

CURRENT STATUS OF THE WHITE MARLIN (*KAJIKIA ALBIDA*) STOCK IN THE ATLANTIC OCEAN 2025: PREDECISIONAL STOCK ASSESSMENT MODEL

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SUMMARY

*Pre-decisional stock assessment configurations, diagnostics and results are described for the 2025 fully integrated assessment model for Atlantic white marlin (*Kajikia albida*). The model was minimally updated from the previous (2019) assessment model. The ad hoc Technical Team identified three models (Group_0, Group_1 and Group_2) to be highlighted, each representing an equally weighted possible state of nature. Diagnostics included profile analysis, run tests on CPUE fits, examination of residual trends, and retrospective analysis. Estimates of maximum sustainable yield ranged from 1,441 t – 1,533 t. Estimates of F/F_{MSY} for the end of 2023 ranged from 0.16 to 0.47. Estimates of SSB/SSB_{MSY} for the beginning of 2024 ranged from 0.41 to 1.19. The model results indicated that overfishing is likely not occurring but the status regarding overfished or not as clear.*

RÉSUMÉ

*Les configurations, diagnostics et résultats pré-décisionnels de l'évaluation du stock sont décrits pour le modèle d'évaluation pleinement intégré de 2025 pour le makaire blanc de l'Atlantique (*Kajikia albida*). Le modèle a été très légèrement actualisé par rapport au modèle d'évaluation précédent (2019). L'équipe technique ad hoc a identifié trois modèles (Group_0, Group_1 et Group_2) à mettre en évidence, chacun représentant un possible état de la nature pondéré de manière égale. Les diagnostics incluaient des analyses des profils, des tests des scénarios sur les ajustements des CPUE, un examen des tendances résiduelles et une analyse rétrospective. Les estimations de la production maximale équilibrée allaient de 1.441 t à 1.533 t. Les estimations de F/F_{PME} pour la fin de l'année 2023 étaient comprises entre 0,16 et 0,47. Les estimations de SSB/SSB_{PME} pour le début de l'année 2024 étaient comprises entre 0,41 et 1,19. Les résultats du modèle indiquaient qu'il est probable que le stock ne fasse pas l'objet de surpêche mais l'état surexploité ou non n'est pas aussi évident.*

RESUMEN

*Se describen las configuraciones, los diagnósticos y los resultados predecisivos de la evaluación de stock para el modelo de evaluación totalmente integrado de aguja blanca del Atlántico (*Kajikia albida*). de 2025. El modelo se actualizó mínimamente con respecto al modelo de evaluación anterior (2019). El equipo técnico ad hoc identificó tres modelos (Grupo_0, Grupo_1 y Grupo_2) a destacar, cada uno de los cuales representa un posible estado de la naturaleza ponderado por igual. Los diagnósticos incluyeron análisis de perfiles, la realización de pruebas de ensayo de los ajustes de CPUE, el examen de tendencias residuales y el análisis retrospectivo. Las estimaciones del rendimiento máximo sostenible oscilaron entre 1.441 t y 1.533 t. Las estimaciones de F/F_{RMS} para finales de 2023 oscilaron entre 0,16 y 0,47. Las estimaciones de SSB/SSB_{RMS} para comienzos de 2024 oscilaron entre 0,41 y 1,19. Los resultados del modelo indicaron que es probable que no se esté produciendo sobrepesca, pero el estado sobreexplotado o no no está tan claro.*

KEYWORDS

Stock Synthesis, white marlin, stock assessment, diagnostics, population dynamics

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1. Introduction

Atlantic white marlin (*Kajikia albida*) are part of the overall ICCAT billfish species group. It was last assessed in 2019 with a terminal year of 2017. Estimates of the status of the stock were derived and reported from two different model types, a stock production model (JABBA) and a fully integrated model (SS3, Stock Synthesis). From this assessment (anonymous 2019), using the SS3 model, the stock was declared to be overfished ($B/B_{MSY} = 0.32$ [0.23-0.41]) with overfishing “not likely” ($F/F_{MSY} = 0.72$ [0.51-0.93]).

In 2012, the Commission implemented Rec. 12-04, intended to reduce the total harvest to 400 t in 2013, 2014, and 2015 to allow the rebuilding of the white marlin stock from the overfished condition. In 2015, the Commission extended the 400 t annual catch limit to 2016, 2017, 2018 (Rec. 15-05), and 2019 (Rec. 18-04). This value of annual catch was based on the 2012 projection that showed that in order to keep the stock from experiencing overfishing with at least a 50% probability the 2013-2022 catch would need to remain at no greater than 400 t. The Committee noted in 2018 that if catches continue to exceed this TAC, as was the case for 2015 and 2016, the rebuilding of the stock will proceed more slowly. Landings of white marlin/spearfish have exceeded 400 t for all years 2013-2017 (**Table 1**). This report is a predecisional update of the 2012 stock assessment.

