**Title:** Climate and ecosystem indicators of the WCPO

State of the climate and ecosystem for the Western and Central Pacific Ocean 2025

**Authors:** Simon Nicol, Bernadette Sloyan, Nicholas Hill, Thomas Moore… etc

**Background/Introduction**

The environment and climate are continuously influencing tuna fisheries in the Pacific Ocean. Since 2015, the Scientific Committee (SC) has explored the development of ecosystem and climate indicators to help inform the management of fisheries targeting tuna and tuna-like species in the WCPFC (Anon 2015; Smith et al. 2016). A series of reports have subsequently been produced since SC11 in 2015 describing the objectives and testing criteria for these indicators, and a set of candidate indicators have been produced since 2019 at SC15 (Juan-Jorda et al. 2019; Allain et al. 2020; SPC 2021; SPC 2022; SPC 2023; SPC 2024).

This report represents a continuation of this work in presenting a set of updated ecosystem and climate indicators for adoption by the SC. These indicators will help inform SC and the WCPFC Commission on the current state of the climate and ecosystem of the WCPO and any prevailing trends that are likely to influence the sustainability and management of tunas, their fisheries and surrounding ecosystems. The intent of this report is that it will be adopted by the Commission and routinely produced to provide up-to-date information to the SC and WCPFC Commission to help inform decision-making and support its application of an ecosystem-based approach to fisheries management (EAFM).

Below is some text from previous SC papers that outlines the terms of reference and process for adopting these indicators (Smith et al. 2015; SPC 2022).

***Terms of Reference***

*A drafted terms of reference for the Ecosystem and Climate Indicators project was provided as Annex 3 to SC18-EB-WP-01 with the following specified objectives and scope of work:*

***Objectives***

* *Develop and test candidate ecosystem and climate indicators to track the impact of climate and ecosystem changes on WCPFC fisheries and ecosystems.*
* *Provide technical advice to the Scientific Committee on the suitability of criteria used for testing and evaluating the performance of candidate indicators.*
* *Support the Scientific Committee in developing tools to communicate ecosystem and climate change impacts to WCPFC and external stakeholders and interest groups.*

***Scope of Work***

* *Technical analyses to develop and test candidate indicators.*
* *WCPFC member and expert workshops to refine indicators.*
* *Scientific Committee reporting.*
* *Routine preparation of adopted indicators.*
* *Development of tools for communication to WCPFC and wider stakeholders.*

*The SSP was tasked by SC18 to develop a workplan for this project to be endorsed by SC19 and to develop an associated budget.*

***Process for adopting indicators***

*SC12 noted that developing a thorough understanding of how to interpret potential indicators, their appropriate reference levels and baselines, and how reliable they are for prediction were critical steps for indicator adoption by the WCPFC Scientific Committee (SC). Criteria for developing and testing candidate indicators has subsequently been proposed to the Scientific Committee:*

* *science and data based;*
* *characterize the states and trends of WCPFC marine ecosystems with respect to fishing activity and/or climate (including reference levels and baselines);*
* *reflect well-defined processes underlying fishing activity and fishery responses to climate;*
* *responsive to changes attributable to fishing pressure and climate (i.e. having minimal time-lags and capability to provide early warning);*
* *estimable on a routine basis with a historical data time-series available;*
* *cost-effectiveness;*
* *scalable across national, sub-regional and regional scales;*
* *linked to existing WCPFC models and decision-making processes (for inclusion in MSE scenarios, validation of predictions and testing of model assumptions);*
* *can be routinely estimated by members without reliance on the Science Service Provider.*

**Objectives**

The intent of this report is to present an up-to-date state of the climate and ecosystem report for the WCPO to help inform the management of tuna and tuna-like species by the WCPFC. The indicators intend to provide an outlook of the current state of the environment, natural variability and any underlying persistent changes across key oceanographic features and associated tuna fisheries that may affect their sustainability and management. Here, we present X indicators that summarise the climate and ecosystem of the WCPO including temperature, warm pool etc as well as several fisheries indicators that detail how the fishery is responding to the underlying climate/ecosystem.

For selection, indicators had to meet the criteria detailed above which required a combination of the indicator being reflective of the current environment, responsive to changes, cost effective, and science-based among others. Based on these criteria, the following indicators selected were:

* Area of the warm pool
* …

Below, a rationale for the inclusion of each indicator is given along with a summary of their status and trends over time.

**2024 summary**

In 2024, the warm pool was increasing/decreasing, El nino in X phase etc.

**Indicator X: Centre of gravity (COG) of the purse seine fishery**

**Rationale:** The WCPFC purse seine fishery predominately operates in the western pacific warm pool. The warm pool is a large, warm body of water at or above 28oC that sits in the equatorial western pacific. The warm pool naturally varies in size and extent with changes in the environment, and in particular with ENSO events, which influences where effort and catch consequently occurs in the purse seine fishery (Senina et al. 2008). The warm pool is also considered as an important spawning ground for tuna species, in particular skipjack tuna and so changes in its size, structure or position may also influence the productivity of tuna (Ashida 2020; Fujioka et al. 2024).

With the impacts of climate change, the warm pool is predicted to increase in size, driving a potential eastward shift in tuna biomass (Lehodey et al. 2013; Bell et al. 2021). By monitoring the centre of gravity (COG) of purse seine effort and catch, we can monitor if fisheries are responding to these predicted changes and by proxy tuna dynamics. Any shift in the location of the purse seine fishery is also relevant as it relates to income for PICTs when fishing occurs in their EEZ.

