Review of size data from Indian Ocean longline fleets, and its utility for stock assessment.

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Executive summary

This report reviews the procedures used to collect and process longline size data for use in IOTC stock assessments. It describes the types of data collected, with a particular focus on data provided by the Japanese, Taiwanese, Korean and Seychelles fleets. It investigates the reliability of size data by comparing spatial and temporal patterns in median size among fleets and time periods. It explores reasons behind sudden changes in the shape of length frequency distributions for the Taiwanese fleet and recommends that stock assessments should in future omit Taiwanese length data but include weight data and observer data. It provides recommendations for analysts preparing size data to include in stock assessments, and proposes future directions for research.

Introduction

Each year the IOTC Secretariat prepares input tables for the assessments of IOTC stocks, including catches in number and weight for tropical tunas, albacore, and swordfish, by fishery, species, length class, year, quarter and fishing area, as defined by the IOTC working parties. Total numbers of tunas and billfish are derived from the available nominal catch, catch-and-effort, and size frequency datasets, as provided by IOTC CPCs1 or other Parties.

For a number of years, the IOTC Scientific Committee has expressed concern about the poor coverage of length frequency samples for several of the major longline fleets, such as those from Japan, Indonesia, and India, and the potential negative impact on stock assessments.

In addition, there have been difficulties reconciling the catch-and-effort and size frequency datasets available for the Taiwanese longline fleets, in which average weights derived from catch-and-effort and size data for the same area and time-period are highly conflicting.

In light of the above, and additional information presented at the previous meetings of the IOTC Working Party for Tropical Tunas (WPTT), in 2013 the Scientific Committee recommended "joint work on the documentation of procedures for the collection, processing and reporting of size frequency data" (SC15.78) for the main longline fleets, given the potential impact on stock assessments.

Also, given that the data collection and processing systems used for distant-water longline fisheries tend to apply to all oceans, the WPTT agreed on the value of informing other tuna-RFMO Secretariats on the issues identified for longline fisheries and facilitate their participation in a review of the datasets reported by longline fleets.

Review of longline size data and processing systems

Review the procedures used for the collection and processing of size data from large-scale tuna longline fisheries in the Indian Ocean, for selected years, in particular:

- Types of size data collected, data sources, and data validation and processing (e.g., stratification, procedures used to convert sizes into fork length, etc., where required).
- Other uses of size frequency data, where applicable (e.g., estimation of catches in weight from numbers recorded in logbooks, or contribution of size data to the estimation of nominal catches for the fishery).

- Address concerns raised by the IOTC Working Parties and Scientific Committee concerning the quality of size data available for Japanese, Korean, Taiwanese, and Seychelles longline fleets.
- Compare length frequency data from different sources (e.g., scientific observers, fishers, training, and research boats) and the effect on the assessments of IOTC species – specifically tropical tunas (as well as albacore tuna, swordfish and marlins depending on the time/resources available).
- For fleets, such as the Taiwanese fleet, that have been collecting both length and weight measurements for the same species, compare measured lengths and lengths derived from weight measurements to validate the reliability of datasets.
- Explore the reasons for discrepancies in average weights derived from the catch and effort and size frequency datasets, and the reasons behind the sudden changes in the shape of length frequency distributions recorded for the Taiwanese longline fleet since the early-2000s; in particular the marked decrease in the number of small fish in the samples recorded for the last decade.
- In coordination with the IOTC Stock Assessment Expert, assess the effect of changes in sampling coverage and contribution of length frequency data from longline fleets have on the assessments of IOTC species, in particular tropical tunas, albacore, swordfish, and marlins.
- Liaise with other tuna-RMFOs and inform them of the main findings of the size data review.
- Identify areas for future work (e.g., inclusion of other species or gears, where appropriate; the extent of historical time series under consideration, in addition to future collaboration with other tRFMOs in the case of overlapping data issues) and propose a road-map for these activities to be carried out, for the consideration and endorsement by the IOTC Scientific Committee.
- The incumbent will be responsible for preparing the following information and final report for dissemination at the IOTC Working Party on Data Collection and Statistics (WPDCS), Working Party on Tropical Tunas (WPTT), and Scientific Committee in 2019. The report will cover the following:
- Documentation of procedures for the collection and reporting of size frequency data used by Japanese Korean, Taiwanese, Seychellois, and other important longline fisheries, including:
- Full description of the type of sampling platforms used (e.g., commercial boats, research boats, training boats, etc.), and data collection source (e.g., fishermen, researchers, scientific observers, etc.)
- Full description of the sampling protocols used (e.g., full enumeration of every set, every other set, first 30 fish from each set sampled for size, etc.), by type of sampling platform and data collection source.
- Type of measurements collected (e.g., gilled-and-gutted weight, fork length, etc.) and measurement tools used (calliper, measuring board, measuring tape, scale, etc.) by type of sampling platform, data collection source, and species.
- Type of time-area stratification used for each species (e.g., quarter and defined area) and procedures used for the estimation of sampled weights in each stratum, including all equations used for the conversion of non-standard measurements into standard measurements, by species (e.g., deterministic conversion using a single length weight equation for all areas and time periods, etc.).
- Description of any other procedures which involve the use of length frequency data (e.g., estimation of weights from the numbers reported in logbooks and substitution scheme in the case that lengths are not available in areas where there are catches and effort recorded, etc.).
- Appraisal of any apparent discrepancies in the longline size frequency data, implications for the stock assessment of IOTC species, and suggested remedial actions (if appropriate).

Investigate the spatial and temporal trend of size distribution by fleet using linear or generalised linear modelling approach; identify and quantify effects that corroborate with CPUE indices or other fishery indicators in explaining spatial and temporal variations of the population.

- Where necessary, recommend changes to the data collection and/or processing systems for longline fleets, and propose a roadmap for the implementation of the activities recommended by the institutions concerned.
- Report the results and provide guidance to the IOTC Working Parties and Scientific Committee on the best use of the available length frequency data for the assessments of IOTC species, including the type of fisheries to be considered and the procedures that are recommended for the preparation of the different datasets.
- Ensure other Tuna-RMFOs are fully informed on the issues discussed by the report findings.

Part A: Review of Sampling Procedures

1. Measurement and weighing on vessels

All fleets weigh fish for their own purposes. However, length measurement is not part of their standard procedures, and it is generally only done because of the scientific requirement. For these purposes, Korea recommends that fishermen and observers measure both length and weight. Taiwanese vessels formerly provided only length data for scientific purposes, but since 2009 have provided the processed weights of individual catches. There was a major change in the Taiwanese fishery in 2003 with many fishermen retiring, after which time length measurements may have become less reliable. Most large-scale vessels report lengths, but only about 20% of small-scale vessels do so. Seychelles vessels provide only length data, which has been collected since 2007.

On Japanese commercial vessels, voluntary measurement by the fleet has been undertaken since 1980, but reporting has declined and currently there is little or no such measurement on Japanese vessels. On Seychelles deep-water longliners (according to a representative of the Seychelles industrial longliners), the "duty to measure the fish is mostly performed by the crew on rotation/random basis under supervision. A minority are performed by the captain and or/ first officer or freezer officer."

On Japanese vessels the protocol is to measure the first 50 fish per set. Fishermen on Taiwanese vessels measure the first 30 fish per set. Korean vessels measure 1 fish per tonne of catch by species. On Seychelles vessels crew members measure the first 30 fish per each set, but before June 2017 they measured 20 fish per set. As for all fleets, "the number of fish measured can be smaller than 20 since about 20% of the fishing sets reported during 2007-2015 included less than 20 fish caught on the longline" (Chassot et al., 2016).

For Japanese vessels it is unclear whether transhipment may have affected sampling in the early period (1950s and 1960s), when there was a system involving motherships and small boats. On Seychelles vessels there is no sampling from transhipment vessels, or from catch after other fish have been transhipped, and there is not believed to be any sorting of the catch prior to sampling. On Taiwanese vessels, fishermen can separate their fish into groups, and it's not possible to control the approach for measurement. Different vessels operate in different ways, and some vessels sort fish before measuring. Sorting of the catch does not occur in the case of observers.

On Japanese vessels, tunas are measured as fork length, billfish as eye fork length. On Korean vessels, tunas are measured as fork length, billfish as lower-jaw fork length. On Taiwanese vessels, tunas and tuna-like species are measured as upper jaw fork length, billfish as lower-jaw fork length, and sharks to total length. On Seychelles vessels, tunas are measured as dorsal fork length (DFL), swordfish as lower maxillary fork length (LMFL), and sharks, as total length. A preliminary analysis of the Seychelles size data presented at IOTC in 2015 however showed some inconsistencies in some of the data that should be further explored, including possible measurements not taken in fork length (IOTC-2016-WPDCS12-17_rev1).

The Japanese voluntary system distributed 180cm poles for measuring length. Korean vessels use T-shaped rulers to measure fish length. Taiwanese fishermen sometimes use measuring sticks, sometimes tape, or callipers – there is no standard equipment. With tape we are unsure if they use curved or straight FL. Scales are often spring balances, belonging to the vessel. On Seychelles vessels, according to a survey in September 2017, most vessels use tape measures (83%) or measuring boards (12%), while a small minority use callipers or flexible tape measures (5%).

On Korean vessels, measurement occurs during the set and on deck beside the place where fishermen process fish. On Seychelles vessels, sizes are measured on the deck just after the fish has been hauled, so close to the forward part of the fishing deck.

Measurement and weight resolutions in logbooks have always been 1 cm and 1 kg for all species, for all fleets. In early years on Japanese vessels the paper record was rounded to 2cm or 5cm to save computer storage space. Some sources state that tunas were measured to the next-highest 2-cm interval, and billfishes to the next-highest 5-cm interval (Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992), but this appears to be based on the rounded values. Japanese rounding procedures for computer storage changed through time, as discussed later in this report. On Korean vessels, measurements are rounded down. On Seychelles vessels, the current version of the protocol does not include the type of rounding used. It will be corrected to include this and to provide clarification about the size resolution. It is assumed that the measurements are rounded “normally”, i.e., rounds digits 1,2,3, and 4 down, and digits 5,6,7,8, and 9 up.

Preliminary analysis of the Seychelles size data suggested inconsistencies in some measurements when compared with mean weights derived from catch data (Chassot et al., 2016). For instance, some samples only include bigeye less than 45 cm fork length when the average weight derived from the logbook indicated bigeye of 30-50 kg. Comparison between length measurements and weight measurements for Seychelles data showed that “size frequency data collected at sea by fishermen are consistent with logbook information in several vessels while some data available from some vessels are spurious” (Chassot et al., 2016).

2. Discards

For the Japanese fleet, discards mainly occur when fish are damaged by sharks or whales. Observers are meant to measure these fish. The damage rate is generally less than 5%. Observers measure lengths of discards if possible, while fishermen don’t measure discards. If there is size-dependent discarding, this may affect observed sizes.

On Korean fleet, discards mainly occur when fish are damaged by sharks or whales. Fishermen don’t measure discards but report them through the electronic reporting system. Observers measure discards except in cases where fish have been predated.

Although the current version of the Seychelles industrial longline logbook includes fields to indicate discards of target species, the vessels do not report any discards. The form includes the fields ‘Released alive’ and ‘Discarded dead’ for all shark species as well as for marine mammals, sea birds, marine turtles and other fish. According to the company representative, there is no discard of target species (tuna and billfish) in the fishery.

On Taiwanese vessels, observers should measure all fish that are landed, even if discarded later. Fish may be discarded if damaged (e.g., bitten by a shark or whale). Like most fleets, small fish size is speculated to be a reason for discarding, particularly for species with quotas. Reasons for discards are recorded.

3. Processing

On Japanese vessels, bigeye and yellowfin tunas are weighed by the crew after processing to a semi-dressed state (gilled and gutted, gg). Albacore are weighed without being gilled and gutted. However, the tail is removed, and the fish is bled. The assumed processed weight ratio is 1.1 for ALB.

The sequence for processing by the crew during the commercial longline haul for each captured bigeye or yellowfin is as follows: land the fish, kill / iki, measure length, bleed, cut off tail, gill and gut, measure weight. Intentional bleeding began in the 1980s.

Billfish heads are usually removed. Large swordfish are filleted, and small swordfish are dressed.

On Korean vessels, bigeye and yellowfin tunas are measured in processed weight (gilled and gutted). Albacore are measured in whole weight.

4. Port sampling

For Japanese vessels before 1980, fish were landed at the market and placed in a row, where scientists from the National Research Institute for Far Seas Fisheries (NRIFSF) (now Fisheries Resources Institute, FRI, since 20/7/2020) could measure them.

During that period, information about catch timing and location was less detailed because the fish were not individually identified. The date and location they applied had to be representative of all longline operations in the trip. "In the case of measurement at unloading site, month is generally determined to the month when catch is the largest in the cruise, and position is determined with an appropriate resolution (1°x1°, 5°x5°, 5°x10° or 10°x20° block in latitude x longitude) so that most of catch is contained in the one particular size of unit area" (Uosaki, 2007). However, during this period trip durations were shorter.

Japanese port samplers used wooden callipers.

Early Japanese port sampling may be affected by size-selection. Suda and Schaefer (1965) note that "more than 50% of the catch is butchered aboard the vessels and processed into fillets. the larger fish tending to be filleted and the smaller fish landed whole, or with only gills and viscera removed. Thus, the size-composition of the un-filleted fish unloaded at the fish markets in Japan by the commercial boats is not representative of the original catch on the fishing grounds."

In 1980 the Japanese market system changed. Buyer companies developed that would buy the entire catch from a vessel and determine the price. As a result, the fish no longer went to the market, and there was no time to measure the fish after landing.

Some Taiwanese length data are also collected at the port, though the main target of port sampling is small-scale longliners inside EEZs. Only domestic vessels are sampled in the Taiwanese EEZ. Staff measure each fish unloaded on a sampling date. Most fish are measured fresh. Coverage rate is 20-30% of the catch.

5. Research and training vessel sampling

Special research projects by Japanese scientists have periodically measured samples of some species, and these are included in size datasets. For example, the Research project on Japanese bluefin tuna (RJB) collected catch totals and size data for Pacific bluefin from 1994 (Sakai et al., 2015), and this still continues.

Kume and Joseph (1966) obtained EPO data from 1555 days of fishing May 1958-March 1964 by NRIFSF research and training vessels. The form only had provision for reporting individuals 82-184 cm. Fish outside this range were sometimes noted but the notes were sometimes questionable. Of bigeye tuna, 1.6% were over 184 cm. Collection methods were described by Suda and Schaefer (1965).

"Records of the size-composition of long-line catches made by the experimental fishing boats were obtained in the following manner: The fork lengths of all yellowfin caught by individual long-line sets were measured by slide callipers and recorded by centimetres, a fractional centimetre being rounded to the next higher whole centimetre. Sex was determined the examination of gonads. Length frequencies were tabulated for each long-line set by sex and by length classes of 2 cm. The reporting form provided by NRFRL to the fishing vessels has provision for entries only for the length range from 83 cm (class 82 cm to 84 cm) to 183 cm (182 to 184 cm). Fish having lengths outside this range were sometimes recorded by individual lengths, but, in other cases, only the number fish less than 82 cm and the number greater than 184 cm were recorded. Therefore in this analysis we have eliminated the data respecting fish less than 82 cm and greater than 184 cm".

6. Observers

Japanese observer coverage varies among fisheries. For the southern bluefin tuna fishery (based on CCSBT regulations) the target is 10% coverage of the effort or catch. Selection of vessels involves identifying 3-4 areas in which fishing will occur and selecting vessels at random for 10% of the probable effort in each area. To allocate observers to vessels there is a lottery. In the rest of the Indian Ocean (non-CCSBT) there is a target of 5% coverage. Coverage is generally taken as the percentage of hooks but is not a requirement – coverage is not defined.

Recently the Korean scientific observer programs in the Indian Ocean have started at the beginning of the southern bluefin tuna fishing season, in April, and continued until they achieve the observer coverage required by the IOTC. Vessel selection is random. Selection of fishing areas and target species depend on captains' fishing strategies. Overall observer coverage is currently 5%, but coverage in space and time depends on captains' fishing strategies.

Taiwanese observer trips are assigned by the government. The Taiwanese Fisheries Agency have a list of vessels and when they will go out, and the observer coordinator visits the company to negotiate observer access. If the company agrees then the FA will assign a randomly-selected observer. In the past some companies would refuse to accept observers, but this is uncommon now - they have a duty to accept. Refusal occurred on occasion because operations are mostly outside Taiwanese waters, and vessels must visit a port to pick up an observer. For large scale longliners, when there were piracy issues in the north, observers were deployed in the southern hemisphere. The Taiwanese Indian Ocean coverage rate is > 5% for large scale longliners. For small scale longliners the coverage is 5%. For the southern bluefin tuna fishery, coverage is about 10%. The number of observers increased substantially in 2017. Each observer does > 2 trips per year on distant water vessels, or 4 to 5 trips on small scale vessels.

Japanese observers measure lengths as follows (Matsumoto et al., 2005). "Length by 1cm interval (round up) and clasper length of sharks by 0.1cm interval, body weight (in principle to the nearest 1 kg, and partly to the nearest 0.1kg), gonad weight (for tunas and billfishes, mainly for female, to the nearest 5 to 100g) and product weight (to the nearest 1 kg) were measured as many as possible. When there were substantial numbers caught, priority was given to tunas and billfishes, but in principle the number of individuals was counted for all catch. Different length measurements were taken: fork length for tunas (for some individuals pre-dorsal length was also measured), eye-fork length for billfishes, precaudal or fork length for sharks, disk length for rays, and total or fork length for other fish. Lengths were measured with a caliper, a scale or a tape measure."

Korean observers collect weight, length, and sex. Weights are taken as whole or processed weight at 1 kg resolution depending on the operating conditions. Lengths are measured at 1cm resolution as fork length for tunas and billfishes, and fork or total length for sharks and other fish. If catches are too large for observers to measure all the fish, they take length and processed weight, head length (optional), and body height (optional). The equipment used is T-shaped rulers (sometimes tape) and scales.

Taiwanese observers collect weight, length, and sex. Observers use callipers. When an observer is on board, the observer will measure fish first. Then a crew member probably records the number from the observer. Observer length measurement requirement involve forms for observers and fishermen. Different forms were used in 2002-3, 2004-8, and then in 2009. For sharks, observers must measure fin weight and carcase weight as well as length. New forms were introduced in 2009 and 2014. Measurement of weights. For SWO the conversion factor is 1.54. It would be possible to analyse average weights and infer diversity of catches.

Japanese observers are meant to be on shift for 8 hours. They take a break of about 20 mins for a meal. Korean observers are supposed to sample as many fish as possible, with a recommendation to measure fish from around 70% of hooks used per set. Taiwanese observers work for 8 hours per day in two periods of 4 hours each. They start to measure when the vessel starts hauling, taking 1-2 hours rest. The Taiwanese observer program started in 2003, initially sampling 30 fish per set. From 2004-2009 they were instructed to sample 60 fish per set. From 2009 they sampled all fish.

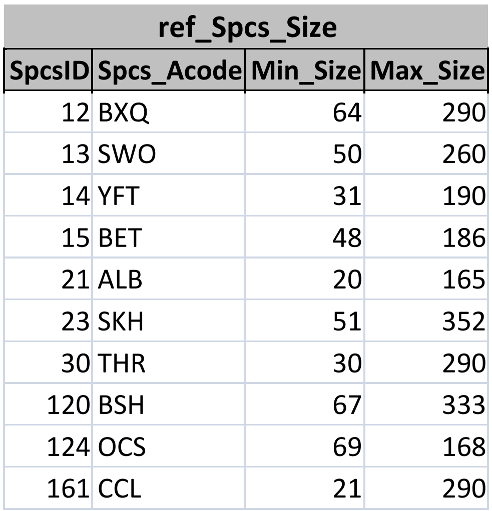
7. Data storage and management

Japanese data are stored in a series of independent MS Access databases, one for each year and data type (observer, training and research, port sampling). R code is then used to generate a flat file of size data. Some early period Japanese size data may be stored at the Fisheries Resources Institute (FRI) that has not been included in the common pool, such as bigeye length data for the period before 1960. Korean size data are stored in a SQL Server database. Taiwanese size data are also stored in a SQL Server database. Seychelles logbook data are stored in a MySQL database (FINSS) which will soon be migrated to a new version of the IRD software ObServe (PostgreSQL/PostGIS). Sampling data are currently stored in a dedicated MS Access database linked to FINSS. The sampling data will also be migrated into the ObServe database.

Japanese data entry is carried out by both FRI staff and others. Entry can occur up to 1 year after the data are provided. Korean data since September 2015 have been reported and stored daily at the National Institute of Fisheries Science (NIFS) via an electronic reporting system. In the past, when paper logbooks were used, there was generally one- or two-month delay and some vessels reported their data after their trips (one or two years later). Taiwanese data before 2015 were entered by OFDC staff after receiving paper logbooks. From 2016 vessels have provided data daily via an electronic logbook system, including small-scale vessels. The e-logbook system has been developed since 2005. There was a transition period of about 2 years from 2014, with duplicate systems. Observer data are recorded daily data at sea using a laptop. Seychelles size data are received as PDF files, stored on a server, and entered into the database by SFA technicians.

Japanese data validation during data entry is based on size ranges and distances from previous sets. The observer data are cross-checked with other data. Korean data are validated by applying range-checking and other data-checking procedures (comparison with landing and transhipment data). Taiwanese data validation was focused on range checking prior to 2009, and an additional check on weight and length relationship by species has been applied to data after 2009.

For Seychelles validation, lengths by species are range-checked against minimum and maximum values as follows:



ref_Spcs_Size

SpcsID	Spcs_Acode	Min_Size	Max_Size
12	BXQ	64	290
13	SWO	50	260
14	YFT	31	190
15	BET	48	186
21	ALB	20	165
23	SKH	51	352
30	THR	30	290
120	BSH	67	333
124	OCS	69	168
161	CCL	21	290

Each sample is compared with logbook entries for dates and positions. Codes are used to flag inconsistent samples or size measurements, etc. (see Metadata). The codes used are:

1	No logbook Received
2	No Fishing
3	Cruising
4	In port on logbook
5	Logbook null for given date
7	Fish length not recorded on form
9	Position significantly different to Logbook
10	Fish size

In Korean data, conversion factors for length and weight measurements are those provided by the tuna RFMOs. Seychelles data are provided as-is: conversion factors for length and weight measurements (e.g., from gilled and gutted to whole weight, including all conversion factors and stratification) are not used. Numbers are not converted to weight as part of the data curation process.

For Seychelles data, the sampling protocol was established by SFA in collaboration with Taiwanese Deep-Sea Fisheries in June 2007 and data are recorded on a sampling form which is submitted to SFA by email on a weekly basis. The data recorded are: Vessel details, Date, Position, and the measurement for the first 30 fish by species. Catch dates and locations are reported on the sampling form by position in degree-minute, to the nearest minute. Examples of forms have been provided.

8. Issues identified

Japanese data were provided with the rules reported in Appendix 1. The rules added 0.5 to the absolute value of each cell, with the expressed aim of defining the middle of each cell. This works when vessels report at 1x1 resolution but does not allow for the fact that the data are also reported at other stratifications: (1 = 10°×20°, 2 = 5°×10°, 3 = 5°×5°, 4 = 1°×1°). Sufficient information was available in the dataset to correct this error, but the IOTC data should be checked to ensure that they are not affected by this problem.

There has been concern about the reliability of Taiwanese length frequency data, given inconsistencies in size composition through time and with other fleets (Geehan and Hoyle, 2013). Data before 2002 include a lot of small fish, which are largely absent after this period. Earlier data are also much more variable.

Since 2009 fishermen have been required to report both length and weight (from spring balances) in logbooks. The Taiwanese government has provided this to IOTC. The weight data are reliable, but length data are not considered reliable.

Since 2009, observer data have been collected. OFDC have compared observer data with logbook data and found a very large number of differences. It may be advisable to use only the post-2009 observer data, although logbook weight data may also be usable.

OFDC has suggested the need for a change to CMM 11/04 because it only describes the need to submit trip reports, rather than the data required for science. Changing the CMM to require submission of the relevant scientific data would make it easier for OFDC to provide this information. IOTC suggest that the CMM already caters for this issue and will follow up with OFDC.

9. Recommendations

Taiwanese length frequency data collected before 2002 should be further explored before they are considered in stock assessments, so they will not be used in stock assessments at this time. Taiwanese length frequency data collected by fishermen since 2002 will not be used in stock assessments.

Taiwanese weight data are likely to be usable once they have been thoroughly explored and compared with other datasets to determine whether they can be used in stock assessments.

There is no evidence of problems in Taiwanese observer length frequency data, and they should be used in stock assessments.

Seychelles length frequency data collected by fishermen on some longline vessels are likely affected by similar problems to the Taiwanese length frequency data collected by fishermen. Analyses to date suggest similar types of inconsistencies within the dataset, with some consistent and some inconsistent data. Checking of the Seychelles data has identified some large outliers, but further checking should be carried out. Until this issue is resolved the length frequency data collected by fishermen on Seychelles longline vessels should not be used in IOTC stock assessments.

Part B: Data exploration

Introduction

The data provided by each fleet have differing characteristics, which in many cases change through time. In some cases, there are differences between data held by the CPC and the data provided to IOTC. Attributes that vary include the proportion of the catch sampled, the areas sampled, the spatial and temporal resolution of samples, and the measurement type (length / whole weight, processed weight). There is also variation in the coverage of the size sampling when the temporal and spatial distributions of size and catch data are compared.

Variation in data characteristics can affect the ability to use data in stock assessments, and the way the data must be prepared before including them in the assessment.

Here we summarise the characteristics of available data, to identify issues that should be considered when preparing data for stock assessments, or that may require clarification or revision by the agency providing the data. Characteristics are summarised for all bigeye and yellowfin size data held by the IOTC, with a particular focus on the Japanese, Korean, Taiwanese and Seychelles fleets. In addition, we compare the data held by the IOTC with the data provided by the Japanese, Korean, Seychelles and Taiwanese fishing agencies. We explore size data coverage by comparing the time-area distributions of the size data and the catch.

Data Description and Methods

Data sources

Data for bigeye and yellowfin tuna held by the IOTC were obtained by download from the IOTC website (https://www.iotc.org/WPTT/23DP/Data/11-SFYFT and https://www.iotc.org/WPTT/23DP/Data/09-SFBET), along with the reference file (https://www.iotc.org/WPTT/23DP/Data/12-SFRef).

IOTC longline data were extracted by linking the 'Gear' codes to the key in the CodeGear reference worksheet and selecting rows with NCCode 'LL'. Spatial resolution was determined from the Grid code, and temporal resolution from the difference between month start and month end, as described in the Reference file. Data with the first digit of the grid code set to 9 (representing either one, two, or all four quadrants of the Indian Ocean) were discarded. No additional cleaning was carried out.

Data held by CPCs was provided in Excel spreadsheets or .csv files (Japanese, Korean and Taiwanese) and an Access database (Seychellois).

Japanese size data have previously been described in detail by Hoyle et al. (2017a).

Taiwanese size data were provided as 3 comma-separated (.csv) datasets: commercial length data 1980 – 2002, commercial weight data 2009 – 2018, and observer data 2009 – 2019. Each dataset was imported into R and cleaned by retaining set locations south of 29 degrees of latitude.

Korean size data were provided in an excel spreadsheet. The data were imported into R and cleaned by a) retaining fish between 50 and 230 cm, and b) retaining set locations between 10 and 130 degrees of longitude, and -42 and 29 degrees of latitude.

Seychelles data were loaded by linking a table with fishing event information to the table that included individual fish measurements. Data for bigeye and yellowfin were selected. Data were cleaned by a) retaining bigeye between 40 cm and 260 cm, and yellowfin between 50 cm and 230 cm; and b) retaining set locations between 10 and 130 degrees of longitude, and -42 and 29 degrees of latitude.

All national datasets were adjusted to the same format for analysis, with the fields shown in Table 1. National datasets and the IOTC dataset were provided with location recorded in various ways, so were adjusted to be consistent. Latitudes and longitudes were identified by the centre of the unit, so one degree stratification was recorded as 0.5, 1.5, 2.5; five degree stratification as 2.5, 7.5, 12.5, and so on. Locations at each spatial resolution were also calculated at all coarser resolutions.

Table 1: Fields used for the analysis, prepared from the data provided by IOTC and the national fleets.

National datasets				**IOTC datasets**	
Variable	**Format**	**Representing**	**Values**	**Variable**	**Format**
flag_id	chr	Flag		flag_id	Factor
species	chr	Species		species	chr
vesselc	chr	Vessel type	commercial, training, NA		
src	chr	source	observer, port, vessel, NA		
sex	chr		M, F, NA		
		Gear type	ELL, ELLOB, FLL, LL, LLOB	gear	chr
		General gear type	LL	gear2	chr
len	num	length		len	num
wt_wh	num	whole weight			
wt_pr	num	processed weight			
nfish	num	number of fish		nfish	num
len_res	num	length resolution	0, 1, 2, 5, NA		
wgt_res	num	weight resolution	0, 1, NA		
dmy	date	dd/mm/yyyy			
				qtr	Factor
yq	num	year-quarter		yq	num
yrqtr	Factor	year-quarter		yrqtr	Factor
yr	Factor	year		yr	Factor
year	num	year		year	num
				MonthStart	num
				MonthEnd	num
strat	chr	spatial stratification	10x10, 10x20, 1x1, 5x5	strat	chr
lat	num	from source		centlat	num
lon	num	from source		centlon	num
lat1	num	1 degree resolution			
lon1	num				
lat5	num	5 degree resolution		lat5	num
lon5	num			lon5	num
lat10	num	10 degree resolution		lat10	num
lon10	num			lon10	num
lon20	num	20 degree resolution		lon20	num
latlon1	Factor	1 degree cell		latlon1	Factor
latlon5	Factor	5 degree cell		latlon5	Factor
latlon10	Factor	10 degree cell		latlon10	Factor
latlon510	Factor	5x10 degree cell		latlon510	Factor
latlon1020	Factor	10x20 degree cell		latlon1020	Factor

Spatial stratification

The IOTC tropical tuna longline size data provided to analysts were in three main spatial resolutions: 1 x 1, 5 x 5, and 10 x 20 (Table 2, Table 3).

The IOTC-held Japanese data included all available 10 x 20 data, covering the period from the start of the time series to 2008. From 2009 to 2019 (latest) the Japanese fleet was represented by 5 x 5 data. Sampling locations of the 10 x 20 data held by IOTC are shown in Figure 1, and the 5x5 data in Figure 2.

Japan-held size data were almost all collected at finer resolutions (Table 6). Data were stored at 5 x 10 starting in 1952, with the dominant resolution changing to 1 x 1 in 1967. Some data were stored at 10 x 20 between 1965 and 1989, but these were always a small subset.

The IOTC-held Korean data provided to analysts were either at 1 x 1 resolution (2001, 2002 (bigeye only), 2006-2007, 2009-2010, 2012-present) or in very coarse Indian Ocean quadrant resolution (1991-2000, 2003-2005) which cannot be used for stock assessment. Sample sizes increased in recent years.

The resolution of the data provided by Korea to this project was also 1 x 1 (Table 7).

IOTC-held Seychellois data provided to analysts were at 1 x 1 resolution from 2007 to the present. Some hundreds of samples per species per year were provided at 10 x 10 resolution for the period 1996 to 2002 – the only data provided at this resolution.

Data provided by the Seychelles to this project (Table 8) were all at fine-scale degree-minute resolution, with usable numbers starting in 2007.

The IOTC-held Taiwanese data provided to analysts were entirely at 5 x 5 resolution. It provided the most data of any fleet at this resolution in all years from 1980 to the end of the time series.

Taiwanese-held data includes vessel-sourced length data from 1980 to the present, but data for this study were provided only for 1980-2002 and for bigeye tuna (Table 9). These data were all at 5 x 5 resolution. Observer data and vessel-sourced weight data for bigeye tuna were provided to this study for the years 1999 – 2018, all at 1 x 1 resolution.

Temporal stratification

IOTC-held data for Japan were provided at quarterly resolution from 1952-2008 (Table 11) and switched to 1-month resolution in 2009.

Japanese-held data were provided at 1-month resolution throughout the time series from 1952.

IOTC-held versions of the Korean, Seychelles and Taiwanese datasets provided to analysts were at 1-month resolution throughout the time series.

Korean, Seychellois, and Taiwanese data provided to this project were reported at daily time intervals.

Measurement type and conversion

Currently, data are used in IOTC tuna assessments only as length data. They are provided to analysts after conversion to fork length using the equations in Appendix 2.

To verify the existence of variability in length-weight relationships, and to check our understanding of factors that may affect it, we used generalized additive models to analyse bigeye tuna data (n = 7363) from Korean longline vessels sampled 1999-2018. We used log(weight) as the response variable, fitted a smoother to the effect of log(length), and used quarterly surfaces to estimate the effect of location.

Measurement resolution

All IOTC-held tuna data provided to analysts were reported in 2 cm length bins.

All Japanese-held length data were initially measured and recorded at 1 cm intervals, but in early years were rounded to either 2 cm or 5 cm due to data storage capacity limits (Table 5, Figure 11).

The direction of rounding for Japanese data is believed to have changed in 1970 from rounding up to rounding down (Hoyle et al., 2017a). Since the current practice is to round up, rounding practices must have changed again after 1988, but the date of the change is unknown. These changes in rounding direction were adjusted for in the analyses of Japanese data in this report, with the date of the second change assumed to be 1989. These adjustments have not been applied to the IOTC data provided to analysts.

Korean, Taiwanese, and Seychellois data were provided at 1 cm or 1 kg resolution.

Data sources

The source of the data can be an indicator of its quality. Data sources are reported to analysts in the data provided by IOTC in the SFRef.xlsx spreadsheet, SFSUMTT worksheet. All data are reported to be unraised. The source of all Japanese, Korean and Seychelles data is ‘reported by a liaison officer’, while Taiwanese data are ‘published data’. Validation is reported as applied to Japanese, Taiwanese, and some Seychelles data, but not to other Seychelles or any Korean data. Information on data quality is meant to be included in these spreadsheets but appears to be missing.

Japanese-held data were sourced either from port sampling of the catch from commercial vessels, from on board commercial vessels, or from research and training vessels. These sources are not identified in the IOTC-held data made available to analysts.

Results of analyses

Length-weight relationships

Length-weight relationships for bigeye tuna in Korean data (Figure 55) included significant spatial and seasonal variation, with fish generally in better condition in the north and northwest, and worse in the southeast. The relationship between log(length) and log(weight) was not linear but varied with length (Figure 56), a departure from the usual assumed relationship weight = $a.length^b$. The quarterly model fitted better than a model that assumed the same pattern throughout the year. An interannual effect was not supported for this dataset.

Discussion and Recommendations

The stratification of size data has several effects. Within a stock assessment, spatial stratification affects the way regions are defined, if regional boundaries are constrained to match the spatial strata. This can be limiting when data are collected at a coarse resolution like 10 x 20, with 5 x 5 or finer resolution preferred. Spatial stratification can also affect understanding of the stock, because sampling at coarser resolution is more likely to include areas with fish of different average sizes. This makes it harder to identify environmental factors affecting size distributions, and harder to adjust for size variation by standardizing the size data (Maunder et al., 2020).