2. Methods

With a few notable exceptions, the methods and model configuration used for this assessment intentionally follow closely to those used in the 2019 assessment.

Growth

During the Data Preparatory meeting the group recommended reviewing and updating the growth model estimates for Atlantic white marlin as part of ongoing research. They decided to use the same growth parameters as the 2019 stock assessment for now, but emphasized the need to integrate new age and size data into future models. Growth estimates were derived from Drew et al. (2006a), Drew et al. (2006b), Drew et al. (2007), and Die et al. (2008). The results of these works indicated that rings had been lost in older fish, and that ring radii differed between males and females. The fitted growth model for white marlin also showed sexual dimorphism in growth parameters. Very few of the sampled fish were age one or two, suggesting that the majority of the fish available to the longline and artisanal fleets in our sample locations are older than two years of age. It should be noted that some members of the Group felt that the L_{∞} for females ($L_{\infty} = 172$ cm LJFL) was small, especially in relation to the Length at 50% maturity ($L_{50} = 160$ cm LJFL). This may be explained by the fast early life stage growth of white marlin that can reach L_{∞} quite early but still be relatively young. Following these results the SS model was configured as a two sex model.

Reproduction

In the 2019 assessment Estimates of maturity and reproductive aspects were taken from the ICCAT manual, which was supported by work reported by Oliveira (2007) and Arocha. Spawning biomass was made proportional to weight and length at 50% was $L_{50} = 160$ cm. However, at the Data Preparatory meeting the Group decided to update the L_{50} parameters for the white marlin assessment according to the new data from Pinheiro *et al.*, 2021. The estimated L_{50} were 145.04 cm and 140.03 cm LJFL1 for females and males, respectively. The peak of maturity was detected in May for both sexes, with a spawning season from April to June.

Natural mortality

As with most all highly migratory fish species, natural mortality estimates from actual data are rare and mostly based on oldest observed ages from growth studies. However, these studies are conducted the population well after fishing has occurred, which decreases the probability of observing the naturally occurring oldest age fish. The estimated age of fish observed in the above mentioned age-and-growth studies ranged 1-13 years, though most were aged 3-8 years. These assigned ages were consistent with a subset of mark-recaptured fish sampled. Mark-recapture records suggest that white marlin are capable of living 15+ years (Orbesen et al., 2008; Ortiz et al., 2003). At the 2018 blue marlin data preparatory meeting, a species thought to live longer than white marlin, were assigned a natural mortality of 0.15 based on oldest observed fish. Following these results the SS model configured with a natural mortality of $M = 0.20$ maximum age of 20 years.

Stock-recruitment relation

A Beverton-Holt stock-recruitment relation was used. The ICCAT 2012 and 2019 white marlin assessment estimated value of steepness of approximately 0.6. The base case model in this work allowed steepness to be estimated with a Bayesian prior of 0.60 and a standard deviation of 0.05 and a normal distribution. Models were also configured with fixed steepness of 0.40, 0.5 and 0.60 for sensitivity analysis. Examination and comparison of the annual standard deviation of recruitment and the residual mean square error of the deviations suggested a sigma-r of 0.20 was appropriate. Too large of a value of sigma-r could artificially account for the most recent decreasing trends in spawning stock biomass to be explained solely by negative recruitment deviations during the same period. Furthermore, some indices of abundance for this stock tended to have suspiciously sporadic year to year deviations, which could also have an undue influence on recruitment deviations with larger values of sigma-r.

Landings. Historic Task 1 reported landings and dead discards are shown in **Figure 1**. The first regulation on white marlin, Recommendation 1997-09, took the following steps:

All Contracting Parties and non-contracting parties, entities or fishing entities

1. *Reduce, starting in 1998, blue marlin and white marlin landings by at least 25% for each species from 1996 landings, such reduction to be accomplished by the end of 1999.*
2. *Promote the voluntary release of live blue marlin and white marlin.*

In 2012, Recommendation 2012-04 the ICCAT put CPC specific quotas on white marlin:

1. *An annual limit of 2,000 t for blue marlin and 400 t for white marlin/spearfish is established for these stocks, for 2013, 2014 and 2015. This landings limit shall be implemented as follows:*

In 2015, Recommendation 2015-05, an annual limit of 400 t for white marlin/spearfish was continued for these stocks, for 2016, 2017 and 2018. Since 2013 total landings have exceeded the total allowable catch set forth in Rec. 2012-04. Dead discards are not included in the Rec. 2012-04 total catch limit. The under reporting of white is thought to have begun in earnest in 1998-1999, when the implementation of management regulations by the Commission began. Therefore, the Group concluded that reported catches after 1998-1999 may not include increased discards at sea particularly from longline fleets as a consequence of the implementation of management recommendations, and thus total removals in Task I statistics may be underestimated since 1998-1999.