**Status:** For effort, there is a clear distinction in trends over time by set type (Figure 1). For free school sets, effort COG shows interannual variability but no clear underlying trend from 1990-2023. In contrast, there is a clear eastward shift in the COG of drifting FAD-associated sets over time. It is difficult to determine if this is a climate related shift in the warm pool and tuna dynamics, or if it is a shift in fishing behaviour driven by increased uptake of FAD-associated fishing. Equally, the lack of movement in the free school component of the fishery could suggest tuna haven’t shifted, or that the fishery has not yet adapted to change and may be driven by other factors such as distance to port.

For catch, there is an underlying eastward shift in all three tuna species, however the strength of these trends is variable (Figure 2). BET shows the most prominent eastward shift over time, followed by SKJ and YFT which show a very small eastward shift. Interannual variability is also present in the COG of catch of all three species as is present in effort. As with effort, it is difficult to disentangle shifts in tuna and changes in fishing behaviour to explain these underlying trends.

**Description:** Best estimates of total purse seine catches of BET, YFT and SKJ were used to determine the COG of catch, and best estimates of effort by set type for the COG of effort. Data used was extracted from SBEST databases using raised (aggregated) 1x1 degree purse seine fishery data where set type information was available. Catches and effort were constrained to WCPFC regions 6-8 (latitude: -20oS – 10oN, longitude: 140oE – 210oE) and from years 1990-2023 (Vidal et al. 2020). Catches and effort from domestic Indonesian, Vietnamese, and Philippines flagged vessels were also not considered given differences in vessel class and fishing strategy. Associated purse seine sets were considered as sets made on drifting FADs only, floating objects and anchored FADs were not considered in this analysis. The COG is an annual estimate of the weighted mean position of catch and effort where the number of sets is used to weight the effort COG, and catch to weight the catch COGs by species.

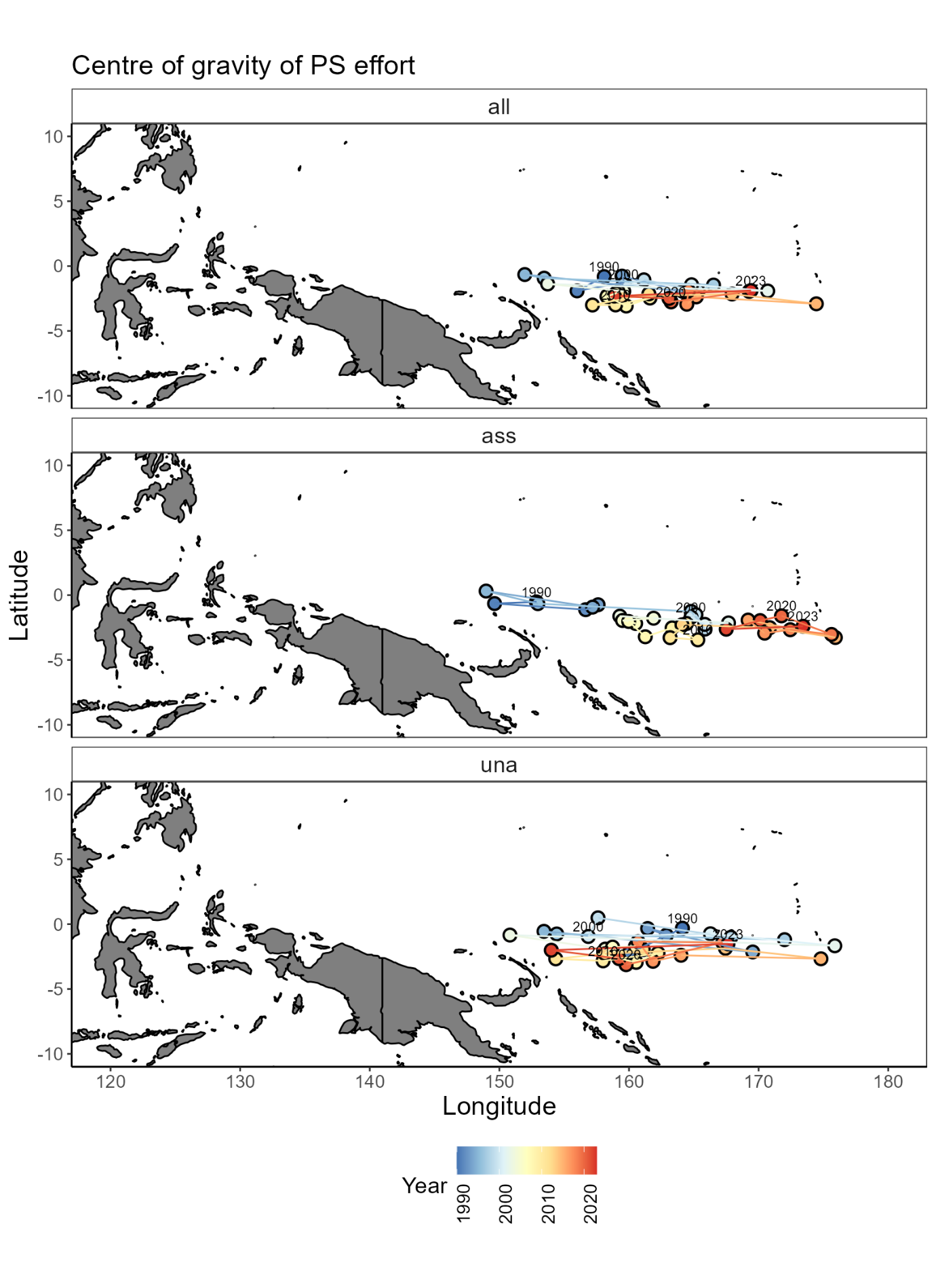


Figure 1: Centre of gravity of WCPFC purse seine effort by set type: all sets (all), drifting FAD-associated sets (ass), and free-school unassociated sets (una) from 1990-2023.

