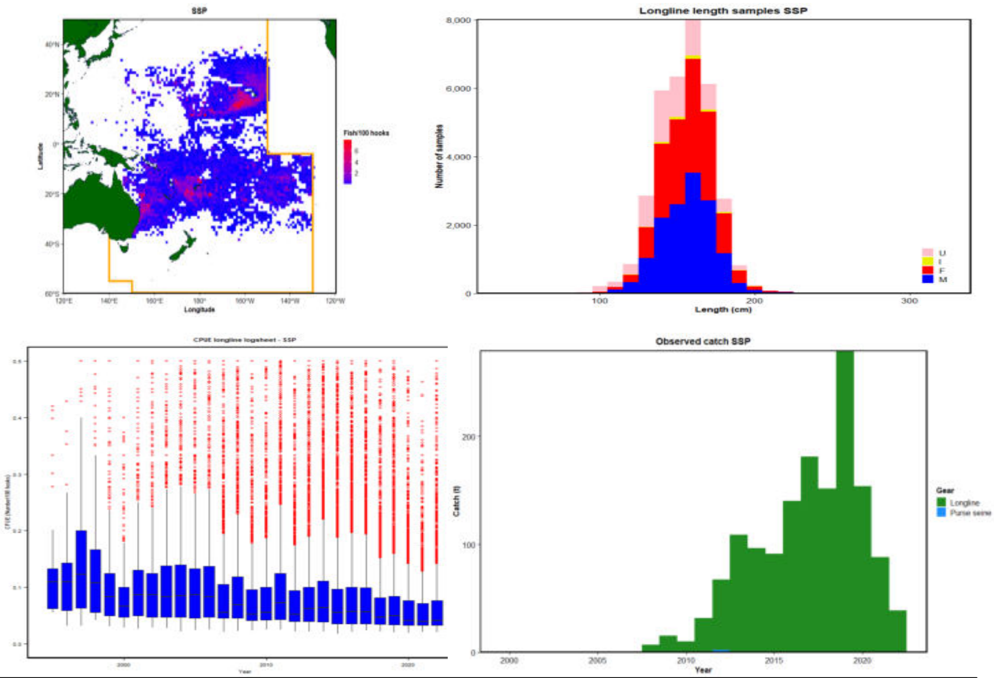
Assessment Results	
Assessment Type	Stock Status
ERA – 2007	Susceptibility – High; Productivity – Medium

Life History							
L max	237–229	Max age	11–21	Length Max	237–229	Natural mortality	0.26–0.27
k	0.11–0.145	t0	–4.207 – –2.781	M	0.26–0.27	r	Unknown
L inf	240.4–261.4	Age mat	5	Len mat	166	Conv factors	Yes

Sex specific parameters	Yes	Steepness	Unknown
Stock delineation	WCPO	Release mortality (%)	Unknown
WCPFC CMMs			
None			

Figure AI - 5: WCPFC research information summary sheet for sailfish (*Istiophorus platypterus*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Shortbill spearfish – WCPO