Live and dead discards

Live and dead discards are known to be under reported to ICCAT. Discards, however, are critical observational data for any stock assessment. Although difficult to account for, the ICCAT Secretariat provided estimates of non-reported live and dead discards from longline fleet 2000-2017 through the use of extrapolation from those CPCs that did report. The estimated dead discards were added to the “catch” (which is standard protocol).

Unaccounted (IUU) landings

Along with discards, unreported landings, either intentional or by error, are also a known issue with reported landings. This under reporting can have unforeseen consequences on both the stability and outcome of the assessment model. All methods of estimating IUU landings will have assumptions. One way to do this is for the purposes of this assessment, and a minimal number of assumptions, is to estimate the IUU landings within the stock assessment model itself. We can use observational data and make a determination as to whether or not the observed landings are in agreement with the remaining observational data. The assumption made here is no different than those of the assessment itself, that the observational data is representative of the stock and the model is relatively stable and free from overt process error. Reported WHM landings show a decreasing trend 1998-2010, and have been relatively consistent 2010-2017 (presumably due to regulations) and well below estimated MSY. However the trend in the consolidated CPUEs has also been flat. Some possible explanations for this are; (1) Bmsy has been over estimated, (2) the stock has reached an equilibrium level below that of the correctly estimated MSY, (3) CPUEs are not indicative of stock abundance trends, (4) recruitment has been below average during that time period, and/or (5) landings are being under reported.

For the first in this assessment, these IUU landings were estimated within the assessment model.

The catch is adjusted by the multiplier is calculated as:

$$C_{exp} = \frac{C_{obs}}{C_{mult}}$$

where C_{exp} is the expected catch from the fishing mortality and C_{mult} is the catch multiplier. Information informing the estimates of these landings would be received from the possible mismatch of observed landings, indices of abundance, and estimated productivity and recruit deviations from the fully integrated assessment model. In the case of white marlin, which presumably has at least some surplus production, the observations of an overall flat population trend via the CPUEs coupled with decreasing landings suggests that landings may be being under reported. This degree of under reporting can then be estimated by the difference between those landings expected from these observations and those observed. Under reported were attributed to the longline fleet only.

Indices of abundance. It should be noted that the U.S. Recreational index for blue marlin (from the same source of tournament observations) was excluded from the final 2024 blue marlin model based on the belief that the increasing trend could have been due to an increase in catchability of the fleet. This increase may have been due to several technological advancement made by the gear and boats used in the tournaments. Communications with fishermen who have participated in the white marlin tournament fishery for many years revealed that they have witnessed a great deal of change in the fishery over the years. These changes include, but not limited to, faster and larger boats that can range further, improvements in gear, and technology reducing the need for exploratory fishing. These concerns were also expressed during the blue marlin assessment. Given the obvious changes in catchability, and to remain consistent with the blue marlin assessment and decision, the US Sport fishery CPUE was omitted from all white marlin models as well. The same argument was made for the Brazilian sport fishing CPUE and it too was removed from this assessment.

Also excluded from the blue marlin assessment was the late Chinese-Taipei. This is because the steep decline in the CPUE was attributed to a lack of reporting discarded blue marlin. The same non-reporting of discarded fish also hold true for the white marlin CPUE. Given that an unknown number of fish that were caught were not included in the CPUE, and to remain consistent with the blue marlin assessment and decision, the Chinese_Taipei_late CPUE was omitted from all white marlin models as well.

Each year of each CPUE was assigned a standard error as provided by during the Data Prep meeting. However, some calculated standard errors were so small as to suggest an overly precise estimation. In the cases where any year of any index had a SE less than 0.30, that year was assigned 0.30, and any years greater than 0.30 where assigned their reported values.

During some overlapping time periods the fourteen indices were not in agreement with regard to the trends in the stock size. This created instability within the assessment model due a flat response surface in the fitting. To address this issue for each of the CPUE times an additional parameter was estimated, an additive constant to be added to the input standard deviation of the survey variability (i.e. variance reweighting). The effect of variance reweighting estimates a higher than input standard deviation for those CPUE's that diverged from the overall trends suggested by the rest of the observational data. Those CPUE's that were in agreement with observational data would have a lower estimate of their input variance.

