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# CATCH ESTIMTES OF INDIAN OCEAN BLUE SHARK *(PRIONACE GLAUCA)*

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***ABSTRACT***

*Catch histories form an important component of stock assessments and so having a reliable and believable catch series is a key part in gauging the level of stock depletion. In data-limited situations, reported nominal catches are often not considered reliable and so reconstruction of catch histories plays an important role. The first Indian Ocean stock assessment of blue shark took place in 2015, however, due to the amount of uncertainty in the assessments, the conclusion regarding stock status remained as uncertain. The historic catch series was considered to be one of the key sources of uncertainty and the Working Party requested that participants develop approaches to reconstructing historic catches to be used as alternate series for assessment. Nominal catch of blue shark was revised in 2025 by some CPCs and this has altered the historical reported catch.*

*This paper uses the available nominal catch data held by the IOTC and two methods to reconstruct historic blue shark catches in the Indian Ocean, the first a generalized additive model (GAM) and the second a ratio-based estimator approach. Both estimates based on based on the reported data as of 2024 with data for 2023 supplied by the 2025 nominal catch,*

*The procedure used to estimate catch for both the ratio and GAM based models assumes that target catches can be used to predict the unreported catches in the case where there are zero reported catches. The accuracy of all of these methods is entirely dependent on the quality of the original data on which they are based. The underlying dataset that was used was a combination of the 2024 nominal catch and the final year from the 2025 nominal catch data. The working party is encouraged to discuss this combination of the data as well as any preferred alternatives.*

*KEYWORDS: Catch reconstruction, catch estimation, GAM, catch history, data-limited stocks, nominal catch, blue shark, stock assessment.*

# 1 Introduction

Catch histories form an important component of stock assessments and so having a reliable and believable catch series is a key part in developing a good estimate of the level of stock depletion. In data-limited situations, reported nominal catches are often not considered reliable and so reconstruction of catch histories plays an important role. This is particularly important for bycatch species where data are often sparse and of varying quality. Nominal catches of blue sharks in the Indian Ocean held by the IOTC (IOTC 2021) are considered to be highly uncertain, and are likely to be 'severe underestimates' of the actual catches taken as concluded by the Working Party on Ecosystem and Bycatch in 2015, 2017 and again in 2021.

The first Indian Ocean stock assessment of blue shark took place in 2015, however, due to the amount of uncertainty in the assessments, the conclusion regarding stock status remained as uncertain (Rice and Sharma 2015). The historic catch series was considered to be one of the key sources of uncertainty and so the Working Party requested that participants develop new approaches to reconstructing historic catches to be used as alternate series for assessment. There a number of approaches that may be used to produce catch history reconstructions. One method that has been used previously for Indian Ocean blue shark was based on information obtained from the shark fin trade (Clarke 2015), providing estimates used in the 2015 assessment (Rice and Sharma 2015) that were approximately four times higher than the IOTC nominal catches (Clarke 2015). In 2017 an attempt at recreating the estimates based on the shark fin trade was undertaken, however this was unsuccessful due to changes in the fin trade, shifts major markets, and data availability. There was not sufficient data to estimate catch in recent years from the shark fin trade. Another method has been developed which is based on expert knowledge of Indian Ocean fisheries to determine catch rates of sharks to target species and separating out the different shark species using a proportioning method (Murua et al 2013). Yet another approach that has been applied for southern bluefin tuna in the southern Ocean involved the use of random forests to predict CPUE of non-members based on the reported CPUE of members (Chambers and Hoyle, 2015).

This paper uses the current and historical (i.e. 2024) nominal catch data held in the IOTC database and explores the use of a ratio based method and a GAM statistical approach to reconstructing historic blue shark catches in the Indian Ocean.

# 2 Methods

**Data sources used: IOTC nominal catches**

Estimates of nominal catches of blue shark in the Indian Ocean are published annually by the IOTC (IOTC 2024, 2025). These are based on catches reported directly to IOTC both contracting and non-contracting parties fishing for tunas in the Indian Ocean and include best estimates in some cases where data are particularly poor or lacking altogether. This data is available by flag state, species (including IOTC species and bycatch), fishing gear and area (east or west Indian Ocean) in live weight equivalent. The data set extends back to the 1950s when industrial longlining began in the Indian Ocean. The data are generally considered representative (though the level of accuracy varies by year) of the nominal catch of the main IOTC target species, however, the reporting of sharks over the time period has been somewhat more inconsistent.

Recently the estimates of reported blue shark catch have changed (Figure 1). Prior to the 2025 revision of catches by Indonesia the majority of nominal blue shark catches are taken by the Indonesian fleet (Figure 1). The Indonesian gillnet fleet is responsible for most of the historic catches of blue shark, followed by a transition to coastal longlines in the mid-1980s. In recent years catches taken by the industrial longline fisheries have expanded, predominantly by the swordfish targeting longliners of EU-Spain and EU-Portugal, the deep-freezing longliners of Japan and Taiwan, China and the fresh longliners of Taiwan, China.

A key issue with this dataset is the presence of the large *"Sharks various nei"* (SKH) category in the database which is assumed to include unidentified blue sharks. However, the extent to which these aggregates are composed of blue sharks relative to other shark species is unknown. Another major issue is the apparent many incidences of 'missing' catch. For example two fleets fishing in the same vicinity catching the same target species using the same gear type but only one reports any catch of (blue) sharks. This is likely a reporting issue. A third key issue is inaccurate reporting, e.g., a fleet catches substantial quantities of blue shark and only reports a small fraction of this. The method descried below aim to address these core problems with the dataset through predicting unreported catch based on historic reporting of blue shark catches. The data revision that resulted in the 2025 nominal catch data resulted in an order of magnitude difference, no historical catch from some fleets prior to 2010, and has large increases in the final year (2023) of the dataset (Figure 2). A combined nominal catch database using the NC_2024 series and the final year of the NC_2025 was used to estimate unreported blue shark catches (Figure 3).

**GAM approach to estimate unreported blue shark catches**

A statistical modelling approach based on generalized additive models (GAMs) was used to predict unreported catches. The estimate blue shark catches are based on the nominal catches in the IOTC database. The model was set up incorporating a number of explanatory variables thought to be influential in determining whether a fleet catches blue sharks, though in practice the number of variables related to the catch records is limited. The model was parameterised based on the records where reported blue shark and the selected covariates were available and the model was run on the remaining dataset where zero blue shark catches were reported, and where sufficient levels of the covariates were available for prediction.
Records with levels outside the model, and so for which prediction was not possible, were dropped.

The log transformed nominal blue shark catches were used as the response variable Outliers were not well predicted by the model so the dataset on which to predict the unreported blue shark catches was also filtered to remove extreme values (records where target catches >80,000 t) which had a disproportionately large effect on the results. This resulted in the removal of 1.42% of the data set.