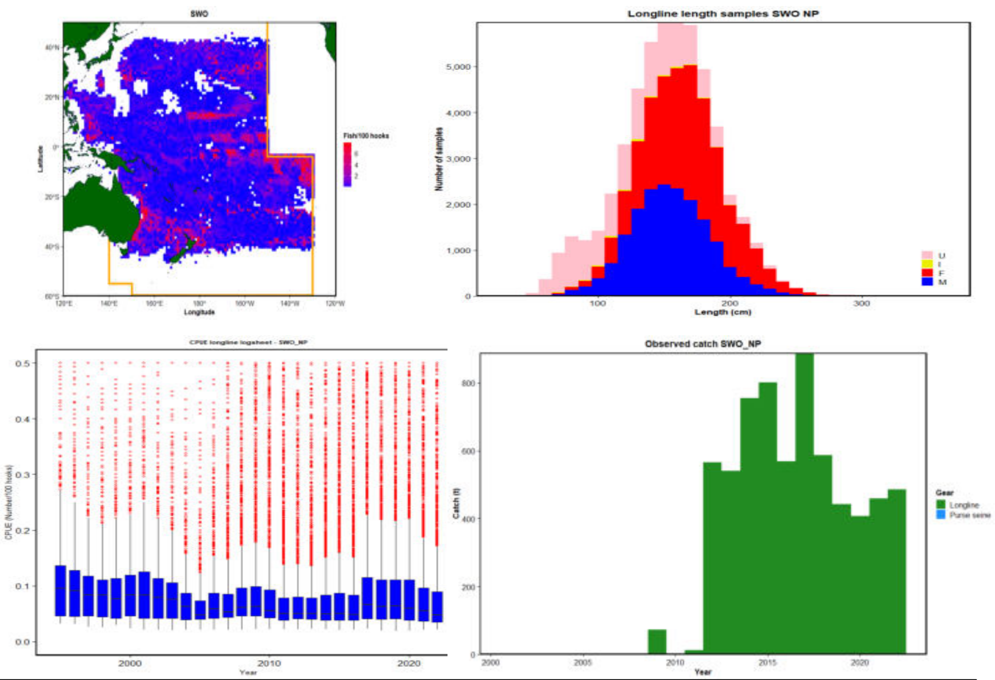


Assessment Results							
Assessment Type				Stock Status			
ERA – 2007				Susceptibility – Mediun–Low; Productivity – Medium			
Life History							
L max	Unknown	Max age	Unknown	Length Max	Unknown	Natural mortality	Unknown
k	Unknown	t0	Unknown	M	Unknown	r	Unknown
L inf	Unknown	Age mat	Unknown	Len mat	Unknown	Conv factors	Yes

Sex specific parameters	No	Steepness	Unknown
Stock delineation	WCPO	Release mortality (%)	Unknown
WCPFC CMMs			
None			

Figure AI - 6: WCPFC research information summary sheet for shortbill spearfish (*Tetrapturus angustirostris*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Swordfish – NP



Assessment Results	
Assessment Type	Stock Status
Quantitative assessment – 2018	Not overfished, No overfishing

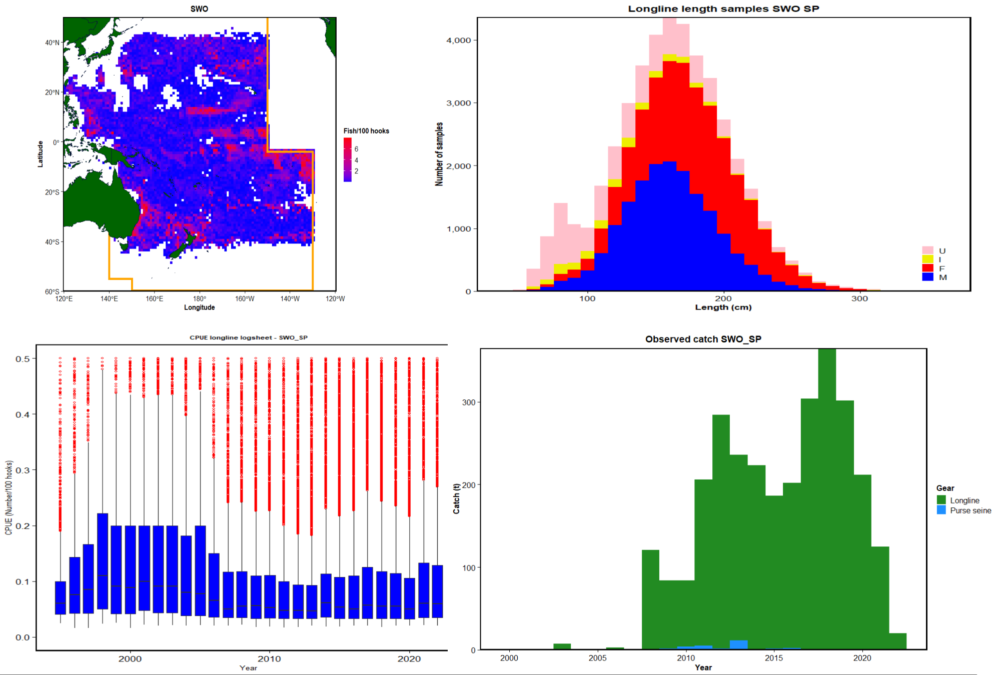
Life History							
L max	235–294	Max age	7–13	Length Max	235–294	Natural mortality	0.448
k	0.07–0.524	t0	–3.204 – –0.15	M	0.448	r	Unknown
L inf	208.9–376.712	Age mat	4–5	Len mat	102–168.2	Conv factors	Yes

Sex specific parameters	Yes	Steepness	0.9
Stock delineation	NP	Release mortality (%)	Unknown

WCPFC CMMs
CMM2022–02

Figure AI - 7: WCPFC research information summary sheet for North Pacific swordfish (*Xiphias gladius*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.

Swordfish − SP



Assessment Results	
Assessment Type	Stock Status
Quantitative assessment − 2021	Not overfished, No overfishing

Life History							
L max	191−249	Max age	17−21	Length Max	191−249	Natural mortality	0.2
k	0.157−0.253	t0	−2.1 − −2.13	M	0.2	r	Unknown
L inf	191−249	Age mat	4.42	Len mat	161	Conv factors	Yes

Sex specific parameters	Yes	Steepness	0.6−0.98
Stock delineation	SP	Release mortality (%)	Unknown

WCPFC CMMs
CMM2009−03

Figure AI - 8: WCPFC research information summary sheet for South Pacific swordfish (*Xiphias gladius*). This table presents the logsheet reported catch distribution (top left); length data by sex (top right); unstandardised CPUE (bottom left); and catch by gear (bottom right), including the available life-history parameters and relevant stock status information.