The 2018 blue marlin Group determined that the US Recreational Bill Survey index of abundance was not suitable for inclusion into the assessment. This was based on information presented during the meeting that suggested the catchability of the fleet has significantly and gradually changed over the time period of the CPUE time series. To determine if the same phenomena was true for white marlin several long time participants of white marlin tournaments were asked for their experiences on this topic. The respondents all agreed that changes in boat speed, power, electronics and gear have increased their catchability. Given this information, its agreement with the blue marlin information, and consistency between assessments, the RBS CPUE was omitted from all analysis.

The marlin Species Group also made the determination that the third stanza (1998-2023) of the Chinese-Taipei CPUE index was inappropriate for use in the blue marlin assessment. This decision was based on the fact that during this time period, due to regulatory restrictions, discards of marlin (both blue and white) were not included in the CPUE analysis. For this reason, and to maintain consistency between assessments, the third stanza of this index was also omitted from all white marlin assessment models.

Selectivity

The Gillnet fishery length compositions were clearly different than those of the other three fisheries and clearly not asymptotic. Gillnet landings are primarily from Venezuela which is a fishery that operates closer to shore, an area where large white marlin are less likely to be found. The longline fishery was assumed to have asymptotic selectivity. The initial base model was configured with the recreational fishery as having asymptotic selectivity. Given that recreational fishing data is from tournament, and that tournament fishing generally fish to maximize size, this seemed a reasonable assumption. However, closer examination of the length compositions revealed that longline gear actually caught larger fish than did recreational gear. A profiling exercise on virgin recruitment was conducted on assuming an asymptotic selectivity and a dome-shaped selectivity. The model with asymptotic selectivity seemed to outperform the model with dome-shaped. For the asymptotic model, nearly every convergence level was lower and the model was able to invert the hessian on more runs. Given these diagnostics, along with knowledge of the fishery, the recreational fishery was assigned an asymptotic selectivity.

Model configurations

Three model configurations were requested by the Technical Team, each representing a different, equally weighted, state of nature. The groupings were formulated by grouping the CPUE times series based on the overall trend in recent years.

- **Group_0** (all CPUE): JPN-LL prior, JPN-LL1, JPN-LL2, JPN-LL3, VEN-LL, VEN-GN, USA-LL, CTP-LL1, MEX-LL, BRA-LL
- **Group_1** (decreasing CPUE): JPN-LL prior, JPN-LL1, JPN-LL2, JPN-LL3, USA-LL, CTP-LL1, MEX-LL
- **Group_2** (increasing CPUE): JPN-LL prior, JPN-LL1, VEN-LL, VEN-GN, CTP-LL1, BRA-LL

The summary of data sources is shown in **Figure 2**.

3. Results

Landings

The estimate of the catch multiplier for Group_0 was 0.58 (SD = 0.08) (**Figure 3**); for Group_1 was 0.74 (SD = 0.11), and for Group_2 was 0.72 (SD = 0.09) (**Table 1**), equaling an average of 32% under reporting of longline landings and dead discards 1998-2023.

Stock recruitment relation

The estimated distributions and priors for virgin recruitment (R_0) and steepness (h) for Group_0 are shown in **Figure 3**. The estimate of steepness for Group_0 was 0.57 (SD = 0.04); for Group_1 was 0.63 (SD = 0.04), and for Group_2 was 0.63 (SD = 0.04) (**Table 1**). The estimate of steepness was different from the prior used ($h = 0.60$) indicating that there was at least some information in the observational data to drive the estimate (**Figure 3, bottom**).

It should be noted that the estimated recruitments were all for similar observations of spawning stock biomass (**Figure 4**). Also, the trend in recruit deviations was estimated negative from 1997-2017, evidence that the decrease in landings may have also partly attributable to low recruitment (**Figure 5**). So, the model fit is a trade-off between estimated/fixed parameters such as steepness and σ_r , and so all of the parameters correlated to them. The trend in recruitment deviations from SS3 are often similar to the trend in process error estimated from the JABBA model, which is to be expected as both are depicting unaccounted for mismatch between the data and the model structure. It should be noted that, unlike the JABBA mode, the negative recruitment deviations from 2010 to 2022 will be directly reflected in the rate of recovery in any projections as those lower recruitments get incorporated into future population size.

All derived quantities and associated standard deviations from each of the three models are provided in **Table 2**.