The explanatory variables year, target species catch, gear, area (E/W) and fishing ground (coastal, pelagic or all). Different classifications of non-blue shark species were also explored including separate covariates for temperate tuna species, tropical tunas, other shark species and all other species, added using splines. To avoid over-parameterisation, models were run sequentially starting from the simplest model and incorporating covariates and interactions, where they made sense theoretically (e.g. area-gear interactions) in an iterative manner. Models were evaluated based on AIC values and the amount of deviance explained.

**Ratio method to estimate unreported blue shark catches**

A second method based on the ratio of blue shark to target species was used in an attempt to estimate the unreported component of blue shark catches. Target species were defined as yellowfin tuna, bigeye tuna, skipjack tuna, albacore and swordfish. Nominal catches of these species are considered to be relatively accurate.

Starting from the nominal, records were separated out into four components where fleets were reporting:

1) Positive catches of target species and positive catches of blue shark where the target species catch is greater than the blue shark catch (used to calculate catch rate)
2) Positive catches of target species but zero blue shark catches (assumed to be non-reporting so were not included in the catch rate calculation)
3) Positive catches of blue shark but zero target species catches or positive catches of target species and positive catches of blue shark where the blue shark catch is greater than the target species catch (it is assumed here that blue sharks are actually the target species in this case and so the reporting is likely to be accurate, hence these records were excluded from the catch rate calculation)
4) Zero catches of both target species and blue sharks reported (these records were not used)

Blue shark catch rates were calculated, defined as the ratio of blue shark to the total target species catch where positive catches of target species and blue shark were caught and where the target species catches were greater than the blue shark catches. These catch rates were calculated by fleet, year and gear type (the finest scale gear classifications stored in the IOTC database). Catch rates were averaged across all fleets reporting blue shark catches for each gear-year combination (Figure *4*). Fleets reporting zero catches of blue sharks for a year-gear combination where other fleets were reporting positive blue shark catches were assumed to be false zeros and so were not used in calculating the average, while records where catches of blue shark were greater than the target species catches were also not used as in these cases, the blue shark was assumed to be the target species and should be more accurately reported. Unclassified gear types were removed to avoid meaningless predictions from unrelated gear types.

These ratios were then used to estimate the unreported blue shark catch component (defined as fleets reporting zero catches of blue sharks for a year-gear combination where other fleets were reporting positive blue shark catches). Fleets reporting zero blue shark catches were allocated catches by multiplying the average catch rate by the target catch for the fleet.

# 3 Results

### Estimation of unreported blue shark catches based on GAMs

A range of explanatory variables were explored through the GAM models: Year, Gear, Area, Fishing Ground, Target Catch (YFT+BET+SKJ+ALB+SWO), Tropical tunas (YFT+BET+SKJ), Temperate species (ALB and SWO), Other (not target or shark), Other sharks and BSH catch. Target catch is the sum of Tropical tuna and temperate catch. Given that the aim of the method was to predict the catches of countries that had not reported BSH catches, country was not used as an explanatory variable. The model was set up using only those records where blue shark was reported and the resultant coefficients were estimated. These were then used to estimate the unreported catch component by predicting the missing values based on the records where blue shark was not reported.

Stepwise model development resulted in the range of models shown in Figure 5. Multiple other models were also fit, however the resulting estimates of catch were often highly variable (with inter-annual fluctuations in the order of 10-20 thousand t), or estimated extremely high catch in the early part of the model when the exploitation was thought to be lightest. The following model was selected as the best based on in part on AIC ranking:

*gam( log(BSH_catch) ~ as.factor(Year) + s(TAR_catch) + Gear :Area)*

The estimated catches based on this formula are similar to the previous estimates in annual scale and trend, though some differences exist (Figure 6). The residual diagnostics are shown in Figure 7, total catch (reported + estimated) is shown by fleet in Figure 8.

**Estimation of unreported blue shark catches based on target species ratios**

The estimated unreported catch component is shown in Figure 9**Error! Reference source not found.** by aggregate gear group. The estimated unreported catches peak in the late 1970s, and then again in the early 2000s. Unreported catch estimates are only available for those gear types that have been reporting catches of blue shark over time (gillnets, longlines and hand lines). The estimates are dominated by the gillnet catches in early years, followed by longline and  the handline associated fishery in the mid 1980s. The final estimates from the ratio method are presented in Figure 10.

# 4 Discussion

The results of the GAM modelling provide final estimates that are very similar to the ratio based estimates, however there are greater estimated catches in the early years resulting in a slightly flatter overall trend (Figure 10). Estimated catches in the early years are primarily attributed to the Japanese longline with a small amount estimated for the Taiwanese longline and the gillnet fleets.

The methods described in this paper attempt to account for two key sources of error in reported catches: (i) not reporting to species, and (ii) not reporting at all. The procedure used to estimate catch for both the ratio and GAM based models assumes that target catches can be used to predict the unreported catches in the case where there are zero reported catches.  The accuracy of all of these methods is entirely dependent on the quality of the original data on which they are based.

The ratio and GAM based methods both provide different approaches to the estimation of the 'missing' blue shark catches. Both methods used the nominal catches as a base and estimated the unreported catch. The underlying dataset that was used was a combination of the 2024 nominal catch and the final year from the 2025 nominal catch data. The working party is encouraged to discuss this combination of the data as well as any preferred alternatives.

A key assumption of both of these methods is that all zero reported catches, where there are reported catches of target species present, are false. This might present an overestimation bias in the results by estimating catches where there were actually zero catches. Nevertheless, the data used were based on aggregated annual values and so, given this time period of aggregation, the assumption that reported zero catches are false seems reasonable. These methods also make the assumption that target catches are reported accurately. If target catches are in fact also under-reported, then this may result in an underestimation bias in the results. Nevertheless, as only the five species for which data are deemed to be of reliable quality are used, this should also be a reasonable assumption.

A further assumption these methods make is that those fleets that are reporting positive blue shark catches are doing so accurately. Due to issues with the reporting of processed weight rather than round weights and retained catches rather than total catches, this may also lead to an underestimation bias in the results. Estimated catches will be greatest for gear types for which there are a large number of zero reporters (with substantial target catches) and a high average catch rate by the reporting fleets. If there are few zero reporters but many under-reporters, this will result in under-inflated catch rates and underestimates for the final catches. A filtering approach was used here to remove fleets which were deemed to be targeting sharks to avoid over-inflated catch rates, however, establishing lower thresholds was more problematic with the data available.

The GAM method uses a statistical approach to fill in the gaps where data are lacking and so provides advantages over the ratio method where simple average catch rates are used. The GAM method also uses a greater number of predictor variables to account for items such as spatial differences in catch rates where the sparse and patchy nature of the data means that this is not appropriate for the ratio method.

Any type of catch reconstruction that is attempted will include some level of error, so in practice it is common to include multiple alternative catch time series in assessments for data limited stocks such as these and to explore the outcomes based on the different sensitivity runs. This paper outlines the methods and results for two new alternative catch series that may be used in the assessment model; a series based on ratio approach to estimation and a GAM estimation method. If a preferred catch series is to be used as an alternative series for the assessment, then it is recommended that the GAM estimated catch is used.