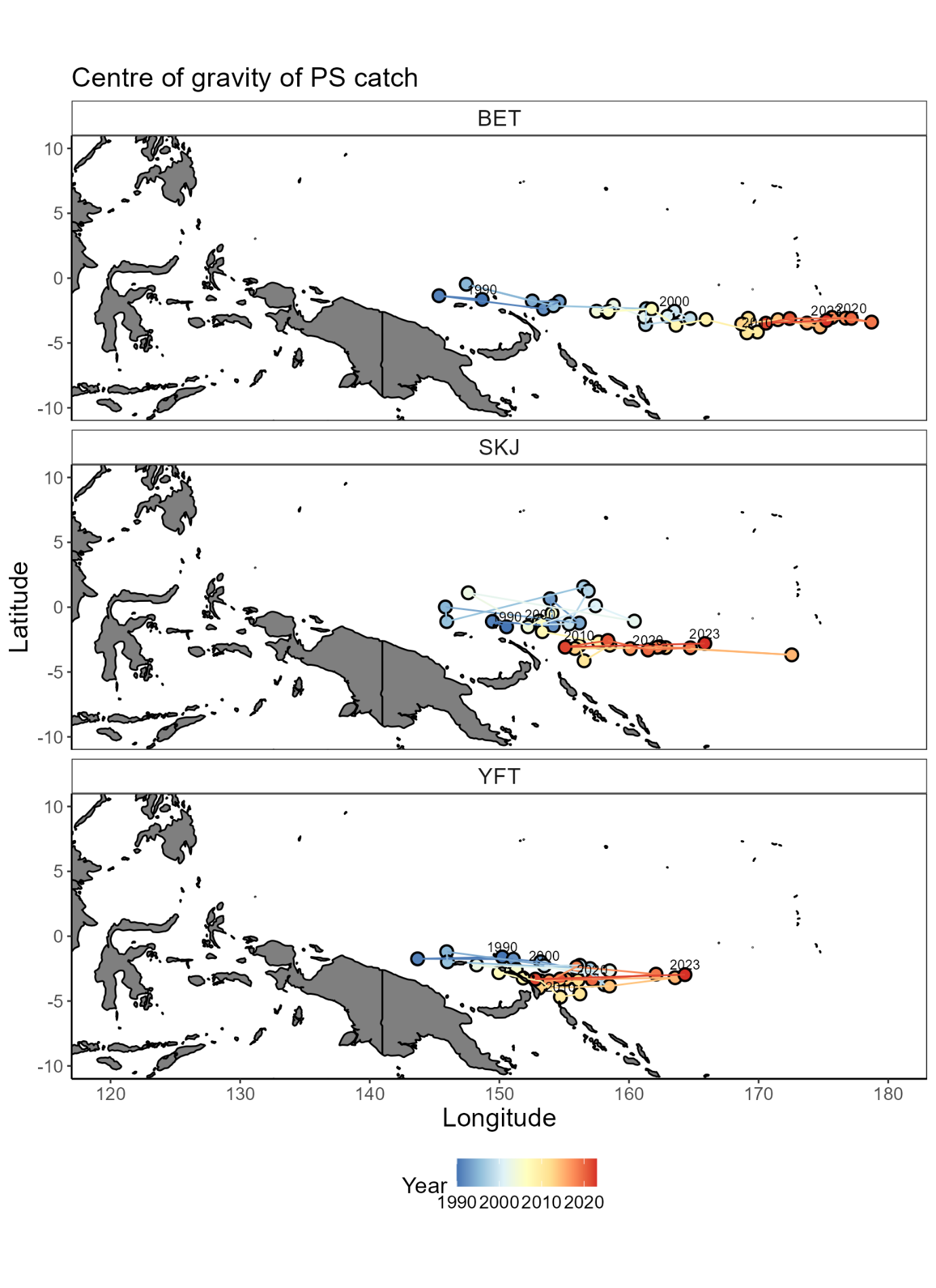


Figure 2: Centre of gravity of WCPFC purse seine catch of bigeye tuna (BET), skipjack tuna (SKJ), and yellowfin tuna (YFT) from 1990-2023. All sets?

**A graph of a graph showing the number of years

AI-generated content may be incorrect.**

**Indicator 2: Size structure of tunas**

**Rationale:** The size composition of a fish population is influenced by a range of factors including fishing and its environment. For example, changing oceanographic conditions could influence prey availability having knock-on effects to fish size composition. How the environment and climate change is influencing tuna size composition is not well known. However, by monitoring tuna size composition, any changes can be identified which can help determine sustainability of the fishery and inform management decisions.

**Status:** Trends in the size composition of tunas has varied throughout the timeseries from 1990-2023 (Figure 3). This is likely a reflection of several factors including changes in sampling design, fishing behaviour, and the underlying environment and populations.

For BET, their size composition has fluctuated over time rising to values above the 1990-2000 average of 122cm from 2007-2012 before declining to apprixmately 2018. In recent years, length composition hs improved and the mean length in 2023 of 125cm is above the historical mean. Throughout this time, most BET catches in the longline fishery are above the length at 50% maturity (Farley et al. 2017).

For SKJ, their size composition has been more variable which is likely a reflection of fishing and sampling programs. In recent years, SKJ size composition has declined with nearly 75% of the length composition below the historical mean length of 51.3cm in 2022. Unlike YFT and BET, catches have predominately been below the length at 50% maturity of 55cm which is in part due to the overwhelming majority of catch and sampling come from the purse seine fishery (Ohashi et al. 2019).