As for spatial data, the temporal resolution of data limits the ways it can be used. Most IOTC stock assessments use quarterly resolution, so data provided at this resolution is sufficient for most purposes. Some assessments operate annually. Modeling at finer temporal resolutions such as monthly may be useful for short-lived species such as skipjack tuna or for tracking the growth of cohorts of young fish, which is particularly relevant to size data from purse seine, bait boat, or troll fleets, and less relevant to the longline data considered here.

Most stock assessment software including Stock Synthesis (Methot and Wetzel, 2013) require all data to have the same time resolution. The quarterly resolution of most of the Japanese data available to IOTC analysts limits IOTC stock assessments to quarterly or larger time steps. However, some stock assessment software (e.g. MULTIFAN-CL, Fournier et al., 1998) can vary time resolution at the fishery level, such as when using monthly time strata for the New Zealand albacore troll fishery to estimate the rapid growth of young fish in the South Pacific albacore stock assessment (Hoyle et al., 2012).

It would be useful to explore the available longline size data at monthly resolution to see if there are datasets and locations where sampling is good enough to identify and follow cohorts. It would also be useful if Japan would grant access to size data at monthly resolution, which would allow analysts to explore running models at monthly scale.

There are some disadvantages to converting between data formats, which will introduce bias when conversion factors are not accurate. In addition, applying the same conversion factors to all fish of the same species will cause bias if the true conversion ratios vary with other factors.

The conversion factors used for bigeye and yellowfin tuna are based on relatively few fish, small areas, few fisheries, and short time series. For example, the weight (gg) to length conversion factors come from the Penang Sampling Programme 1992-93, with 2361 and 316 fish for YFT and BET respectively. Other conversion factors are based on data from the Atlantic, and from sampling (6752 fish for length-weight relationship) at the Seychelles canneries (Marsac et al., 2006).

To be accurate, conversion factors should adjust for factors that affect the relationship between the two measurements. Length-weight relationships essentially measure fish condition, which is affected by spatial and seasonal factors, environmental conditions, and may vary through time due to density-dependent factors. Length-weight relationships will vary between sexes to some degree. They will also change as fish grow, which is reflected in the fact that different length-weight relationships are used for purse seiners and longliners.

Similarly, fish preparation (gilling and gutting) will vary to some extent between fleets and fisheries, which will also affect the length-weight relationship.

Reflecting these effects, various studies have obtained different length-weight relationships (see Marsac et al. (2006)).

Through time, Japanese data have been collected and/or stored in several different formats. Tropical tunas were either weighed gilled and gutted or measured to fork length (Table 10), with the proportions changing through time. The IOTC data

Adjustments for the changes in rounding direction in 1970 and after 1988 should be explored with Japanese data providers, to improve the quality of the data used in the assessments.

To better support conversion of weights to lengths, broad-based length-weight conversion models should be developed that cover as many fisheries, fleets, locations, seasons, and years as possible. We recommend the development of a shared database that IOTC members can contribute to. These data should then be modelled using modern statistical techniques to develop length weight relationship that can more reliably convert weights into lengths.

Part C: Recommendations for use in stock assessments

How does size data affect stock assessments?

Tuna stock assessments are very dependent on size data, which have been collected in many fisheries and for long time series. Given the models' reliance on these data, it is important to understand the impact of data quality on assessment outcomes.

Size data informs the estimation of selectivity. Selectivity affects how catch is extracted from the modelled population. It also affects how the model fits to the observed CPUE. In IOTC tropical tuna assessments, the selectivity of longline fisheries linked to CPUE indices has always been constrained to be constant through time. However, the current version of Stock Synthesis can also estimate time-varying selectivity. It should be noted that longline sizes can vary significantly within regions of the Indian Ocean (Figure 13 to Figure 20) (Hoyle et al., 2017b).

Size data provide information about the relative strengths of recruitments. This is particularly true for size data from fisheries that take small fish, such as purse seiners, and is less the case for longline fisheries which mostly take large fish.

Size data also inform the model about the average size of the fish being caught. The average size of fish caught is affected both by the size structure of fish in the population (or the sub-population within the region), and by selectivity. When selectivity is assumed to be constant through time (rather than time-varying), the model interprets trends in observed fish sizes as changes in the population. These changes can have a large impact on assessment results. If the average size of observed fish decreases through time, the model will tend to explain this trend as due to an increase in fishing mortality, which will reduce the proportion of old and large fish in the population. The essence of fishing mortality is catch / abundance. Since catch is known and fixed, the model cannot change it, but it can adjust the abundance trend by changing the recruitment trend, or to some extent by changing the overall population scaling.

Poor quality size data can substantially affect stock assessment results by introducing bias through the mechanisms described above. There are different ways that size data can be of poor quality for the purposes of stock assessment. Moderately unrepresentative sampling that has the same features through time will result in worse fit to the size data but may not seriously bias the results. The most serious problems are caused by highly unrepresentative sampling, and changes through time in the quality of sampling.

A number of different factors can affect the sizes of fish caught, including location, year, time of year, the type of fishing gear used and the way it is deployed, and random chance, reinforced by the fact that tunas tend to associate with conspecifics of similar sizes. Location is particularly important for tunas, since there can be significant spatial size variation (see Figures 13-20 for yellowfin tuna, and Figures 35-40 for bigeye tuna). Seasonality is important since tuna distributions are affected by environmental conditions. Estimating different distributions by quarter considerably improves the AIC of gams of size distribution for both yellowfin and bigeye (Figures 22 and 44).

It should be noted that the population selectivity (the realised selectivity of a fishery) is defined differently from contact selectivity. Population selectivity defines the relationship between the size distributions of the catch taken by the fishery and the population potentially vulnerable to the fishery, so it must allow for the effects of spatial distribution of fishing relative to spatial size variation within the vulnerable population. Contact selectivity defines probability of capture at size for individual fish (Sampson, 2014).

The current fishery definitions for tunas include within individual fisheries areas with different size distributions, which vary seasonally. Since tuna longline fishery effort distribution varies through time, the realised selectivities of these fisheries also vary through time and by season.

What information in size data is reliable?

Sampling is usually designed to be representative of the catch, and this is achieved for different datasets with varying degrees of success. Here we list the various data sources, note potential concerns, and make recommendations for how they should be used in stock assessments, in the short and the long term.

Methods

To explore this issue, we applied several approaches to explore size patterns. First, we applied a simple standardization model to size data by location and year-quarter, with the formula: size ~ year-quarter + location, implemented as follows using the R package mgcv (Wood, 2011).

```
mod <- gam(len ~ yrqtr + te(lon, lat, k = c(10,10)), data=dat, weights = dat$nfish)
```

Models to explore quarterly size distribution changes included an additional term.

```
mod_qtr <- gam(len ~ yrqtr + te(lon, lat, qtr, k = c(10,10,4)), data=dat, weights=dat$nfish)
```

Spatial and spatial-seasonal effects were fitted using 2D or 3D smooths, and temporal effects were fitted as factors. The models assumed Gaussian residuals. The gam was fitted with ‘gamma’ parameter set to 2, to reduce effective sample sizes in the smooths by 50%. To present results, in each case the spatial smooth was extracted from the fitted gam model using the sm() function from mgcViz (Fasiolo et al., 2020), and plotted on a map to show relative sizes. The time series of year-quarter factors were plotted relative to the level of the base factor in the model, which was the first year-quarter with an observation.

Further exploration of early time trends in Japanese data was carried out by examining trends in different locations, using the data provided by Japan, and confirming results with IOTC-held data. Length data for effort prior to 1970 and stratified at 5x5 and 1x1 resolution were separated into 10 x 20 spatial cells. Nineteen cells with fewer than 10000 fish measured during this period were omitted from further analysis, and 14 cells were included.

For each cell, the following two gam models were fitted. The first included a temporal trend across year-quarters, and factors to account for spatial effects within the four quadrants of the 10x20 cell. The second gam was the same as the first, apart from fitting a factor to the temporal effect.

```
mod <- gam(len ~ as.factor(latlon510) + s(yq, k=6), data = dat, weights=dat$nfish, gamma=1)
```

```
mod <- gam(len ~ as.factor(latlon510) + yrqtr, data = dat, weights=dat$nfish, gamma=1)
```

For each model, the median expected length for each time period was predicted and both results were plotted on the same axes.

Similar analyses were carried out for Seychelles data in the area affected by piracy, from latitudes 0 to 10 and from longitudes 50 to 90.

Results

Results of the spatial size models (maps of relative sizes in space, and time series of relative sizes) are provided in Figures 13 to 32 for yellowfin tuna, and Figures 35 to 54 for bigeye tuna.

These models indicate for yellowfin tuna that spatial size patterns are similar between IOTC-held Japanese data (Figure 13), Japanese-held data at finer spatial scales (Figure 15, as expected since this is mostly the same data), and Korean-held data despite relatively small sample sizes. IOTC-held Taiwanese length data have very large sample sizes and might be expected to show a similar pattern to the other fleets, but in fact the spatial pattern is somewhat different with less spatial variation (Figure 14). IOTC-held Seychelles length data, which also have quite large sample sizes, show a different spatial size distribution from other datasets (Figure 17). IOTC-held Chinese length data (Figure 19), and length datasets from other fleets (Figure 20), are too sparsely sampled to estimate spatial size distributions.

Time series of predicted sizes from the IOTC-held data and the national datasets show some distinct differentiation among fleets. The Japanese yellowfin data indicate stable patterns since about 1965, with more variability when data become sparse in the early 2000s (Figure 23). Standardizing the IOTC-held Japanese 5 x 5 size data indicated similar stability (Figure 24). Standardizing the Japanese 5 x 10 and 1 x 1 length data provided by Japan at 5 x 10 resolution gave a similar time series to the 10 x 20 size data held by IOTC, though extending through to 2018 with the inclusion of small amounts of 1 x 1 data.

Time series from the IOTC-held Seychelles (Figure 27) and Taiwanese (Figure 29) yellowfin size data, show more time-series variation. The Taiwanese time series is very variable from 1980 until 1992, when the expected size suddenly drops to over 20cm less than the start of the time series, and then from 2000 steadily increases to reach an average of almost 10 cm more than the start of the time series. The IOTC-held Chinese dataset is still relatively sparse which may explain its high variability (Figure 30). The predicted length time series was relatively stable for data from fleets submitting 5 x 5 data other than the Japanese and Taiwanese (Figure 31). Most of these data came from India and Sri Lanka, with smaller amounts from Portugal, Maldives, Mozambique, Mauritius, and the European Union. Length data provided by Korea also showed relatively stable time series despite low sample sizes (Figure 32).

For bigeye tuna, models indicate that spatial size patterns are similar between IOTC-held Japanese data (Figure 35), Japanese-held length data and weight data at finer spatial scales (Figure 36 and Figure 37), and even for Korean-held data with relatively small sample sizes (Figure 38). Size maps based on Taiwanese-held observer data (Figure 39) and vessel-sourced weight data (Figure 40) show patterns that are somewhat similar, with differences that may be due to small sample sizes and differences in the period covered. Maps based on IOTC-held Taiwanese length data with very large sample sizes show a similar spatial pattern with to other datasets the largest fish in the northwest (Figure 41). IOTC-held Seychelles length data also have quite large sample sizes and but the spatial pattern is less distinct than most of the other fleets (Figure 42).

Differentiation among fleets for predicted sizes of bigeye tuna was similar to the results for yellowfin tuna. The Japanese data started in 1965, so any decline as seen in the yellowfin until about 1965 would not have been apparent. Expected sizes were relatively stable thereafter, with more variability when data become sparse in the early 2000s (Figure 45). Standardizing the Japanese 5 x 10 and 1 x 1 length data provided by Japan at 5 x 10 resolution gave a similar time series to the 10 x 20 size data held by IOTC, though extending through to 2018 with the inclusion of small amounts of 1 x 1 data (Figure 46). Standardizing the Japanese-held weight data also showed relatively stable size trends through time (Figure 47).

Time series from the IOTC-held Seychelles (Figure 48) and Taiwanese (Figure 50) size data, show more time-series variation and are similar to one another. The Seychelles bigeye time series has a remarkably similar pattern to yellowfin, with low points in early 2011 and high points in late 2015. The Taiwanese time series also shows very similar patterns in both bigeye and yellowfin, dipping from local highs in 1996 to lows in 2000, after which sizes steadily increase. Sizes for both species dip in 2010 and then increase again to reach high points near the end of the time series.

Predictions for the Taiwanese bigeye tuna observer data (Figure 51) and weight data (Figure 52) are much less variable than the 5 x 5 IOTC-held data, and both suggest a trend of slightly increasing size between the 2009-2013 period and 2014-2018.

In contrast, the predicted length time series suggested slightly decreasing size over the same period for fleets submitting 5 x 5 data other than the Japanese and Taiwanese (Figure 53), although the estimates are uncertain. Most of these data came from India and Sri Lanka, with smaller amounts from Portugal, Maldives, Mozambique, Mauritius, and the European Union. Length data provided by Korea predicted relatively stable time series with some decline in the 2014- 2018 period compared to 2005-2010 period (Figure 54), but these trends are also relatively uncertain.

These analyses support the understanding that there is consistent spatial variation in bigeye and yellowfin tuna sizes, both within and between the current region definitions.

Size trends after the start of fishing

Size trends through time are apparent in the expected sizes for yellowfin tuna in Japanese data from 1952 until about 1965 (Figure 23, Figure 25).

Analyses of these data by spatial cell show that there is a similar decline at the start of the time series in almost all cells (Figure 33). After the initial decline patterns are more variable among longitudes, with the eastern cells (130°) increasing after about 1960 while those further west (110° and 90°) level off or become variable, while those furthest west (70° and 50°) continue to decline in mean size until 1970. This spatially varying trend appears to reflect the steady expansion of Japanese fishing effort from east to west across the Indian Ocean.

Similar analyses were applied to data from the Seychelles national dataset for the period starting in 2010, immediately after fishing returned to the areas it was excluded from during the piracy period. For yellowfin tuna, results did not show any clear size trends, while bigeye tuna sizes appeared to follow an increasing trend in most cells (Figure 34).

Summaries and recommendations by fleet

Japanese data for yellowfin show a large and steady decline in average size before 1965. This change may represent a real decline in fish sizes. Sampling practices changed during this early period and there has been doubt about their consistency, but the spatially varying trend appears to reflect the steady expansion of Japanese fishing effort from east to west across the Indian Ocean. Such a spatial-temporal relationship between fishing effort and observed sizes is consistent with the hypothesis that fishing caused the change in observed sizes. An alternative hypothesis, that the trend was due to a time trend in sampling bias, would be expected to cause the same time trend in all locations at the same time, and is not supported by the results of this analysis.

Past assessments have been unable to fit these data with the same selectivity. A plausible explanation for a change in selectivity is that catchability varies between individual fish, and average selectivity changed as large fish with higher catchability were preferentially removed from the population. Given the uncertainty about what happened, the large influence of these data on results, and the fact that this proposed explanation could not be accommodated by the assessment, they should either be omitted from the assessment or accommodated with time-varying and spatially varying selectivity. In preference, we recommend omitting these pre-1965 data from the assessment, to allow the model to fit better to the rest of the data. After 1965 the Japanese data are reasonably consistent and show coherent spatial patterns, so may be included pending further investigation of some parts of the time series.

Taiwanese and Seychelles length-sampled logbook data held by IOTC show evidence of changing size sampling behaviour through time, with patterns that are similar across species, inconsistent with data from other fleets, but similar between these two fleets. Spatial patterns for Seychelles bigeye and yellowfin and for Taiwanese yellowfin are dissimilar from other fleets. Given these inconsistencies and the strong influence of these data on the assessment, we recommend omitting all Taiwanese and Seychelles logbook length data until the problems can be addressed. We understand this includes all Taiwanese length data currently held by IOTC. As discussed earlier, measuring fish for length is not a standard part of vessel work practices on most longline vessels, whereas fishermen weigh the fish for their own purposes.

In contrast, Taiwanese weight-sampled logbook data and Taiwanese observer data show temporal patterns that are consistent with one another, and spatial patterns that are consistent with one another and with other fleets. They do not show signs of sampling problems and may be included in the assessment. This conclusion is based on the Taiwanese observer and logbook weight data for bigeye tuna since we did not have access to the yellowfin data. We therefore recommend checking the yellowfin data before including it in the model.

Size data for the Korean fleet and for other fleets providing 5 x 5 data appear to have spatial and temporal patterns without major anomalies and are not inconsistent with the Japanese data. We therefore do not currently recommend removing these data, pending further investigation and comparisons among fleets.

How should analysts configure assessments, given size data quality?

After sampling, further data preparation should depend on the assumptions of the stock assessment model. Traditionally, all available size data have been included in the model, apart from samples known to be biased. Each longline fishery has been assumed to have the same selectivity throughout the time series, and that selectivity has often been shared across all longline fisheries. The same selectivity has been used for extracting catch and for fitting to the index of abundance. These have been the approaches used in recent stock assessments for Indian Ocean yellowfin tuna (Fu et al., 2018; Langley, 2015).

However, alternatives to these approaches have been developed which should be considered for Indian Ocean tuna assessments. These new approaches differentiate between the selectivity used to extract catch and the selectivity applied to longline CPUE indices (Maunder et al., 2020). Catch selectivity is defined as time-varying, and the size data are structured to be representative of the catch. The longline CPUE indices are included in separate fisheries, and index selectivity is defined as constant through time. The size data associated with the index fisheries are structured to be representative of the population, so that the variation in fishing location does not affect the size data. This is achieved by standardizing the size and CPUE data together and predicting standardized size distributions (Thorson and Haltuch, 2019). This approach has been applied in both IATTC and WCPFC stock assessments (Ducharme-Barth et al., 2020; Minte-Vera et al., 2020; Vincent et al., 2020; Xu et al., 2020).

Longline selectivities should not be shared among regions, but estimated independently (Hoyle and Langley, 2020). We would also argue for using dome-shaped selectivity for most longline fisheries.

Waterhouse et al. (2014) showed that, using an areas-as-fleets approach, both population-level selectivity and individual-fishery selectivity are likely to be dome-shaped and to vary individually even when the gear selectivity of each fishery is asymptotic. Spatial structuring withing regions is inevitable at the scale of tuna assessments and is evident from the spatial size patterns identified in this report. This suggests that the selectivity within each region should be modelled as dome-shaped. Moreover, wild populations have attributes, such as spatially varying growth rates, that cannot be modelled effectively by stock assessment packages. Selectivity ogives must be flexible and non-asymptotic to fit to the resulting spatial patterns in size data. Poorly fitting size data can affect model scaling and population trends, so it is important to avoid systematic lack of fit. We therefore recommend using dome-shaped selectivity patterns for longline fisheries, with the possible exception of fisheries in the region where the largest fish are caught.

Similar arguments apply to seasonal variation in fish sizes. Such patterns are widespread in tuna fisheries, with seasonal movements affecting distribution as indicated by CPUE patterns (Hoyle and Langley, 2020), mean sizes (Figures 22 and 44), and selectivity estimates (Fu et al., 2021; Hoyle et al., 2008). Estimating parameters reliably and avoiding data conflict will require approaches that avoid lack of fit due to these seasonal patterns.

There is unlikely to be time to develop an index fishery approach for the 2021 yellowfin assessment, so the assessment will require an approach that is robust to temporal changes in population selectivity.

The stock assessment currently assumes constant selectivity though time. Estimating this selectivity only requires a relatively short size data time series. Longer time series that include periods with different population selectivity (which the model does not address) only result in data conflict, which the model tries to resolve by changing the population scale, and fitting poorly to other datasets such as the CPUE index. This conflict can be reduced in various ways: a) improve the fit to the size data by developing fishery definitions that better reflect size variation in space and time, b) reduce the bias caused by poorly fitting size data by reducing effective sample sizes, generally well below the recommendations of methods such as McAllister and Ianelli (1997), c) improve the size data by fixing anomalies such as inaccurate weight conversions, d) where there is evidence of changing selectivity within a fishery time series, remove the size data except for periods that best represent the selectivity.

We recommend a combination of the above approaches, with an initial focus on step d: removing or severely downweighting any conflicting parts of the longline size data time series. Including conflicting data in a stock assessment leads only to unreliable results. When constant selectivity is assumed for a fishery, selectivity changes will cause changes in observed sizes that the model cannot fit. This has no local effect on the sizes of fish removed from the population. There is therefore no benefit for removals from including these conflicting size data.

An SS assessment model does not need a full time series of longline size data to estimate stock status. There is information about population scaling in tagging data, information about population trends in CPUE time series, and information about recruitment in the size data from purse-seine fisheries. Two areas potentially affected by reducing data conflict in this way are information about the movements of large fish, and information about spatial recruitment distributions. Movement rates are constrained to be constant through time, and in many current model scenarios are estimated to be unrealistically high. Current models also estimate strong spatial trends through time in recruitment distribution. Reducing data conflict may help to improve estimates of these parameters.

1. Tables

YFT

Table 2: Number of length measurements in data held by IOTC for yellowfin tuna by spatial resolution, flag, and year.

10x10

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1996	0	0	0	0	0	0	0	0	0	0	0	0	485	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	256	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	229	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	207	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	111	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	409	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	157	0	0

10x20

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1952	0	0	0	0	0	0	2903	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	8195	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	17238	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	88499	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	70220	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	68746	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	55250	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	61602	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	74271	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	39437	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	58072	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	20915	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	68093	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	74321	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	62999	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	40244	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	62470	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	44304	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	37065	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	49929	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	39765	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	20249	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	19873	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	22939	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	26204	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	26717	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	21479	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	19020	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	13527	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	16684	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	26160	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	30829	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	56765	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	66140	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	56580	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	22162	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	28183	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	25051	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	31081	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	13888	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	10876	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	11204	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	6418	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	9501	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	7456	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	6985	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	17620	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	11297	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	9034	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	5577	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	1449	0	0	0	0	0	0	0	0

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
2003	0	0	0	0	0	0	920	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	255	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	1039	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	2970	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	1403	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	1760	0	0	0	0	0	0	0	0

1x1

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
2001	0	0	0	0	0	0	0	267	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	299	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	687	0	0	0	0	11677	0	82
2008	0	0	0	0	0	0	0	0	0	0	0	0	7219	0	106
2009	406	0	0	0	0	0	0	470	0	0	0	0	3708	0	122
2010	647	0	0	0	0	0	0	139	0	0	0	0	714	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	6763	0	0
2012	1310	0	0	0	0	0	0	46	0	0	0	0	7345	0	0
2013	1419	0	0	0	0	0	0	198	0	0	0	0	10398	0	0
2014	20	0	0	0	0	0	0	522	0	0	0	0	14726	0	0
2015	28	0	0	0	0	0	0	799	0	0	0	0	1013	0	0
2016	1432	0	0	0	139	0	0	765	0	0	0	0	1925	0	0
2017	1928	63	11	0	124	0	0	4057	0	0	0	0	4820	0	0
2018	3007	0	0	0	104	0	0	3237	0	0	0	0	2561	0	4210
2019	0	0	0	0	184	0	0	1582	0	0	0	0	8760	0	0

5x5

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	7251	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	20502	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	24730	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	32298	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	31445	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	35820	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	61600	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	38925	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	30428	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	8872	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	20118	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	3500	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	2792	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	75072	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	34114	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	39099	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	95575	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	77225	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	53235	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	38503	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	41678	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	52602	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	95511	584
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	166706	483
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	230602	1071
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	635930	114
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	350435	212
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	232499	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	112575	0
2009	0	0	0	0	0	0	313	0	0	0	0	0	0	80998	0
2010	0	0	0	0	0	0	192	0	0	0	0	0	0	78135	241
2011	0	0	0	30	0	0	363	0	0	0	0	0	0	80158	0
2012	0	0	0	20	0	0	1778	0	0	0	0	0	0	77799	0
2013	0	0	0	36	0	0	2807	0	0	0	0	0	0	70578	0

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
2014	0	0	0	25	0	10182	718	0	0	163	0	0	0	70656	0
2015	0	0	0	29	0	14622	2063	0	0	189	138	0	0	40145	0
2016	0	0	0	43	0	9549	1903	0	4864	38	153	0	0	53553	0
2017	0	0	0	62	0	5017	4234	0	6680	99	0	233	0	39389	0
2018	0	0	0	56	0	5594	5212	0	8716	0	0	604	0	67591	0
2019	0	0	0	81	357	2408	5659	0	10940	0	0	0	0	47686	0

BET

Table 3: Number of length measurements in data held by IOTC for bigeye tuna by spatial resolution, flag, and year.

10x10

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	PHL	SYC	TWN	ZAF
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	603	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	181	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	295	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	253	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	204	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	87	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0

10x20

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	PHL	SYC	TWN	ZAF
1965	0	0	0	0	0	0	58466	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	42635	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	38134	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	39015	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	43847	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	35320	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	38832	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	19816	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	14285	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	17209	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	14866	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	11831	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	14374	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	24674	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	38035	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	33436	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	33098	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	45542	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	61349	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	74645	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	95433	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	91036	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	45043	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	47141	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	38046	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	25508	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	20778	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	15902	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	7019	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	4897	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	7848	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	3306	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	7868	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	13126	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	3191	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	4271	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	2848	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	2118	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	1039	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	1512	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	2195	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	2865	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	2381	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	570	0	0	0	0	0	0	0	0	0

1x1

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	PHL	SYC	TWN	ZAF
2001	0	0	0	0	0	0	0	200	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	152	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	382	0	0	0	0	0	29753	0	22
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	48660	0	316
2009	2873	0	0	0	0	0	0	179	0	0	0	0	0	35951	0	245
2010	3800	0	0	0	0	0	0	79	0	0	0	0	0	9030	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	42321	0	0
2012	2805	0	0	0	0	0	0	383	0	0	0	0	0	77612	0	0
2013	5606	0	0	0	0	0	0	839	0	0	0	0	0	61792	0	0
2014	128	0	0	0	0	0	0	192	0	0	0	0	0	44460	0	0
2015	128	0	0	0	0	0	0	288	0	0	0	0	0	5362	0	0
2016	1853	0	0	0	300	0	0	327	0	0	0	0	0	2402	0	0
2017	810	40	38	0	166	0	0	1312	0	0	0	0	0	7857	0	2624
2018	2762	0	0	0	132	0	0	981	0	0	0	0	0	3934	0	0
2019	0	0	0	0	114	0	0	414	0	0	0	0	0	2952	0	0

5x5

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	PHL	SYC	TWN	ZAF
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21775	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38632	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62901	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61660	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54440	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58176	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60608	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35012	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23025	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12388	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17645	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7673	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8171	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10809	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33930	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34828	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117609	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107517	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107912	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100623	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104275	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110749	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221538	1234
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	546294	746
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	531335	511
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	621246	298
2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	522237	554
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	491508	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	306218	0
2009	0	0	0	0	0	0	1098	0	0	0	0	0	0	0	405095	0
2010	0	0	0	0	0	0	2674	0	0	0	0	0	0	0	243280	295
2011	0	0	0	1955	0	0	2834	0	0	0	0	0	0	0	241444	0
2012	0	0	0	185	0	0	4081	0	0	0	0	0	1500	0	354009	0
2013	0	0	0	74	0	0	3665	0	0	0	0	0	907	0	202821	0
2014	0	0	0	36	0	21492	9254	0	0	911	0	0	634	0	145955	0
2015	0	0	0	341	0	26207	8540	0	0	305	140	0	0	0	81819	0
2016	0	0	0	99	0	23115	11966	0	1017	42	92	0	0	0	86788	0
2017	0	0	0	85	0	18312	12546	0	1733	0	0	195	0	0	82485	0
2018	0	0	0	50	0	10150	3304	0	0	0	0	263	0	0	79728	0
2019	0	0	0	61	180	2261	8002	0	2877	0	0	0	0	0	89796	0

Table 4: Number of yellowfin tuna size measurements in data held by IOTC by flag and gear type.

	ELL	ELLOB	FLL	LL	LLOB
CHN	0	0	0	6503	3694
EUFRA	0	63	0	0	0
EUGBR	0	0	0	0	11
EUPRT	0	0	0	0	382
EUREU	357	551	0	0	0
IDN	0	0	2408	44964	0
JPN	0	0	0	1694182	24891
KOR	0	0	0	9162	3906
LKA	0	0	31200	0	0
MDV	0	0	0	489	0
MOZ	291	0	0	0	0
MUS	837	0	0	0	0
SYC	1854	0	0	81629	0
TWN	0	0	52000	3270546	33784
ZAF	3015	0	0	4210	0

Table 5: Japanese-held yellowfin tuna size samples by measurement type and resolution.

Year	Wt 1kg	Len 1cm	Len 2cm	Len 5cm
1952	0	0	13279	0
1953	1513	0	15522	0
1954	0	0	22469	0
1955	0	0	96059	0
1956	10717	0	60244	0
1957	33104	0	10825	0
1958	23237	0	23563	0
1959	22803	0	27579	0
1960	21893	0	47491	0
1961	11449	0	18604	0
1962	30038	0	26263	0
1963	13838	0	8623	0
1964	33395	0	13859	0
1965	27360	74	29630	0
1966	27097	20	31490	0
1967	14753	0	14698	0
1968	25698	46	24472	0
1969	10902	0	27873	0
1970	7693	0	28557	0
1971	10179	0	35560	0
1972	4469	48	34791	0
1973	2948	0	20882	0
1974	4000	0	17799	0
1975	3381	218	20943	0
1976	355	1359	25275	0
1977	1308	2360	23571	0
1978	1583	2113	17239	0
1979	1342	2511	15207	0
1980	455	3324	9297	0
1981	953	2140	12638	0
1982	4894	4985	11388	0
1983	5955	3919	15220	0
1984	17944	10245	10633	0
1985	24426	5848	11702	0
1986	22083	3465	8950	0
1987	6122	2926	6992	0
1988	10484	5686	2068	0
1989	8451	8150	0	0
1990	10724	9633	0	0
1991	4953	5002	0	0
1992	4613	1661	0	0
1993	3691	3822	0	0
1994	1149	4120	0	0
1995	1685	6163	0	0
1996	1784	3895	0	0
1997	4	6999	0	0
1998	3397	10844	0	0
1999	1	5847	5518	895
2000	29	7965	1818	0
2001	91	4575	834	0
2002	0	1451	0	0
2003	2	887	0	0
2004	19	1170	0	502
2005	15	1046	140	1025
2006	0	1979	992	0
2007	0	1403	0	0
2008	0	1752	0	0
2009	0	313	0	0
2010	3	191	0	0
2011	0	363	0	0
2012	0	1778	0	0
2013	0	2807	0	0
2014	0	718	0	0
2015	0	2063	0	0
2016	0	1903	0	0
2017	0	4234	0	0
2018	0	2250	0	0

Table 6: Number of yellowfin tuna size measurements attributed to Japan in data held by Japan and the IOTC by spatial stratification and year.

Year	Japan 10x20	Japan 1x1	Japan 5x10	IOTC 10x20	IOTC 5x5	Japan Total	IOTC Total
1952	0	0	13279	2903	0	13279	2903
1953	0	0	17035	8194	0	17035	8194
1954	0	0	22469	17238	0	22469	17238
1955	0	0	96059	88499	0	96059	88499
1956	0	0	70961	70219	0	70961	70219
1957	0	0	43929	68745	0	43929	68745
1958	0	0	46800	55249	0	46800	55249
1959	0	0	50382	61602	0	50382	61602
1960	0	0	69384	74271	0	69384	74271
1961	0	0	30053	39436	0	30053	39436
1962	0	0	56301	58071	0	56301	58071
1963	0	0	22461	20914	0	22461	20914
1964	0	0	47254	68093	0	47254	68093
1965	11483	0	45581	74320	0	57064	74320
1966	9807	0	48800	62999	0	58607	62999
1967	6526	14322	8603	40244	0	29451	40244
1968	12045	22855	15316	62469	0	50216	62469
1969	3025	27873	7877	44304	0	38775	44304
1970	1580	28557	6113	37064	0	36250	37064
1971	3210	35560	6969	49928	0	45739	49928
1972	1194	34839	3275	39764	0	39308	39764
1973	971	20882	1977	20248	0	23830	20248
1974	1146	17799	2854	19872	0	21799	19872
1975	1245	21161	2136	22938	0	24542	22938
1976	0	26772	217	26203	0	26989	26203
1977	254	25931	1054	26716	0	27239	26716
1978	0	19352	1583	21478	0	20935	21478
1979	0	17718	1342	19019	0	19060	19019
1980	0	12621	455	13526	0	13076	13526
1981	232	14778	721	16683	0	15731	16683
1982	145	16373	4749	26160	0	21267	26160
1983	924	19139	5031	30828	0	25094	30828
1984	1052	20878	16892	56765	0	38822	56765
1985	372	17550	24054	66139	0	41976	66139
1986	862	27202	6434	56579	0	34498	56579
1987	0	15521	519	22161	0	16040	22161
1988	0	16698	1540	28183	0	18238	28183
1989	170	14237	2194	25051	0	16601	25051
1990	0	19949	408	31080	0	20357	31080
1991	0	9445	510	13887	0	9955	13887
1992	0	6274	0	10875	0	6274	10875
1993	0	7483	30	11203	0	7513	11203
1994	0	5269	0	6418	0	5269	6418
1995	0	7848	0	9501	0	7848	9501
1996	0	5679	0	7456	0	5679	7456
1997	0	7003	0	6985	0	7003	6985
1998	0	14241	0	17619	0	14241	17619
1999	0	12261	0	11297	0	12261	11297
2000	0	9812	0	9033	0	9812	9033
2001	0	5500	0	5576	0	5500	5576
2002	0	1451	0	1449	0	1451	1449
2003	0	889	0	920	0	889	920
2004	0	1691	0	255	0	1691	255
2005	0	2226	0	1039	0	2226	1039
2006	0	2971	0	2970	0	2971	2970
2007	0	1403	0	1403	0	1403	1403
2008	0	1752	0	1760	0	1752	1760
2009	0	313	0	0	313	313	313
2010	0	194	0	0	192	194	192
2011	0	363	0	0	363	363	363
2012	0	1778	0	0	1778	1778	1778
2013	0	2807	0	0	2807	2807	2807
2014	0	718	0	0	718	718	718
2015	0	2063	0	0	2063	2063	2063
2016	0	1903	0	0	1903	1903	1903
2017	0	4234	0	0	4234	4234	4234
2018	0	2250	0	0	5212	2250	5212

Table 7: Korean yellowfin tuna size samples by measurement type, source, and year. For all data the spatial resolution is 1 x 1.