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# 6 Tables

Table 1.

Table 1 . IOTC nominal catches and total catch estimates.

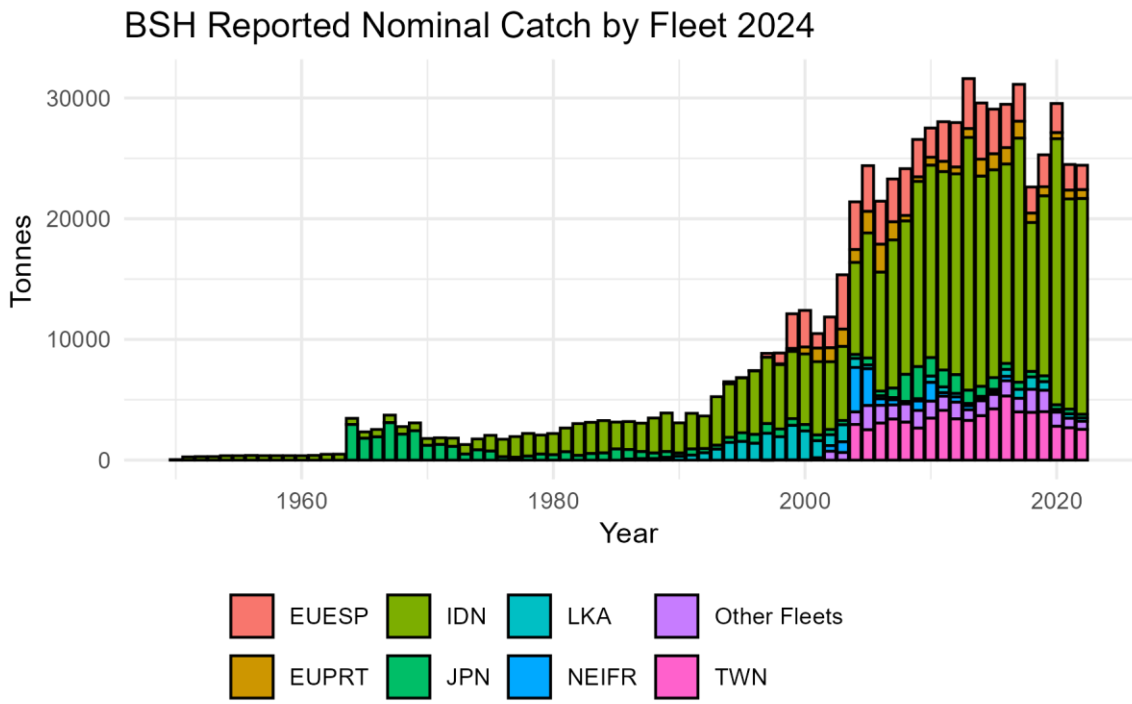
| Year | BSH_Reported | BSH_RatioEst | BSH_GAM |
|---|---|---|---|
| 1950 | 47 | 468 | 368 |
| 1951 | 269 | 724 | 1263 |
| 1952 | 293 | 735 | 2824 |
| 1953 | 297 | 805 | 3834 |
| 1954 | 367 | 884 | 6673 |
| 1955 | 367 | 893 | 7555 |
| 1956 | 389 | 901 | 4644 |
| 1957 | 372 | 1331 | 8815 |
| 1958 | 371 | 979 | 11251 |
| 1959 | 372 | 993 | 10472 |
| 1960 | 367 | 1093 | 7433 |
| 1961 | 394 | 1125 | 9528 |
| 1962 | 488 | 1515 | 6927 |
| 1963 | 497 | 1926 | 11155 |
| 1964 | 3462 | 5607 | 11483 |
| 1965 | 2342 | 4410 | 7590 |
| 1966 | 2542 | 5603 | 8782 |
| 1967 | 3729 | 7311 | 16246 |
| 1968 | 2777 | 7368 | 10411 |
| 1969 | 3084 | 10101 | 16249 |
| 1970 | 1792 | 6126 | 8023 |
| 1971 | 1850 | 5775 | 8230 |
| 1972 | 1824 | 7324 | 9226 |
| 1973 | 1291 | 6122 | 5702 |
| 1974 | 1753 | 8563 | 7040 |
| 1975 | 2054 | 8673 | 6815 |
| 1976 | 1730 | 8766 | 8044 |
| 1977 | 1953 | 10516 | 8619 |
| 1978 | 2211 | 13048 | 8437 |
| 1979 | 2080 | 15891 | 12306 |
| 1980 | 2205 | 12606 | 10621 |
| 1981 | 2662 | 16158 | 13711 |
| 1982 | 3028 | 15955 | 10579 |
| 1983 | 3133 | 11708 | 11789 |

| | | | |
|---|---|---|---|
| 1984 | 3274 | 11598 | 12890 |
| 1985 | 3152 | 7610 | 9012 |
| 1986 | 3194 | 9174 | 12169 |
| 1987 | 3065 | 7621 | 11078 |
| 1988 | 3489 | 9200 | 12442 |
| 1989 | 3903 | 12009 | 15996 |
| 1990 | 3086 | 8643 | 10768 |
| 1991 | 3878 | 12320 | 12833 |
| 1992 | 3657 | 11905 | 13856 |
| 1993 | 5256 | 14436 | 15215 |
| 1994 | 6499 | 12818 | 18333 |
| 1995 | 6841 | 17547 | 20569 |
| 1996 | 7421 | 18339 | 21032 |
| 1997 | 8847 | 18927 | 22289 |
| 1998 | 8876 | 19037 | 17462 |
| 1999 | 12123 | 24691 | 22775 |
| 2000 | 12404 | 30092 | 26137 |
| 2001 | 10484 | 27671 | 26330 |
| 2002 | 11854 | 23030 | 35243 |
| 2003 | 15354 | 30143 | 42191 |
| 2004 | 21396 | 34896 | 46990 |
| 2005 | 24393 | 37687 | 46714 |
| 2006 | 21447 | 34107 | 50064 |
| 2007 | 23290 | 34612 | 45922 |
| 2008 | 24144 | 42978 | 44183 |
| 2009 | 26561 | 37777 | 47572 |
| 2010 | 27512 | 41513 | 47050 |
| 2011 | 28033 | 36391 | 44541 |
| 2012 | 27963 | 39809 | 46176 |
| 2013 | 31606 | 43746 | 53295 |
| 2014 | 29587 | 34429 | 48847 |
| 2015 | 29075 | 31705 | 43579 |
| 2016 | 29478 | 41009 | 49159 |
| 2017 | 31130 | 39633 | 49709 |
| 2018 | 22626 | 31470 | 28595 |
| 2019 | 25293 | 32808 | 37031 |
| 2020 | 29500 | 35482 | 38467 |
| 2021 | 24484 | 32528 | 40186 |
| 2022 | 24383 | 33379 | 34461 |
| 2023 | 26356 | 33543 | 40564 |