Fit to CPUE indices

After the Data Preparatory meeting and several Technical Team meetings a total of ten indices of abundance were selected to finally be used to index stock biomass. Fits of model Group_0 (all ten indices) to these indices are shown in **Figure 6**. Greater details of the fit to each of the fourteen are provided on the shared drive for the meeting as they are too extensive to be published within this document.

Selectivity

The selectivity at length for each of the four fishing fleets and the associated indices of abundance are shown in **Figure 7**. The gillnet length compositions made it evident that this gear does not catch the largest fish, thus its selectivity was allowed to be dome-shaped while the longline and recreational gears were made to be asymptotic.

Fit to length compositions

The fit to each of the length compositions are shown in **Figure 8**. Individual fits by year and gear are provided on the shared drive as they are too extensive to be published within this document. The residual pattern seen in the longline in the later part of the time series is possibly due to the minimum size regulation put in place in the late 1990's. However, without better information on the amount and size of discards modeling that portion of the length compositions remains challenging. Efforts were made to fit the longline lengths better by using three stanzas for time-varying selectivity but the results were not discernably different making the additional parameters of little value.

CPUE jack-knife

The examine model sensitivity to each of the CPUE's each CPUE index was removed one at a time and the trends in spawning stock biomass were compared (**Figure 9**). Note that this analysis was conducted prior to the Technical Team determining that CHT_2 (late) should be removed from consideration. The most influential indices for the estimation of SSB were the CHT_2 and the (VEN_GN, MEX_LL, US_LL) times series. Removal of the CHT_2 resulted in an increase in SSB, while removal of either the (VEN_GN, MEX_LL, US_LL) times series resulted in a decrease in the estimated spawning stock biomass. The lack of agreement between all of indices of abundance motivated the Technical Team to create the three states of nature explored in this paper.

The input variance and input+estimated-additional-variance are shown in **Figure 10**. Each of the ten indices of abundance were estimated to have a positive addition variance. The estimated additional variance of the Venezuelan longline and gillnet CPUEs were the highest, suggesting a lack of agreement to the rest of the input data. The variance on Japan_early, Japan_mid and Brazil_Sport had their input variances decreased, indicating an agreement with the rest of the observational data.

Model diagnostics

Several standard diagnostic techniques were investigated and/or applied to the three models to evaluate the stability of the parameter estimates and the model in general.

1. Run Test on CPUEs (an examination of fit-to-CPUE residuals)
2. Profiling $R0$ (virgin recruitment)
3. Profiling h (steepness of S/R function)
4. Retrospective analysis with hindcast cross-validation

Run Test on CPUEs

The runs test (Carvalho et al. 2017) is used to test for randomness of residuals of the model fit the CPUE time series. Failure to pass run tests is seen as an indication that process error is not being adequately characterized in either the CPUE standardization or the assessment model and that further development is warranted. The results of the Run Test for Group_0, Group_1 and Group_2 are shown in **Figure 11**. For Group_0 five of the ten CPUEs failed the test, those being JPN_prior, JPN_3 (late), VEN_GN, CHT_1 and MEX_LL. For Group_1 four of the eight CPUEs failed the test, those being JPN_3 (late), US_LL, CHT_1 and MEX_LL. For Group_2 three of the six CPUE's failed the test, those being VEN_LL, VEN_GN and CHT_1. To summarize, for each of the three configurations, exactly half of the CPUEs passed the runs test while half did not.

Profile on R_0

The profiling of the virgin recruitment parameter (R_0) for each of the three assumed states of nature (Group_0, Group_1 and Group_2) is shown in **Figure 12**. The curvature of the total likelihood profile makes evident the fact that the R_0 parameter was reasonably well estimated. However, in each of the Groups the length data was in conflict with index data. It should be kept in mind that, although there was a prior placed on the steepness parameter, the profiling suggests that this prior did not have as strong of an influence on the estimation of R_0 as did the observational data.

Profile on steepness. The profiling of the steepness parameter (h) for each of the three assumed states of nature (Group_0, Group_1 and Group_2) is shown in **Figure 13**. Generally speaking, the profiling suggests that the estimation of steepness was fairly well defined, as evidenced by the shape of the profile curve. Although, some oddities were evident in the shape as it was not a “perfectly” smooth progression between values. Furthermore, although the profiling suggests a reasonable estimation of the parameter it should be noted that the majority of the recruitment values came from very similar values of spawning stock biomass (see section above). In all three models the length data had the most influence on the estimated value while the index data fit best at very low values of steepness. None the less, the observational data was able to pull the estimate away from the prior, suggesting some signal was contained within the data. As always, estimates of steepness should be viewed with caution.