Year	wt_observer	wt_vessel	len_observer	len_vessel
1999	0	18	0	18
2000	0	380	0	380
2001	0	288	0	288
2002	0	12	0	12
2003	0	525	0	525
2004	0	849	0	849
2005	0	622	0	622
2006	0	568	0	568
2007	0	251	0	251
2008	0	63	0	63
2009	0	587	0	587
2010	61	78	61	78
2012	23	0	24	0
2013	3	104	3	104
2014	19	78	19	78
2015	1169	851	1225	851
2016	1403	779	1464	779
2017	1004	2104	993	2104
2018	0	1926	0	1926

Table 8: Seychelles yellowfin tuna size samples by year, made available by the Seychelles and by the IOTC. For IOTC-held data the spatial resolution is 1 x 1, measurement type is length, and the source is the vessel. Seychelles-held data resolution is

Year	Seychelles	IOTC 1x1	IOTC 10x10
1996			485
1997			256
1998			229
1999			207
2000			111
2001			409
2002			157
2005	0	0	
2006	3	0	
2007	12243	11677	
2008	7655	7219	
2009	3883	3708	
2010	746	714	
2011	7369	6763	
2012	7991	7345	
2013	12123	10398	
2014	17224	14726	
2015	15003	1013	
2016	12133	1925	
2017	25557	4820	
2018	6926	2561	
2019	0	8760	

Table 9: Taiwanese bigeye tuna size samples by measurement type, source, spatial stratification, and year.

Year	len_vessel_5x5	wt_vessel_1x1	len_observer_1x1	wt_observer_1x1
1980	21775	0	0	0
1981	38631	0	0	0
1982	62876	0	0	0
1983	61660	0	0	0
1984	54440	0	0	0
1985	58176	0	0	0
1986	60627	0	0	0
1987	35012	0	0	0
1988	23025	0	0	0
1989	12388	0	0	0
1990	17645	0	0	0
1991	7673	0	0	0
1992	8171	0	0	0
1993	10841	0	0	0
1994	33902	0	0	0
1995	34828	0	0	0
1996	117610	0	0	0
1997	107517	0	0	0
1998	107912	0	0	0
1999	100623	0	0	0
2000	104275	0	0	0
2001	110749	0	0	0
2002	221301	0	0	0
2009	0	2896	8568	8568
2010	0	17992	8455	8455
2011	0	9354	4593	4593
2012	0	2932	3271	3271
2013	0	18013	4015	4015
2014	0	12185	3376	3376
2015	0	9950	2542	2542
2016	0	23758	2321	2321
2017	0	40719	2136	2136
2018	0	35402	2642	2642
2019	0	0	127	127

Table 10: Number of yellowfin tuna size measurements in data held by Japan for by measurement type, spatial stratification, and year.

Year	len 10x20	len 1x1	len 5x10	wt 10x20	wt 1x1	wt 5x10	len Total	wt Total
1952	0	0	13279	0	0	0	13279	0
1953	0	0	15522	0	0	1513	15522	1513
1954	0	0	22469	0	0	0	22469	0
1955	0	0	96059	0	0	0	96059	0
1956	0	0	60244	0	0	10717	60244	10717
1957	0	0	10825	0	0	33104	10825	33104
1958	0	0	23563	0	0	23237	23563	23237
1959	0	0	27579	0	0	22803	27579	22803
1960	0	0	47491	0	0	21893	47491	21893
1961	0	0	18604	0	0	11449	18604	11449
1962	0	0	26263	0	0	30038	26263	30038
1963	0	0	8623	0	0	13838	8623	13838
1964	0	0	13859	0	0	33395	13859	33395
1965	1423	0	28281	10060	0	17300	29704	27360
1966	2841	0	28669	6966	0	20131	31510	27097
1967	376	14322	0	6150	0	8603	14698	14753
1968	467	22855	1196	11578	0	14120	24518	25698
1969	0	27873	0	3025	0	7877	27873	10902
1970	0	28557	0	1580	0	6113	28557	7693
1971	0	35560	0	3210	0	6969	35560	10179
1972	0	34839	0	1194	0	3275	34839	4469
1973	0	20882	0	971	0	1977	20882	2948
1974	0	17799	0	1146	0	2854	17799	4000
1975	0	21161	0	1245	0	2136	21161	3381
1976	0	26634	0	0	138	217	26634	355
1977	0	25931	0	254	0	1054	25931	1308
1978	0	19352	0	0	0	1583	19352	1583
1979	0	17718	0	0	0	1342	17718	1342
1980	0	12621	0	0	0	455	12621	455
1981	0	14778	0	232	0	721	14778	953
1982	0	16373	0	145	0	4749	16373	4894
1983	0	19139	0	924	0	5031	19139	5955
1984	0	20878	0	1052	0	16892	20878	17944
1985	0	17550	0	372	0	24054	17550	24426
1986	0	12415	0	862	14787	6434	12415	22083
1987	0	9918	0	0	5603	519	9918	6122
1988	0	7754	0	0	8944	1540	7754	10484
1989	0	8150	0	170	6087	2194	8150	8451
1990	0	9633	0	0	10316	408	9633	10724
1991	0	5002	0	0	4443	510	5002	4953

Year	len 10x20	len 1x1	len 5x10	wt 10x20	wt 1x1	wt 5x10	len Total	wt Total
1992	0	1661	0	0	4613	0	1661	4613
1993	0	3822	0	0	3661	30	3822	3691
1994	0	4120	0	0	1149	0	4120	1149
1995	0	6163	0	0	1685	0	6163	1685
1996	0	3895	0	0	1784	0	3895	1784
1997	0	6999	0	0	4	0	6999	4
1998	0	10844	0	0	3397	0	10844	3397
1999	0	12260	0	0	1	0	12260	1
2000	0	9783	0	0	29	0	9783	29
2001	0	5409	0	0	91	0	5409	91
2002	0	1451	0	0	0	0	1451	0
2003	0	887	0	0	2	0	887	2
2004	0	1672	0	0	19	0	1672	19
2005	0	2211	0	0	15	0	2211	15
2006	0	2971	0	0	0	0	2971	0
2007	0	1403	0	0	0	0	1403	0
2008	0	1752	0	0	0	0	1752	0
2009	0	313	0	0	0	0	313	0
2010	0	191	0	0	3	0	191	3
2011	0	363	0	0	0	0	363	0
2012	0	1778	0	0	0	0	1778	0
2013	0	2807	0	0	0	0	2807	0
2014	0	718	0	0	0	0	718	0
2015	0	2063	0	0	0	0	2063	0
2016	0	1903	0	0	0	0	1903	0
2017	0	4234	0	0	0	0	4234	0
2018	0	2250	0	0	0	0	2250	0

Time stratification: YFT

Table 11: Number of length measurements in data held by IOTC for yellowfin tuna by temporal resolution, flag, and year.

`1 month`

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	7251	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	20502	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	24730	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	32298	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	31445	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	35820	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	61600	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	38925	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	30428	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	8872	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	20118	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	3500	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	2792	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	75072	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	34114	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	39099	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	485	95575	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	256	77225	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	229	53235	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	207	38503	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	111	41678	0
2001	0	0	0	0	0	0	0	267	0	0	0	0	409	52602	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	157	95511	584
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	166706	483
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	230602	1071
2005	0	0	0	0	0	0	0	0	0	0	0	0	0	635930	114
2006	0	0	0	0	0	0	0	299	0	0	0	0	0	350435	212
2007	0	0	0	0	0	0	0	687	0	0	0	0	11677	232499	82
2008	0	0	0	0	0	0	0	0	0	0	0	0	7219	112575	106
2009	406	0	0	0	0	0	313	470	0	0	0	0	3708	80998	122
2010	647	0	0	0	0	0	192	139	0	0	0	0	714	78135	241
2011	0	0	0	30	0	0	363	0	0	0	0	0	6763	80158	0
2012	1310	0	0	20	0	0	1778	46	0	0	0	0	7345	77799	0
2013	1419	0	0	36	0	0	2807	198	0	0	0	0	10398	70578	0
2014	20	0	0	25	0	10182	718	522	0	163	0	0	14726	70656	0
2015	28	0	0	29	0	14622	2063	799	0	189	138	0	1013	40145	0
2016	943	0	0	43	139	9549	1903	765	4864	38	153	0	1925	53553	0
2017	1928	63	11	62	124	5017	4234	4057	6680	99	0	233	4820	39389	0
2018	3007	0	0	56	104	5594	5212	3237	8716	0	0	604	2561	67591	4210
2019	0	0	0	81	541	2408	5659	1582	10940	0	0	0	8760	47686	0

`3 months`

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1952	0	0	0	0	0	0	2903	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	8195	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	17238	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	88499	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	70220	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	68746	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	55250	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	61602	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	74271	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	39437	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	58072	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	20915	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	68093	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	74321	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	62999	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	40244	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	62470	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	44304	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	37065	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	49929	0	0	0	0	0	0	0	0

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
1972	0	0	0	0	0	0	39765	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	20249	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	19873	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	22939	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	26204	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	26717	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	21479	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	19020	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	13527	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	16684	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	26160	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	30829	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	56765	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	66140	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	56580	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	22162	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	28183	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	25051	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	31081	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	13888	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	10876	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	11204	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	6418	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	9501	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	7456	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	6985	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	17620	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	11297	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	9034	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	5577	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	1449	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	920	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	255	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	1039	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	2970	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	1403	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	1760	0	0	0	0	0	0	0	0

7 months

	CHN	EUFRA	EUGBR	EUPRT	EUREU	IDN	JPN	KOR	LKA	MDV	MOZ	MUS	SYC	TWN	ZAF
2016	489	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2. Figures

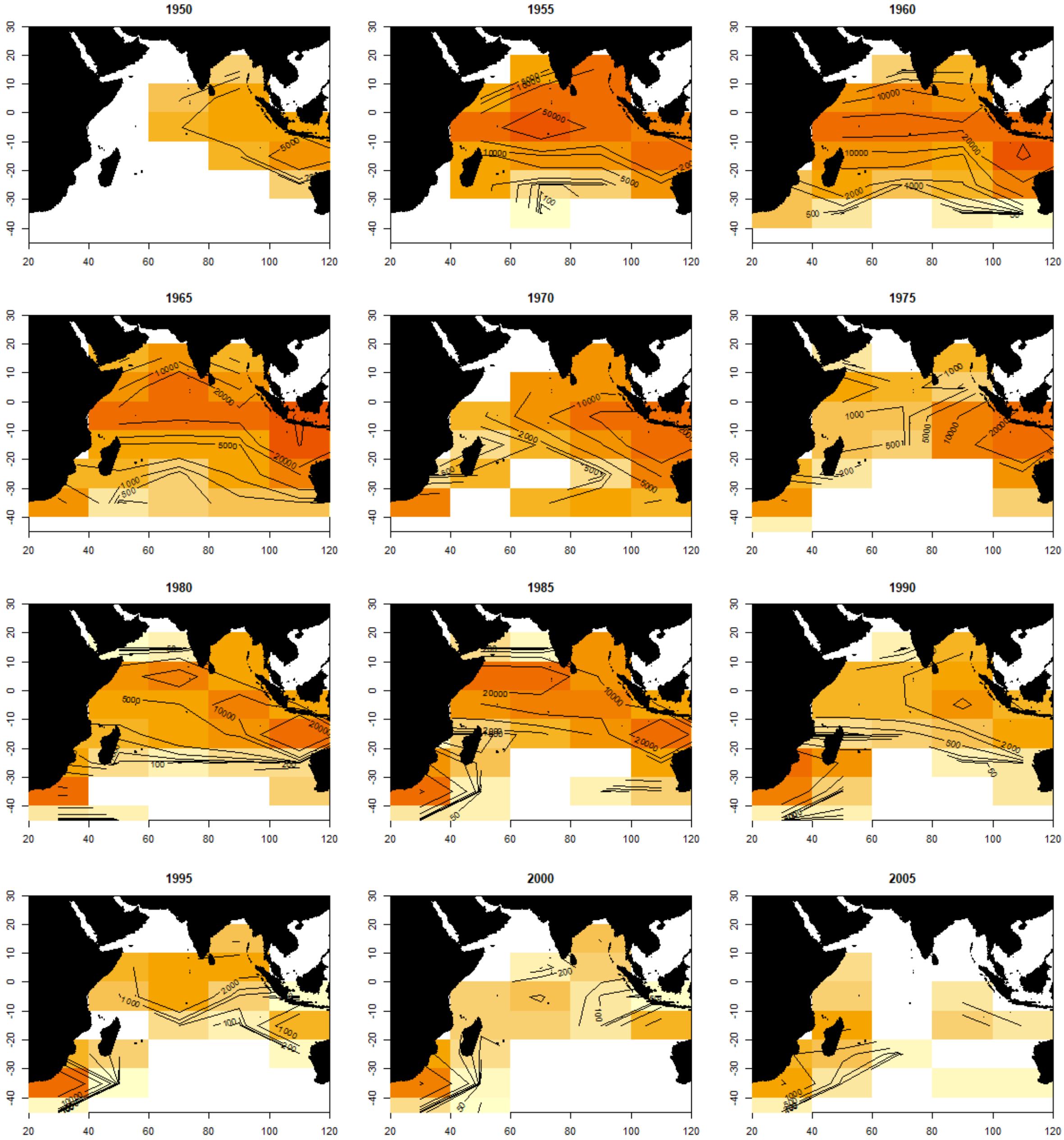


Figure 1: Sampling locations of Japanese 10 x 20 yellowfin size data in IOTC dataset.

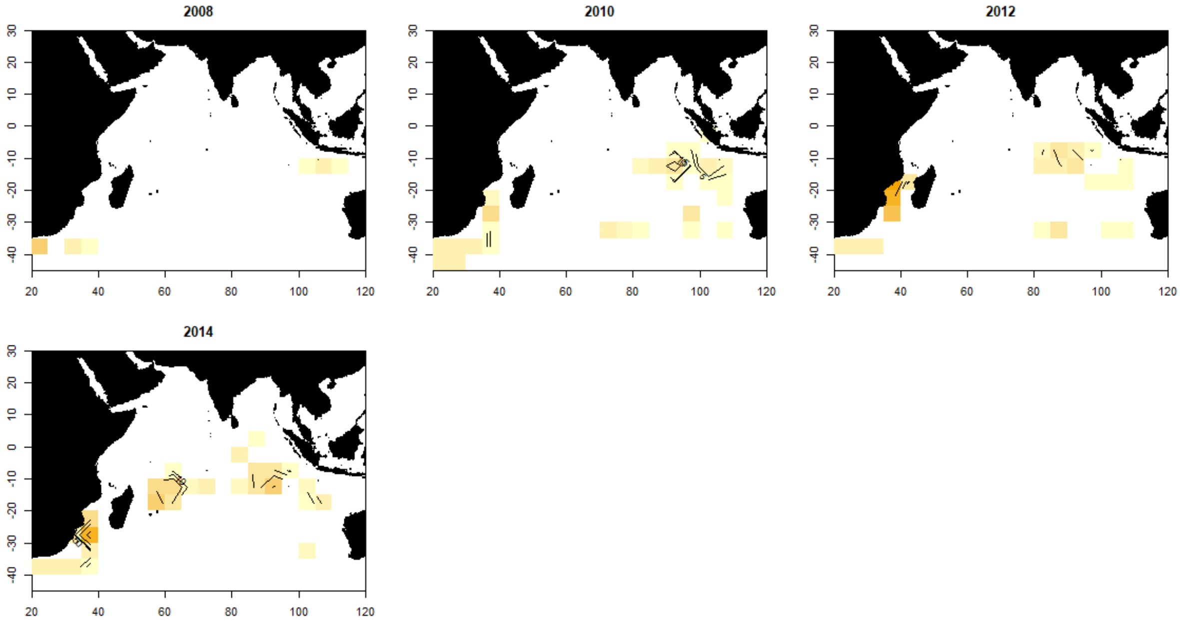


Figure 2: Sampling locations of Japanese 5 x 5 yellowfin size data in IOTC dataset.

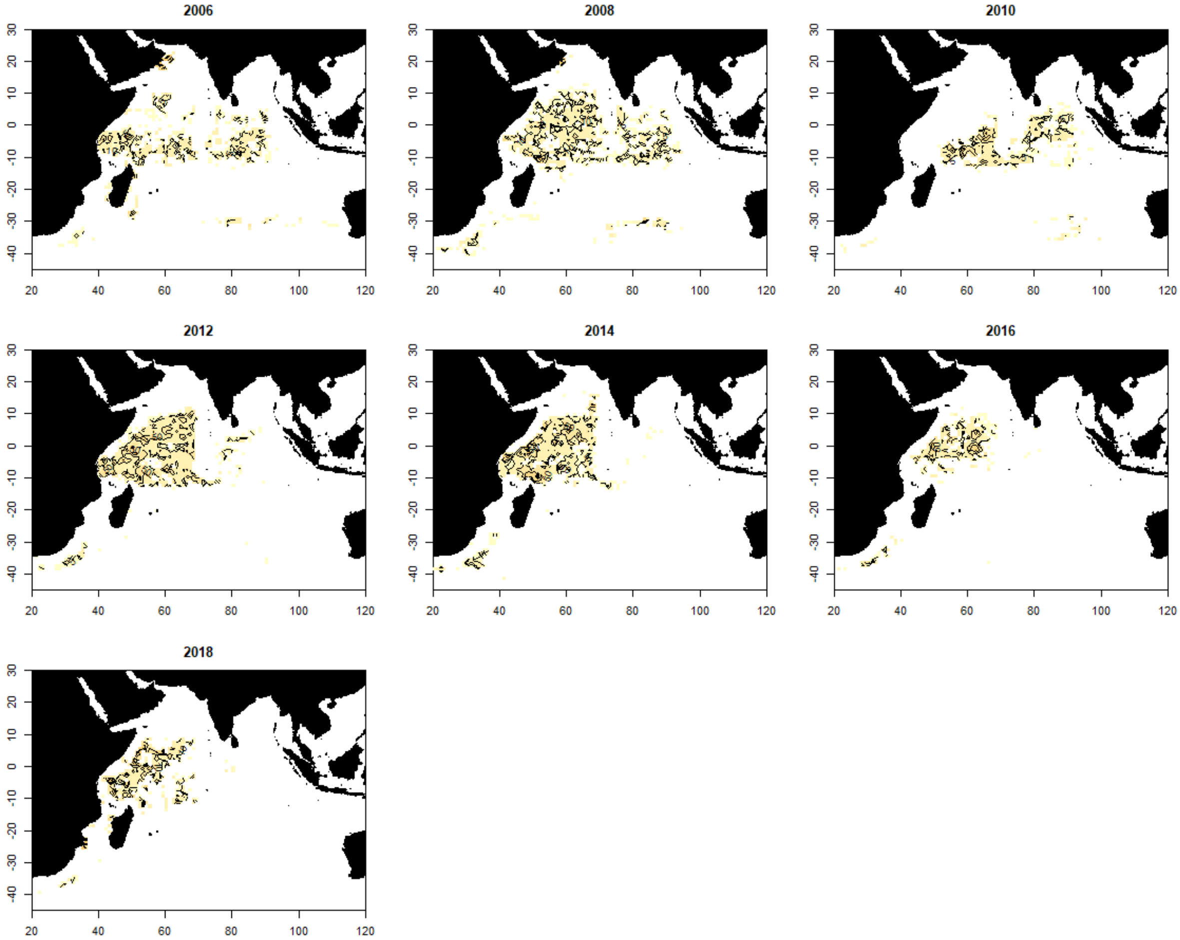


Figure 3: Sampling locations of Seychelles 1 x 1 yellowfin size data in IOTC dataset.

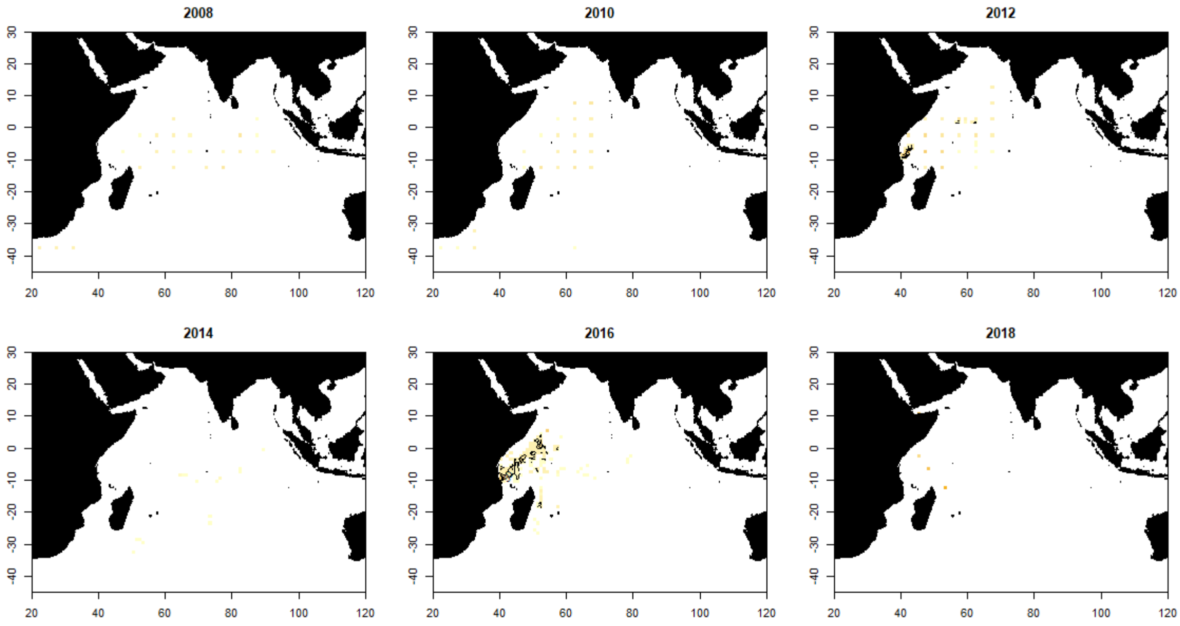


Figure 4: Sampling locations of Chinese 1 x 1 yellowfin size data in IOTC dataset.

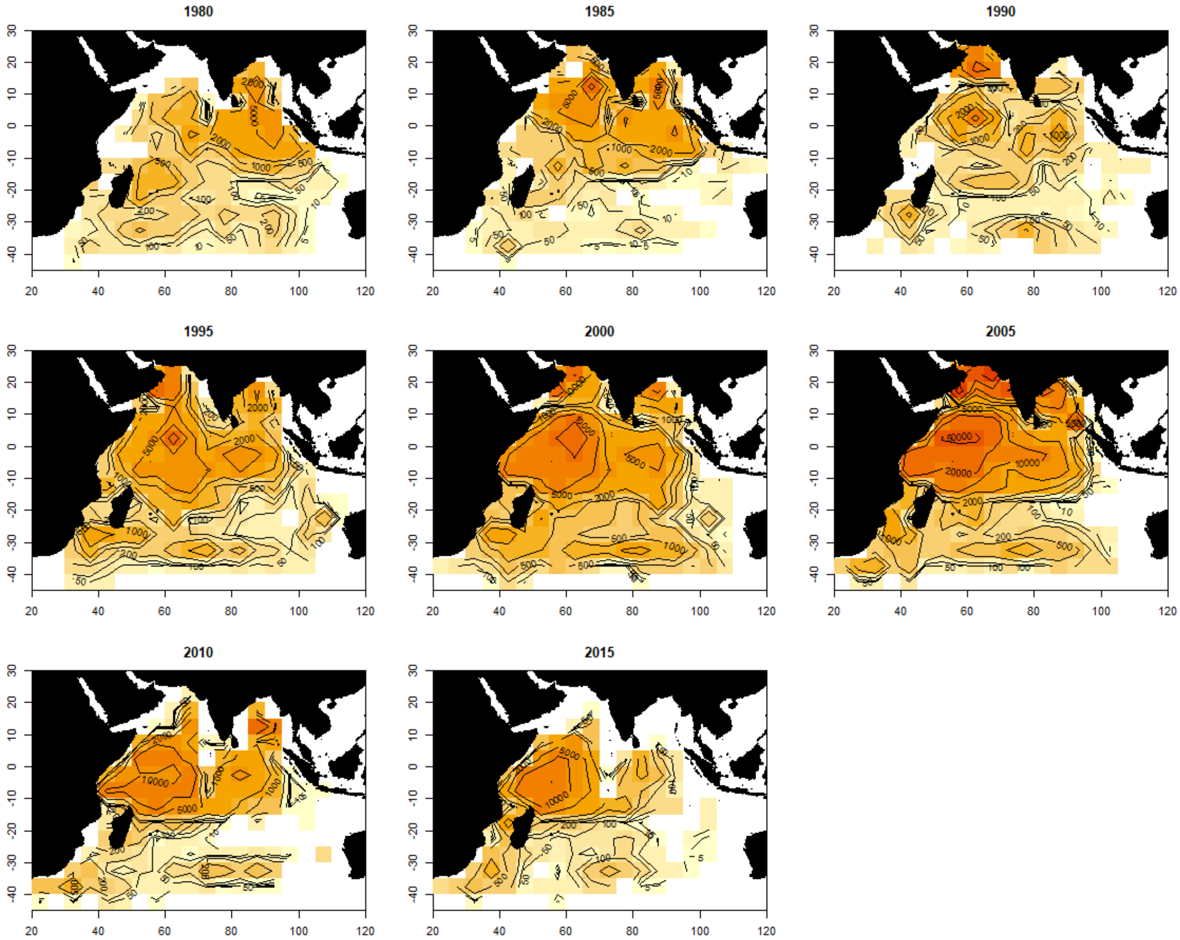


Figure 5: Sampling locations of Taiwanese 5 x 5 yellowfin size data in IOTC dataset.

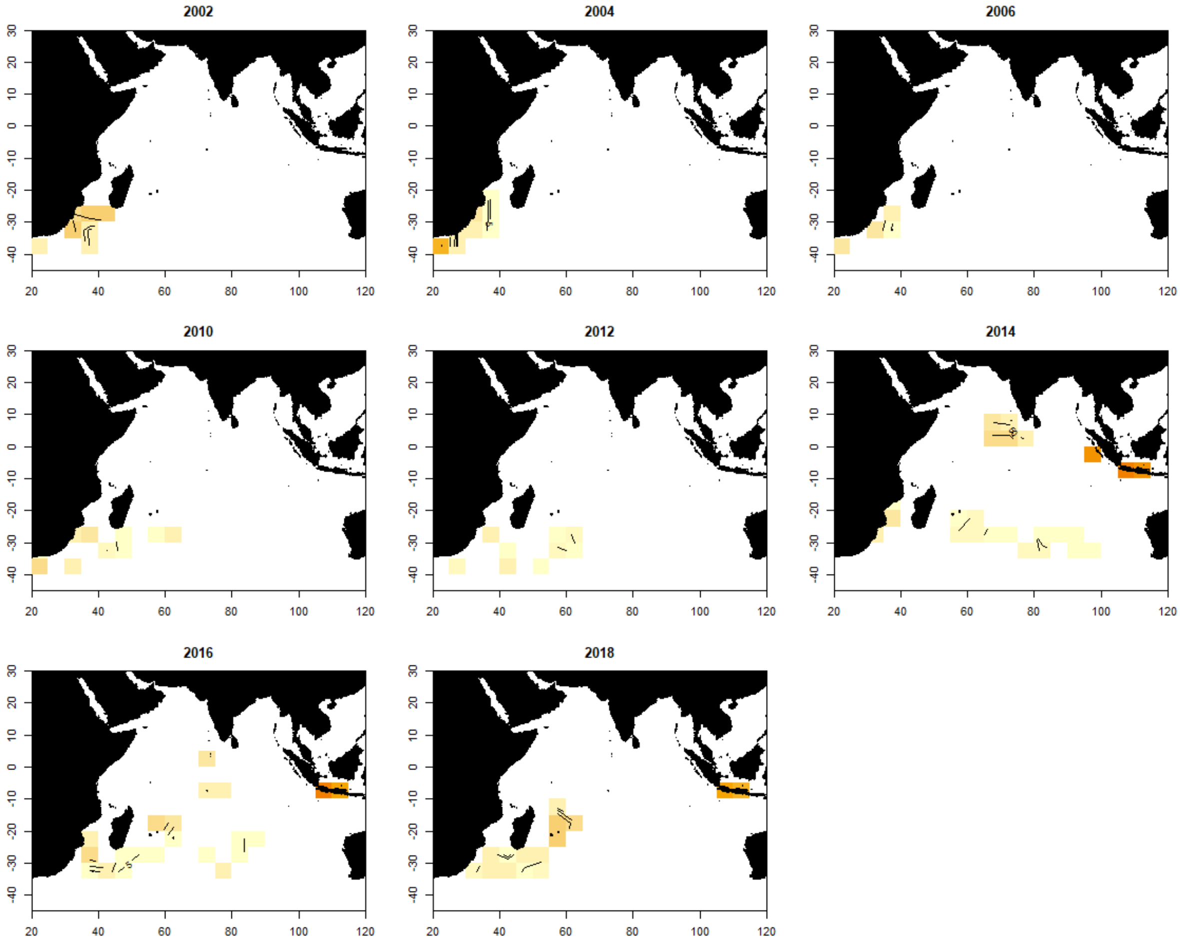


Figure 6: Sampling locations of other fleets 5 x 5 yellowfin size data in IOTC dataset.

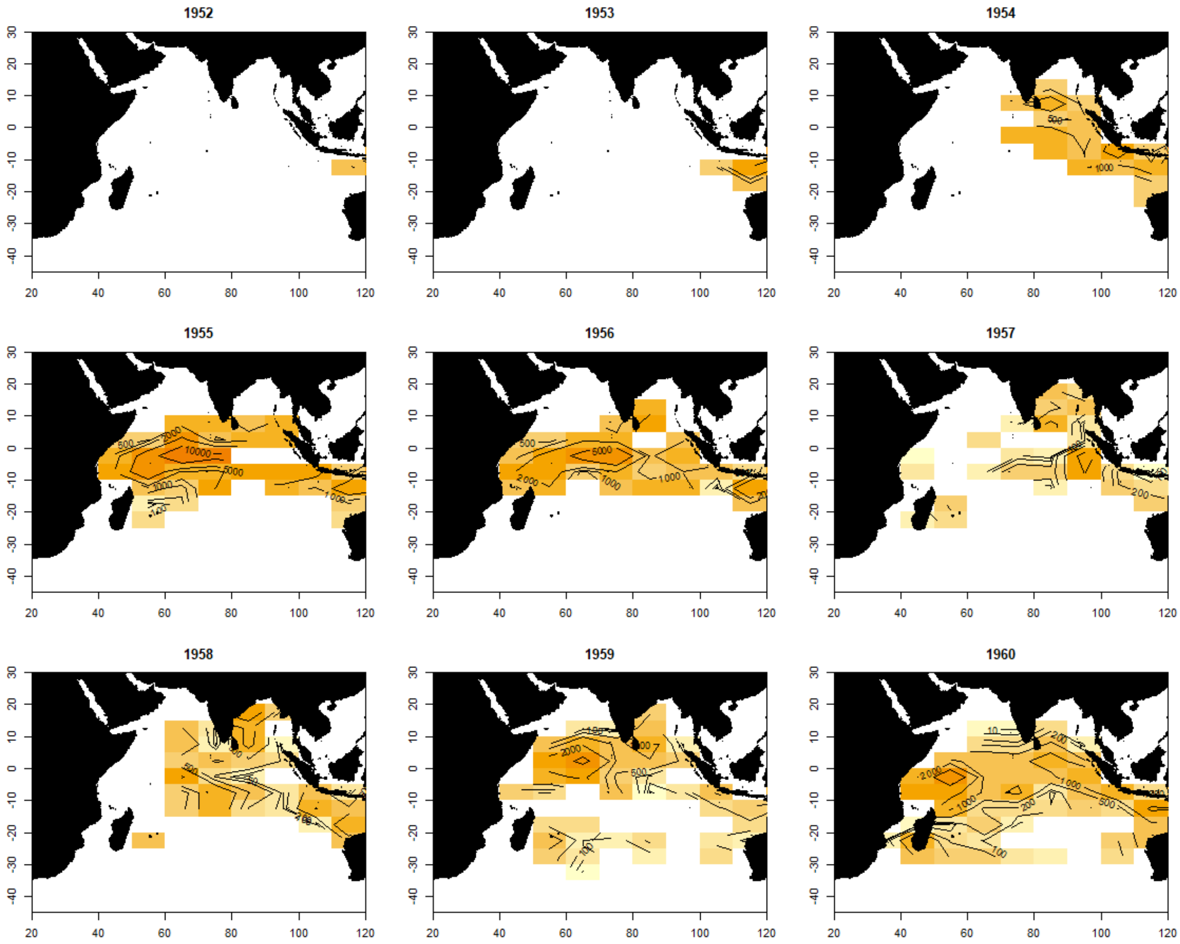


Figure 7: Sampling locations of Japanese length data by year from 1952-1960, held at 5 x 10 and 1 x 1 resolution and displayed at 5 x 10 resolution.

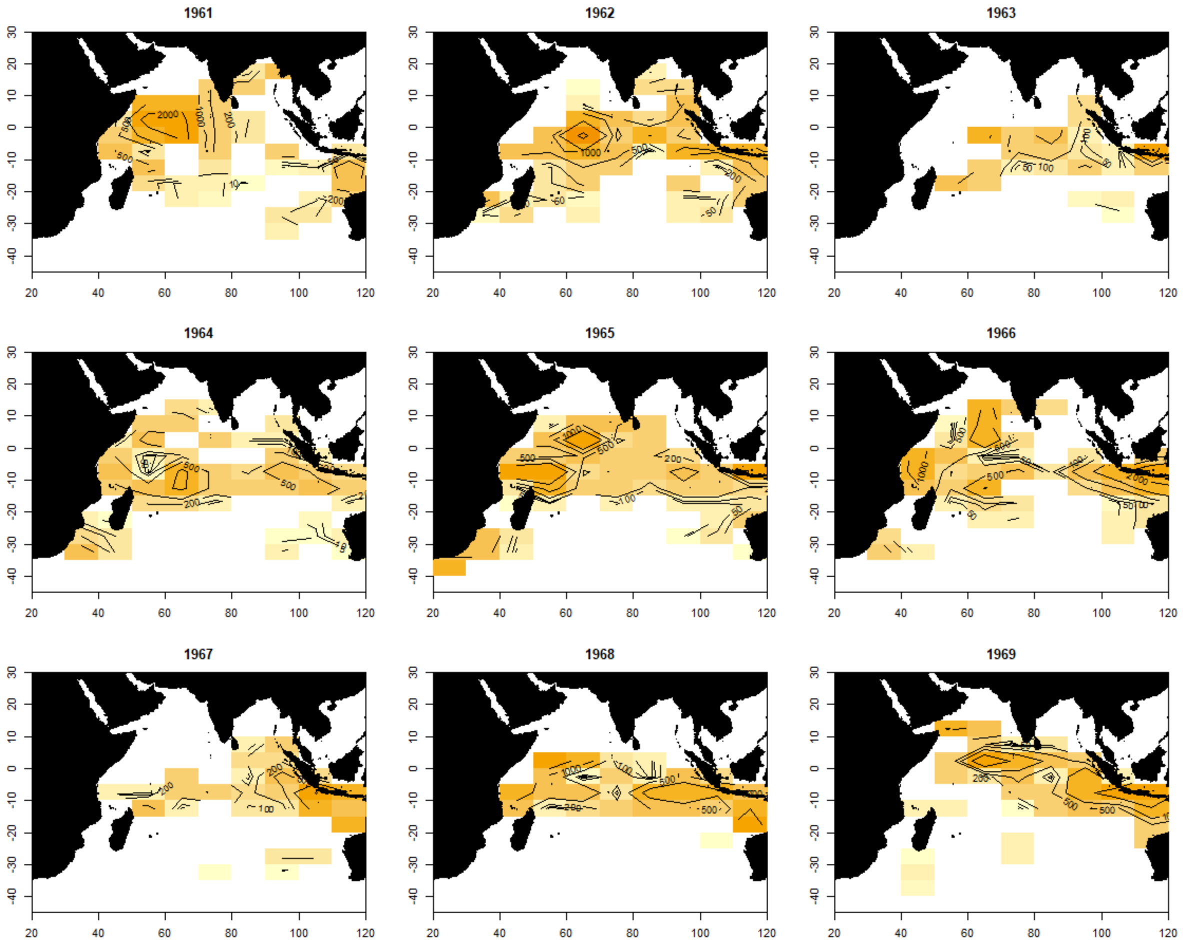


Figure 8: Sampling locations of Japanese length data by year from 1961-1969, held at 5 x 10 and 1 x 1 resolution and displayed at 5 x 10 resolution.