Table 2. AIC and model information for the various GAM models used. The bolded model (Model 5) is the model rec0mended for the stock assessment.

| Model Number | Model | Resid. Df | Resid. Dev | Df | Deviance | AIC |
|---|---|---|---|---|---|---|
| 1 | log(BSH ) ~ Year | 881.0 | 5692.9 | NA | NA | 4565.1 |
| 2 | +Target Catch | 872.1 | 4007.2 | 8.9 | 1685.6 | 4246.7 |
| 3 | +Gear | 857.0 | 2452.2 | 15.0 | 1555.0 | 3807.9 |
| 4 | +Area | 856.0 | 2451.3 | 1.0 | 0.9 | 3809.6 |
| **5** | **+Gear:Area** | **846.1** | **2284.2** | **10.0** | **167.1** | **3762.1** |
| 6 | +Gear * Area | 846.1 | 2284.2 | 0.0 | 0.0 | 3762.1 |
| 7 | +Fgrounds" | 843.0 | 2089.0 | 3.0 | 195.2 | 3683.0 |

# **7** Figures



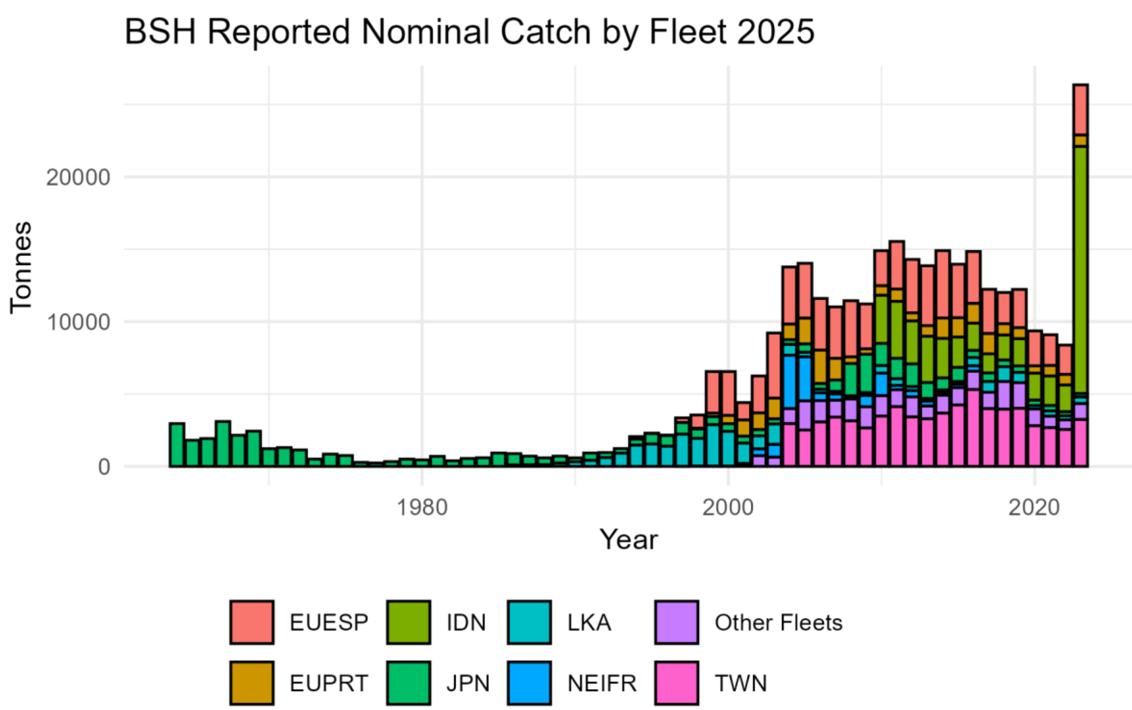




Figure 1. Reported nominal catches of blue sharks in the IOTC area of competence by main fleets, based on reported data in 2024 and 2025 (bottom panel))

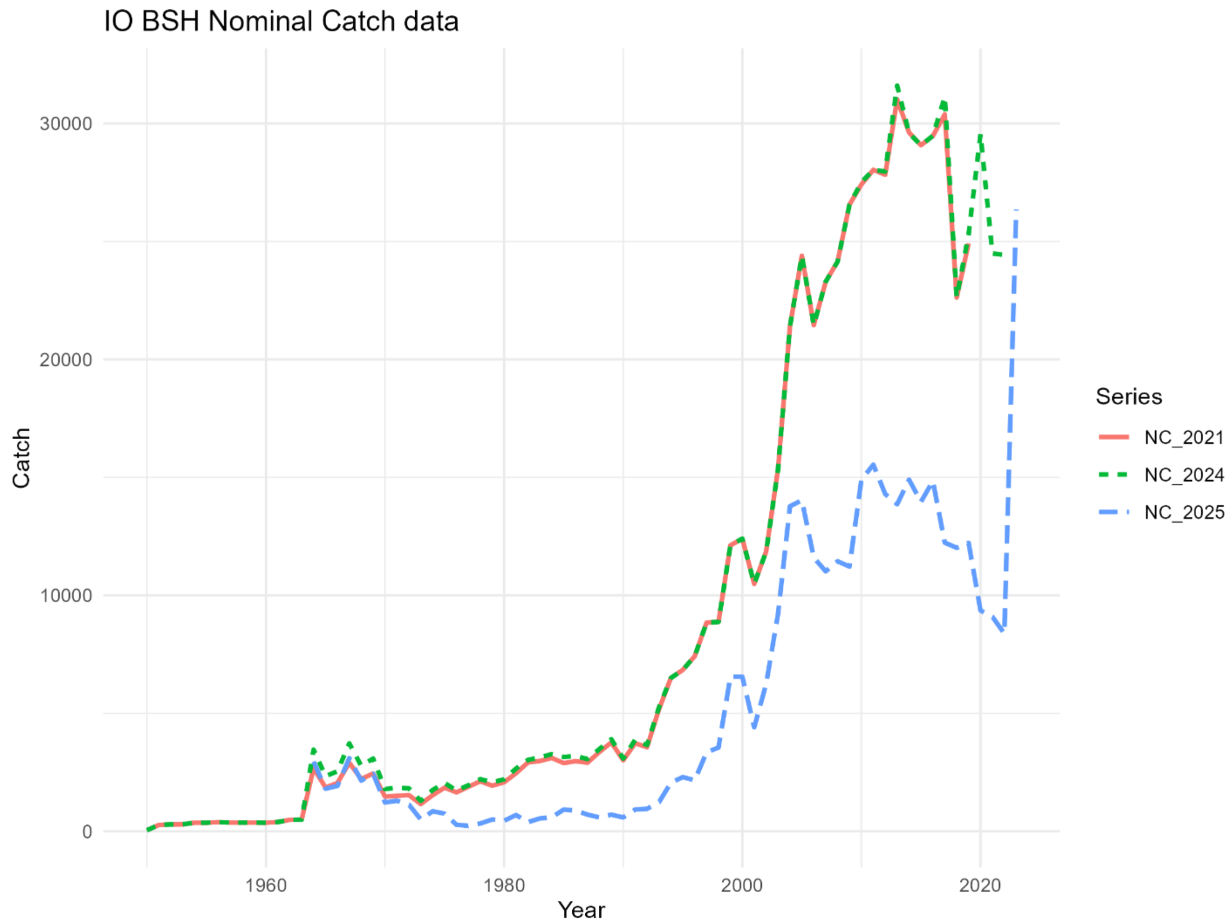



Figure 2. Reported nominal catches (t) of blue shark in the Indian Ocean by publication year, the NC_2021 series was used to estimate the catch during the 2021 assessment.