For YFT, a decline in their size composition since 2012 is apparent. From 2000-2010, they show a similar trend to BET where their size composition declined in the early 2000s before rising around 2010. However, in contrast their size composition has since declined and consistently remained below the historical mean value of 120.8cm since 2012, with a 2023 mean length of 113.9cm. Like BET, most of the size composition remains above the length at 50% maturity of 105cm (Magnusson et al. 2023).

For both BET and YFT, there is a slight upward trend in the proportion of small fish caught (<105cm), and a decrease in the proportion of large fish caught (>140cm) throughout the timeseries. However, this trend is not clear, and recent years have shown a shift in the opposing direction. This could be driven by fishing pressure and the removal of large individuals from the population, or an increase in small individuals in the population from enhanced recruitment for example. There were no clear trends in the size composition of SKJ. Proportion of big fish X%, small fish Y% etc.

**Description:** Length composition data for the three tuna species were derived from observer and port sampling programs from SPC databases for the years 1990-2023. Longline data was used for BET and YFT, and a combination of longline and purse seine data for SKJ. Where required, lengths were converted to for length measurements using well established conversion factors (Macdonald et al. 2023). Any outliers in the data were removed and length composition metrics extracted including the 20th, mean and 80th percentiles to represent small, mean and large fish in each species. By monitoring these three indicators rather than just the mean length, an improved understanding of a species size composition is gained. For example, a change in recruitment can be identified by changes in the proportion of small individuals.

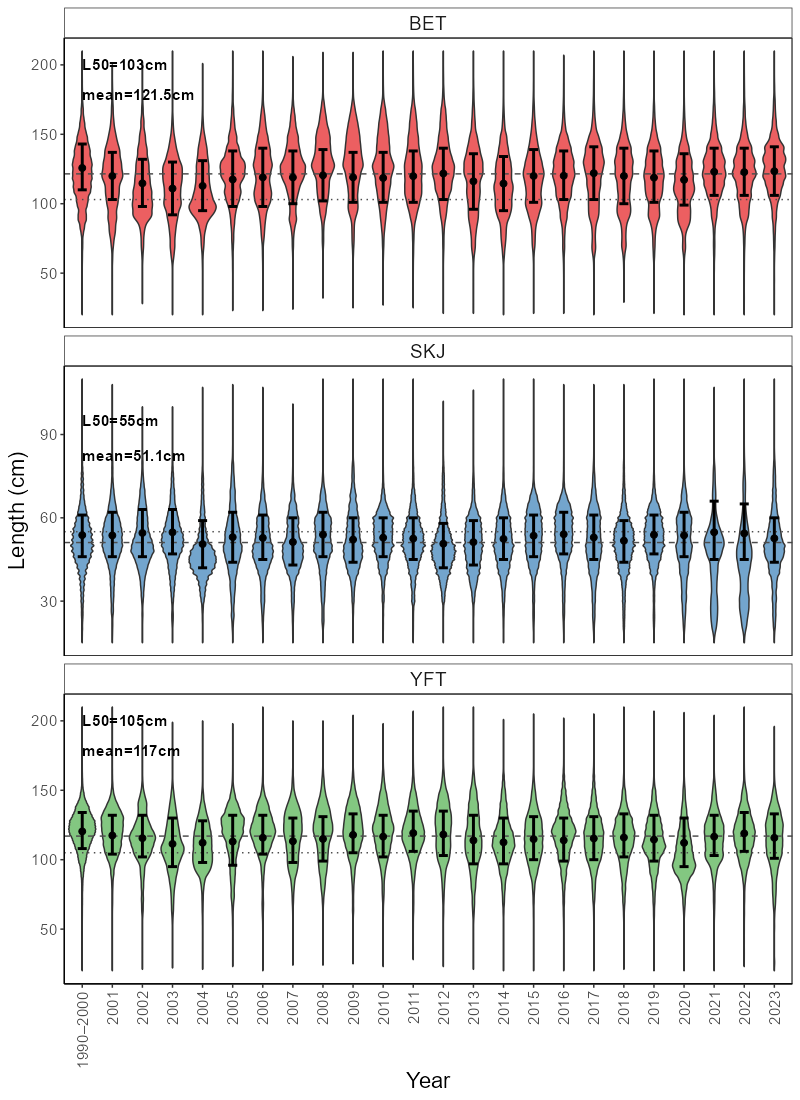


Figure 3: Length composition of bigeye tuna (BET), skipjack tuna (SKJ, and yellowfin tuna (YFT) in WCPFC longline fisheries (plus purse seine for SKJ) from 1990-2023. Dashed line = mean length from 1990-2000, dotted line = length at 50% maturity. Black dot = mean length with 25th-75th percentile error bars.

**Modelling of purse seine centre of gravity**

The centre of gravity (COG) for catch and effort has been extracted in previous ecosystem and climate indicator reports to explore shifts in the location of the purse seine fishery over time (SPC 2023). Predictions from SEAPODYM suggest that tuna biomass may shift eastwards with an expanding western pacific warm pool because of climate change (Bell et al. 2021). These COG indicators provide a simple, empirical indicator that can help to track underlying changes in catch and effort and therefore potentially tuna. However, there are myriad factors that influence where purse seine catch and effort occurs such as ENSO phase, set type and vessel flag. For example, drifting FAD sets occur on average further east than other sets. When using COG only, these factors cannot be explicitly accounted for and so it is difficult to determine what is driving shifts in the purse seine fishery over time and whether there is a long term, underlying change occurring.

The aim of this study was to model changes in the longitudinal position of purse seine effort over time while accounting for variables known to influence catch and effort dynamics. Generalised additive models were applied in the R environment using the ‘*mgcv’* package with both logbook and SBEST 1x1o aggregated purse seine data (R Core Team 2024; Wood et al. 2011). Outcomes from these models can help to explain how different variables influence the dynamics of the purse seine fishery, and to see if a clear, longitudinal shift over time is apparent.