Retrospective analysis with hindcast cross-validation

The results of the retrospective analysis for all three assumed states of nature are shown in **Figure 14**. Following rule of thumb when determining whether a retrospective pattern should be addressed explicitly, values of Mohn’s ρ higher than 0.20 or lower than -0.15 for longer-lived species (Carvalho et al. 2017) it can be concluded that Group_0 had a slight retrospective pattern (Mohn’s $Rho = 0.23$), Group_1 a concerning pattern (Mohn’s $Rho = 1.49$) and Group_2 somewhat concerning pattern (Mohn’s $Rho = 0.44$). The patterns are likely due to the remaining conflicts in the trends of the CPUEs within each Group, despite the attempt to group the indices by like trends. Despite the values of the Mohn’s Rho Group_0 and Group_2 fell within the 95% confidence bounds of the analysis while Group_1 did not.

The results of the cross validation for all three assumed states of nature are also shown in **Figure 14**. Following rule of thumb that a MASE scores < 1 indicated an adequate prediction skill for the corresponding mean age estimates it can be concluded that none of the CPUEs within any of the models strictly passed this test. For Group_0 the VEN_GN had the lowest MASE (MASE = 1.19) while the MEX_LL had the highest (MASE = 3.84). For Group_1 the JPN_3 (late) had the lowest (MASE = 1.75) while the MEX_LL had the highest (MASE = 3.71). For Group_2 the only index available for this analysis was the VEN_GN which had a MASE of 2.33.

Comparison of trends

A comparison of the spawning stock, recruitment, F/F_{MSY} and SSB/SSB_{MSY} for all three models is shown in **Figure 15**. The greatest difference in trends between the models occur after 2010 when Group_2 showed a more rapid increase in SSB than did either Group_0 or Group_1.

The only two indices that covered the years of this rapid increase that also showed a rapid increase were the VEN_GN and VEN_LL. Subsequent jack-knife analysis revealed that this rapid increase was due to the inclusion of the VEN_LL index (**Figure 16**). Further analysis suggests several possible reasons for the marked increase in the VEN_LL CPUE. Effort was separated from CPUE by dividing the CPUE by the reported Venezuelan longline landings. From 2011 to 2012 there was a marked decrease in effort but not catch, which led to a sharp increase in the CPUE (**Figure 17**). Subsequently increases in catch led to a continuation of this trend. Notable, however, is that landings dropped off in the years following the last year of the CPUE analysis.

4. Discussion

The results report here are similar to those reported in the 2019 white marlin assessment. Because of the limited amount of observational data and lack of a clear signal within it, the uncertainty around the derived quantities associated with MSY are likely to be under estimated. Attempts were made to group indices by like trend to reduce this uncertainty however much of the uncertainty is expressed as “between model” uncertainty rather than “within model” uncertainty.

Basic biological information is absent for white marlin. Estimates of growth are one of the most influential but least understood life history traits. Because of a lack of age and growth information the longevity of the species, even in a fished population, is highly uncertain. This leads to greater uncertainty in the rate of natural mortality. The assumption of one Atlantic-wide stock is also lacking data. Correct species identification remains a contributing factor to the overall uncertainty of the management of this stock.

The consistently declining trend in fishing mortality is an indication that perhaps recent management actions are in fact working as desired. However, the slow increase in spawning biomass for the same period indicates that the stock may not highly productive and may be slow to recover to the spawning stock biomass target. Unaccounted for landings and dead discards have a great influence on the uncertainty in the estimation of stock status and the effectiveness of management actions. The estimated catch multiplier parameter suggests that catch (and dead discards) could be under reported by 32%. All these factors could also be contributing to the slower than expected recovery rate.