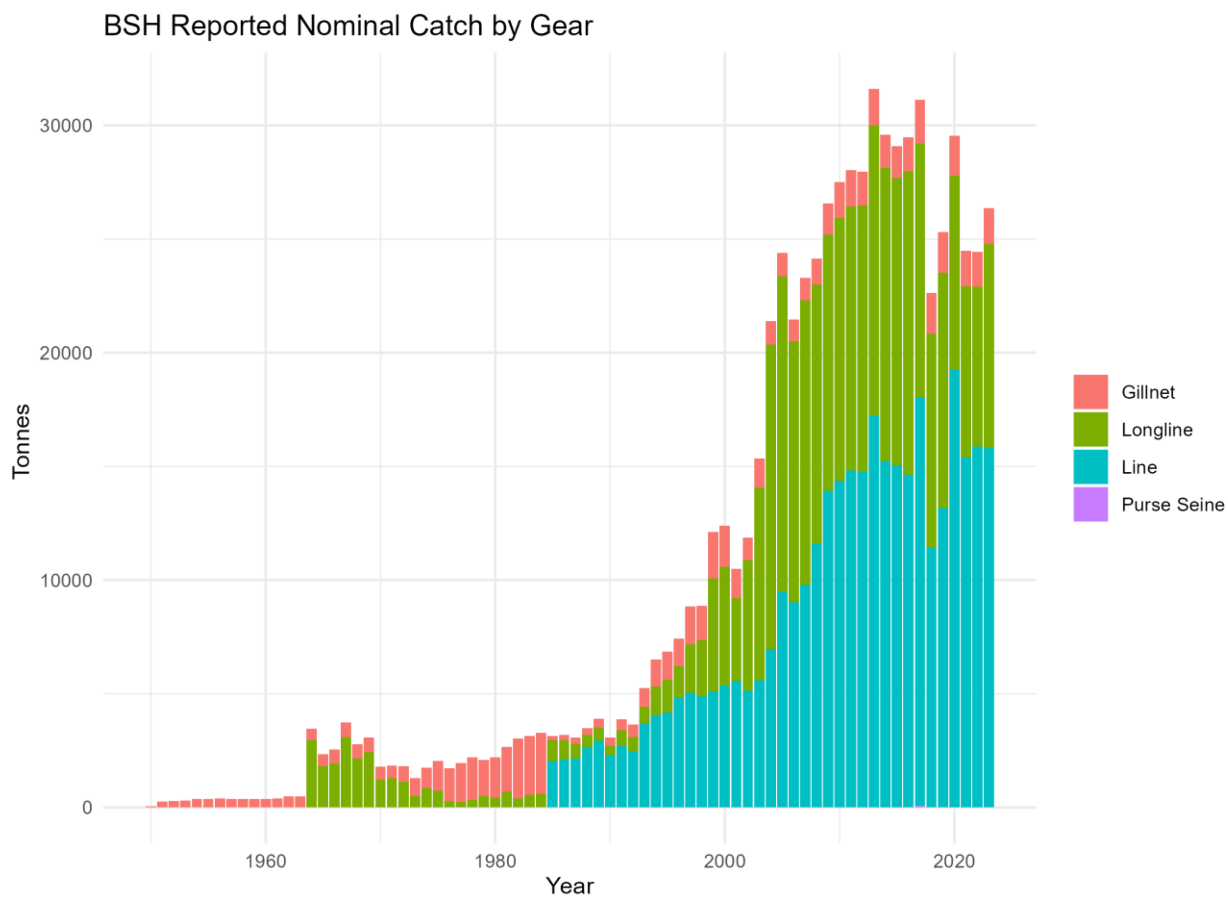



Figure 3. Reported catches of blue sharks Indian Ocean  by main gear type, from the combined nominal catch data set.