**Method**

**Data**

Both logbook and SBEST aggregated 1x1o tuna purse seine data were extracted from 1990-2023 and constrained to an area of -15o to 10 o degrees latitude, and effort beyond 130 o longitude. The SBEST data is aggregated to the 1x1o grid cell at a monthly timestep for each combination of flag and set type. Given that the SBEST data is aggregated and therefore each row is not a uniform amount of effort, this data was disaggregated by the set column so that each row reflected an equivalent amount of effort approximately. Logbook data was extracted at the operational set level. SBEST was used as the primary data source as it should be more complete than the logbook data (Fig if needed), with the logbook data was as a secondary source to test model robustness and reliability As effort was being modelled, sets both with and without catch were included which contrasts with previous standardised CPUE approaches (Magnusson et al. 2023). Removal of data numbers…

What country a vessel originates from can be an important variable in determining fishing strategy. Flag is a routinely recorded field that is used to determine this however, it is imperfect as vessels can change their flag for various reasons and have done so through time such as countries chartering vessels to fish their domestic waters. Given the inability to reliably disentangle this issue, flag is used herein as a proxy for this as a catchability variable. Due to poor temporal coverage of many flags, only 10 flags were included in the model: Federated States of Micronesia (FM), Japan (JP), Kiribati (KI), Korea (KR), Papua New Guinea (PG), Philippines distant water fleet (PH), Solomon Islands (SI), Taiwan (TW), United States of America (US), and Vanuatu (VU).

Set type is another important variable in determining fishing strategy. The most important distinguishing feature is whether the set was unassociated (i.e a free school set), or associated with some object (i.e. log, whale, man-made fish aggregating device (FAD)). In previous analyses, set type is either filtered to unassociated sets only (Magnusson et al. 2023), or set type is included as a variable with data grouped into associated or unassociated sets (Vidal et al. 2020). Given that the objective of this analysis was to model longitudinal shifts in effort distribution over time, three groups were assigned included unassociated sets, drifting-FAD associated sets, and anchored FAD associated sets. This allowed the distribution of drifting-FAD associated sets to differ from anchored-FAD sets which behaved differently. Given low sample sizes across time, sets made on animals (e.g. whales) were omitted from the data.

The El Nino-Southern Oscillation (ENSO) is a large recurring climate pattern that drives changes in the distribution of warm waters in the Pacific Ocean. These shifts in the Pacific Ocean dynamics drive concomitant changes in the distribution of purse seine effort and catch. Most notably, an eastward shift in purse seine catch and effort with the eastward expansion of the western pacific warm pool (Lehodey et al. 2013). Monthly oceanic nino index (ONI) data were downloaded and categorised into el nino, la nina, or neutral events to be used as a variable I the model (<https://psl.noaa.gov/data/timeseries/month/>).

**Model**

Generalised additive models (GAM) were applied in the R environment using the ‘*mgcv’* package with both logbook and SBEST 1x1o aggregated purse seine data (R Core Team 2024; Wood et al. 2011). Use of GAMs allows the model to flexibly fit non-linear relationships to the data which were to be expected. Models were fit with longitude as the response variable, and a range of variables known to influence catch and effort (Table 1). Variables explored included set type, flag, ENSO phase, year, month, and latitude. As shifts in longitude over time was the objective of this analysis, the other variables were incorporated and then could be ‘standardised’ out.

Several different ways of treating both year and flag were explored to see their effect on model robustness and performance. This included year as a linear variable and flag as a factor, year and flag as factors, year and flag as an independent interaction term, and year and flag as a common interaction term. Modelling year and flag with an independent interaction term was fit using thin plate regression splines and allows the model to assume that each smooth term across year and flag are independent with no information shared between them. In contrast, fitting year and flag with a common interaction term means that a smooth is fit across years for each flag, but that there is shared information across them with a factor-smooth interaction.

Once a preferred model was identified, this model was run with several variations including: with logbook data instead of SBEST, with log CPUE per set as a weighting variable, and with free school sets only which more closely aligns with models undertaken for the skipjack tuna stock assessment (Magnusson et al. 2023). This was done to explore the robustness of the model results and how different data inputs influence them.

**Results**

Model performances are summarised in Table 2. Overall, all models provided relatively stable and consistent trends across the year effect and variable responses. model D using a year:flag common interaction term performed best with the lowest overall AIC across the four models that used the same input dataset, and the most deviance explained with 52.8%. Similar model results were achieved using the logbook data instead of SBEST, with cpue weights, and when running the model with unassociated schools only (fig X). Across the models approximately 50% of deviance was explained by the model, compared to lower scores from other model configurations (Table 2).

Model D used a common interaction term between year and flag. This interaction term allowed the model to flexibly fit to flags which can have different operating behaviours within and across years but a common underlying trend (Figure X).There were two prominent ‘modes/trends’ identified across year and flag, with one group of flags (Kiribati, Korea, Taiwan, United State of America, Vanuatu) showing a slight trend eastwards which largely consisted of the distant water fleets that are wide ranging and can flexibly move throughout the convention area. A second group of flags (Federated States of Micronesia, Japan, Papua New Guinea, Philippines, Solomon Islands) did not show this same trend eastwards, and consisted of PICT flags, Japan which generally fishes a similar area each year, and the Philippines which focuses on the high seas pockets. Greater uncertainty in the smooths was apparent in early and late years of the timeseries where less data were present for certain flags including Vanuatu and Kiribati in the early part of the time series, and Philippines in recent years.

Across the variables, several trends that were apparent in the raw data were effectively captured by the model (figure X). For example, the model successfully captured that effort shifts longitudinally during ENSO events, namely eastwards during el nino events. The model also showed that drifting-FAD associated sets occur further east than anchored-FAD and unassociated sets. Lastly, it captured a minor seasonal trend with an eastward shift in effort during the second half of the year.