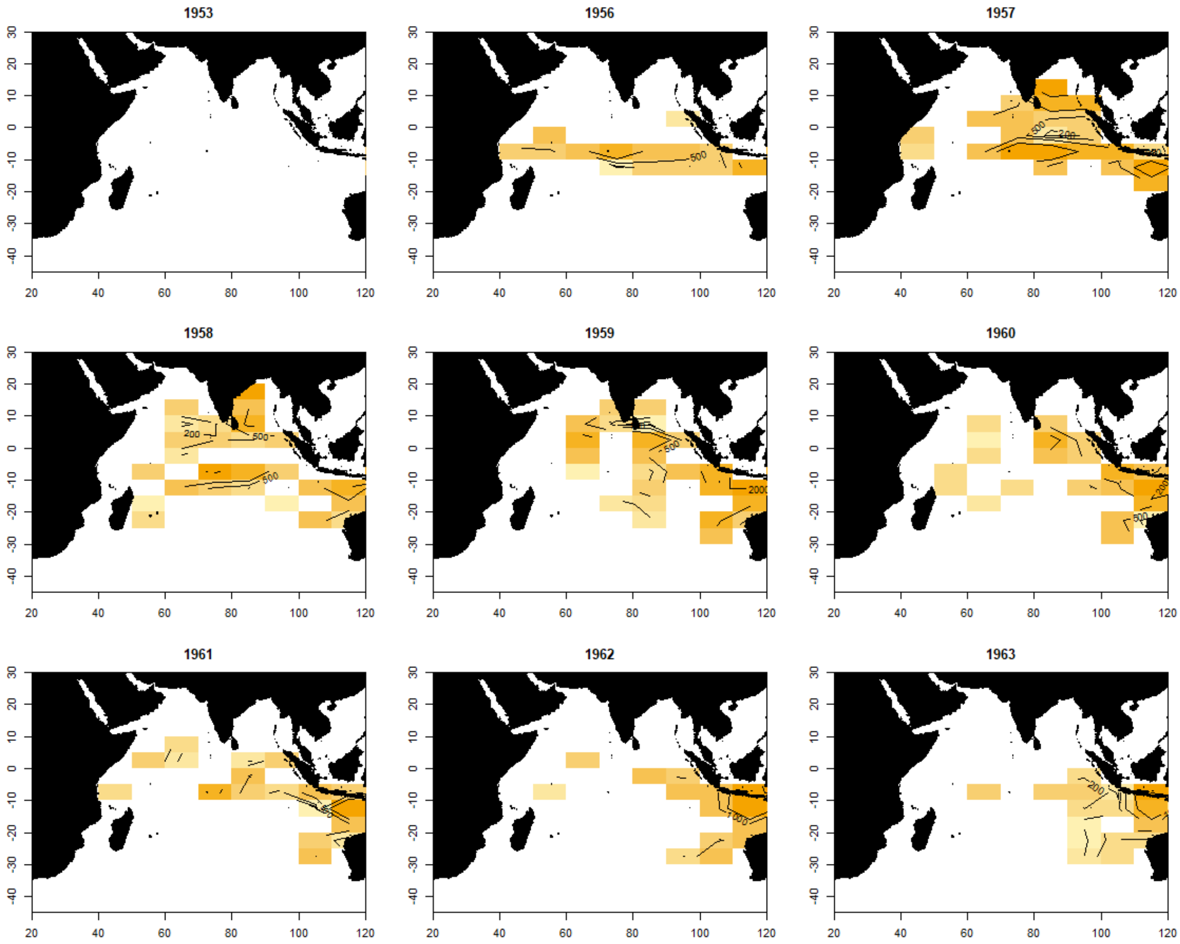


Figure 9: Sampling locations of Japanese weight data by year from 1953-1963, held at 5 x 10 and 1 x 1 resolution and displayed at 5 x 10 resolution.

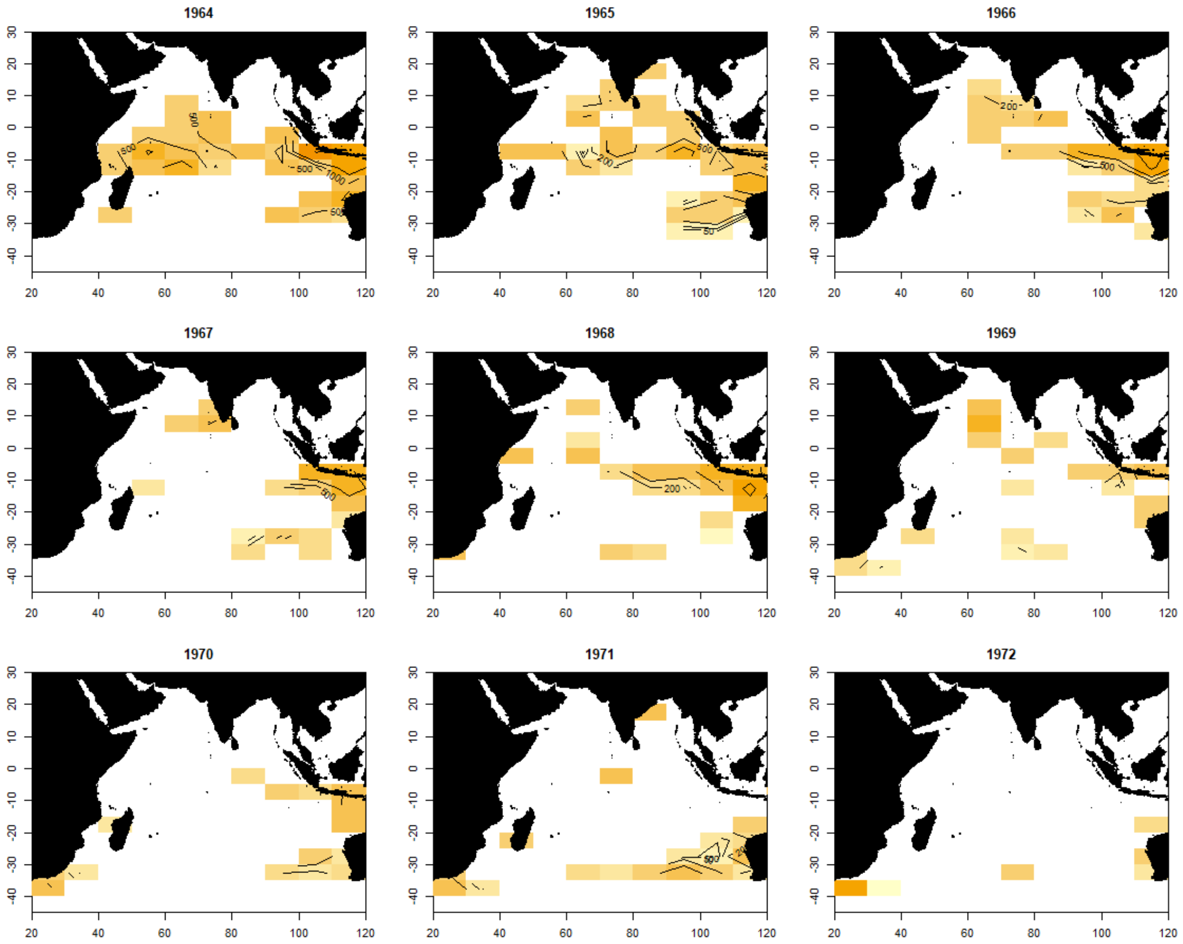


Figure 10: Sampling locations of Japanese weight data by year from 1964-1972, held at 5 x 10 and 1 x 1 resolution and displayed at 5 x 10 resolution.

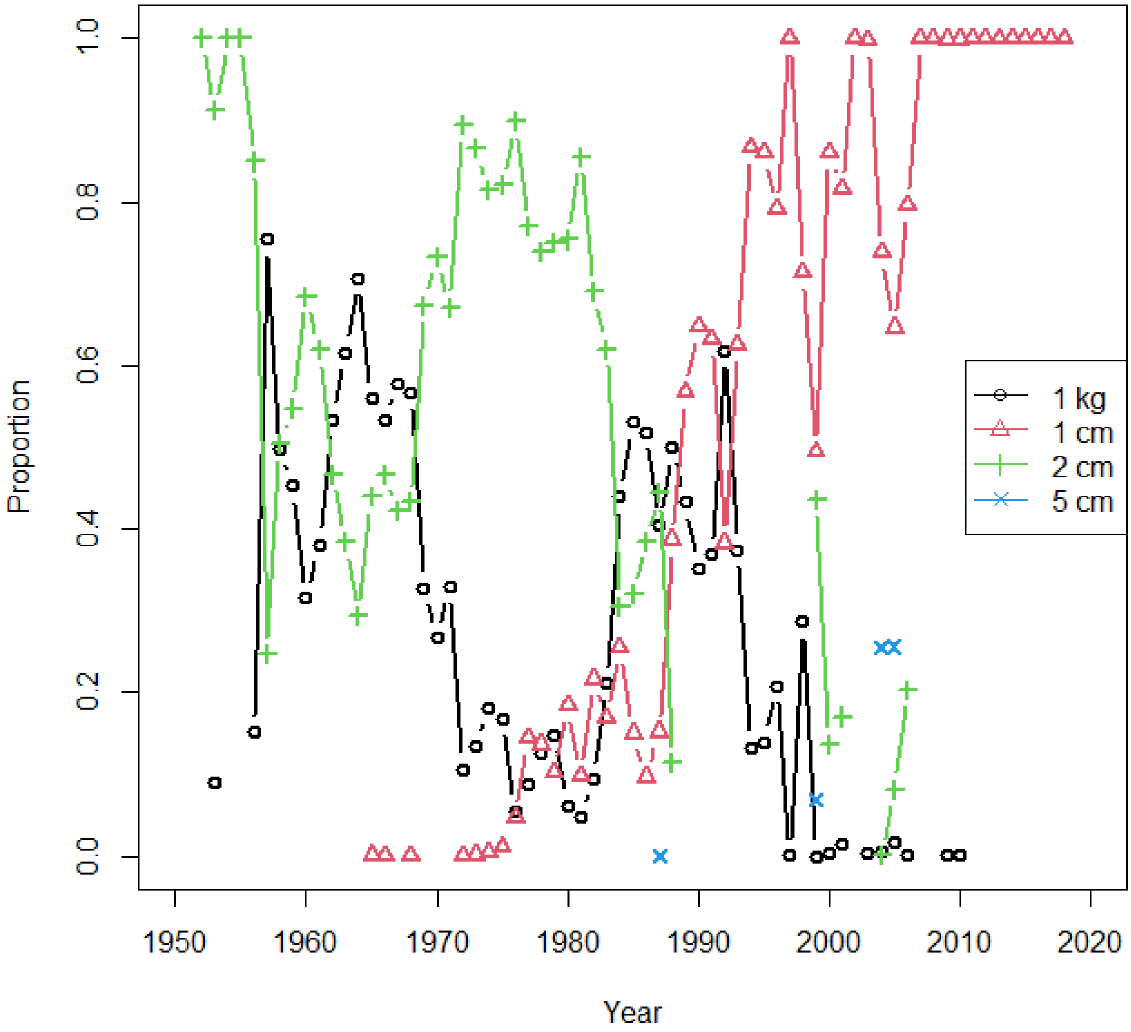


Figure 11: Proportions of measurements by year and measurement unit (1 kg weights, and 1, 2, and 5 cm lengths), for bigeye and yellowfin combined.

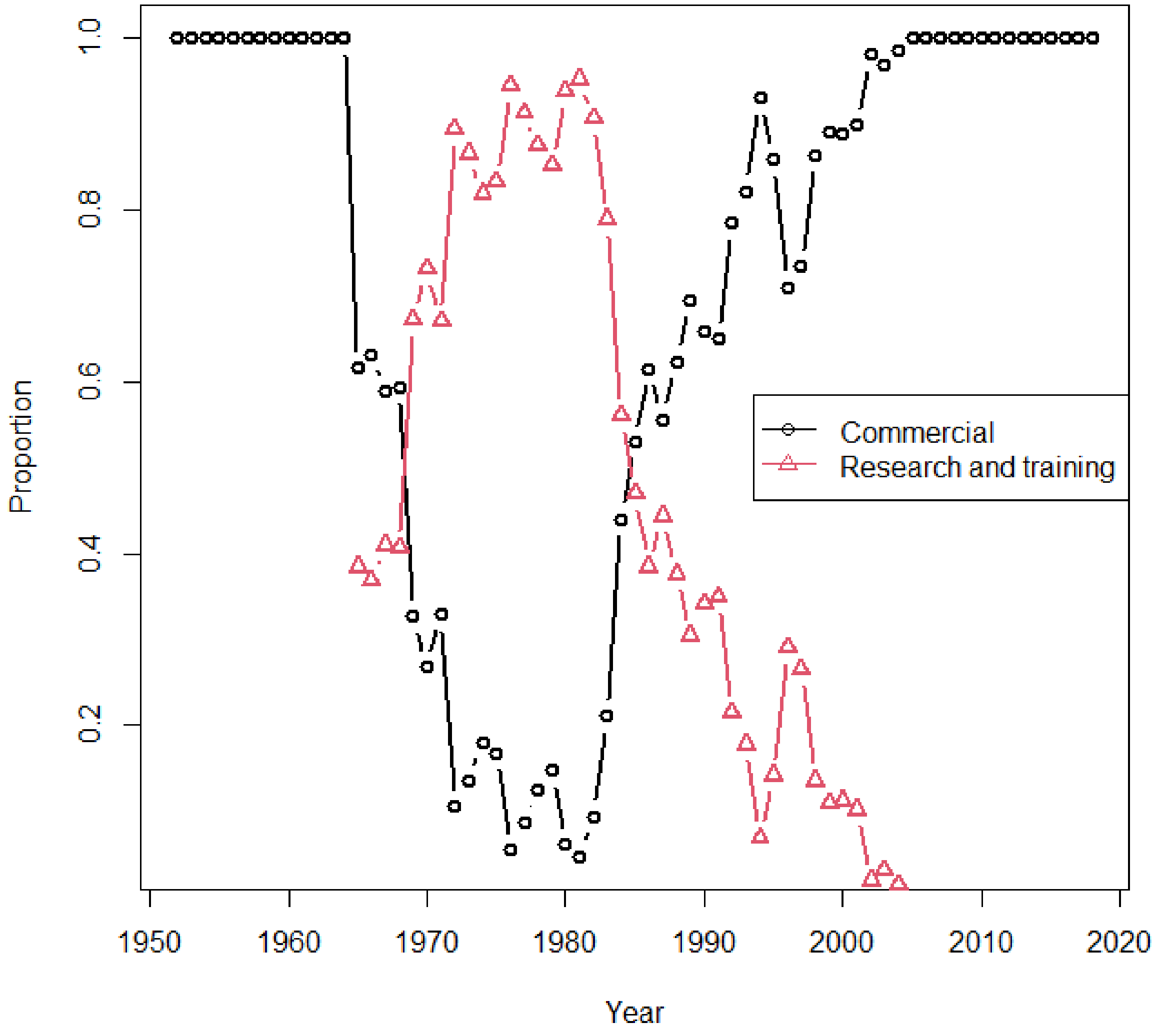


Figure 12:Proportions of measurements by type of vessel and year, for bigeye and yellowfin combined.

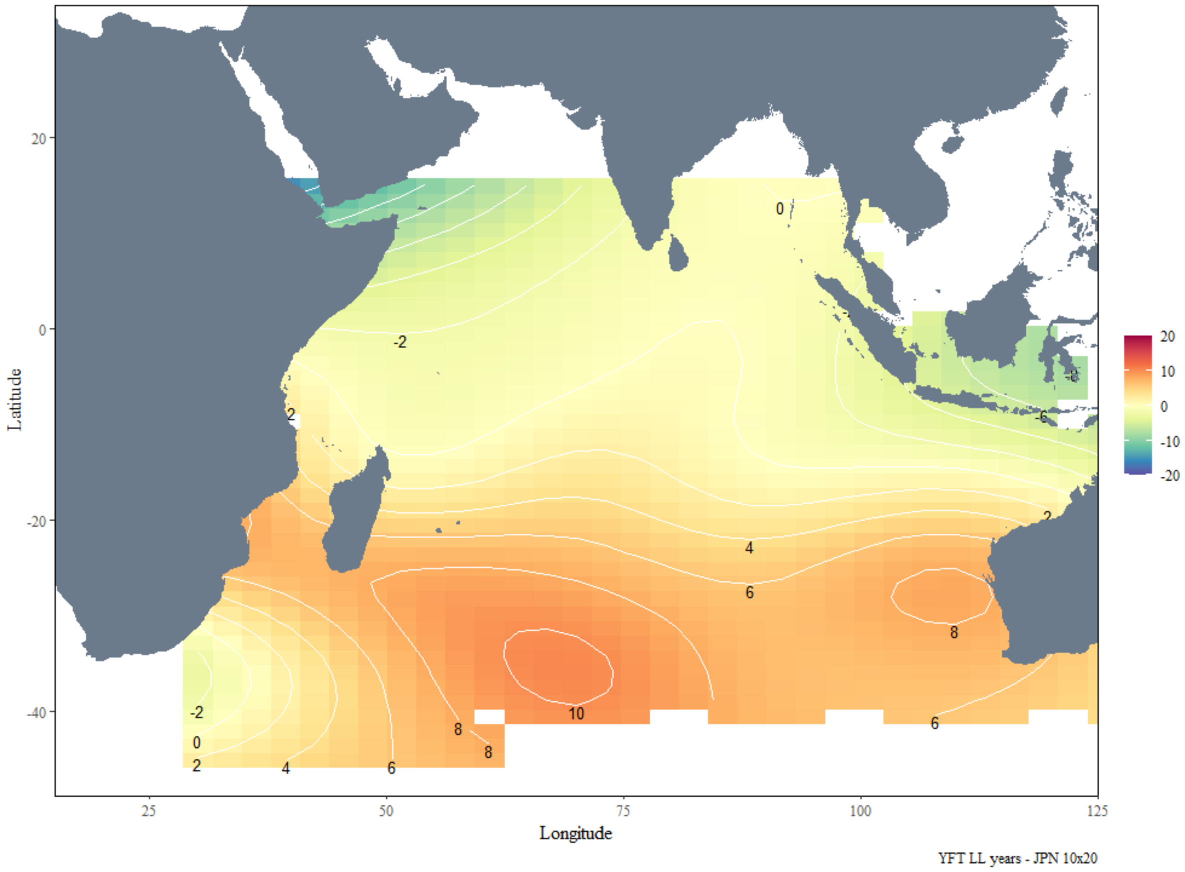


Figure 13: Map of predicted relative lengths from gam model of Japanese 10 x 20 size (lengths and converted weights) data for yellowfin tuna held by IOTC.

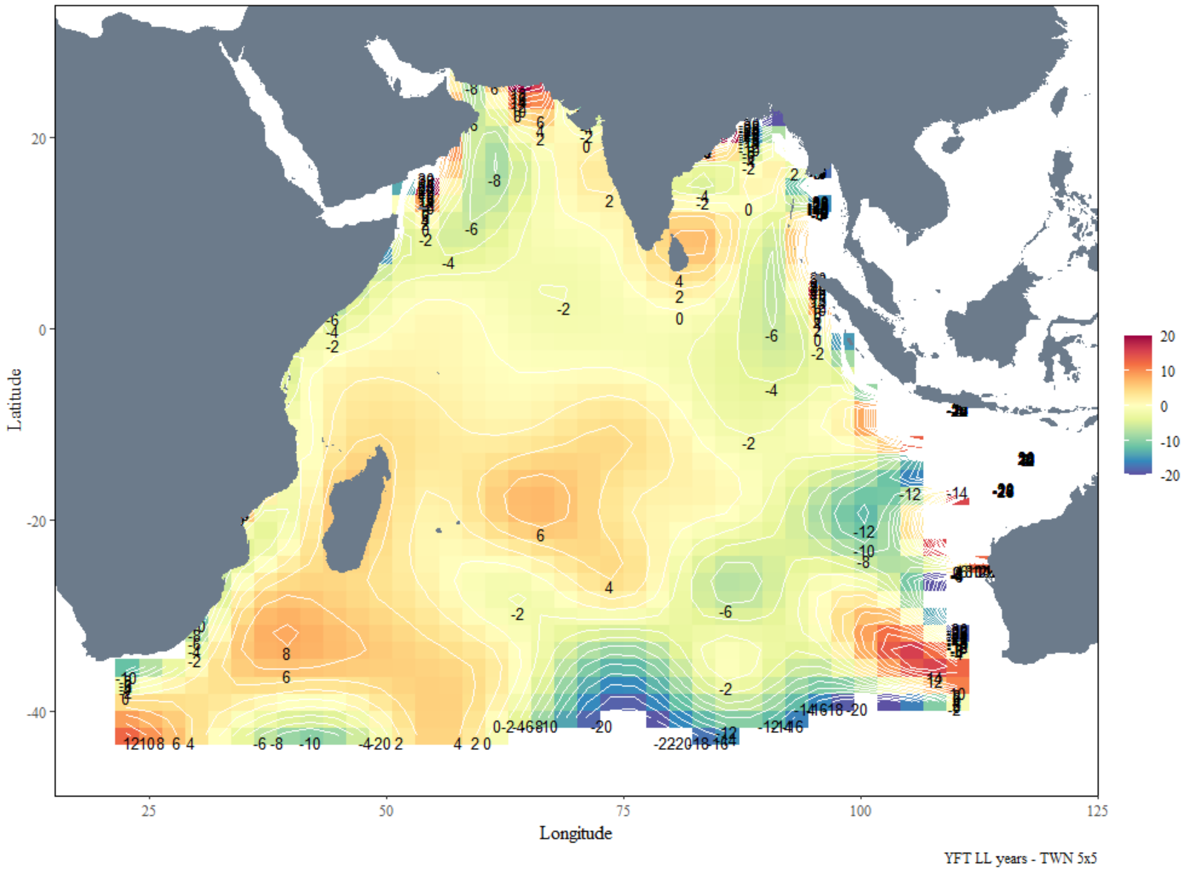


Figure 14: Map of predicted relative lengths from gam model of Taiwanese 5 x 5 length data for yellowfin tuna held by IOTC.

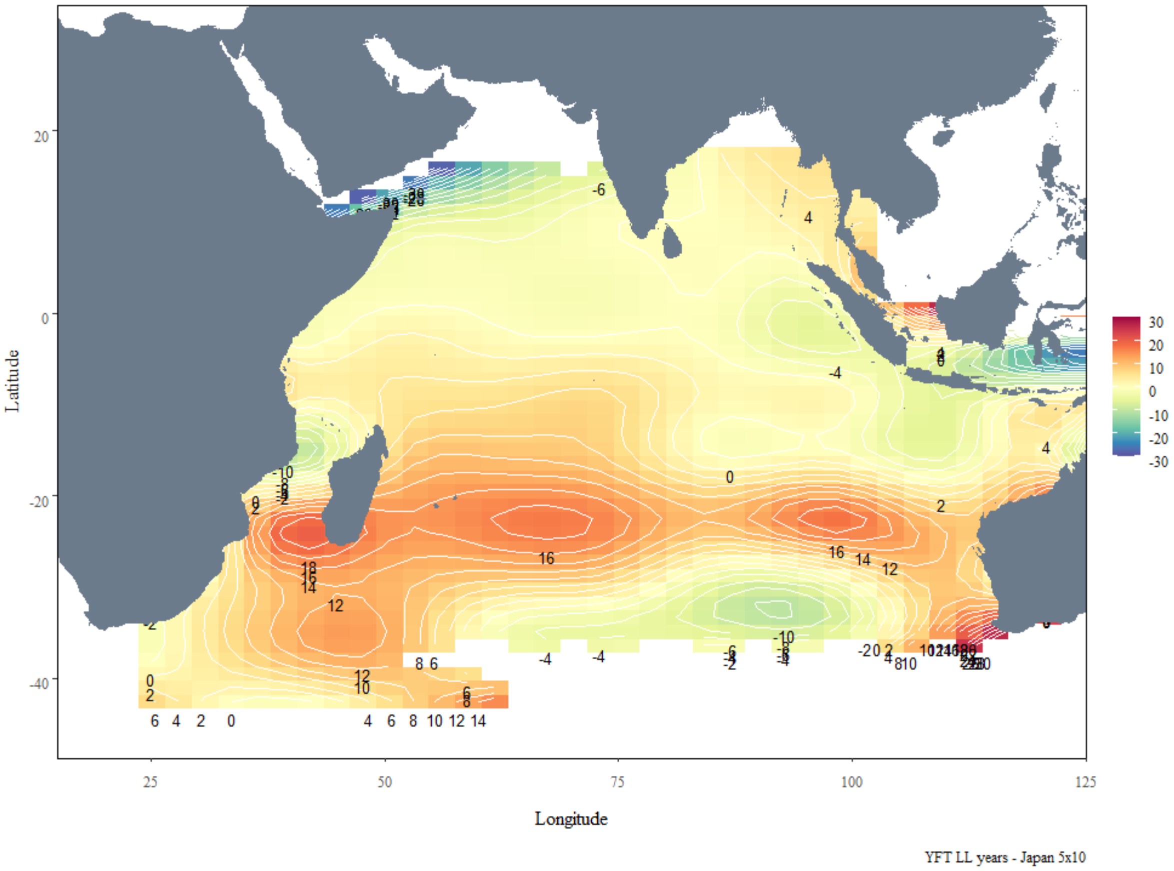


Figure 15: Map of predicted relative lengths from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 length data for yellowfin tuna held by Japan.

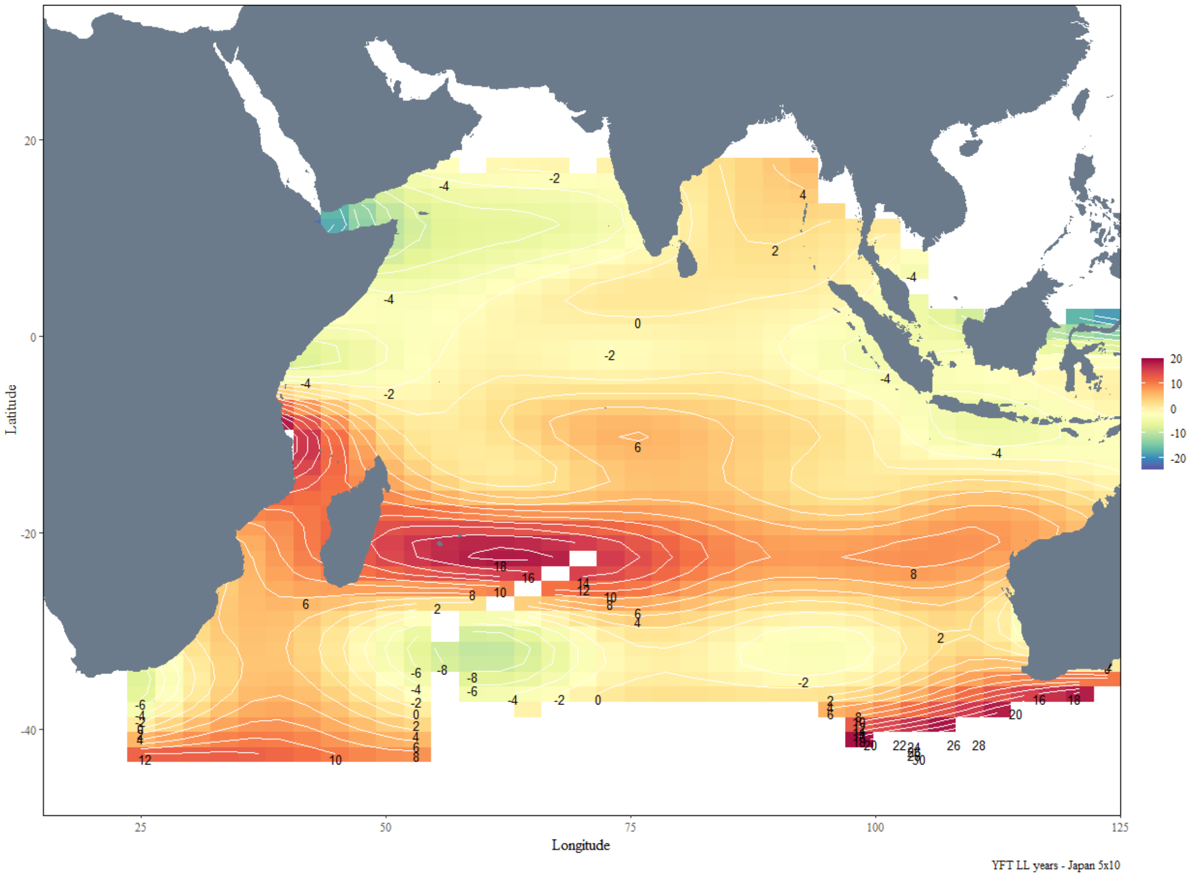


Figure 16: Map of predicted relative weights from a gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 weight data for yellowfin tuna held by Japan.

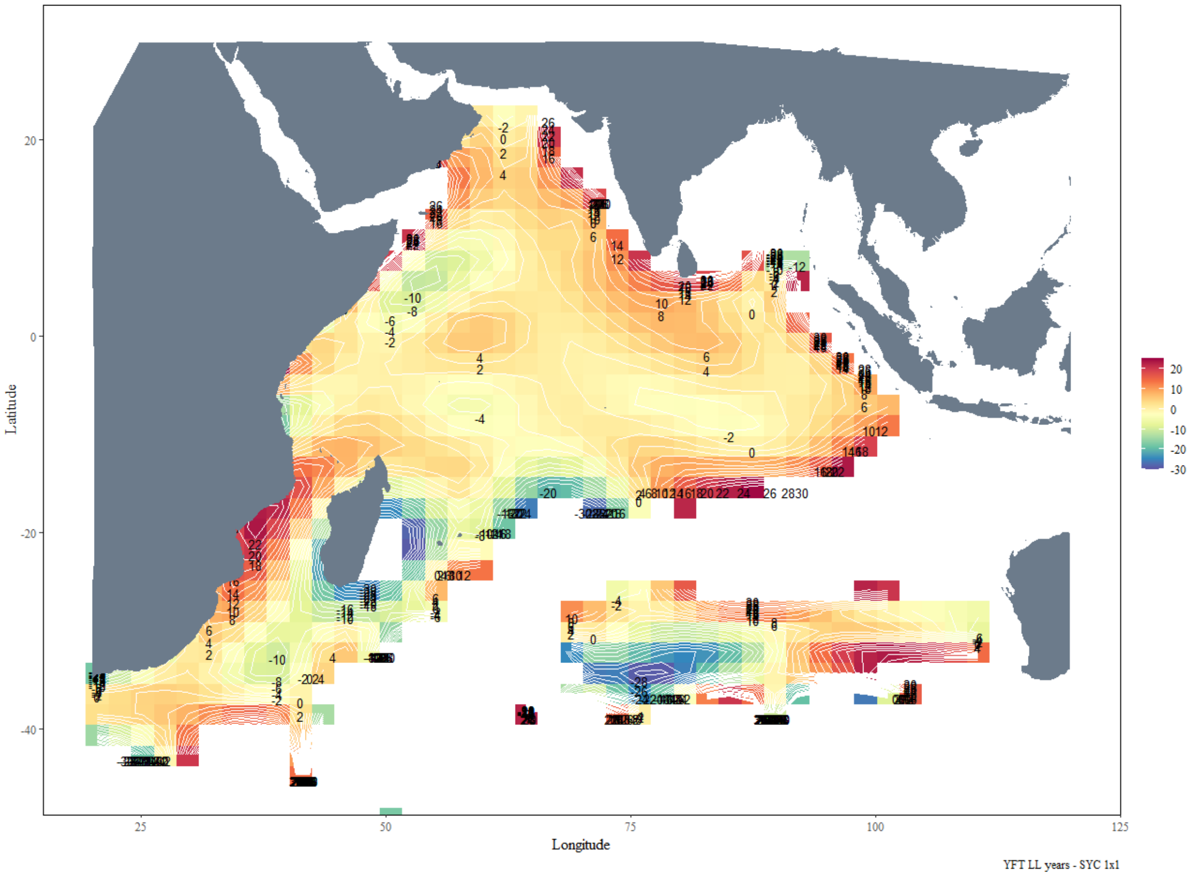


Figure 17: Map of predicted relative lengths from gam model of Seychelles 1 x 1 length data for yellowfin tuna held by IOTC.