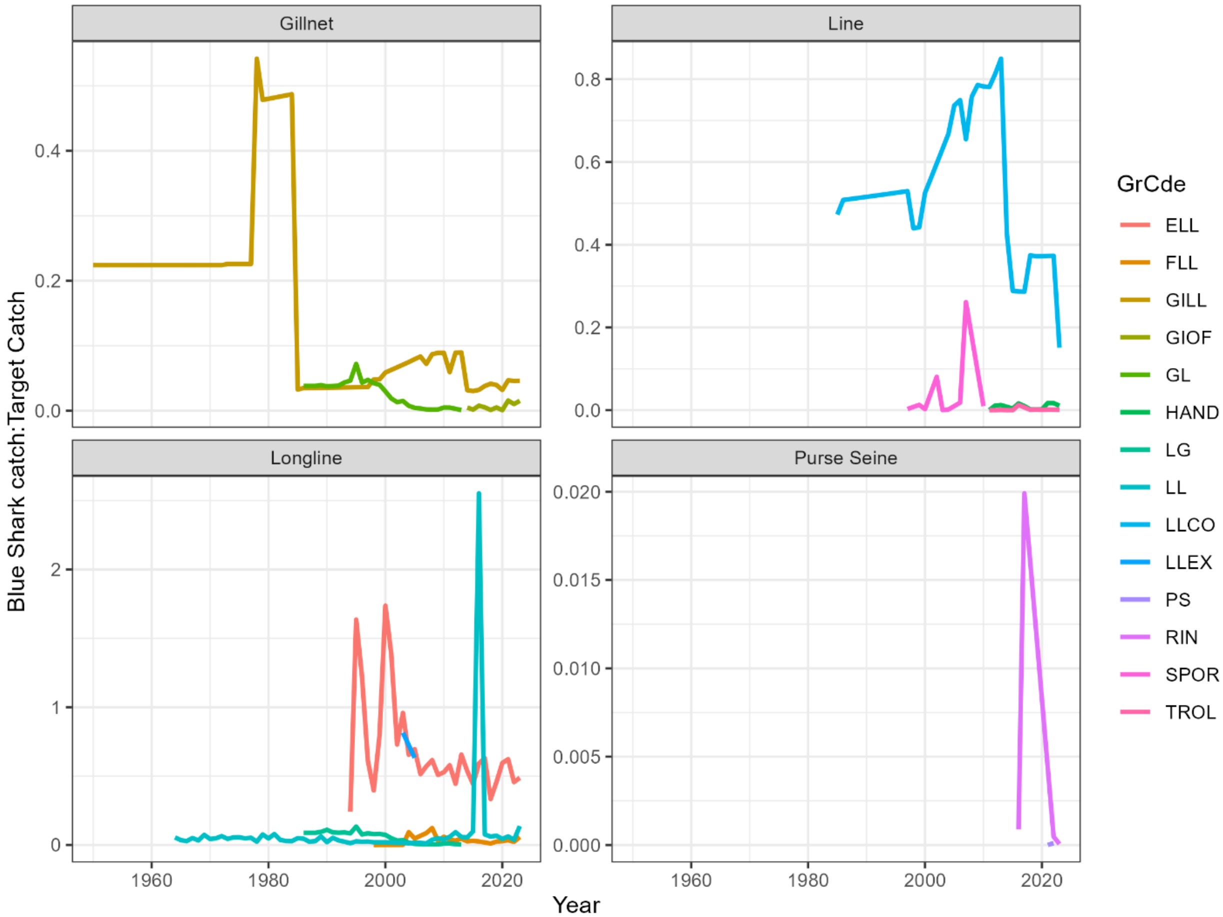



Figure 4. Ratio of reported blue shark catch to target catch by gear over time for gillnet, handline (line), Purse seine and longline fisheries.

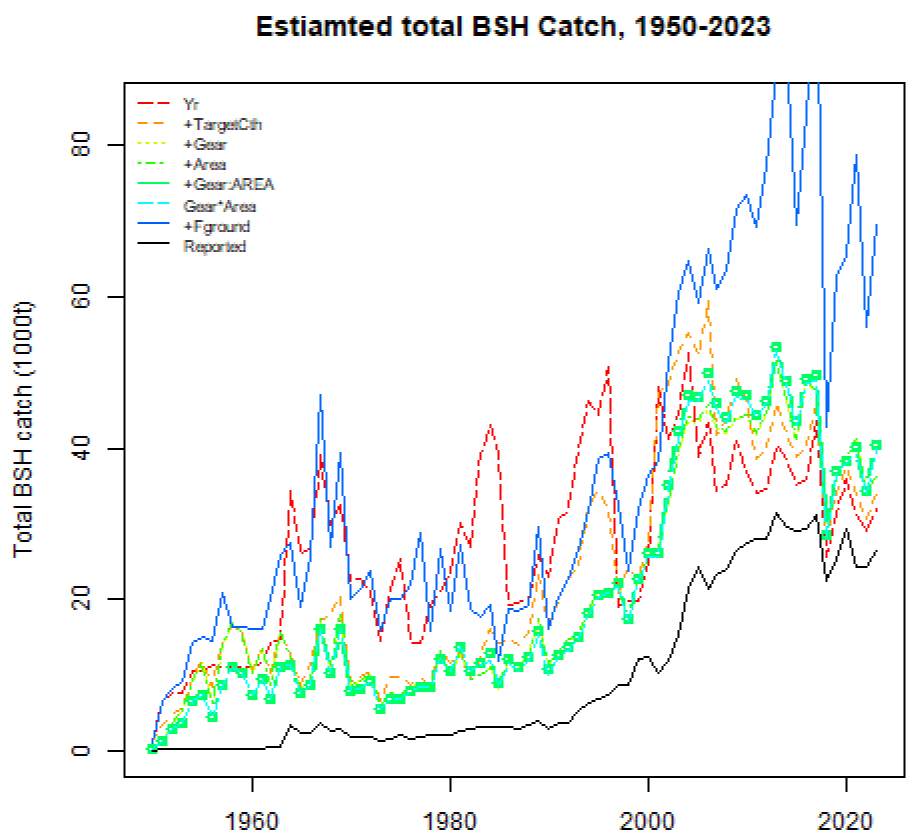



Figure 5 Stepwise results of predicted catch via GAM on the nominal catch data set (selected model = green line, the +Gear:Area).

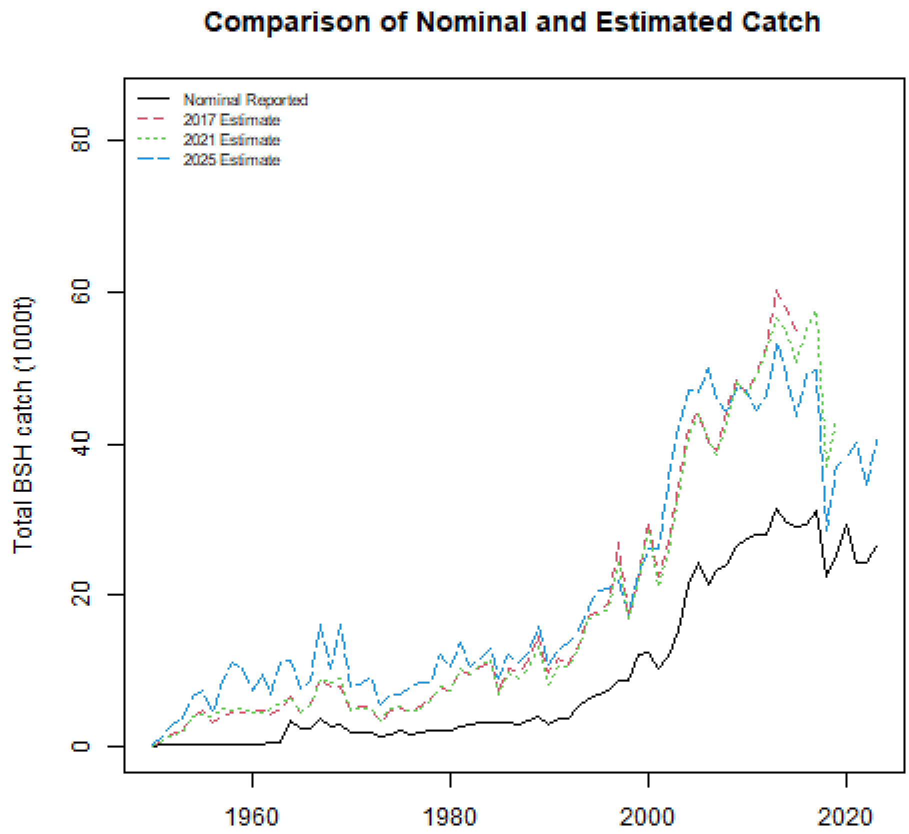



Figure 6 Comparison of Nominal (black line) 2017 estimated catch (red line) 2021 estimated catch (green line) and the 2025 estimates of the catch based on the combined nominal catch data set.