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References

- Anonymous. 2018a. Blue Marlin Data Preparatory Meeting, Madrid, Spain, 12-16 March 2018. Document SCRS/2018/001: 39 pp.
- Anonymous. 2018b. Blue Marlin Stock Assessment, Miami, United States, 18-22 June 2018. Document SCRS/2018/001: 45 pp.
- Anonymous. 2019. White Marlin Data Preparatory Meeting, Madrid, Spain, 12-15 March 2019. Document SCRS/2018/000 (in press): 32 pp.
- Carvalho, F., Punt, A.E., Chang, Y.J., Maunder, M.N., Piner, K.R. 2017. Can diagnostic tests help identify model misspecification in integrated stock assessments? *Fisheries Research*, 192, pp.28-40.
- Drew, K., Die, D., Arocha, F. 2006a. Current efforts to develop an age and growth model of blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*). Coll. Vol. Sci. Papers ICCAT 59: 274–281.
- Drew, K., Die, D.J., Arocha, F. 2006b. Understanding vascularization in fin spines of white marlin (*Tetrapturus albidus*). *Bulletin of Marine Science*, 79(3), pp.847-852.
- Drew, K., Die, D.J., Arocha, F. 2007. Ring counts and timing of ring formation in fin spines of white marlin (*Tetrapturus albidus*) from the Venezuelan longline and artisanal fisheries. *Collect. Vol. Sci. Pap. ICCAT*, 60(5), pp.1726-1730.
- Die, D.J., Drew, K. 2008, March. An Atlantic-wide study of age and growth of Atlantic marlins. In *Proceedings from the Atlantic Billfish Research Program Symposium* (pp. 67-84).
- Oliveira, I.M., Hazin, F., Travassos, P., Pinheiro, P., Hazin, H.G. 2007. Preliminary results on the reproductive biology of the white marlin, *Tetrapturus albidus* Poey 1960, in the western equatorial Atlantic Ocean. *ICCAT Col. Vol. Sci. Pap.*, 60: 1738-1745.
- Orbesen, E.S., Hoolihan, J.P., Serafy, J.E., Snodgrass, D., Peel, E.M., Prince, E.D. 2008. Transboundary movement of Atlantic istiophorid billfishes among international and U.S. domestic management areas inferred from mark-recapture studies. *Marine Fisheries Review*, 70: 14-23.
- Ortiz, M., Prince, E.D., Serafy, J.E., Holts, D.B., Davy, K.B., Pepperell, J.G., Lowry, M.B. and Holdsworth, J.C. 2003. Global overview of the major constituent-based billfish tagging programs and their results since 1954. *Marine and Freshwater Research*, 54: 489-507.
- Pinheiro, P., Da Mata Oliveira, I., Gomes do Rêgo, M., Mourato, B., Hazin, F. 2021. Reproductive biology of the white marlin (*Kajikia albida*) in the southwestern and equatorial Atlantic Ocean. *Journal of Applied Table* YY. Parameter table for models Group_0, Group_1 and Group_3. Table does not include fishing mortality values which were estimated as parameters.

Table 1. Parameter table for models Group_0, Group_1 and Group_3. Table does not include fishing mortality values which were estimated as parameters.