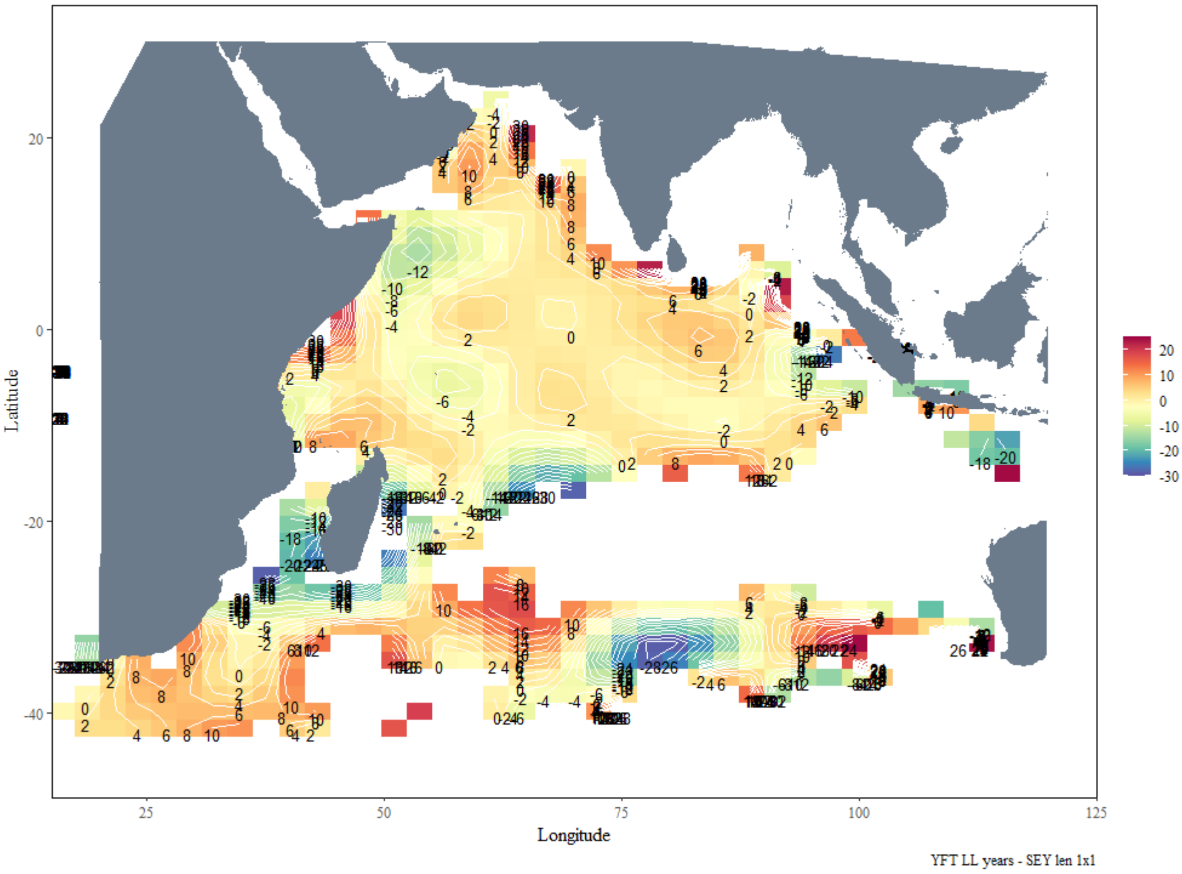
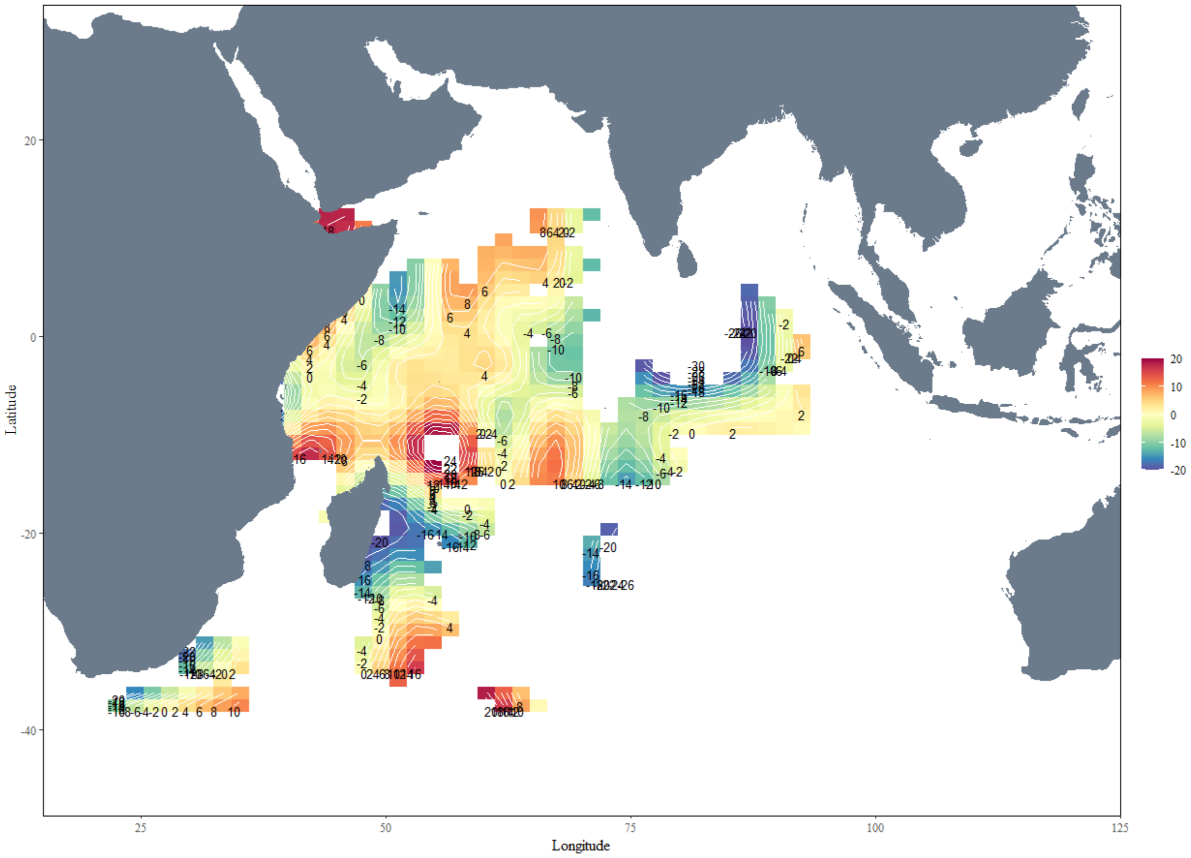


Figure 18: Map of predicted relative lengths from gam model of Seychelles 1 x 1 length data for yellowfin tuna held by the Seychelles.



YFT LL years - CHN 1x1

Figure 19: Map of predicted relative lengths from gam model of Chinese 1 x 1 length data for yellowfin tuna held by IOTC.

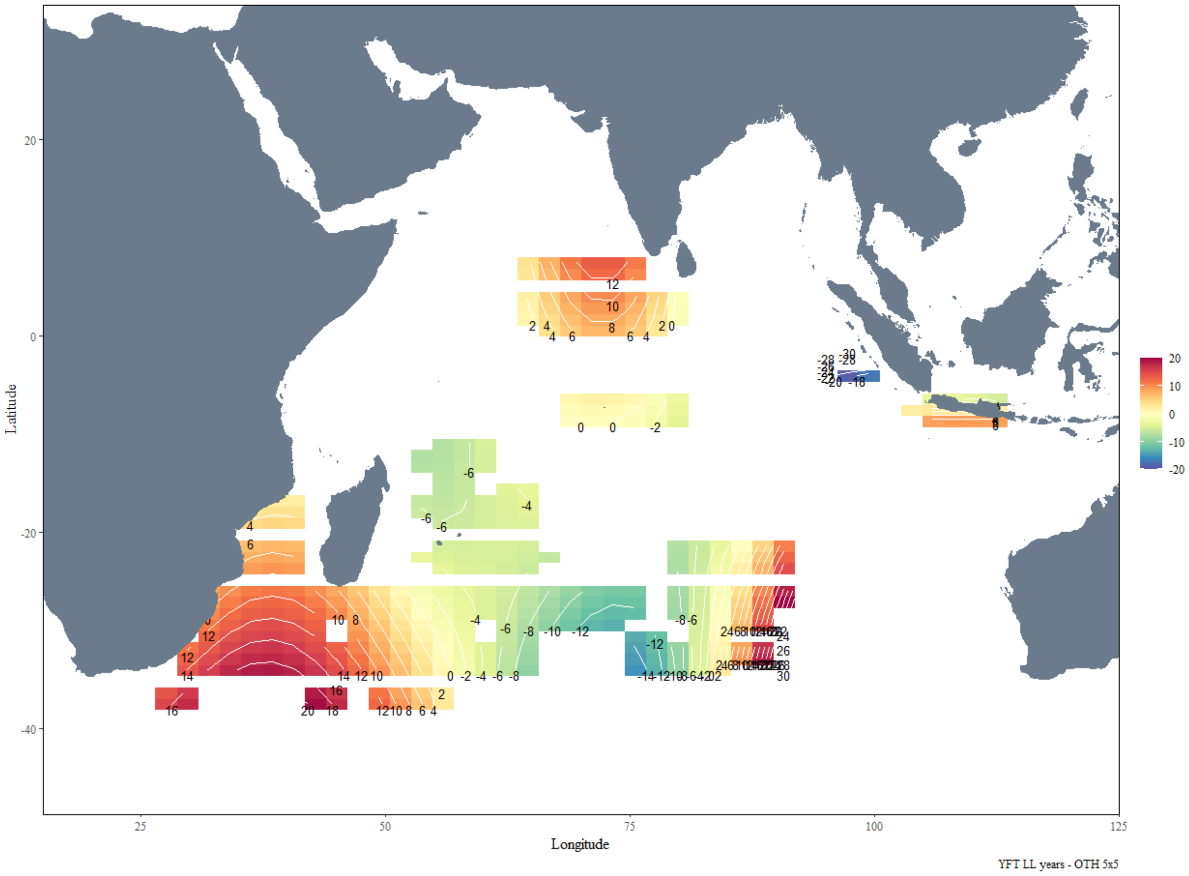


Figure 20: Map of predicted lengths from gam model of other flags 5 x 5 size data (lengths and converted weights) for yellowfin tuna held by IOTC.

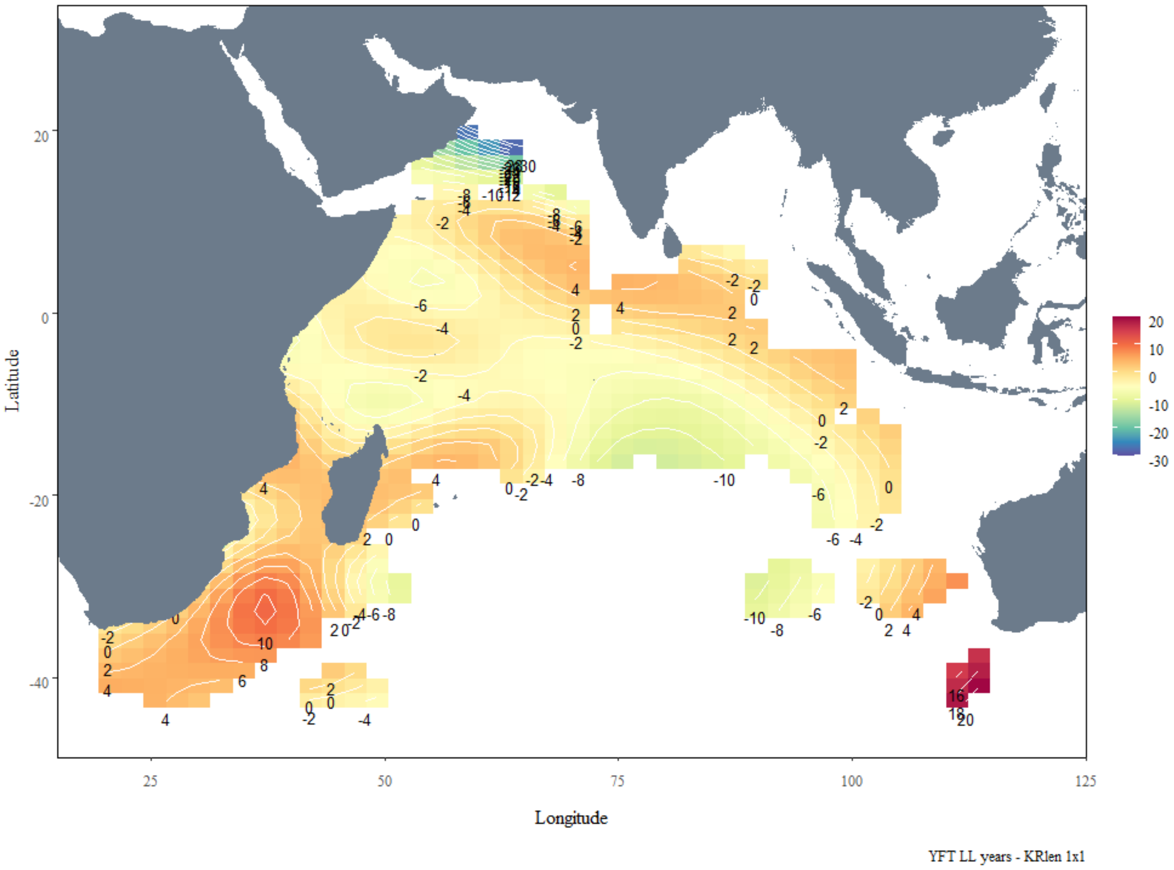


Figure 21: Map of predicted lengths from gam model of Korean 1 x 1 length data for yellowfin tuna held by the Korean government.

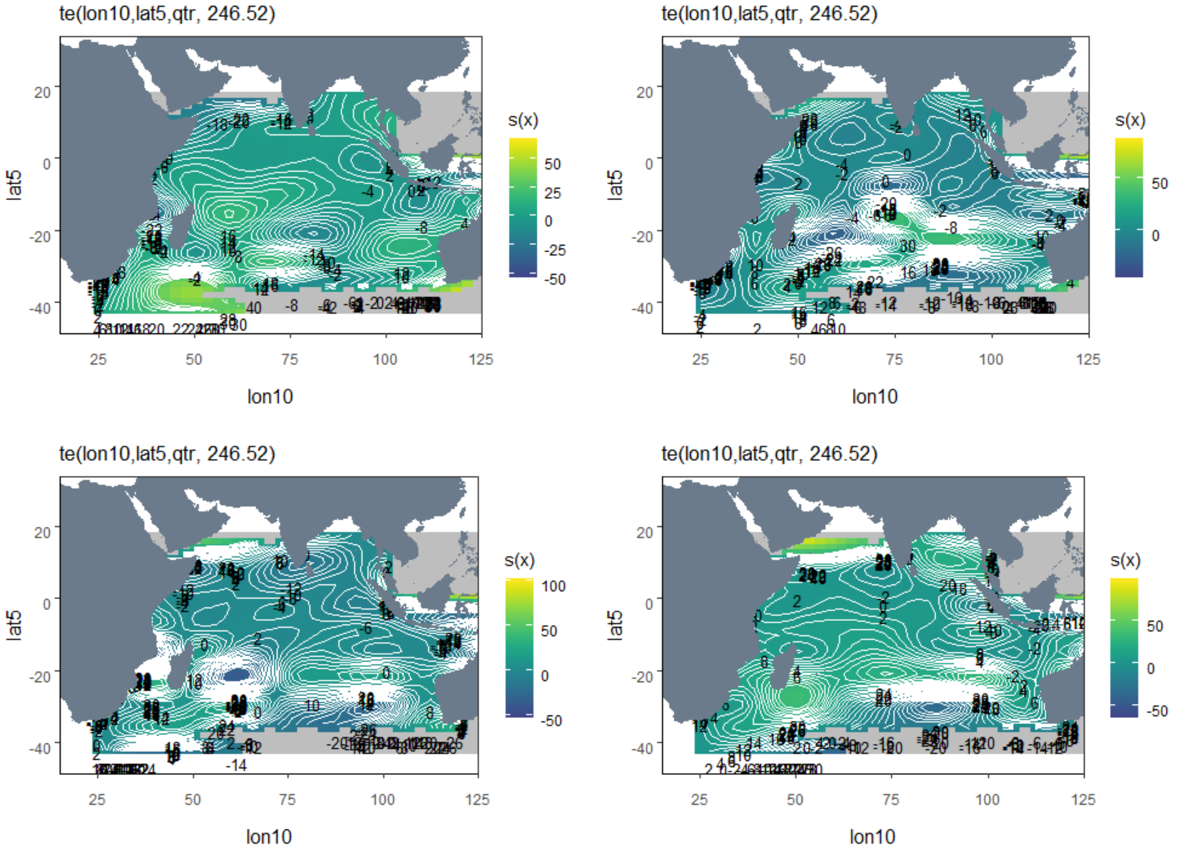


Figure 22: Quarterly maps of predicted relative lengths from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 length data for yellowfin tuna held by Japan.

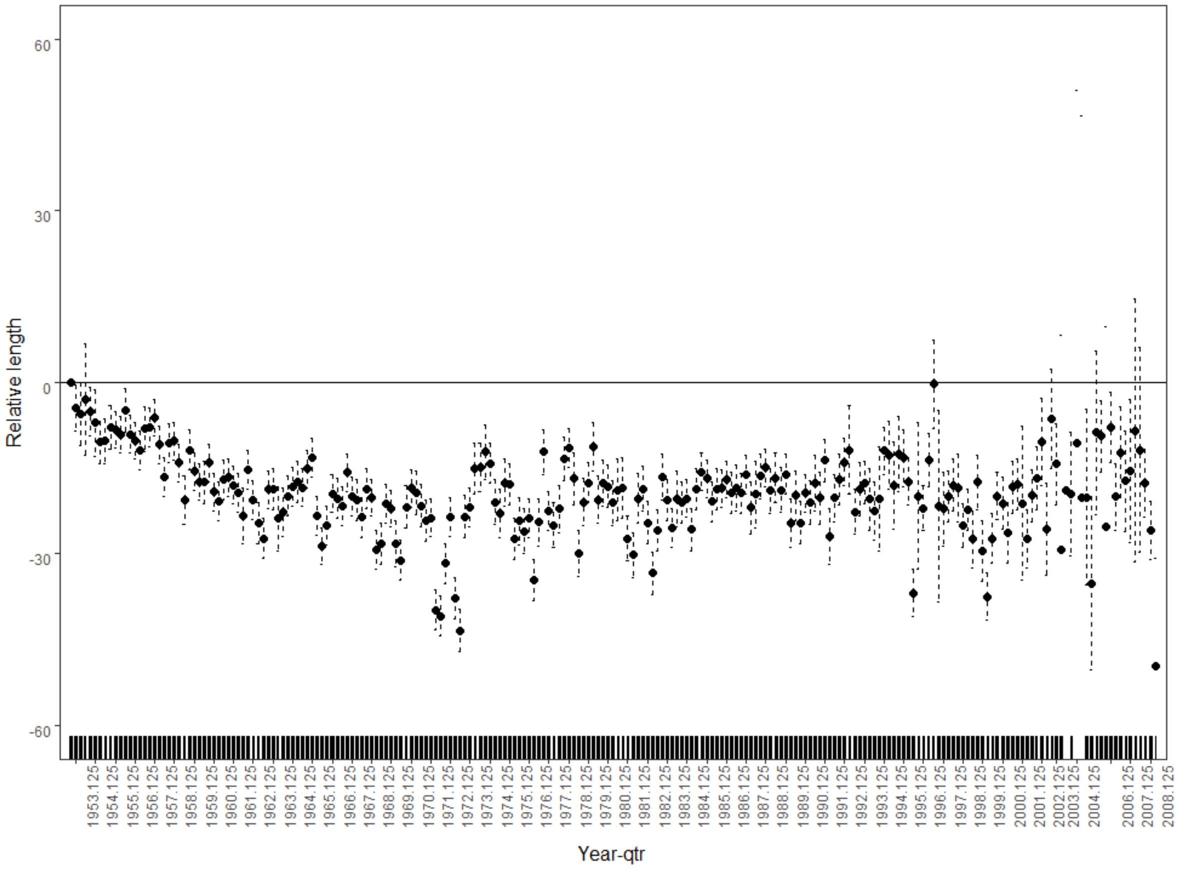


Figure 23: Plot of predicted relative lengths by year-quarter from gam model of Japanese 10 x 20 yellowfin tuna size data (lengths and converted weights) held by IOTC.

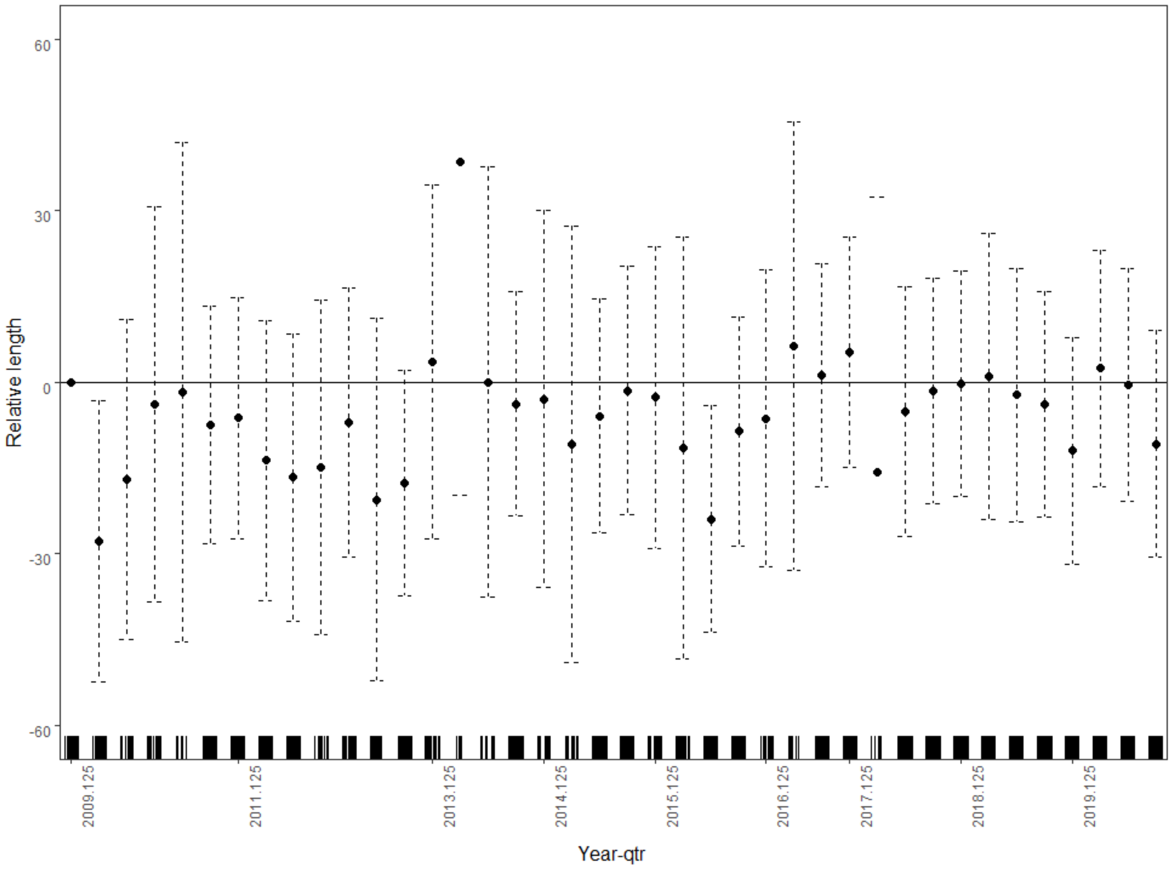


Figure 24: Plot of predicted relative lengths by year-quarter from gam model of Japanese 5 x 5 yellowfin tuna size data (lengths and converted weights) held by IOTC.

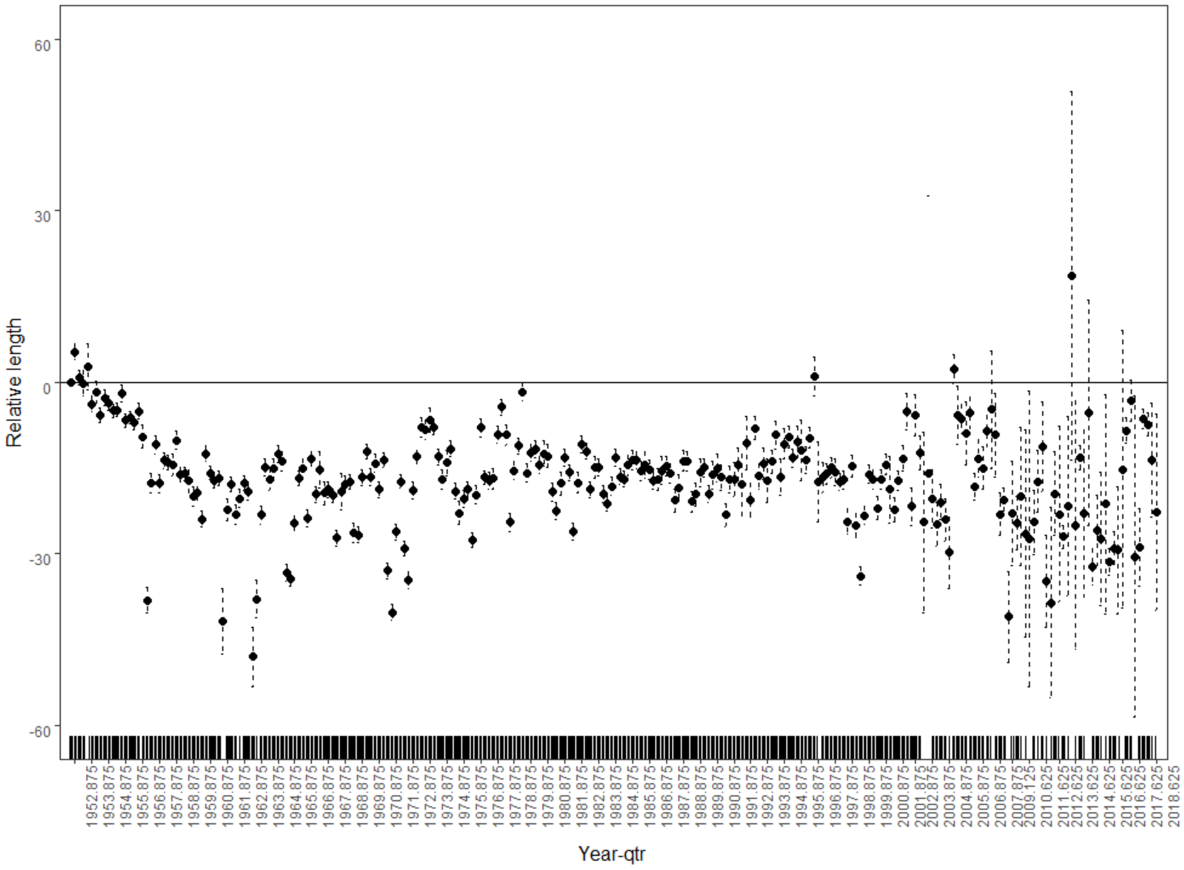


Figure 25: Plot of predicted relative lengths by year-quarter from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 yellowfin tuna length data held by Japan.

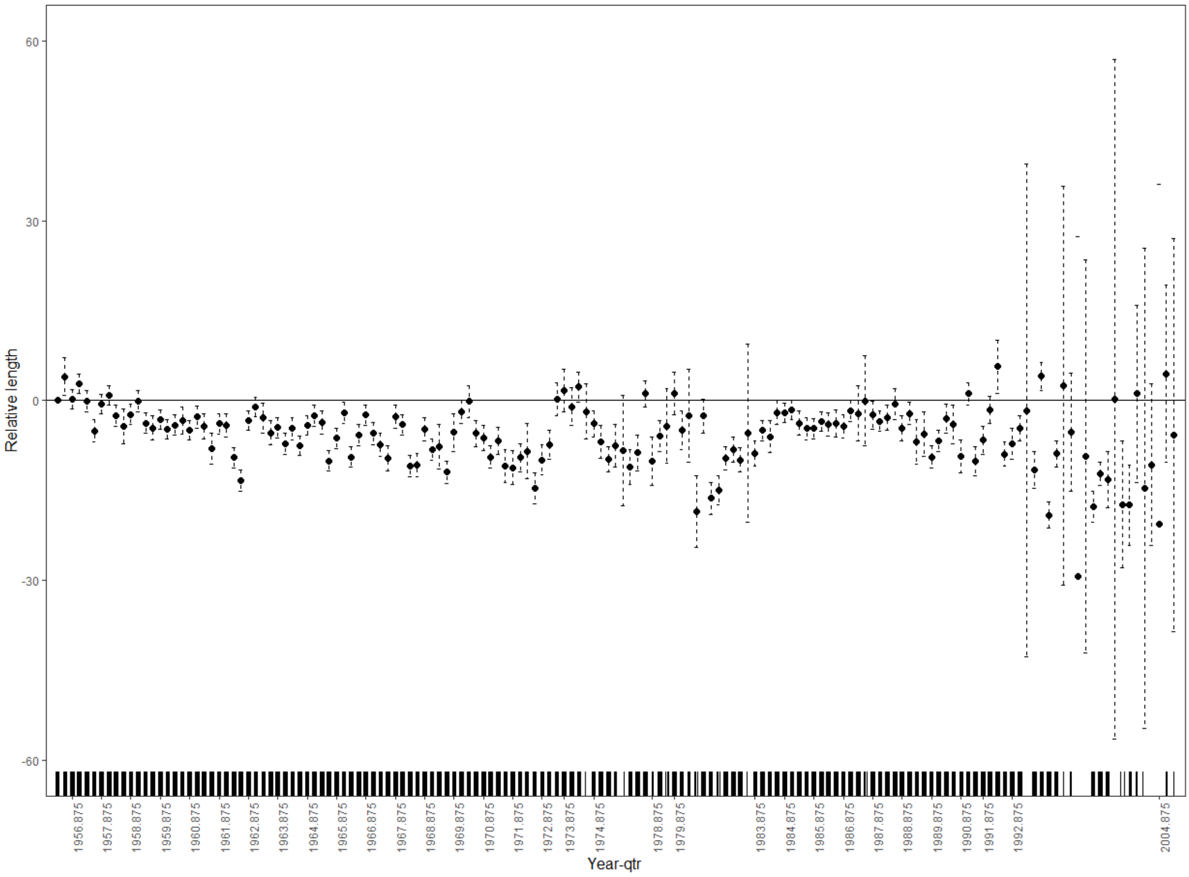


Figure 26: Plot of predicted relative weights by year-quarter from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 yellowfin tuna weight data held by Japan.

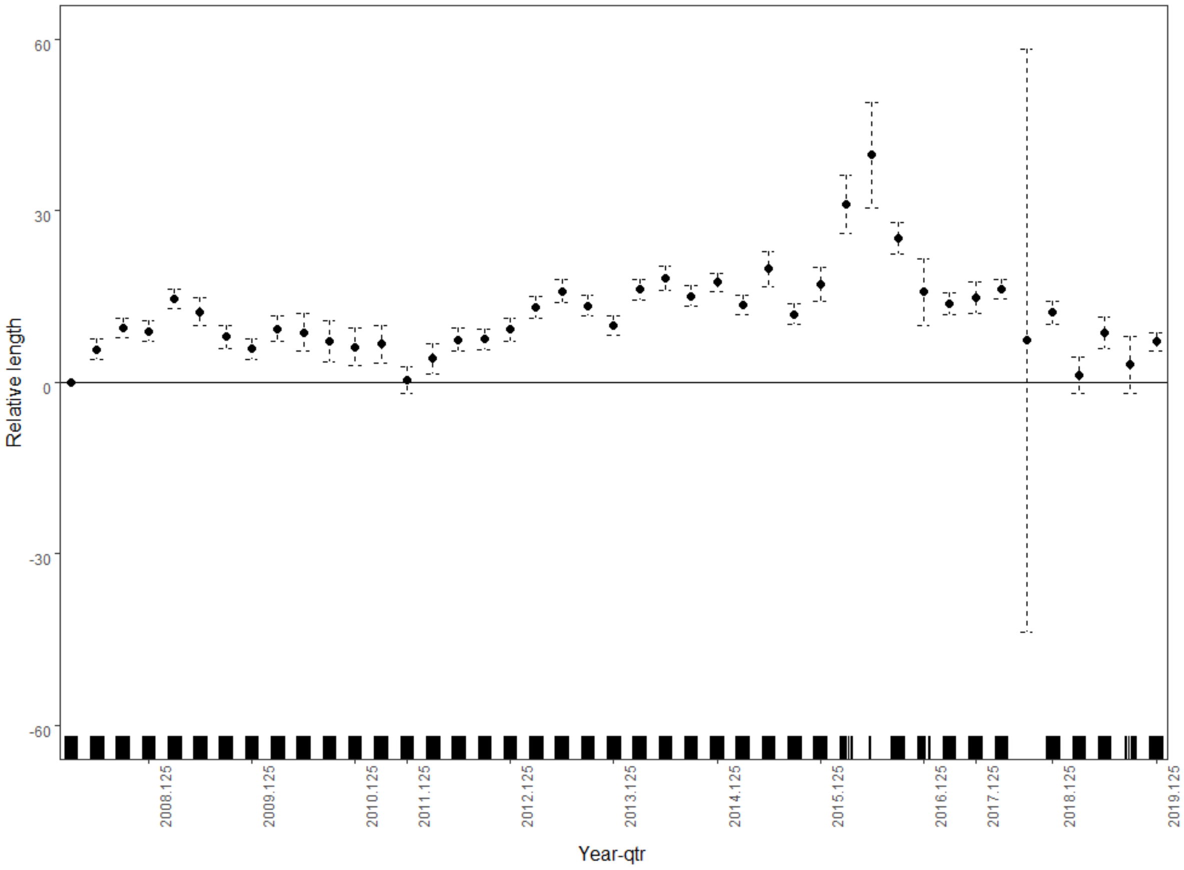


Figure 27: Plot of predicted relative lengths by year-quarter from gam model of Seychelles 1 x 1 yellowfin tuna length data held by IOTC.

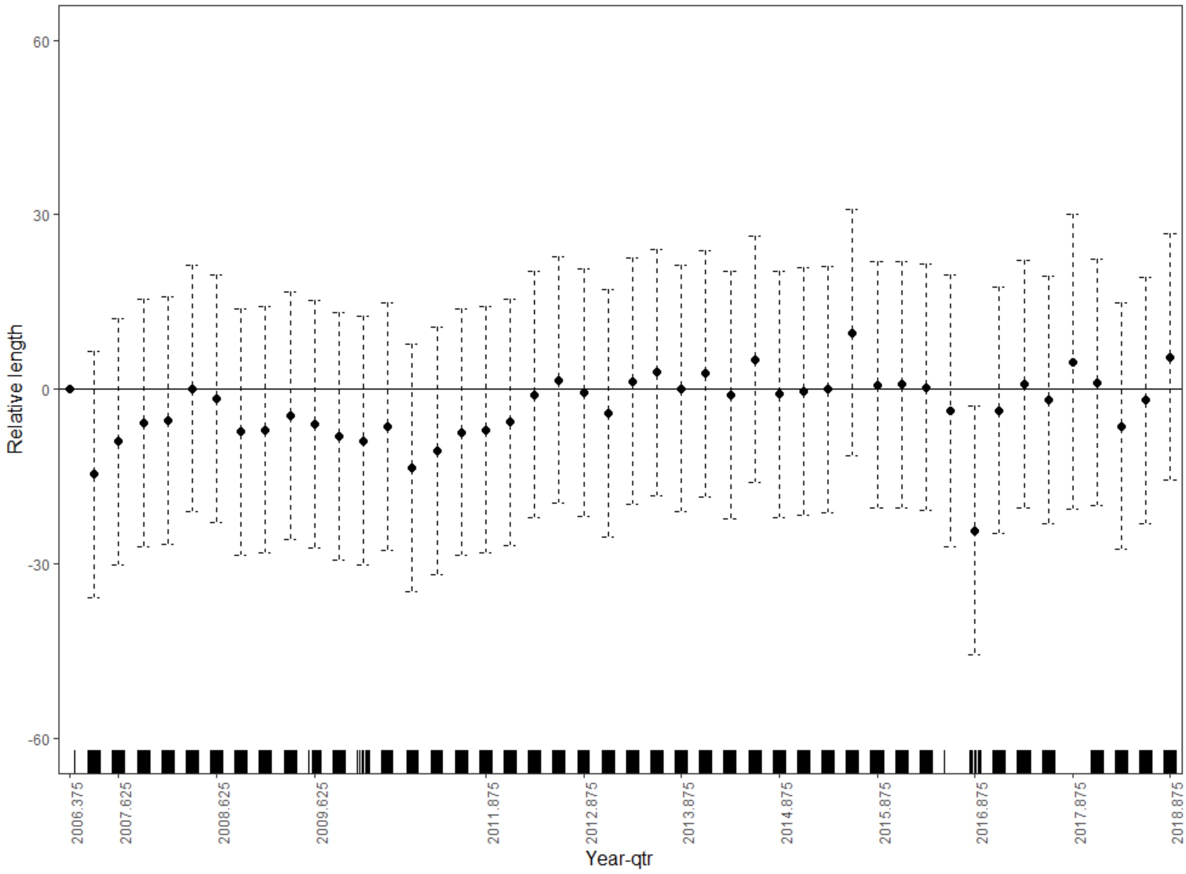


Figure 28: Plot of predicted relative lengths by year-quarter from gam model of Seychelles 1 x 1 yellowfin tuna length data held by the Seychelles.