**Discussion**

This analysis represents one of the first attempts to model long-term distribution shifts in effort of the WCPFC purse seine fishery to explore evidence of the impacts of climate change. Although preliminary, these results present a substantial step forward in understanding the underlying drivers of change in the spatial distribution of purse seine effort. Results show disparate trends between two different ‘modes’ of vessel flag, with some flags showing an eastward shift which are generally distant water flags that can flexibly move throughout the convention area. The second mode showed no longitudinal trend over time and are generally static in their spatial distribution of effort. These results do not show conclusive evidence of a climate-driven shift in purse seine effort or tuna as has been predicted (Bell et al. 2021), but it does suggest that if such a shift is occurring, it will impact vessels/flags differently and their ability to adapt will vary.

What drives fishing effort location in the WCPFC purse seine fishery is dynamic and has changed over time. This analysis identified that several of the major distant water flagged vessels/fleets have shown a slight, albeit variable shift eastwards in their effort distribution over time. This is likely driven by a range of factors including the environment such as ENSO events, but also the increasing use of drifting FADs, management changes such as the Vessel Day Scheme, agreements with certain nations to fish in their EEZs and so on (Simon/Sam/Steven input). For another group of flags, the distribution of effort was largely static over time. These flags were either PICT nations that do not necessarily need to fish elsewhere given favourable conditions within their own EEZs and the fishing of anchored FADs (e.g. PG, SI), or flags that are restricted in their spatial distribution for some other reason like the Philippines which largely fishes in the high seas pockets, and Japan whose fleet generally fishes a similar area most years.

With the effects of climate change, predictions suggest an eastward expansion of the western pacific warmpool and with it, an eastward shift in tuna biomass (Bell et al. 2021). Since 2015, the WCPFC has explored ways in which underlying shifts in the western and central pacific ocean (WCPO) ecosystem and climate can be monitored using a series of indicators to capture any underlying changes (Anon 2015; Smith et al. 2016). Since this time, a range of indicators that monitor catch and effort location, environmental indicators (e.g. sea surface temperature), and tuna biology (e.g. mean length of catch) have been monitored and presented to the Scientific Commission. However, the empirical nature of many of these indicators make it difficult to disentangle natural climate variability, changes in fishing behaviour, and any underlying trends. This analysis has shown that several variables not previously considered (e.g. set type, ENSO, flag) do indeed influence the longitudinal distribution of effort, but that also there is some congruence between trends in empirical catch and effort centre of gravity indicators and model-derived indicators.

This analysis has several limitations. Firstly, is the overall difficulty associated with analysing purse seine fishery catch and effort data. It has proven difficult to determine a robust measure of effort and consequently CPUE for the purse seine fishery given continuous technological (e.g. drifting FADs) and management changes. This analysis relied on sets as the measure of effort which does not incorporate pertinent factors like search time. Secondly, is the quality and resolution of the aggregated and logbook input data. The aggregated data does not report information at the operational level which is important for identifying trends at an appropriate resolution while a lack of reporting means that the logbook data is incomplete. Other studies that have attempted to analyse the WCPFC purse seine fishery to inform skipjack tuna stock assessments have generally relied on the more robust observer program data, but this information is only complete from 2010 onwards and so was too short a timeseries for this type of analysis. Another limitation is the use of the flag column as a variable to group fleet/fishing behaviour. Vessels can interchange their designated flag for various reasons depending on where they’re fishing, charter arrangements and so on. For example… the X flag represents blah blah.

Recommendations – explore SDMTMB model, other data? Other model structures, more model structures? Try to model abundance, not effort?

Consequently, attempts to use purse seine fishery data to inform skipjack tuna stock