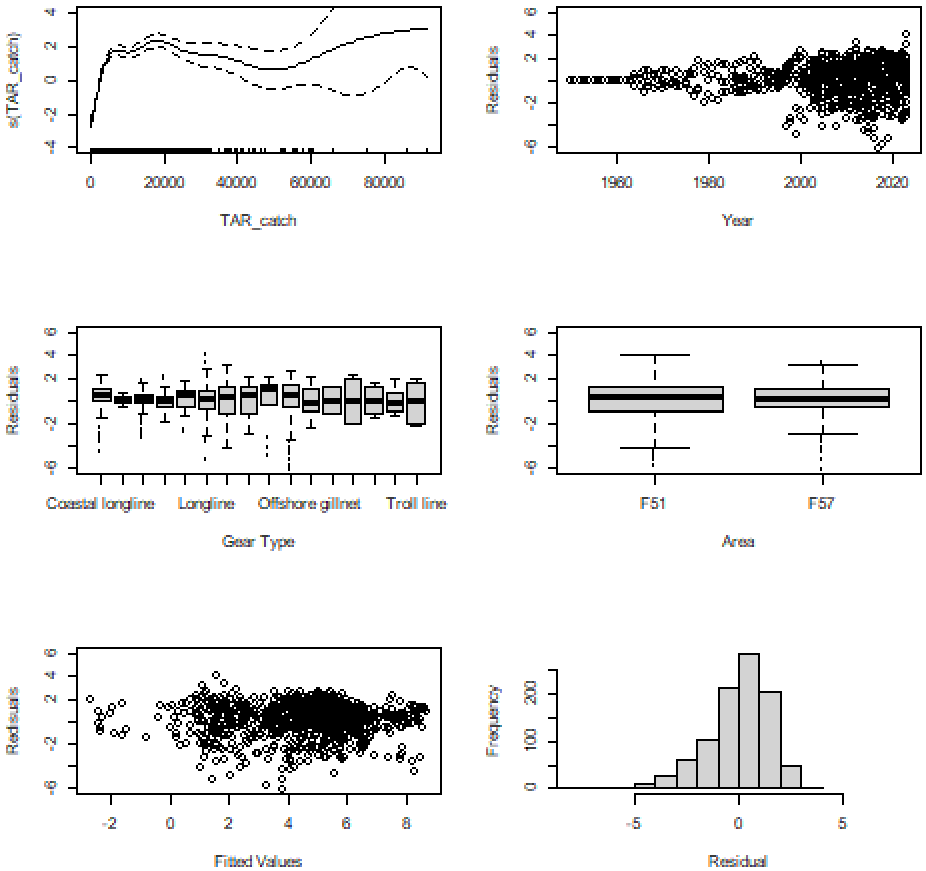



Figure 7. Residual plots of final GAM model

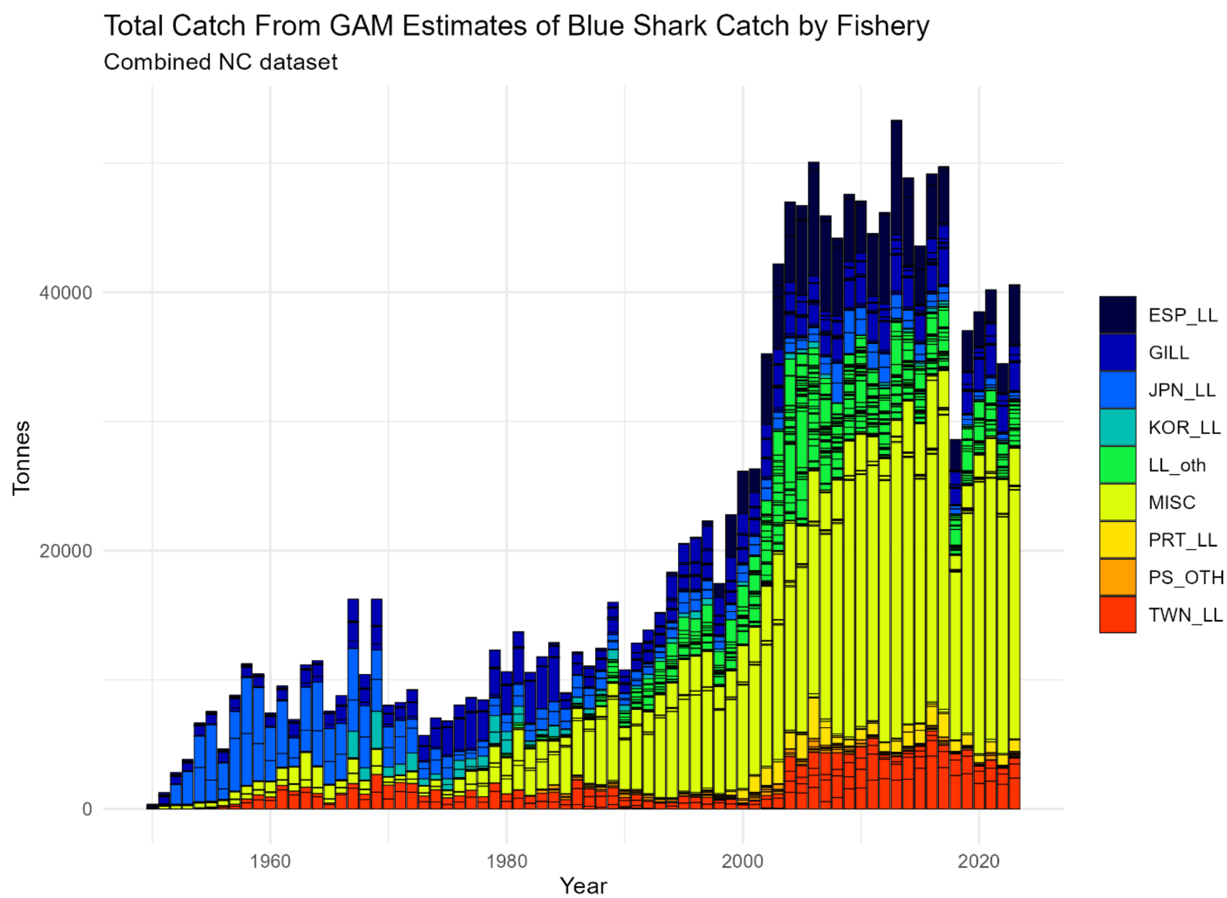



Figure 8. Total catch (reported + estimated) based on the GAM estimated catches, by fishery used in the assessment.