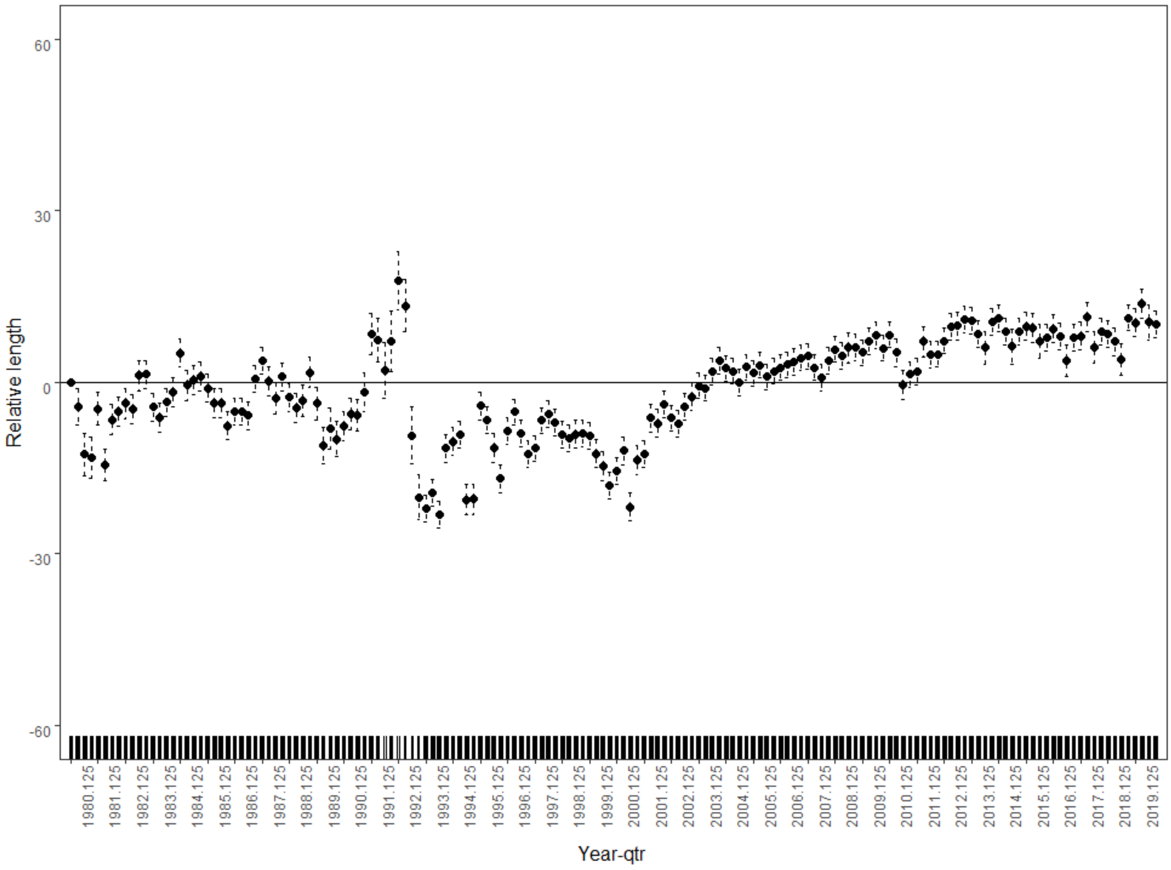


Figure 29: Plot of predicted relative lengths by year-quarter from gam model of Taiwanese 5 x 5 yellowfin tuna length data held by IOTC.

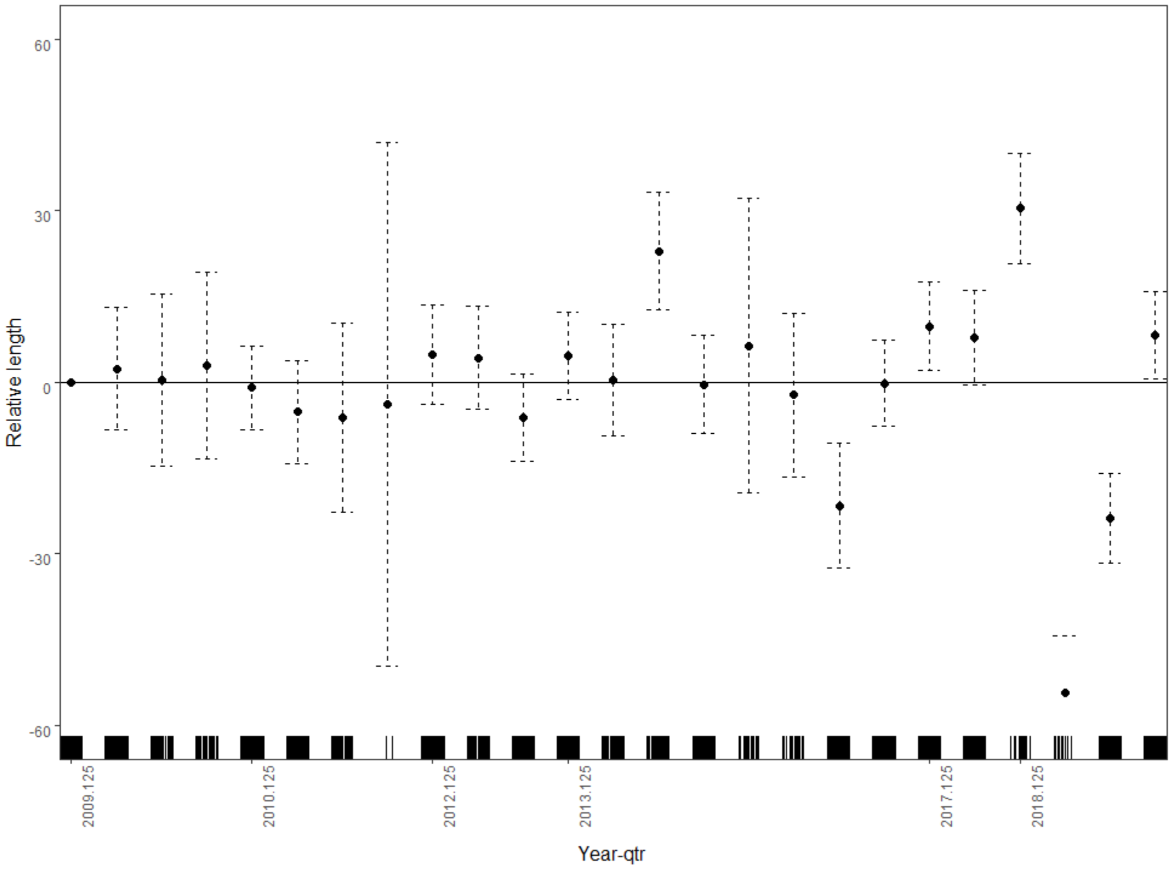


Figure 30: Plot of predicted relative lengths by year-quarter from gam model of Chinese 1 x 1 yellowfin tuna length data held by IOTC.

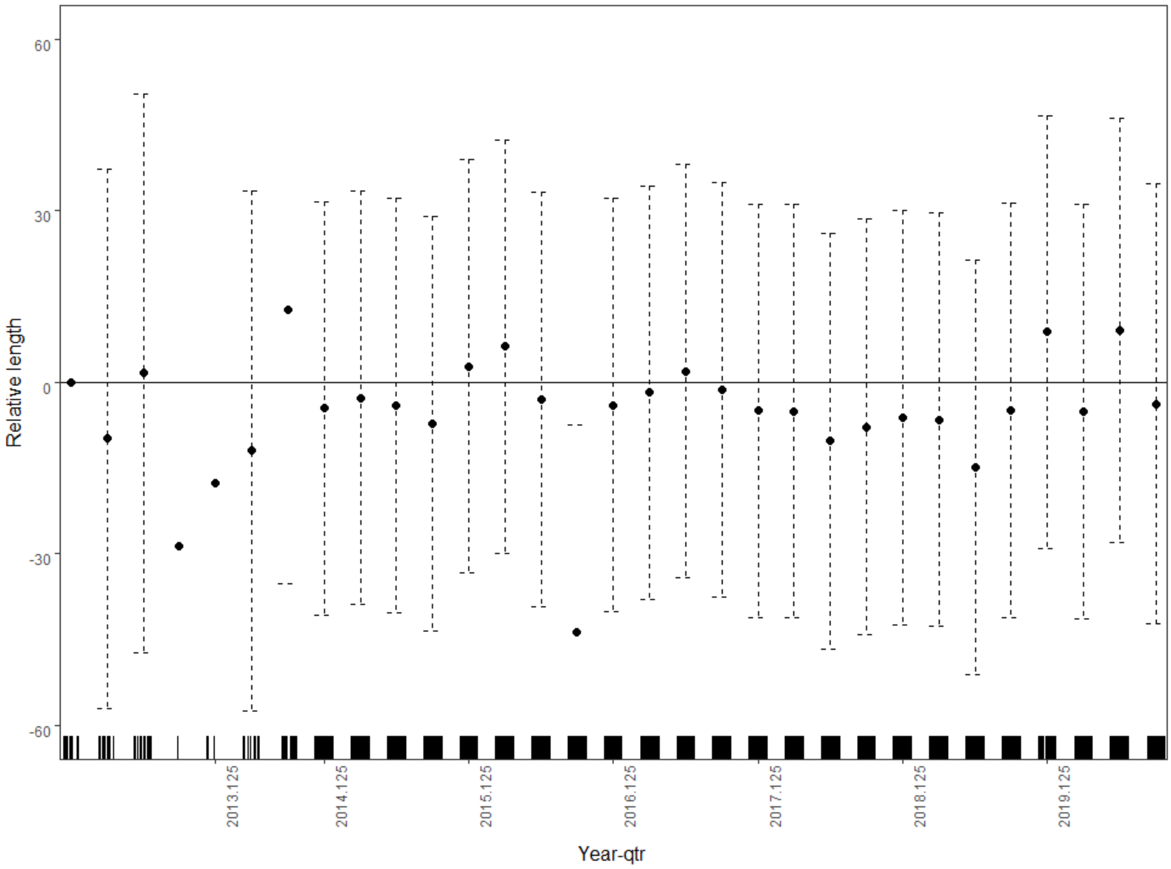


Figure 31: Plot of predicted relative lengths by year-quarter from gam model of other fleets 5 x 5 yellowfin tuna length data held by IOTC.

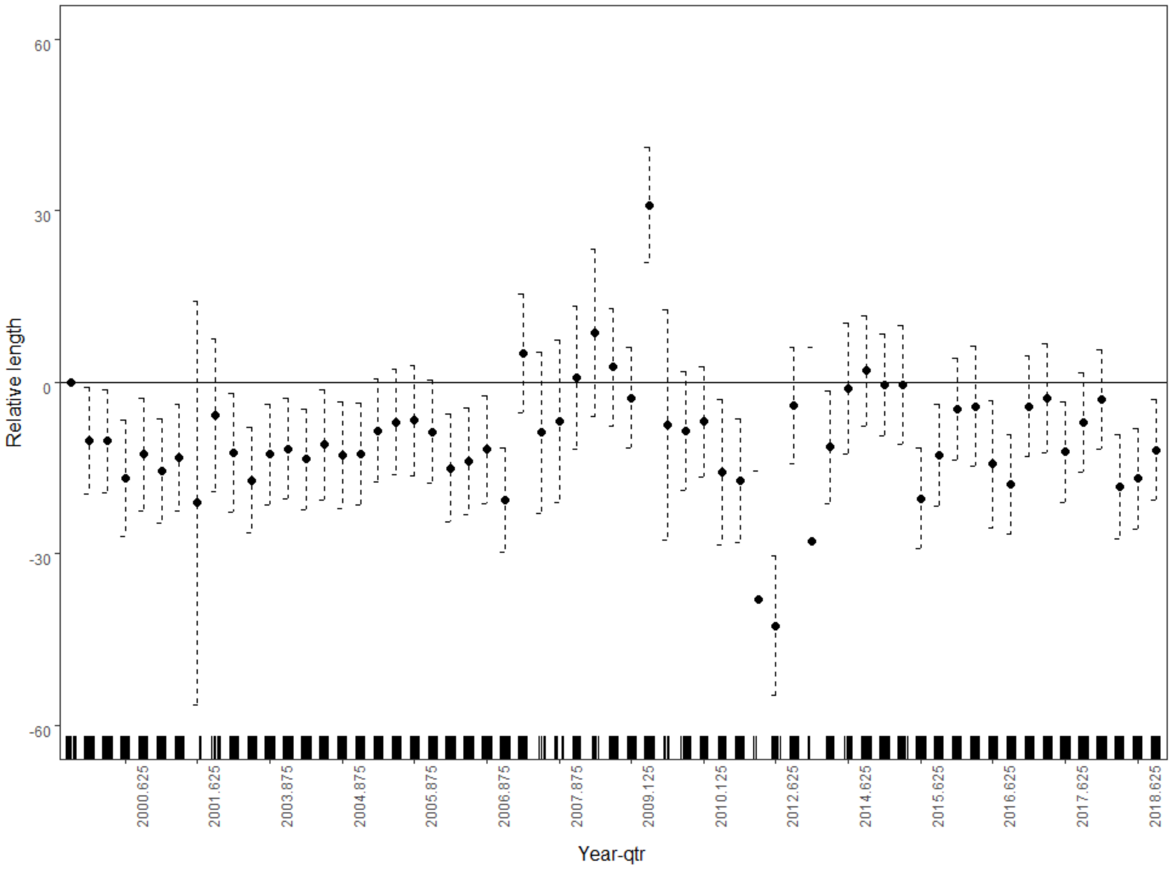


Figure 32: Plot of predicted relative lengths by year-quarter from gam model of Korean 1 x 1 yellowfin tuna length data provided by the Korean government.

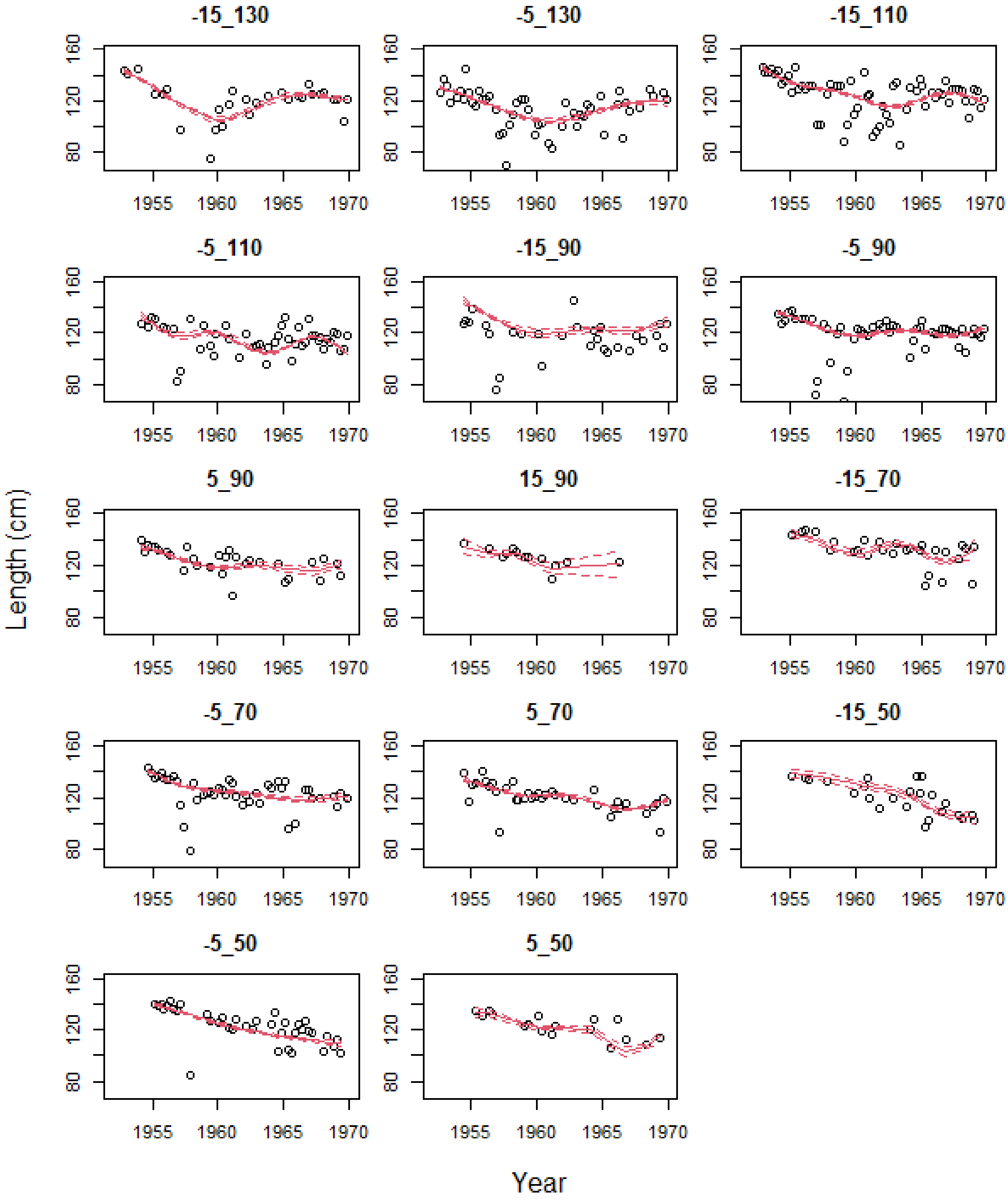


Figure 33: Size trends fitted independently by spatial cell to length data from individual 10 x 20 strata in the Japanese national dataset prior to 1970, based on data recorded at 5 x 10 and 1 x 1 resolution.

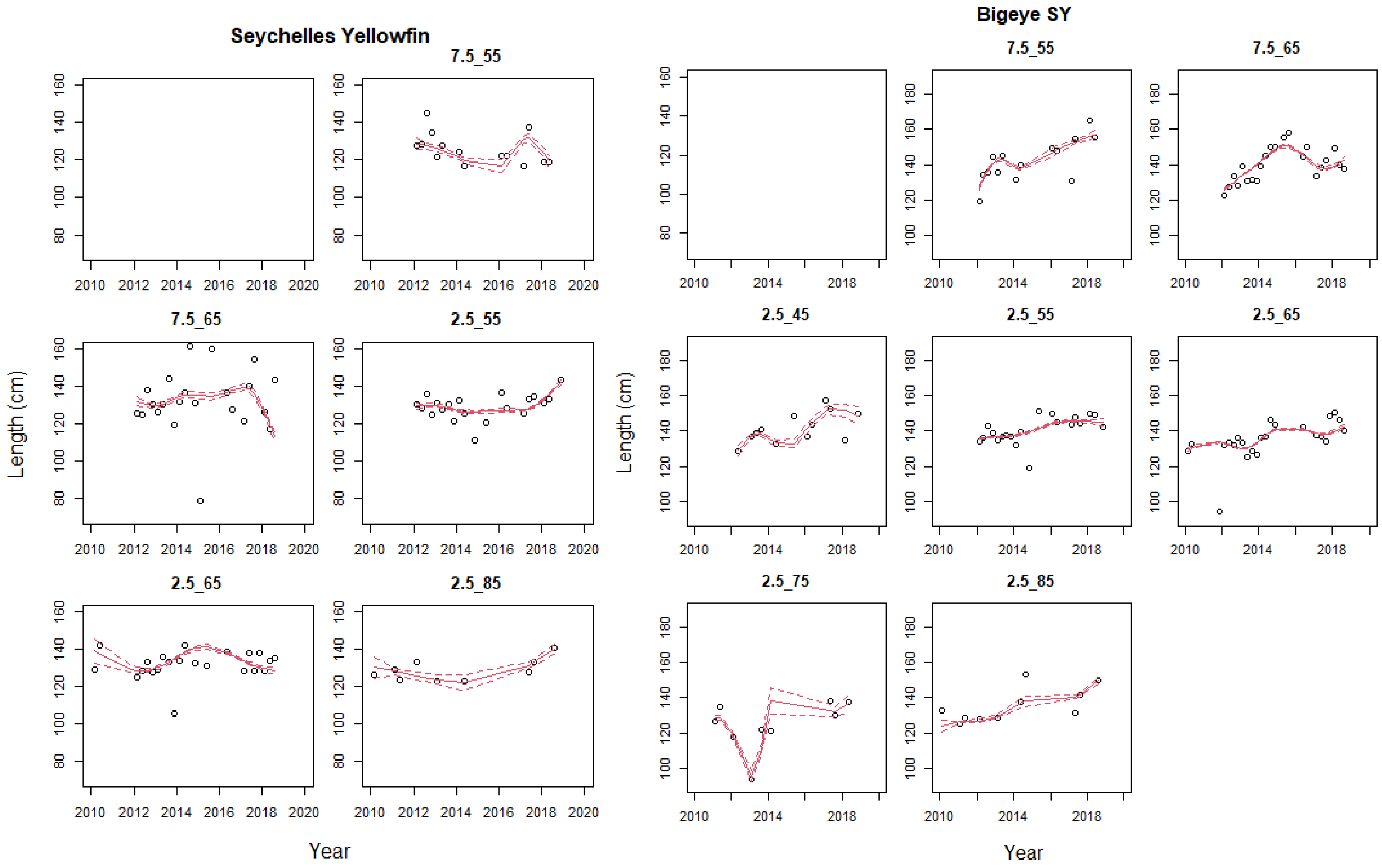


Figure 34: Size trends fitted independently by spatial cell to length data from individual 5 x10 strata in the Seychelles national dataset immediately following the piracy period of fishing exclusion, for yellowfin tuna (left) and bigeye tuna (right).

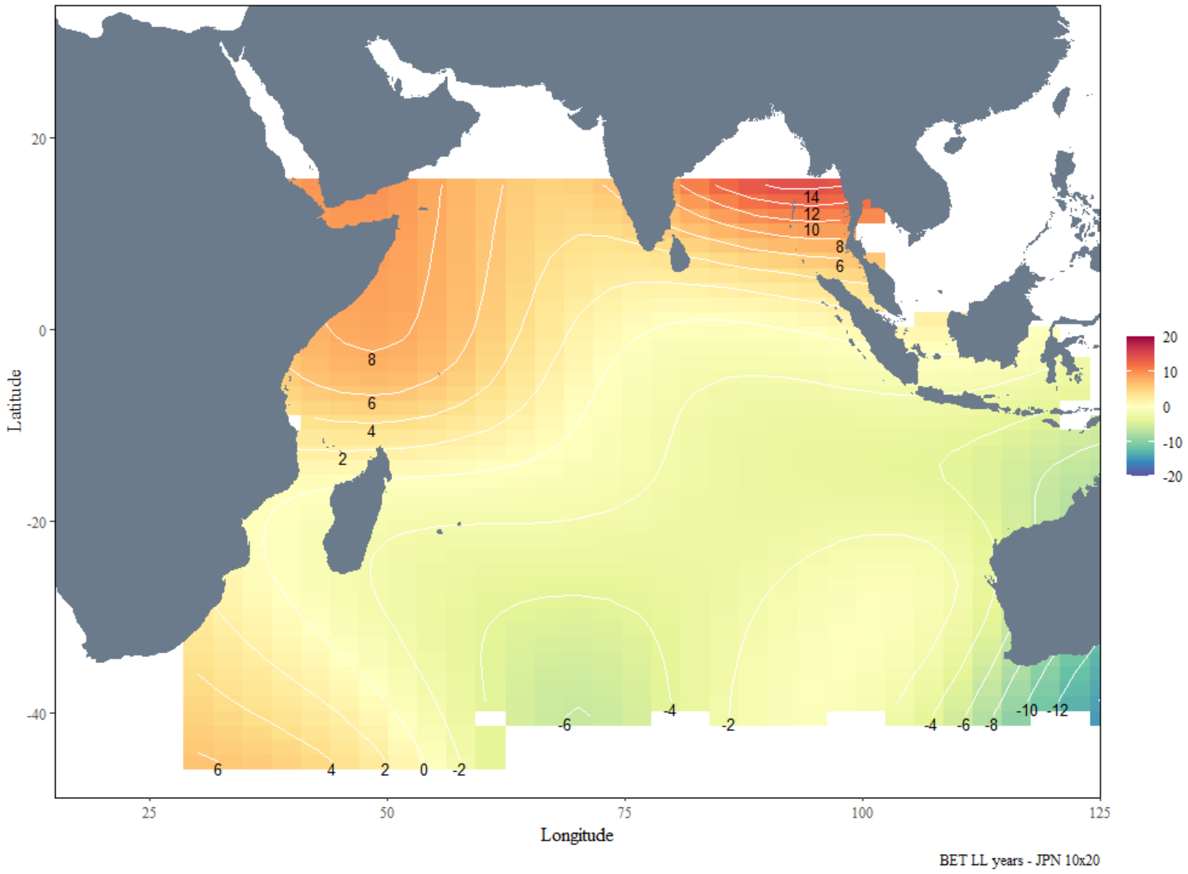


Figure 35: Map of predicted relative lengths from gam model of Japanese 10 x 20 size (lengths and converted weights) data for bigeye tuna held by IOTC.

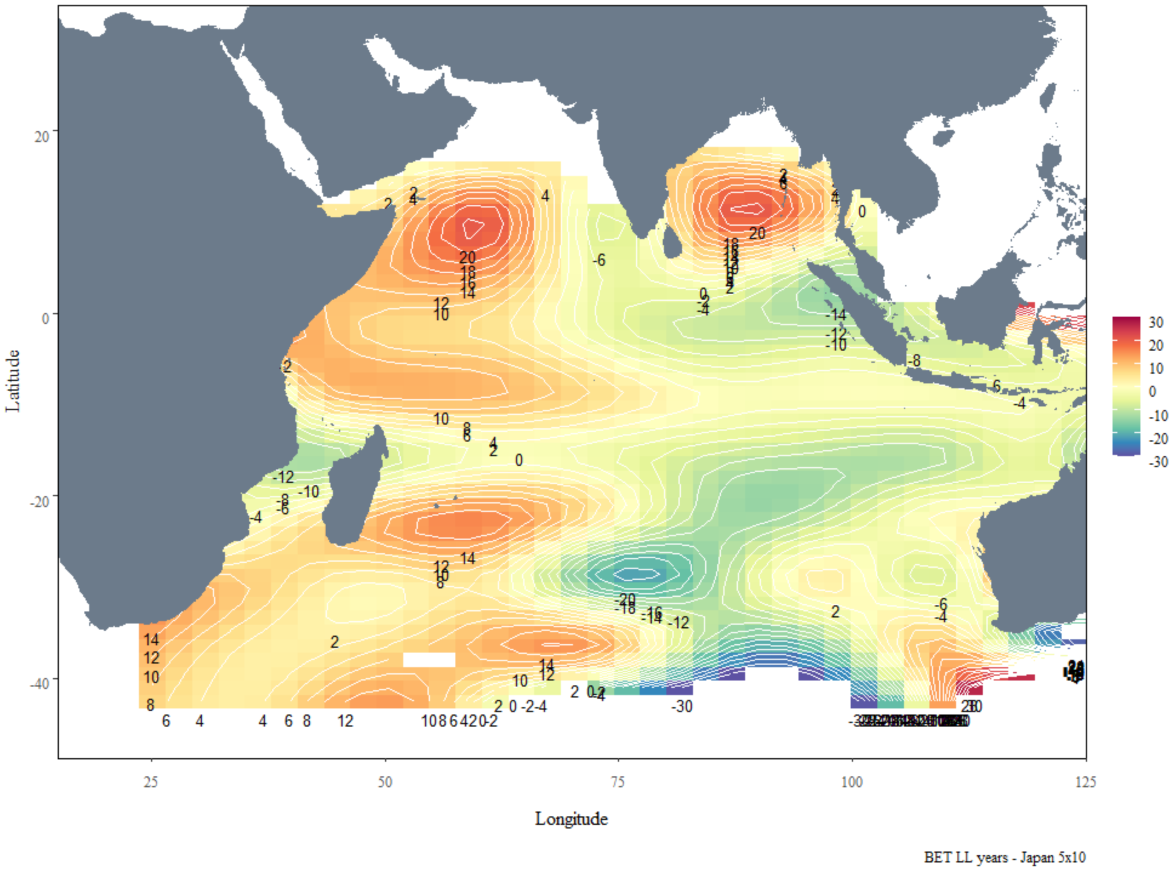


Figure 36: Map of predicted relative lengths from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 length data for bigeye tuna held by Japan.

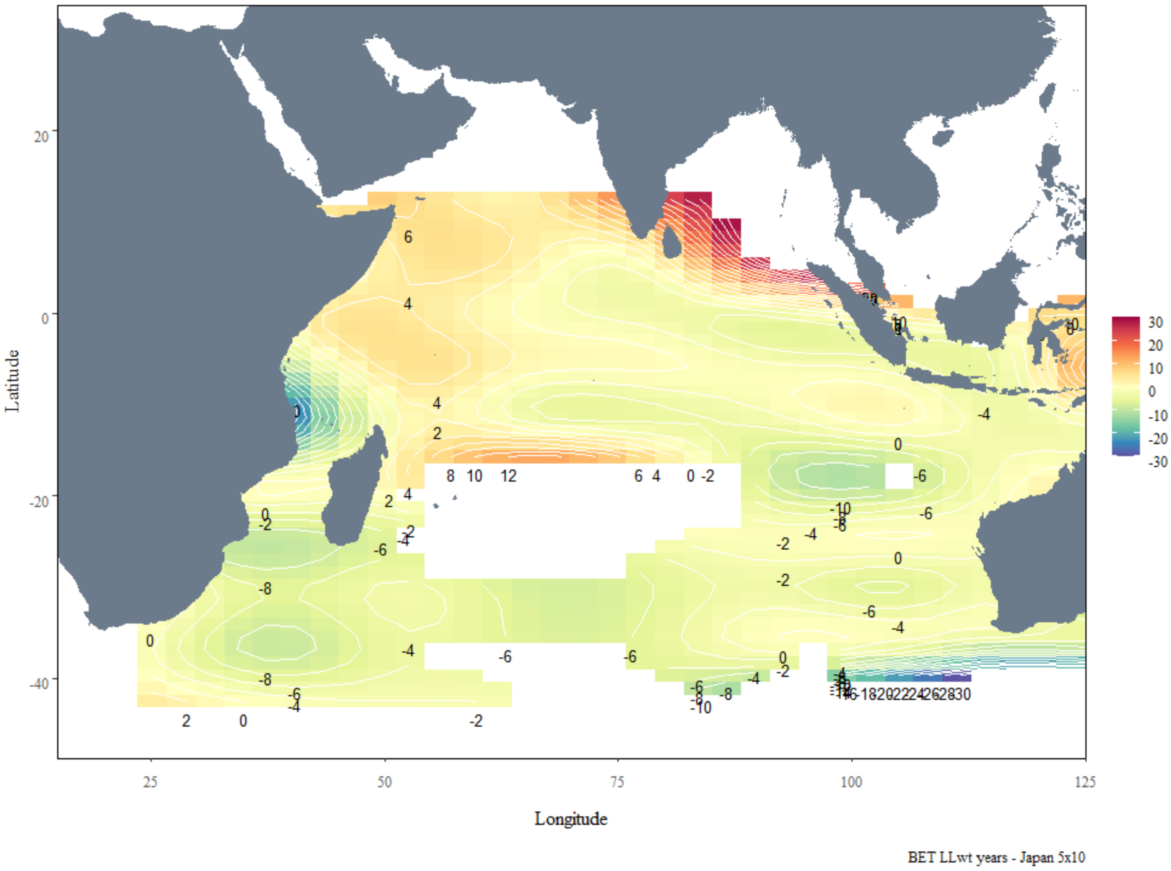


Figure 37: Map of predicted relative weights from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 weight data for bigeye tuna held by Japan.