Main results

Data/model limitations

Recommendations - sdmTMB

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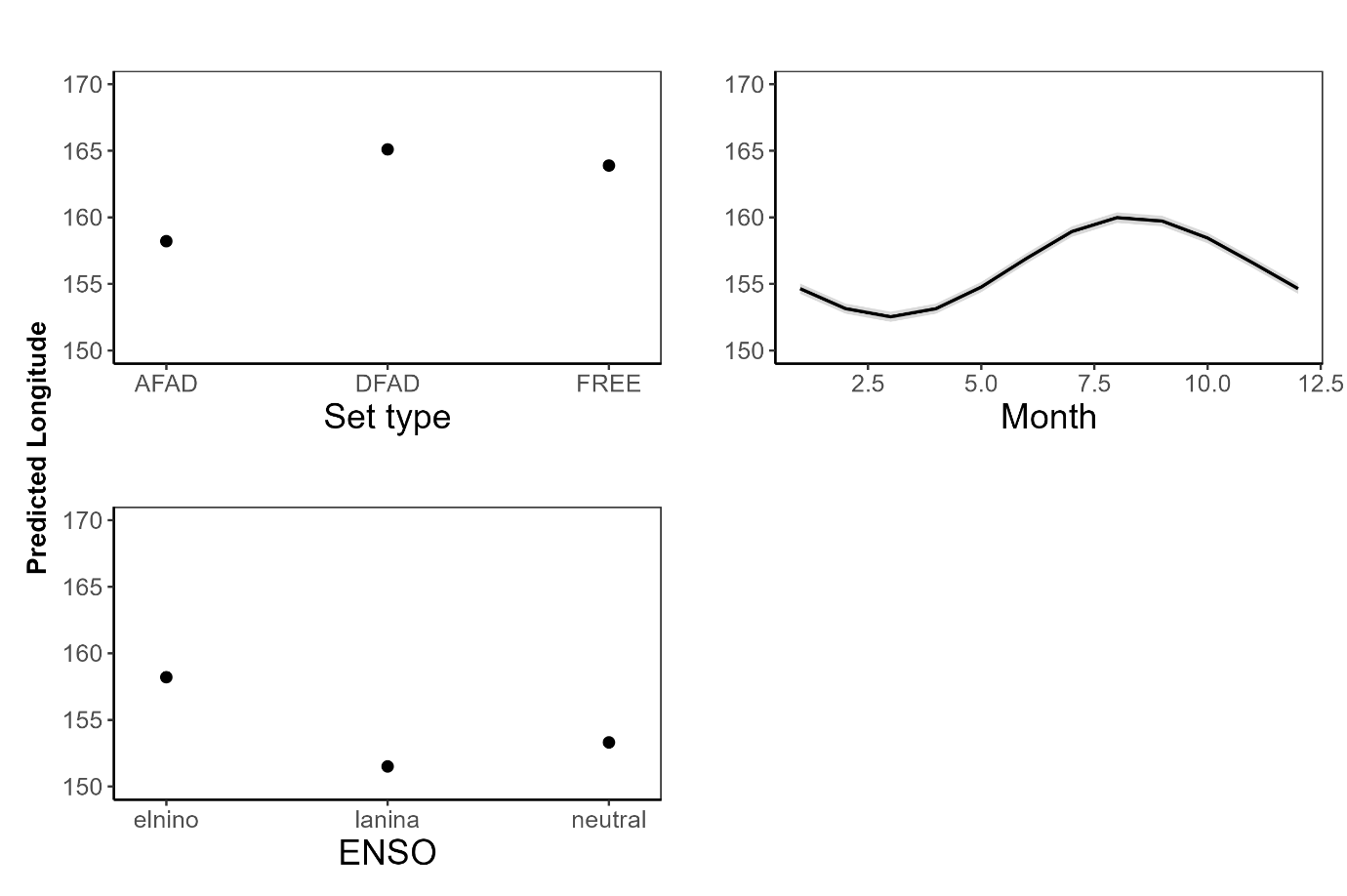


Figure 4 Variable response plots for model D including set type, month, and ENSO.

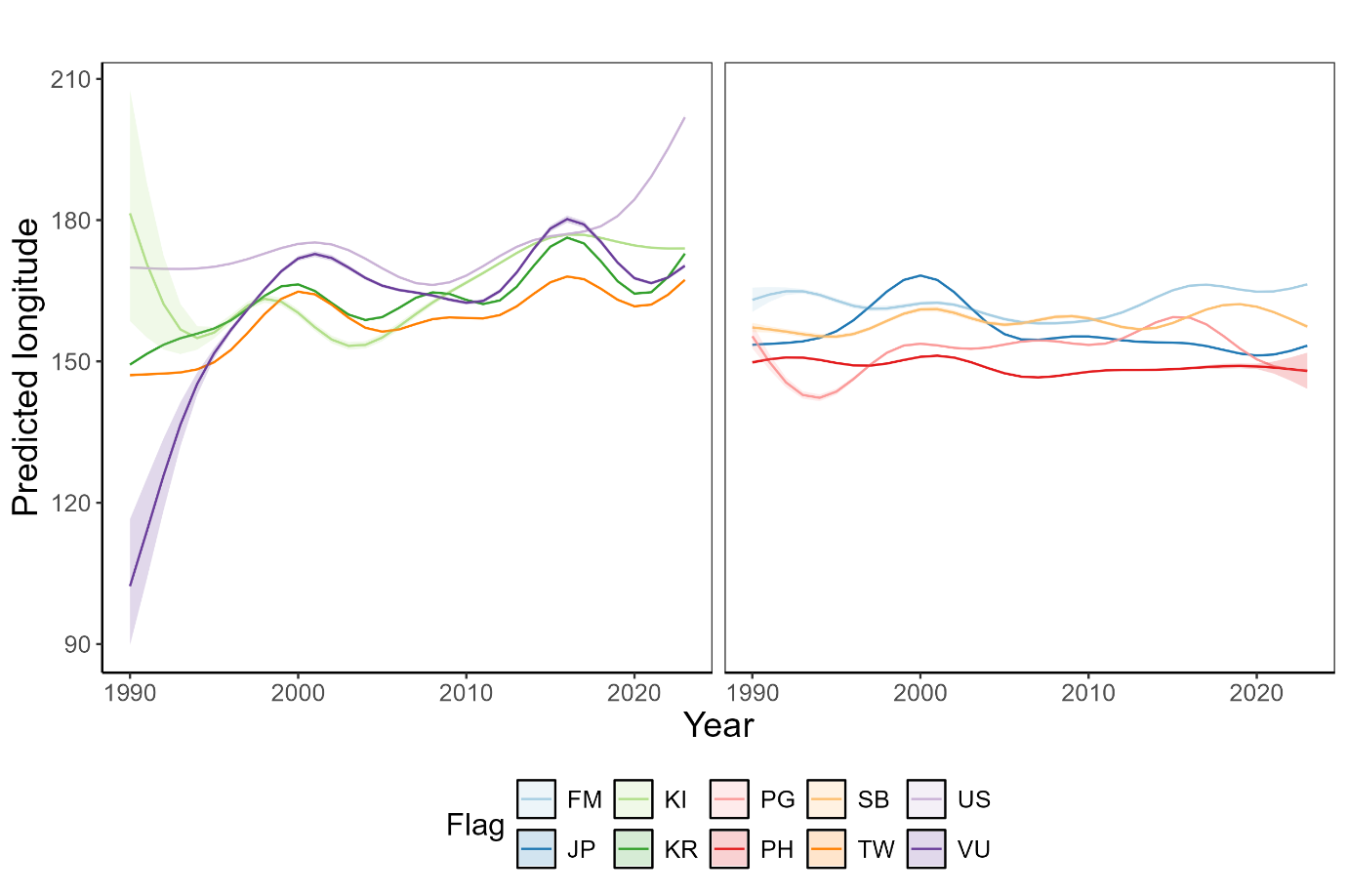


Figure 5 Year:flag common interaction smooths from model D split into flags that seem to show an eastward trend over time, and those where longitude has remained steady over time.