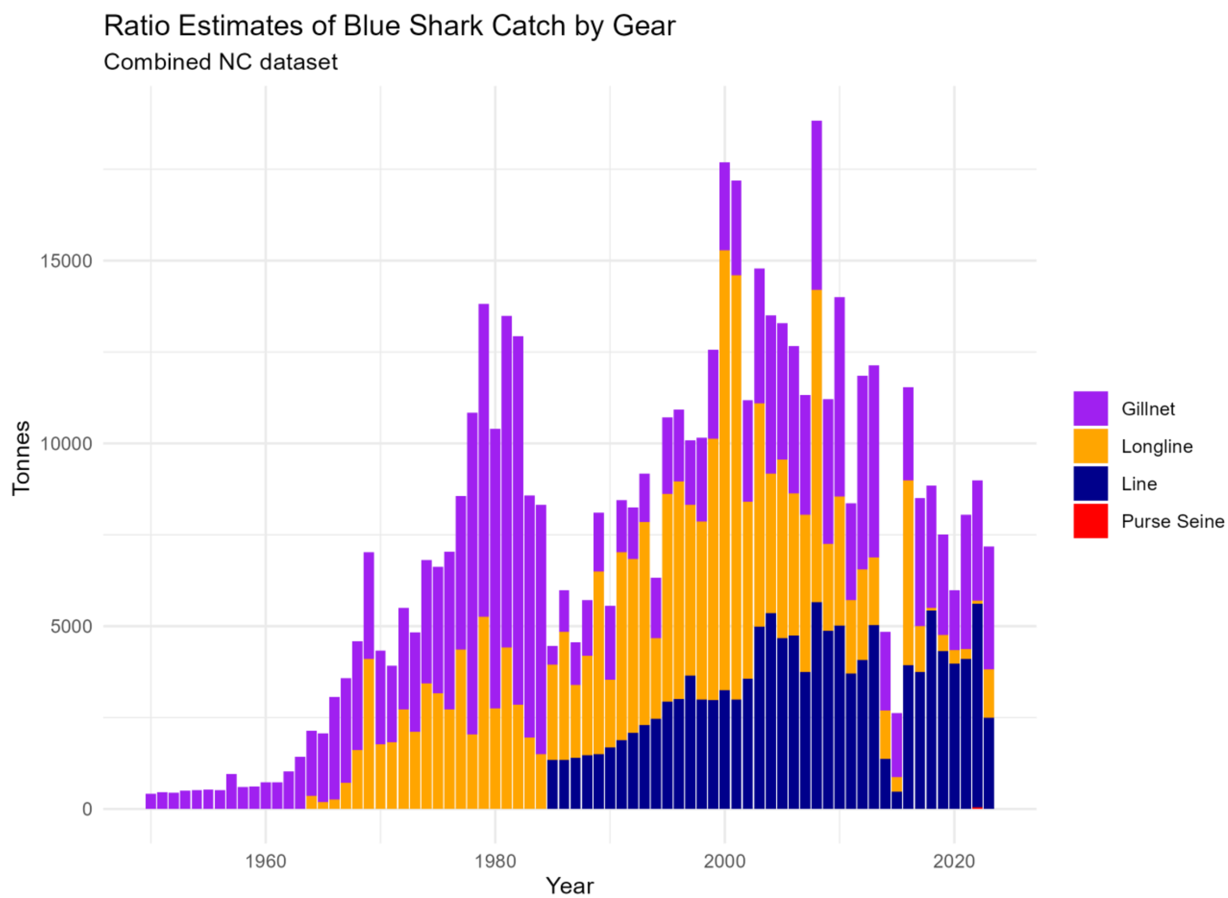



Figure 9. Estimated unreported catch component by gear type from the ratio based estimate.

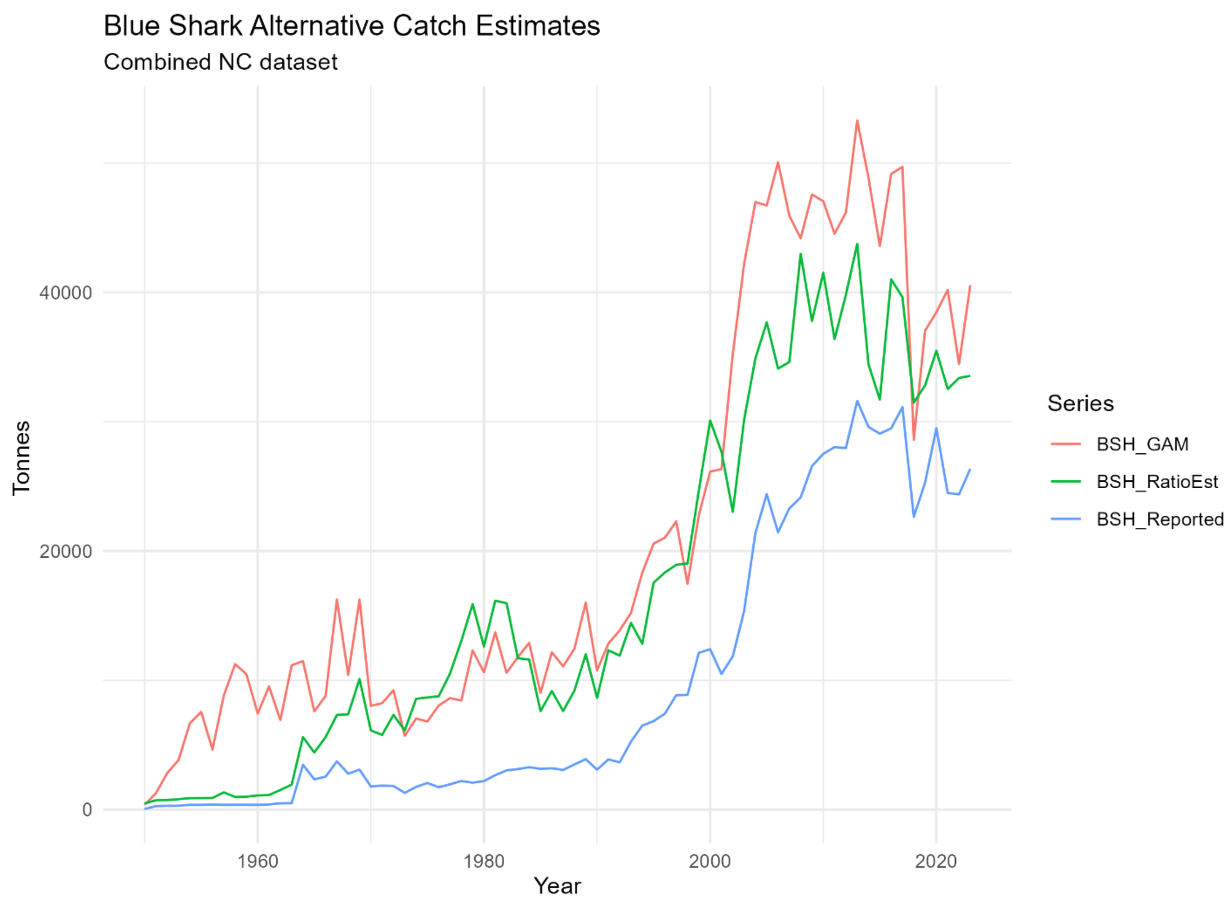



Figure 10. Comparisons of nominal reported catch, 2017 GAM catch estimates, 2021 GAM catch estimates and the 2021 ratio based estimate.