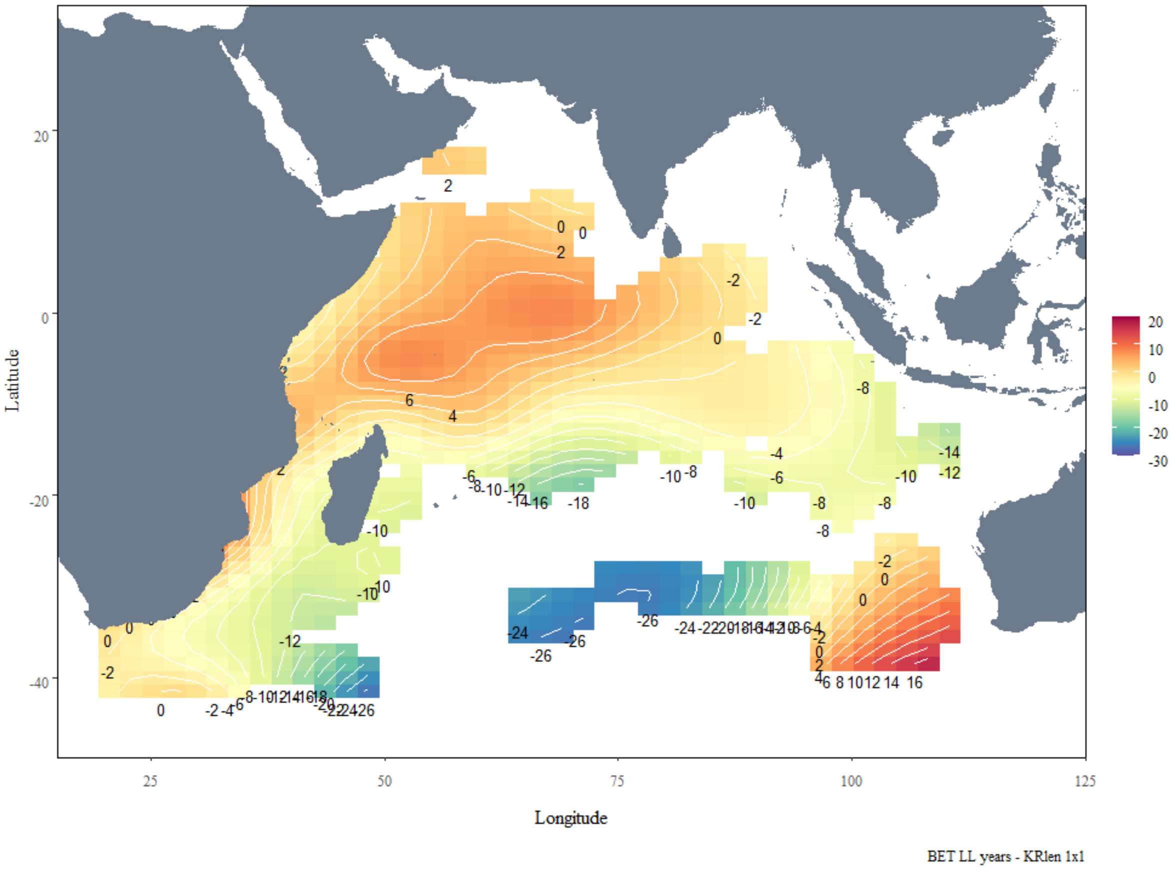


Figure 38: Map of predicted relative lengths from gam model of Korean 1 x 1 vessel and observer length data for bigeye tuna held by the Korean government.

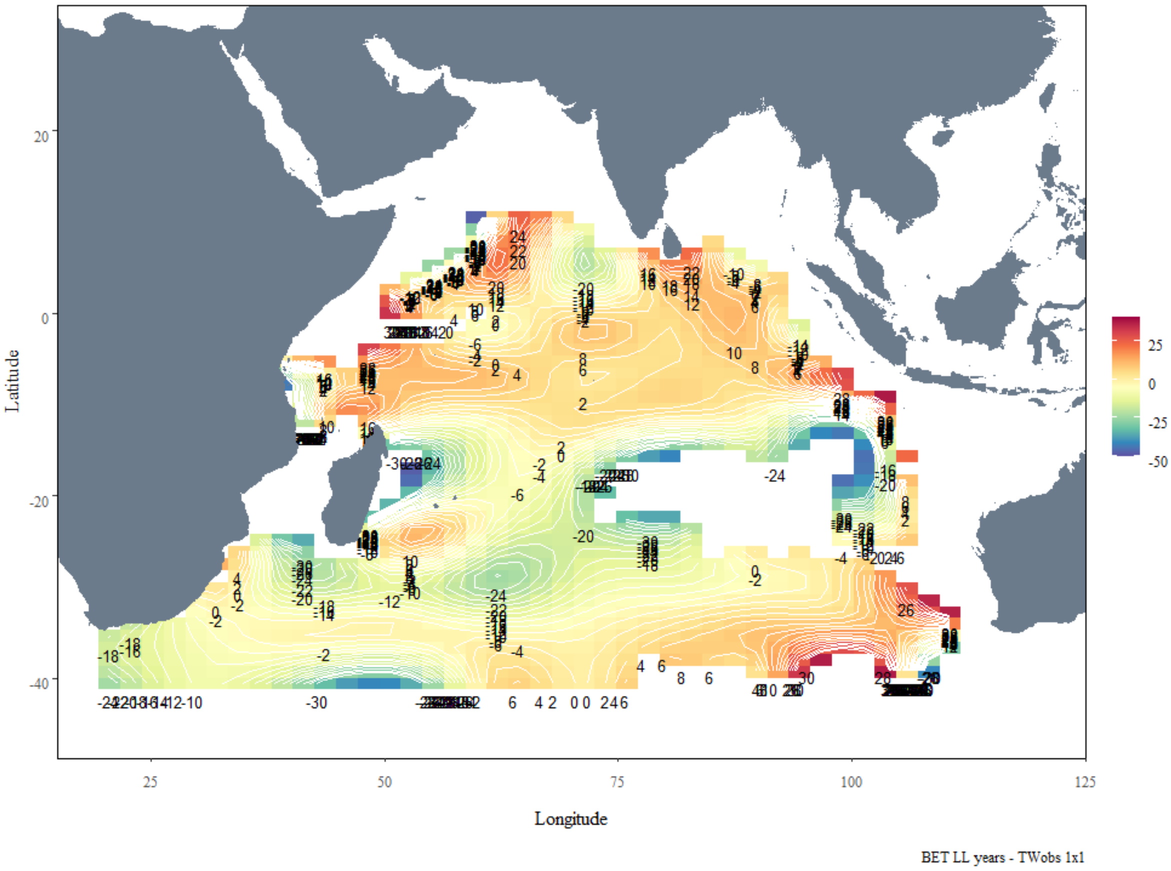


Figure 39: Map of predicted relative lengths from gam model of Taiwanese 1 x 1 observer length data for bigeye tuna held by the Taiwanese government.

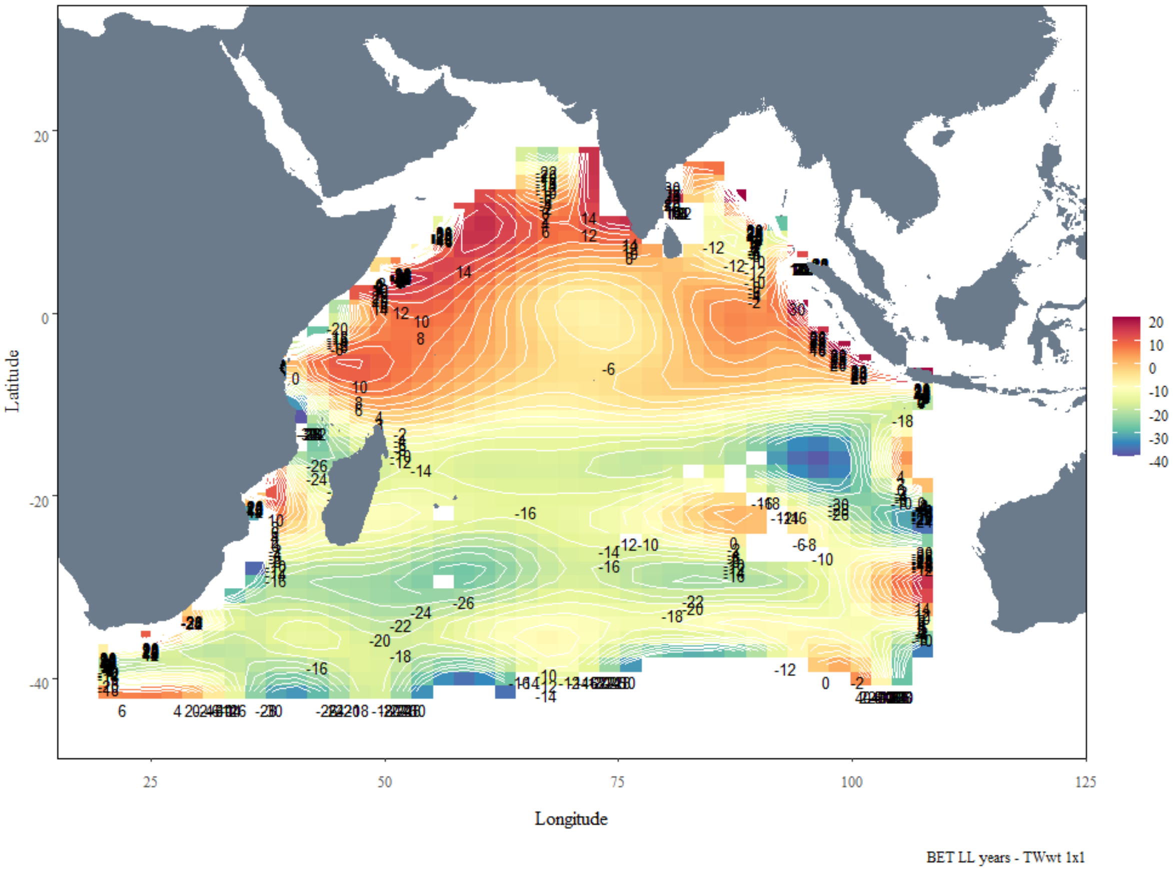


Figure 40: Map of predicted relative weights from gam model of Taiwanese 1 x 1 weight data for bigeye tuna held by the Taiwanese government.

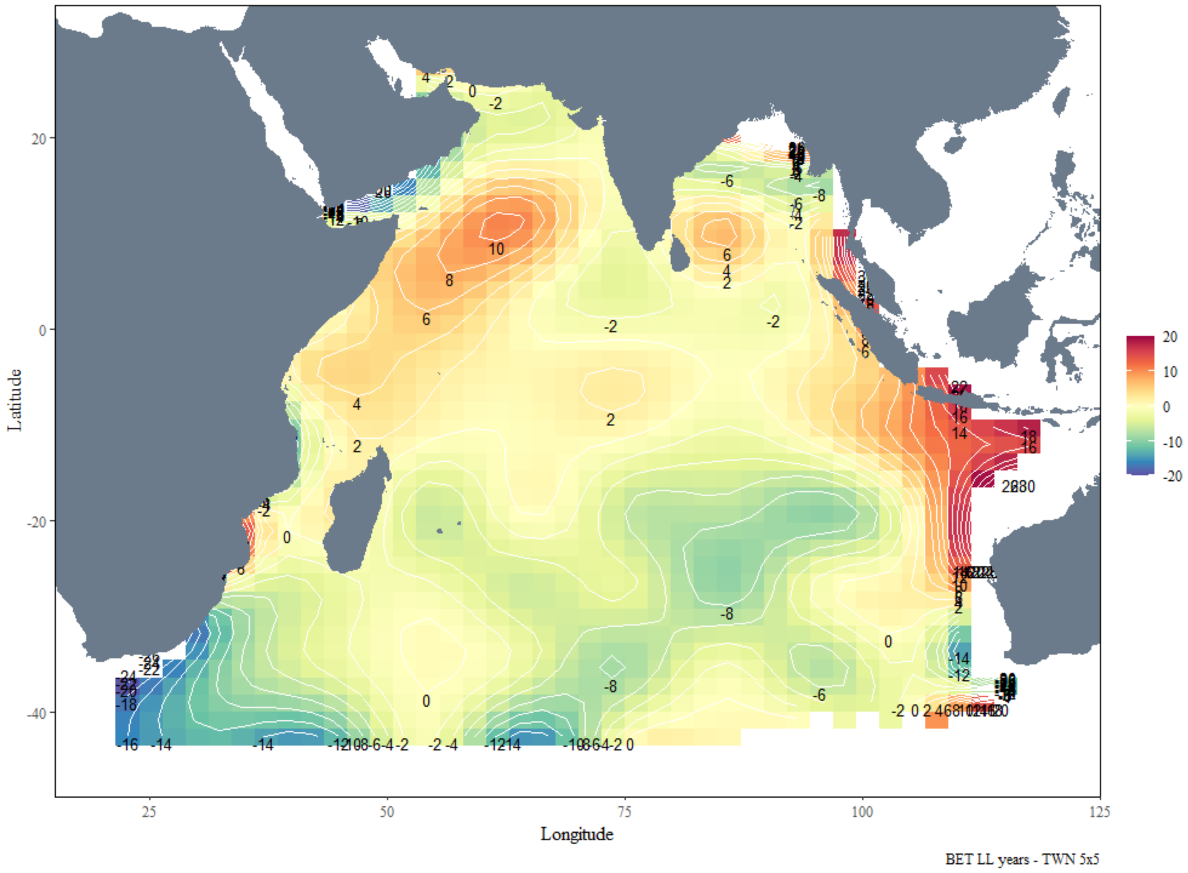
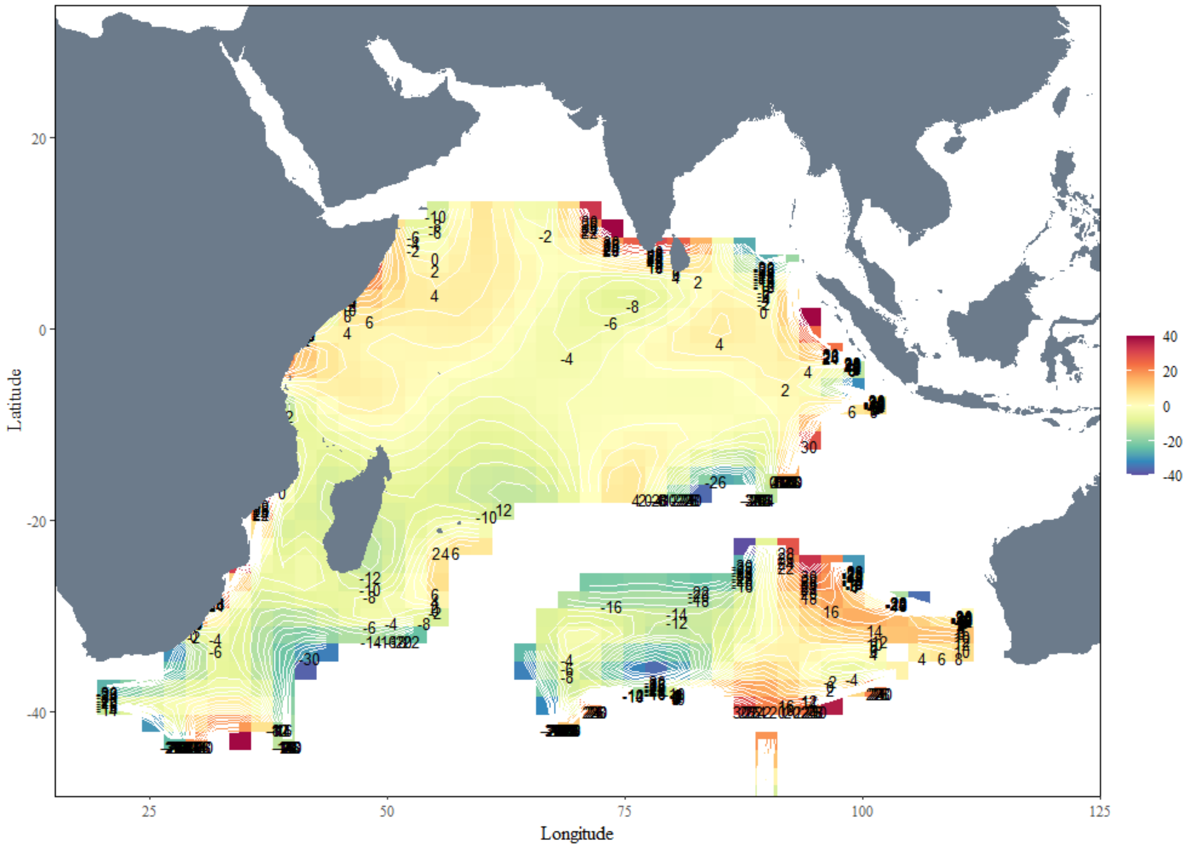
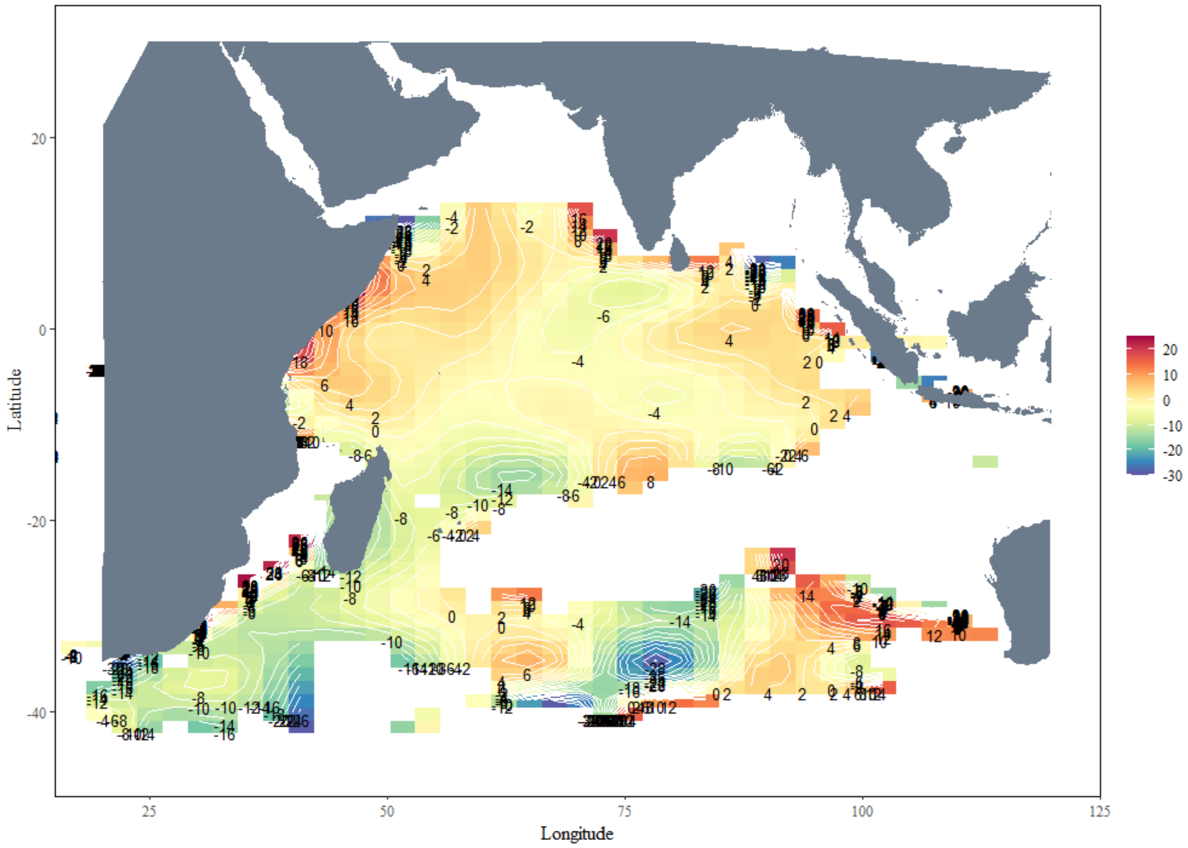


Figure 41: Map of predicted relative lengths from gam model of Taiwanese 5 x 5 length data for bigeye tuna held by the IOTC.



BET LL years - SYC 1x1

Figure 42: Map of predicted relative lengths from gam model of Seychelles 1 x 1 length data for bigeye tuna held by the IOTC.



BET LL years - SEY len 1x1

Figure 43: Map of predicted relative lengths from gam model of Seychelles 1 x 1 length data for bigeye tuna held by the Seychelles.

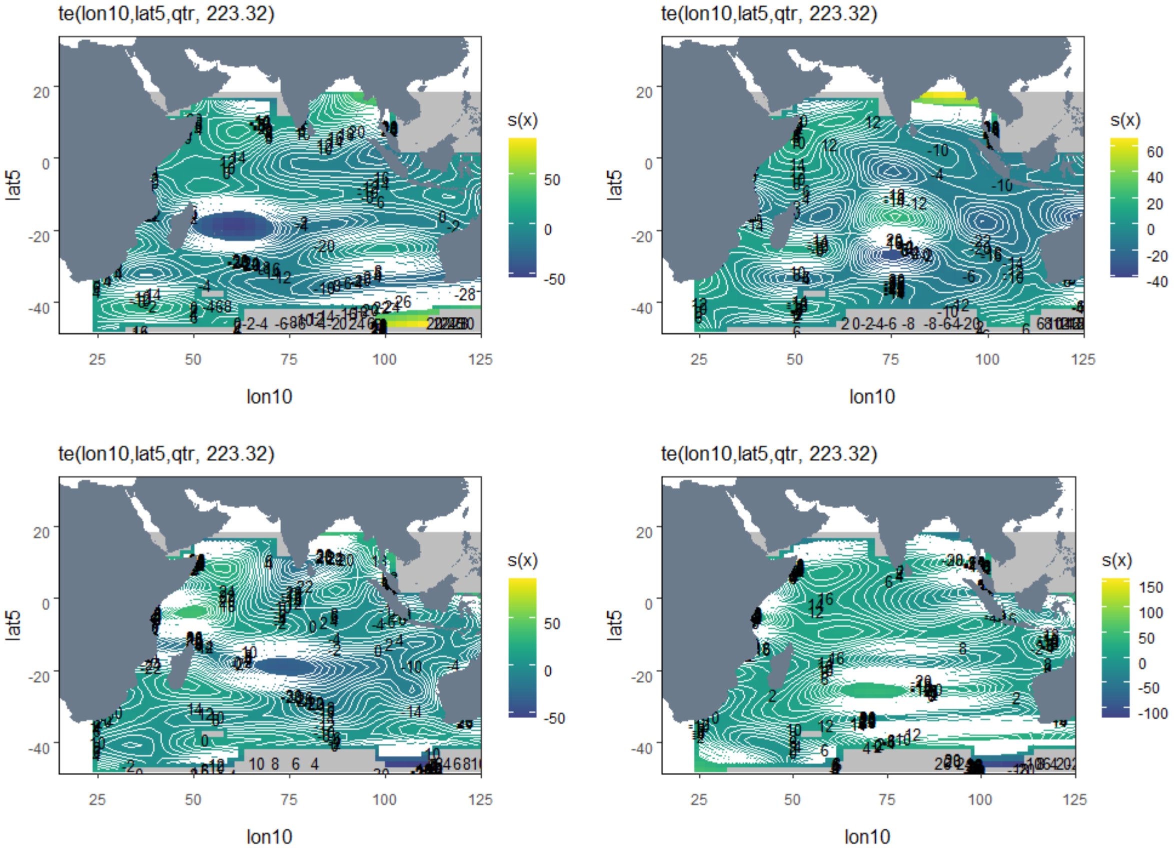


Figure 44: Quarterly maps of predicted relative lengths from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 length data for bigeye tuna held by Japan.

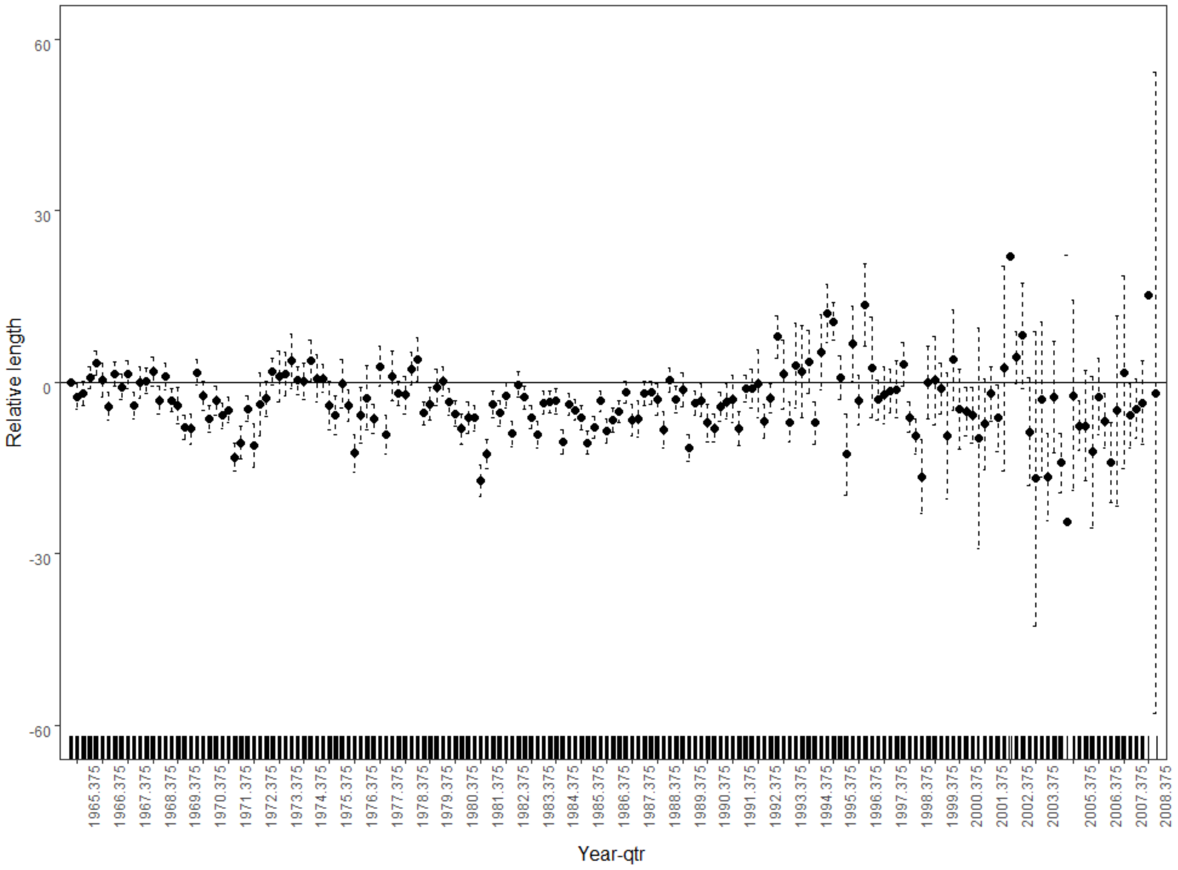


Figure 45: Plot of predicted relative lengths by year-quarter from gam model at 5 x 10 resolution of Japanese 10 x 20 bigeye tuna length and converted weight data held by IOTC.

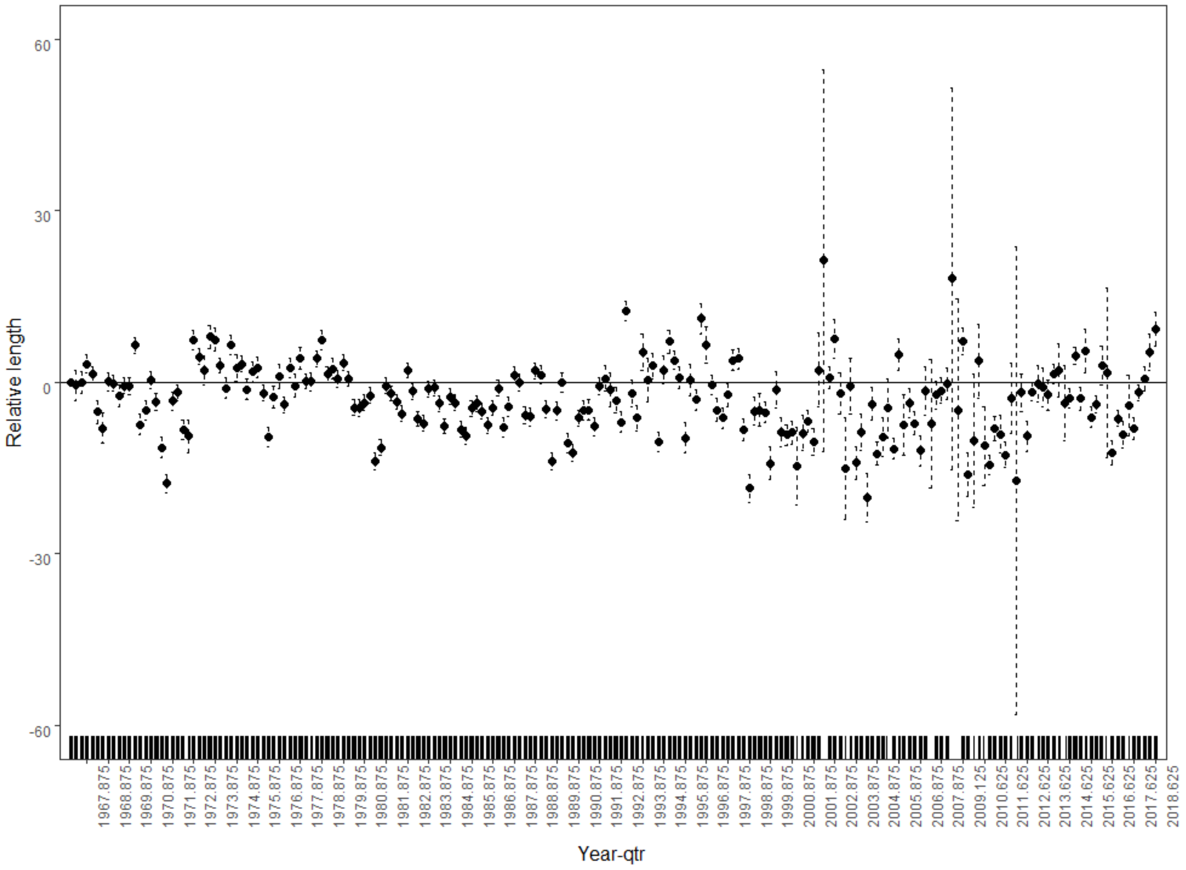


Figure 46: Plot of predicted relative lengths by year-quarter from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 bigeye tuna length data held by Japan.

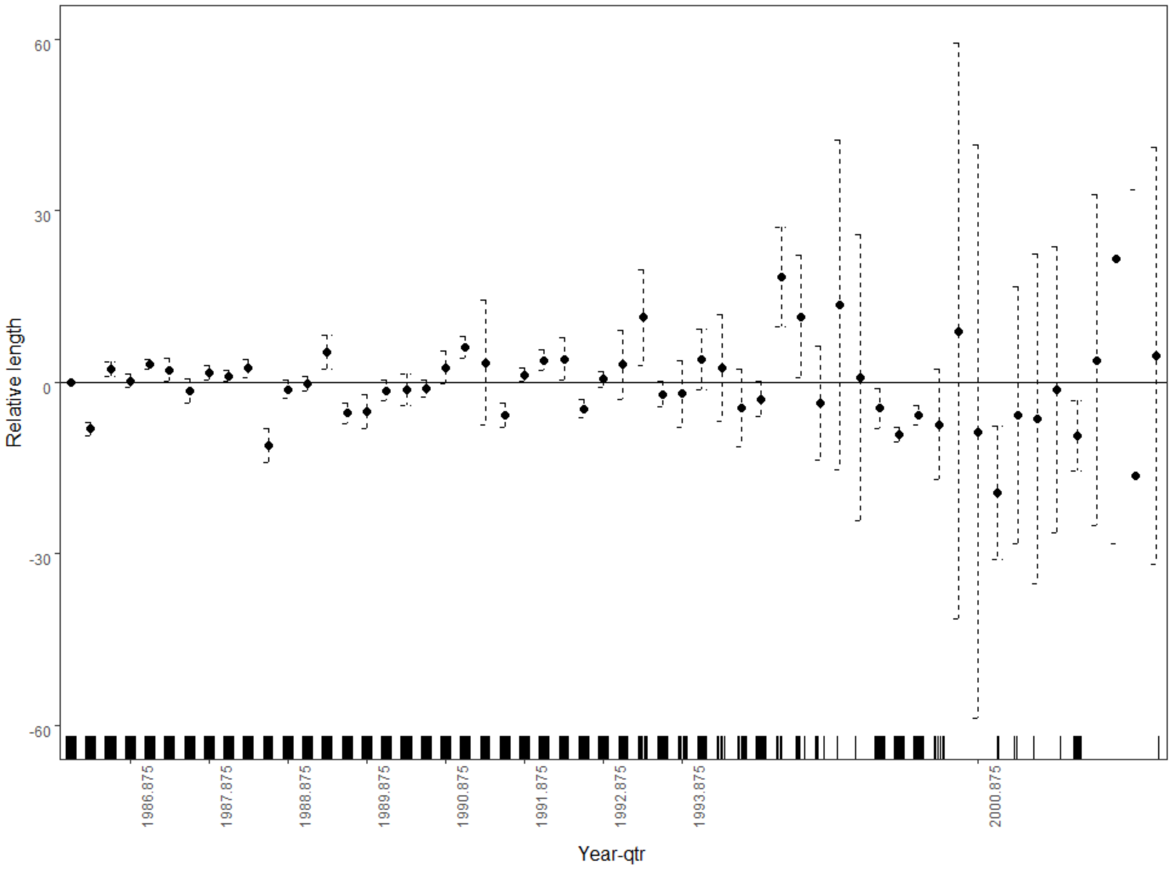


Figure 47: Plot of predicted relative weights by year-quarter from gam model at 5 x 10 resolution of Japanese 5 x 10 and 1 x 1 bigeye tuna weight data held by Japan.

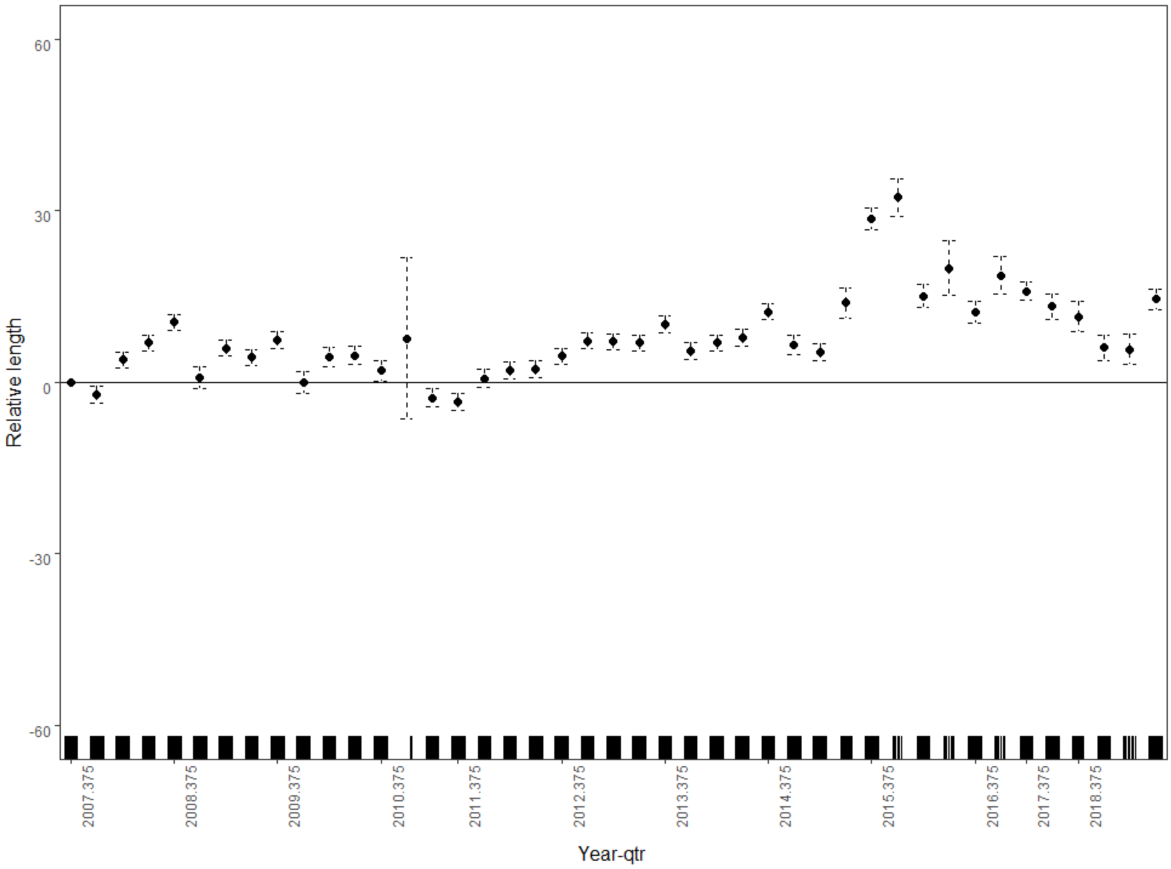


Figure 48: Plot of predicted relative lengths by year-quarter from gam model of Seychelles 1 x 1 bigeye tuna length data held by IOTC.