**Table 1: Description of generalised additive models applied to determine shifts in the longitudinal position of WCPFC tuna purse seine fishery over time. Longitude was the response variable for all models, and all models had family = Gamma(ling = ‘log”).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Model** | **Name** | **Data** | **Formula** | **Weights** | **Distribution** |
| **modA** | Linear | SBEST 1x1 | *lond ~ yy + s(mm, k = 6, bs ="cc") + flag + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |
| **modB** | Factor | SBEST 1x1 | *lond ~ yyF + s(mm, k = 6, bs ="cc") + flag + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |
| **modC** | Year:flag independent smooth | SBEST 1x1 | *lond ~ s(yy, by = flag) + s(mm, k = 6, bs ="cc") + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |
| **modD** | Year:flag common smooth | SBEST 1x1 | *lond ~ s(yy, flag, bs = ‘fs’) + s(mm, k = 6, bs ="cc") + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |
| **modE** | Year:flag common smooth wts | SBEST 1x1 | *lond ~ s(yy, flag, bs = ‘fs’) + s(mm, k = 6, bs ="cc") + set\_type + oniF + s(latd, k=5)* | Log(cpue) | Gamma(link = "log") |
| **modF** | Year:flag common smooth FS | SBEST 1x1 (free school subset) | *lond ~ s(yy, flag, bs = ‘fs’) + s(mm, k = 6, bs ="cc") + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |
| **modG** | Year:flag common smooth logbook | Logbook | *lond ~ s(yy, flag, bs = ‘fs’) + s(mm, k = 6, bs ="cc") + set\_type + oniF + s(latd, k=5)* |  | Gamma(link = "log") |

A table with numbers and a black border

AI-generated content may be incorrect.**Table 2: Evaluation statistics of generalised additive models applied to determine shifts in the longitudinal position of WCPFC tuna purse seine fishery over time.**

Domestic fleets from Vietnam, Philippines, and Indonesia were removed as is commonly done in other similar analyses (Vidal et al. 2020).

Models explored fitting to all vessels, and to distant water fleets and free school sets only which more closely follows the approach used to standardise skipjack purse seine CPUE indices for stock assessment purposes (Magnusson et al. 2023). Two different types of models were fit based on what their response variable was: longitude and CPUE. A list of models fit are described in Table 1, and their performance statistics in Table 2.

All assoc sets considered assoc, free school unassoc as per (Teears et al. 2022)

Models fit with longitude as a response variable used skipjack CPUE as a weighting variable to incorporate skipjack abundance into the model which otherwise would only reflect purse seine effort dynamics. Given that it was difficult to determine how well this approach modelled tuna abundance and not just effort dynamics, a second suite of models were fit that more closely followed a traditional standardised cpue approach, fitting data to skipjack CPUE. For these models, a year:longitude interaction term was fit, providing a smoother of longitude for each year. A weighted mean of these smoothers was then extracted to see how the longitudinal position of skipjack CPUE has shifted over time. However, with these models it was difficult to discern their reliability as the smoothers are likely to be more uncertain at their extremes. It is also notoriously difficult to extract a reliable index of abundance for purse seine fisheries due to issues determining what is a reliable measure of effort.

**Results**

Models fit with longitude as a response variable showed similar trends in longitude over time as the catch and effort COG indicators with a slight, eastward trend over time from 1990-2023 present although variable (fig). There was also good congruence between data sources for these models, with the SBEST and logbook data showing similar trends whether using full data sets or the free school, distant water fleet subsets. The model also captured several trends that are apparent in the raw data, showing that el nino events lead to an eastward shift in the fishery/skipjack tuna, and that drifting FAD sets are likely to occur further east than other set types also. The similarity of longitudinal trends between the model and the empirical catch and effort COGs is both reassuring in that outputs are not unrealistic, however it also suggests the model may not be explaining much compared to the raw data. Given their similarity with the catch and effort COGs, these models may more closely resemble a standardised shift in fishing effort rather than necessarily skipjack abundance. Across the four models that used longitude as a response variable, approximately 50% of deviance was explained. AIC and BIC scores as well as deviance explained suggests these models fit better than the cpue response variable models.

Models fit with CPUE as a response variable did not perform as well. They explained very little deviance and had poorer AIC and BIC scores than models that used longitude as the response variable. Standardising purse seine CPUE is notoriously difficult as it is hard to accurately determine an appropriate measure of effort. In an attempt to overcome this, observer data is generally used to model skipjack abundance from the purse seine fishery. However, this data does not have a long enough timeseries to meaningfully determine long term shifts and so could not be used for this analysis. It was also difficult to determine if using a year:longitude interaction term was an appropriate way to address the research question in mind. Variable responses suggested that la nina events resulted in higher CPUE along with drifting FAD sets. Interestingly, this analysis showed a slight upward trend in CPUE over time which does/does not align with other similar analyses of skipjack CPUE over time. The annual longitudinal smoothers were variable across years which is to be expected and had large uncertainties at the extremities. When averaged across all years, no trend in the longitudinal position of skipjack CPUE over time was apparent, but was estimated to be further to the east at approximately 180 degrees in contrast to the COGs and longitudinal models which estimated it to be at ~160 degrees.