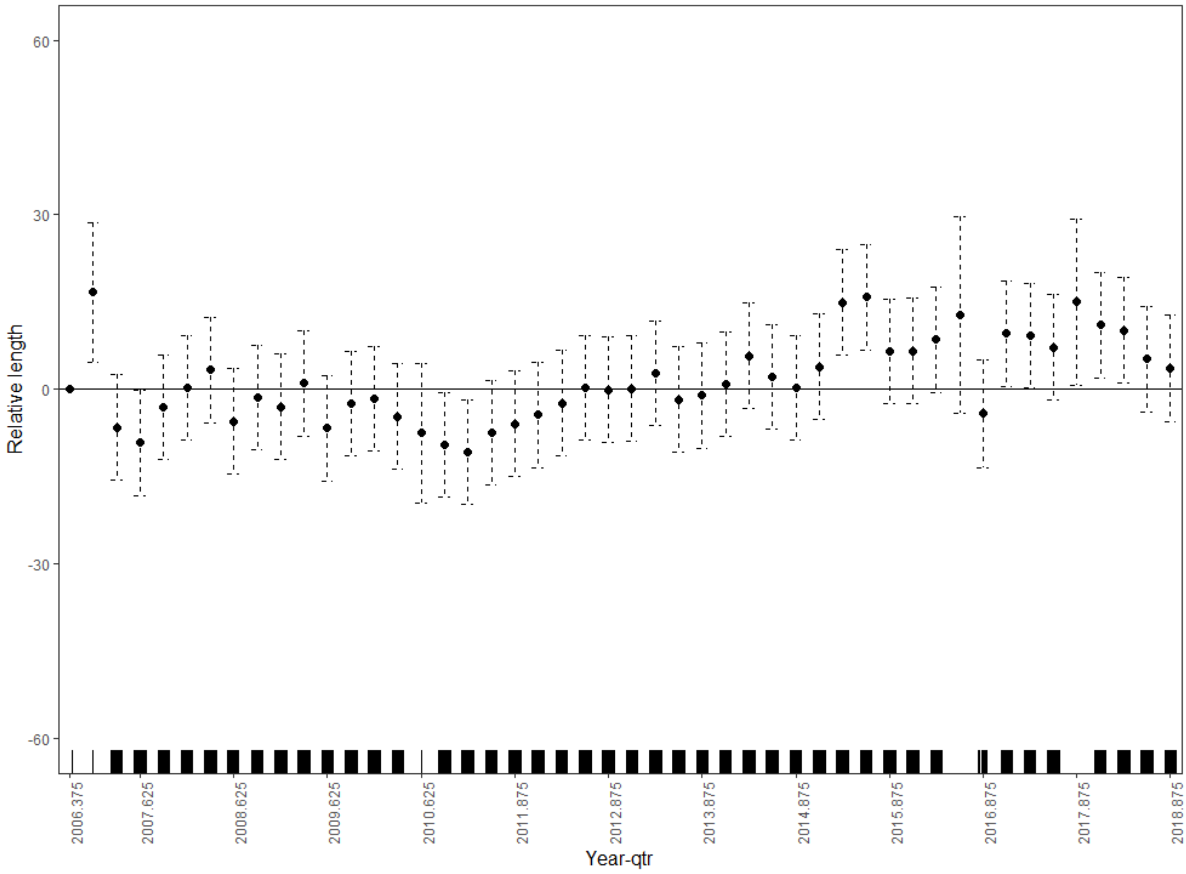


Figure 49: Plot of predicted relative lengths by year-quarter from gam model of Seychelles 1 x 1 bigeye tuna length data held by the Seychelles.

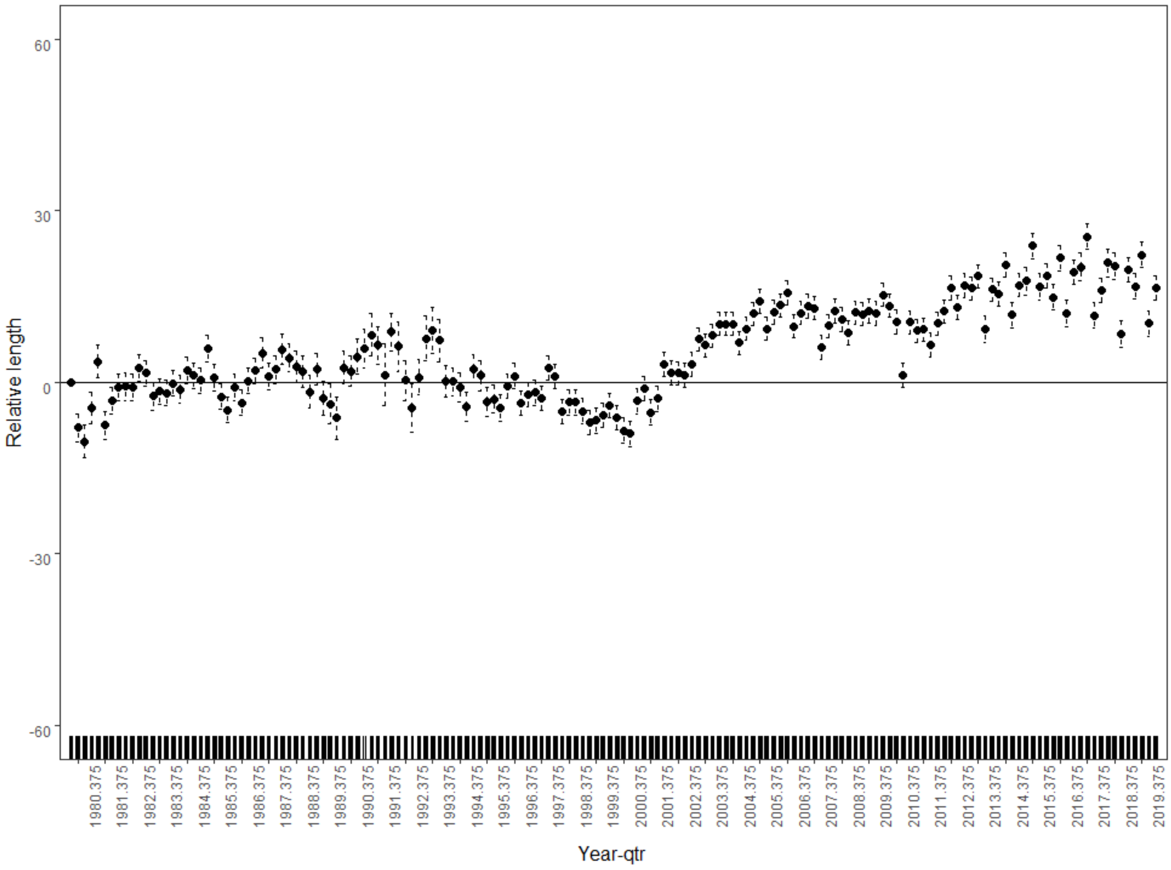


Figure 50: Plot of predicted relative lengths by year-quarter from gam model of Taiwanese 5 x 5 bigeye tuna length data held by IOTC.

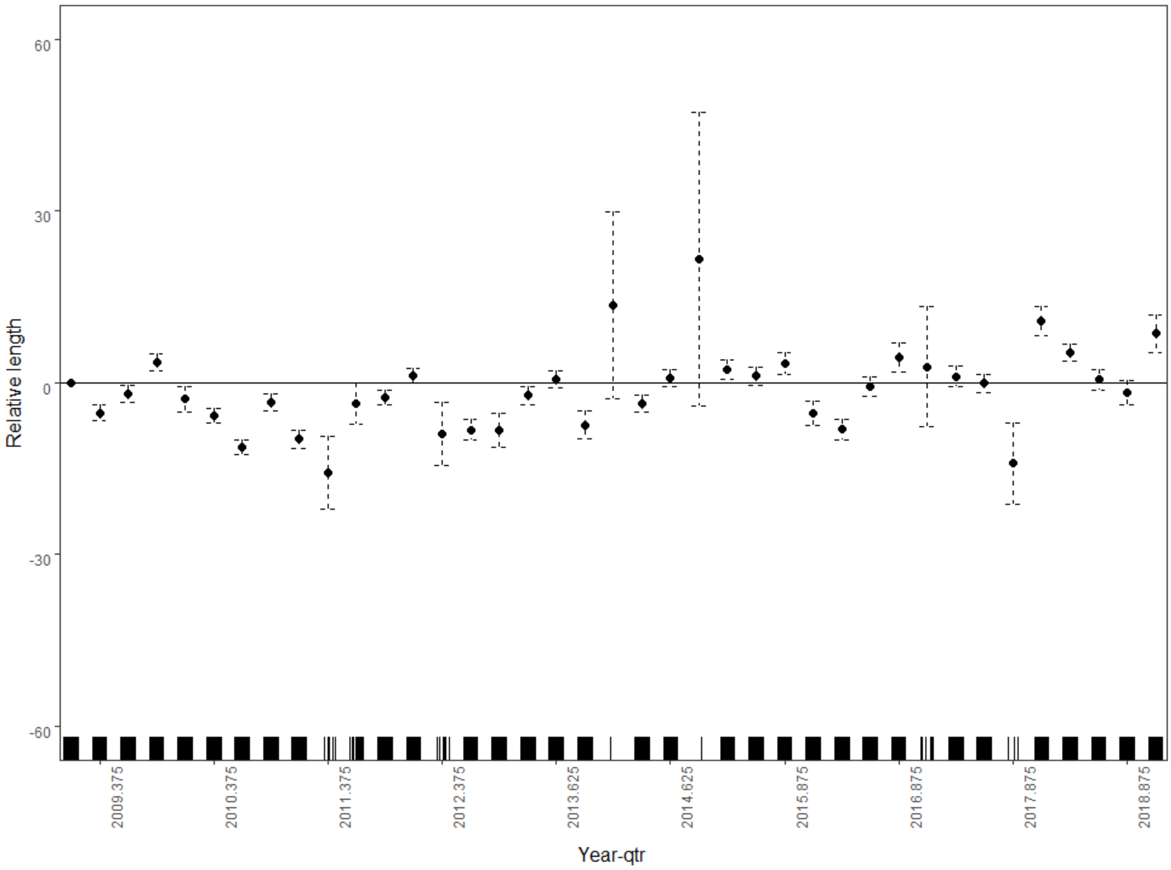


Figure 51: Plot of predicted relative lengths by year-quarter from gam model of Taiwanese observer 1 x 1 bigeye tuna length data held by the Taiwanese government.

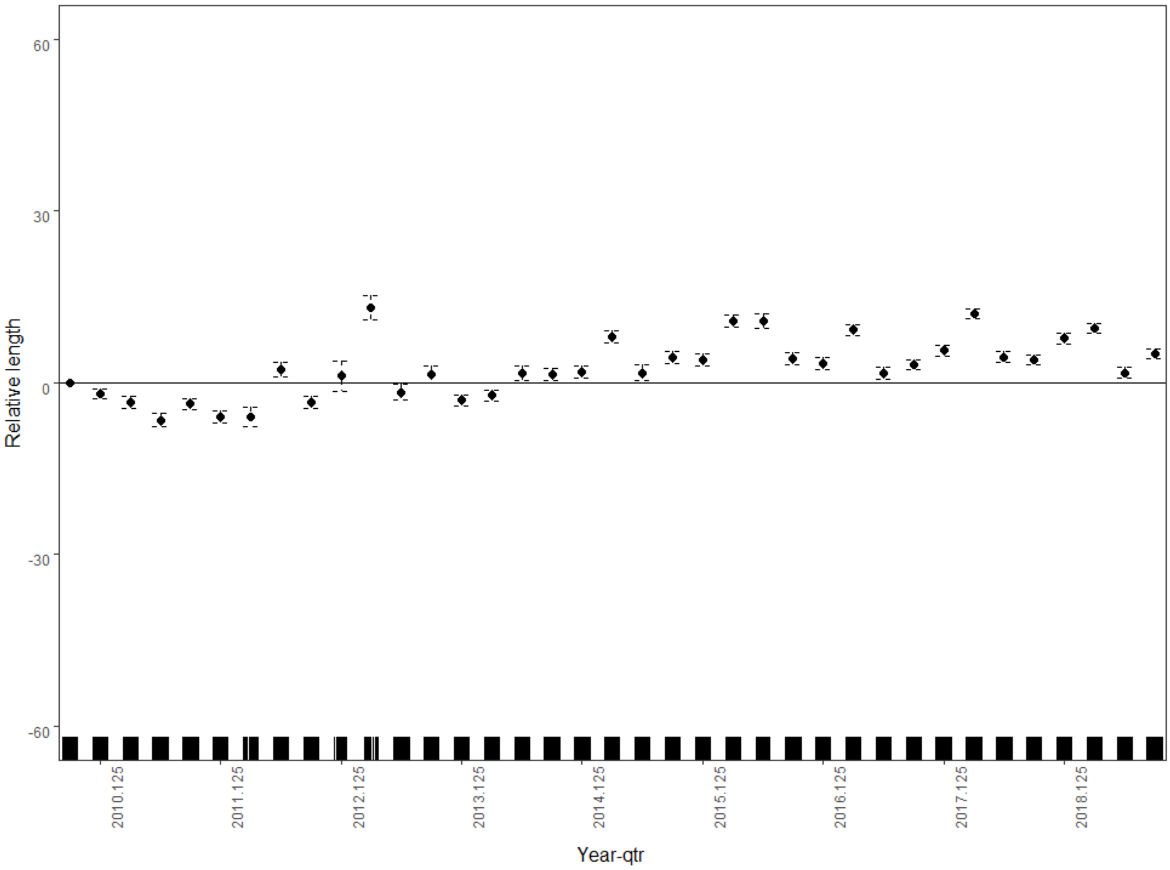


Figure 52: Plot of predicted relative weights by year-quarter from gam model of Taiwanese 1 x 1 bigeye tuna weight data held by the Taiwanese government.

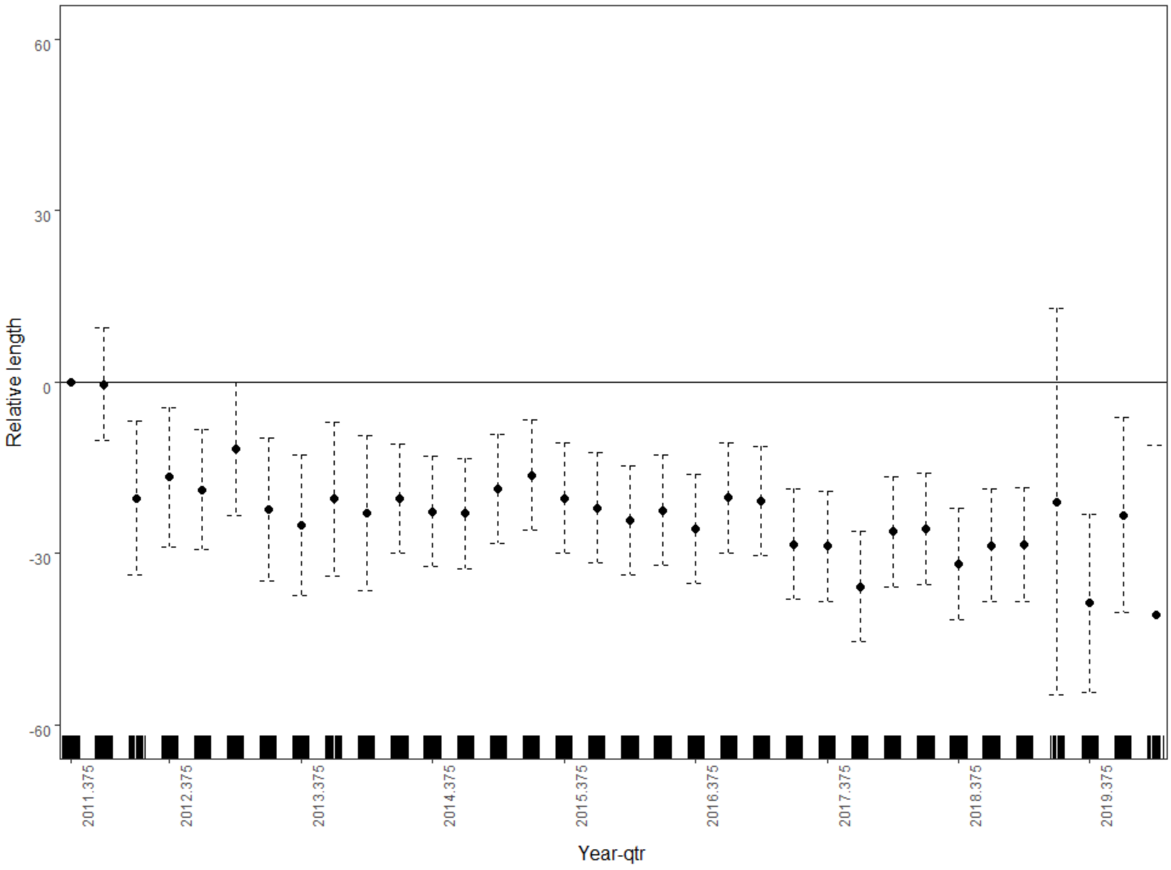


Figure 53: Plot of predicted relative lengths by year-quarter from gam model of other fleets 5 x 5 bigeye tuna length data held by the IOTC.

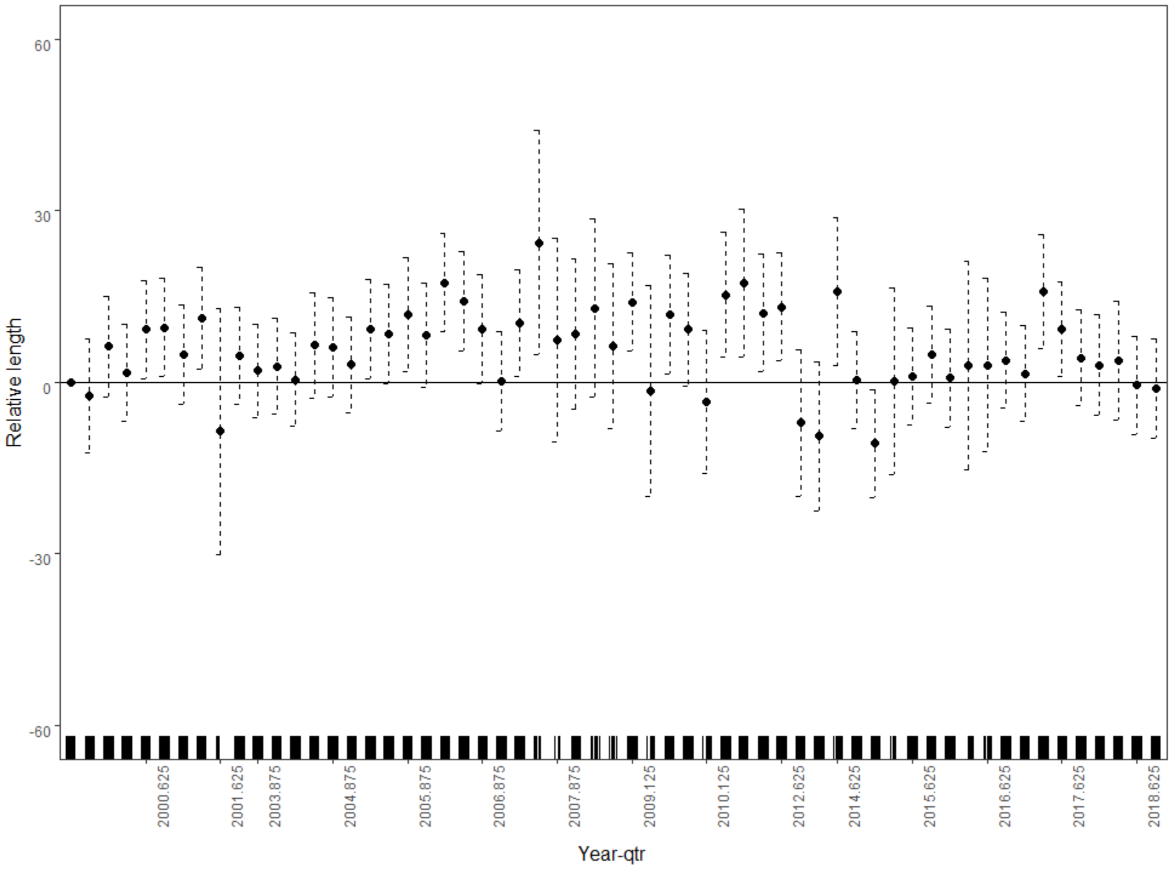


Figure 54: Plot of predicted relative lengths by year-quarter from gam model of Korean 1 x 1 bigeye tuna length data provided by the Korean government.

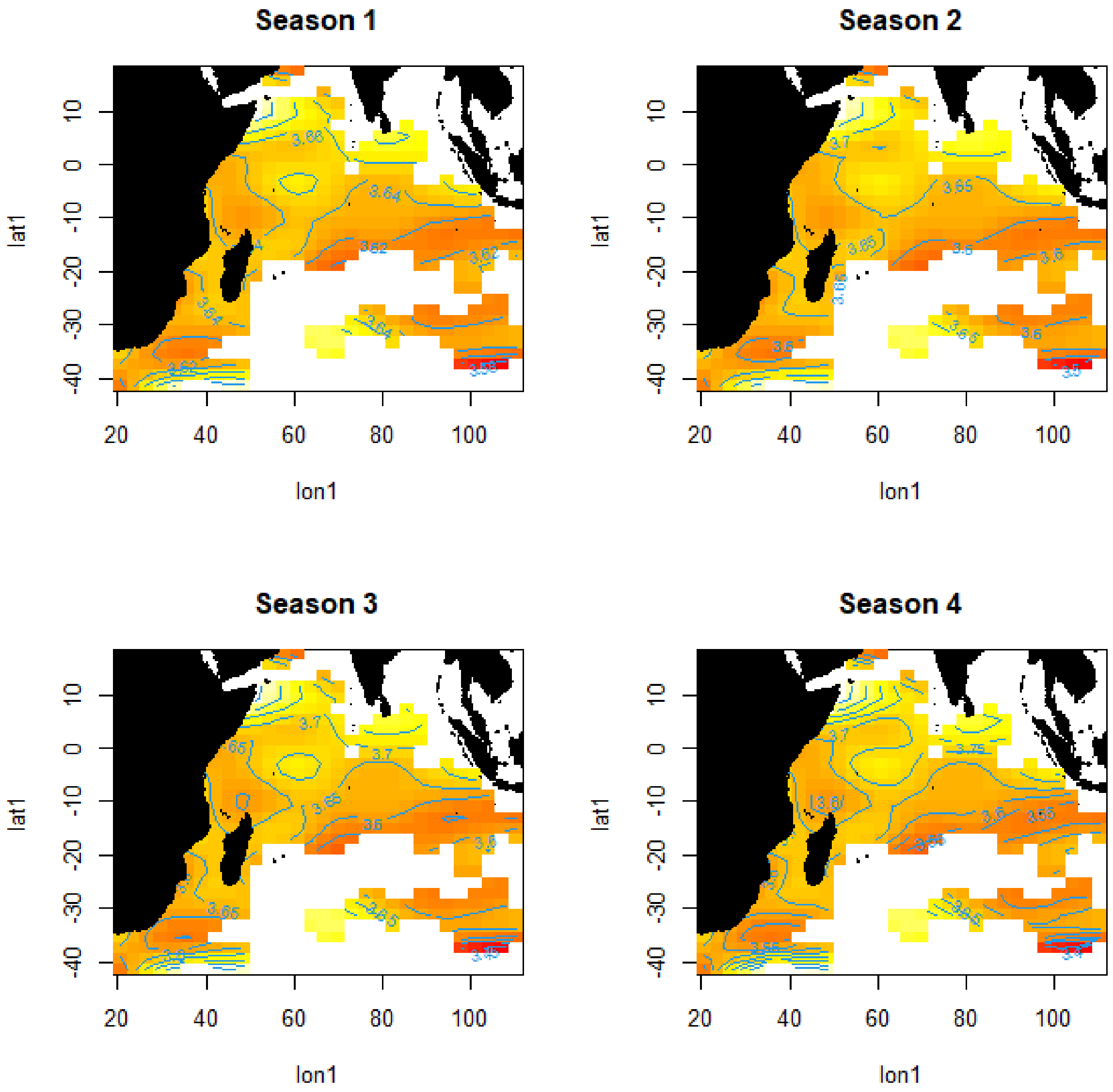


Figure 55: Seasonal and spatial variation in length-weight relationship of bigeye tuna, based on data from the Korean longline fishery.

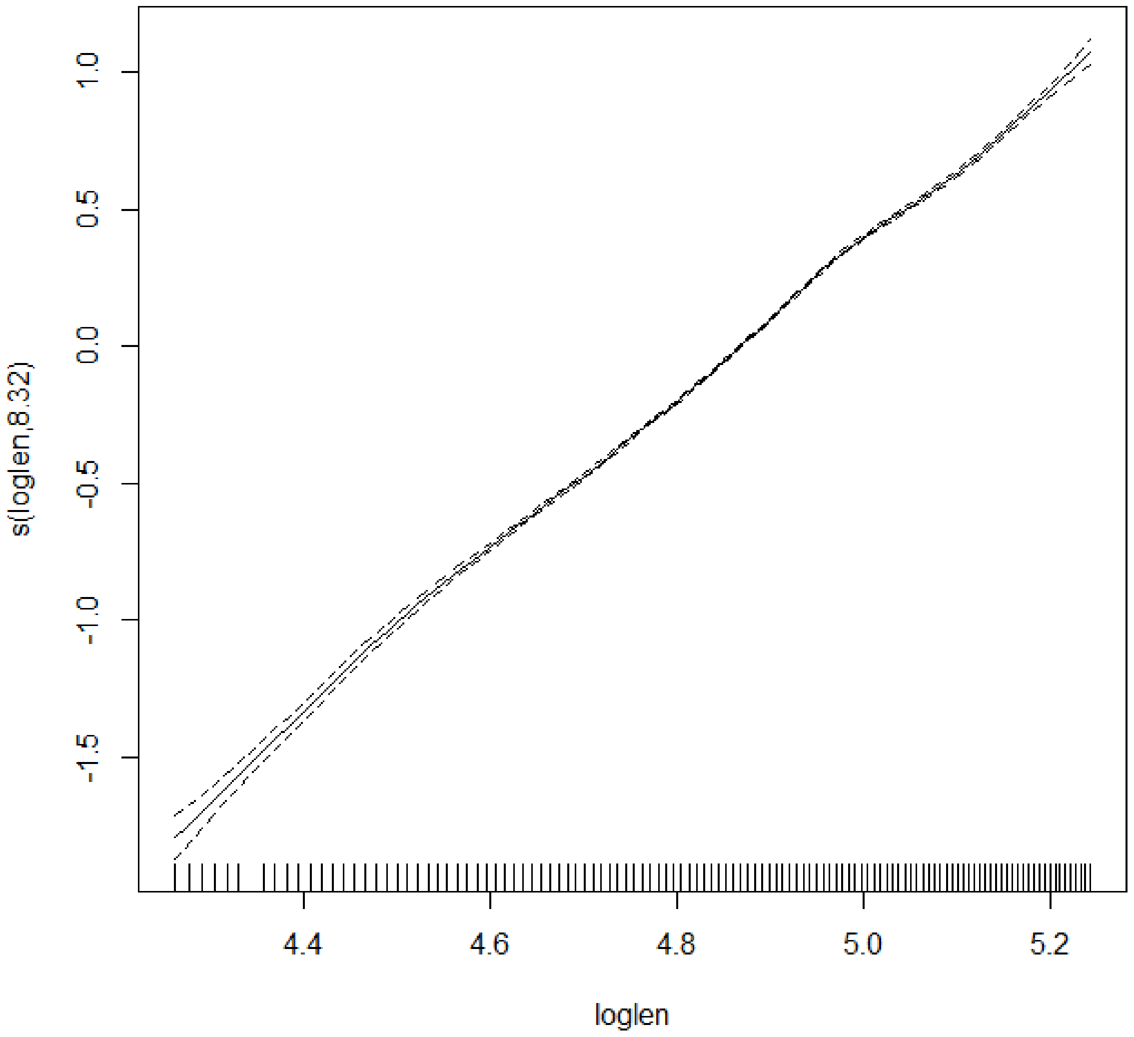


Figure 56: Relative log(weight) at log(length) for bigeye tuna in the Indian Ocean, based on data from the Korean longline fishery.

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Appendix 1: Format of JPN LL size data for 2019 IOTC collaborative analysis

Keisuke Satoh and Takayuki Matsumoto (NRIFSF)

August 15, 2019

Data format (csv format)

- "-9999" in any data fields means that the data is not available.
- Species; 4; bigeye, 5; yellowfin
- YY; Catch year
- MM; Catch month
- level; Spatial resolution (1; 10°×20°, 2; 5°×10°, 3; 5°×5°, 4; 1°×1°)
- Position (latitude and longitude); The position is transformed using following rules. If in the northern hemisphere, Y = (latitude+0.5). If in the southern hemisphere, Y = -1*(latitude+0.5). If in the east longitude area, X = (longitude+0.5). If in the west longitude area, X = 360-(longitude+0.5). Thus, the position Y (latitude) -1.5 means the vessel operates at >= 1S and < 2S. The position X (longitude) 135.5 means the vessel operates at >=135E and <136E, while the position 182.5 means the at >=177W and <178W).
- M_unit; Size unit (3; weight 1 kg, 6; length 1 cm, 7; length 2 cm, 8; length 5 cm)
- NGYO; Vessel type (1; commercial vessel, 2; training vessel)
- Sex; (1; female, 2; male, -9999: not available).
- CLS; Size
- Num; Number of fish
- ioc; ocean code -> only Indian Ocean (2) is available
- place; location for measurement. (1: On board (fisherman), 2 - 12, >=14: Port sampling, 13; On board (observer))
- ocean; basically equivalent to "ioc"

Delete abnormal data and/or outline

- If YY =. then delete, if YY <=1950 then delete, if YY >=2020 then delete, if DD >=32 then delete. Abnormal date is also deleted including 31th in April, June, September and November, and Feb. 29 when it is not a leap year.
- If longitude=. then delete, if longitude=180 then delete, if longc=. then delete, if longc=0 then delete, if longc>=3 then delete, if latitude=. then delete, if latc=. then delete, if latc=0 then delete.
- If CLS=. then delete, if CLS=0 then delete.
- If Num=. then delete, if Num=0 then delete.

Notes

- Several gear codes in the IOTC size database are missing from the SFRef reference file
- "BBOF","LIFT", "HLOF", "TROLM"

Appendix 2: Estimation of catches at size for IOTC species

Copied from the document ‘Equations.doc’ (https://www.iotc.org/documents/length-frequency-equations-used-estimate-standard-lengths-and-weight).

Equations used to convert from non-standard measurement to fork length (Table 1) and from fork length to round weight (Table 2)

Table 1: Regression equations used to convert from non-standard measurements into standard lengths (tunas: tip of the snout to fork length; swordfish: lower-jaw to fork length) per species

Species: Yellowfin tuna	***Standard length: Tip of snout to fork of tail***

Type Measurement	*Equation*	*Parameters*	*Sample size*	*Size*	*Variance*	*Covariance ab*	*Mean Residual*	*Gradient*
Weight gilled and gutted[A]	$a*W^{b}$	a= 44.28699 b= 0.3008591	2,361	Min:14 Max:71	a=0.00752476509 b=2.86244E-07	-4.626246E-05	4.095958	a=3.033852 b=495.6385
Length to the base of the 1st dorsal fin[B]	$a*L^{b}$	a=2.0759 b=1.1513	7,036	Min: 29 Max: 164				

Species: Bigeye tuna	***Standard length: Tip of snout to fork of tail***

Type Measurement	*Equation*	*Parameters*	*Sample size*	*Size*	*Variance*	*Covariance ab*	*Mean Residual*	*Gradient*
Weight gilled and gutted[A]	$a*W^{b}$	a= 42.2186 b= 0.3012349	316	Min:12 Max:107	a=0.0321755341 b=1.299934E-06	-0.0002034041	3.98137	a=3.03806 b=473.1455
Length to the base of the 1st dorsal fin[C]	$\frac{(L+a)^{2}}{(b)^{2}}$	a=21.45108 b=5.28756	2,858	Min:13 Max:48				

A: Data from Penang Sampling Programme (1992-93)

B: Data from the Indian Ocean (Marsac, F. et al in IOTC-2006-WPTT-09)

C: Data from the Atlantic Ocean, Champagnat et Pianet (1974) (ibid. B)

Table 2: Equations used to convert from standard length into round weight, per species

Species	*Gear Type/s*	*From type measurement –* *To type measurement*	*Equation*	*Parameters*	*Sample size*	*Length*
Yellowfin tuna	Purse seine Pole and Line Gillnet	Fork length – Round Weight(kg)[A]	RND=a*L^^{b}	a= 0.00001886 b= 3.0195	6,752	Min: 29 Max: 164
	Longline Line Other Gears	Fork length(cm) – Gilled and gutted weight(kg)[B] Gilled and gutted weight(kg) - Round Weight(kg)[C]	GGT=a*L^^{b} RND=GGT*1.13	a= 0.0000094007 b= 3.126843987	15,133	Min:72 Max:177
Bigeye tuna	Purse seine Pole and Line Gillnet	Fork length(cm) – Round Weight(kg)[D]	RND=a*L^^{b}	a= 0.000027000 b= 2.95100	n/a	n/a
	Longline Line Other Gears	Fork length(cm) – Gilled and gutted weight(kg)[B] Gilled and gutted weight(kg) - Round Weight(kg)[C]	GGT=a*L^^{b} RND=GGT*1.13	a= 0.0000159207 b= 3.0415414023	12,047	Min:70 Max:187

A: Data from the Indian Ocean (Marsac, F. et al in IOTC-2006-WPTT-09)

B: Multilateral catch monitoring Benoa (2002-04)

C: ICCAT Field Manual (Appendix 4: Population parameters for key ICCAT species. Product Conversion Factors)

D: Cort (1986)