Parameter	GROUP_0						Group_1						Group_2					
	Value	Status	Parm_StDev	Pr_type	Prior	Pr_SD	Value	Status	Parm_StDev	Pr_type	Prior	Pr_SD	Value	Status	Parm_StDev	Pr_type	Prior	Pr_SD
Catch_Mult: 2_LongLine_2_BLK2repl_1998	0.579	OK	8.16E-02	Normal	1	99	0.741	OK	1.08E-01	Normal	1	99	0.716	OK	9.15E-02	Normal	1	99
SR_LN(R0)	5.475	OK	8.28E-02	Normal	5	99	5.355	OK	7.02E-02	Normal	5	99	5.294	OK	5.78E-02	Normal	5	99
SR_BH_steep	0.572	OK	4.24E-02	Normal	0.6	0.05	0.633	OK	4.45E-02	Normal	0.6	0.05	0.682	OK	3.82E-02	Normal	0.6	0.05
LnQ_base_Japan_LL_prior(5)	-5.916	OK	2.75E-01	No_prior	NA	NA	-5.578	OK	2.71E-01	No_prior	NA	NA	-5.422	OK	2.62E-01	No_prior	NA	NA
Q_extraSD_Japan_LL_prior(5)	0.459	OK	1.25E-01	No_prior	NA	NA	0.486	OK	1.31E-01	No_prior	NA	NA	0.510	OK	1.36E-01	No_prior	NA	NA
LnQ_base_Japan_LL_early(6)	-5.136	OK	3.45E-01	No_prior	NA	NA	-4.600	OK	3.21E-01	No_prior	NA	NA	-4.398	OK	3.09E-01	No_prior	NA	NA
Q_extraSD_Japan_LL_early(6)	0.068	OK	7.49E-02	No_prior	NA	NA	0.056	OK	7.46E-02	No_prior	NA	NA	0.054	OK	7.59E-02	No_prior	NA	NA
LnQ_base_Japan_LL_mid(7)	-4.951	OK	4.27E-01	No_prior	NA	NA	-4.082	OK	3.52E-01	No_prior	NA	NA	-2.413	OK	1.24E+05	No_prior	NA	NA
Q_extraSD_Japan_LL_mid(7)	0.183	OK	8.00E-02	No_prior	NA	NA	0.150	OK	7.43E-02	No_prior	NA	NA	0.499	OK	1.84E+03	No_prior	NA	NA
LnQ_base_Japan_LL_late(8)	-4.948	OK	5.90E-01	No_prior	NA	NA	-3.646	OK	5.35E-01	No_prior	NA	NA	-2.181	OK	1.24E+05	No_prior	NA	NA
Q_extraSD_Japan_LL_late(8)	0.391	OK	1.68E-01	No_prior	NA	NA	0.414	OK	1.82E-01	No_prior	NA	NA	0.499	OK	1.84E+03	No_prior	NA	NA
LnQ_base_Ven_LL(9)	-5.189	OK	4.62E-01	No_prior	NA	NA	-2.050	OK	1.24E+05	No_prior	NA	NA	-4.275	OK	3.87E-01	No_prior	NA	NA
Q_extraSD_Ven_LL(9)	0.344	OK	1.16E-01	No_prior	NA	NA	0.482	OK	1.84E+03	No_prior	NA	NA	0.390	OK	1.52E-01	No_prior	NA	NA
LnQ_base_Ven_GN(10)	-6.571	OK	4.48E-01	No_prior	NA	NA	-2.823	OK	1.23E+05	No_prior	NA	NA	-5.792	OK	3.78E-01	No_prior	NA	NA
Q_extraSD_Ven_GN(10)	0.141	OK	8.32E-02	No_prior	NA	NA	0.515	OK	1.84E+03	No_prior	NA	NA	0.301	OK	1.14E-01	No_prior	NA	NA
LnQ_base_US_LL(11)	-4.825	OK	4.58E-01	No_prior	NA	NA	-3.822	OK	3.84E-01	No_prior	NA	NA	-2.259	OK	1.24E+05	No_prior	NA	NA
Q_extraSD_US_LL(11)	0.100	OK	5.75E-02	No_prior	NA	NA	0.153	OK	6.84E-02	No_prior	NA	NA	0.498	OK	1.84E+03	No_prior	NA	NA
LnQ_base_Chin_Tai_LL_early(14)	-10.855	OK	3.39E-01	No_prior	NA	NA	-10.338	OK	3.17E-01	No_prior	NA	NA	-10.159	OK	2.95E-01	No_prior	NA	NA
Q_extraSD_Chin_Tai_LL_early(14)	0.409	OK	9.57E-02	No_prior	NA	NA	0.396	OK	9.67E-02	No_prior	NA	NA	0.364	OK	9.35E-02	No_prior	NA	NA
LnQ_base_Chin_Tai_LL_late(15)	-4.689	OK	1.21E+05	No_prior	NA	NA	-3.909	OK	1.22E+05	No_prior	NA	NA	-4.922	OK	1.20E+05	No_prior	NA	NA
Q_extraSD_Chin_Tai_LL_late(15)	0.441	OK	1.83E+03	No_prior	NA	NA	0.488	OK	1.84E+03	No_prior	NA	NA	0.500	OK	1.84E+03	No_prior	NA	NA
LnQ_base_Mex_LL(16)	-8.793	OK	4.70E-01	No_prior	NA	NA	-7.770	OK	4.01E-01	No_prior	NA	NA	-5.057	OK	1.20E+05	No_prior	NA	NA
Q_extraSD_Mex_LL(16)	0.254	OK	8.21E-02	No_prior	NA	NA	0.372	OK	9.79E-02	No_prior	NA	NA	0.499	OK	1.84E+03	No_prior	NA	NA
LnQ_base_Brazil_LL(18)	-7.175	OK	3.78E-01	No_prior	NA	NA	-6.477	OK	3.30E-01	No_prior	NA	NA	-6.375	OK	3.03E-01	No_prior	NA	NA
Q_extraSD_Brazil_LL(18)	0.287	OK	7.81E-02	No_prior	NA	NA	0.281	OK	7.83E-02	No_prior	NA	NA	0.267	OK	7.58E-02	No_prior	NA	NA
Size_DblN_peak_Gill_Net_1(1)	163.478	OK	1.82E+00	Normal	164.30	99	164.481	OK	1.81E+00	Normal	164.30	99	164.545	OK	1.79E+00	Normal	164.30	99
Size_DblN_top_logit_Gill_Net_1(1)	-10.324	OK	5.54E+01	Normal	-10.00	99	-9.705	OK	6.66E+01	Normal	-10.00	99	-9.658	OK	6.76E+01	Normal	-10.00	99
Size_DblN_ascend_se_Gill_Net_1(1)	5.304	OK	1.95E-01	Normal	4.97	99	5.322	OK	1.84E-01	Normal	4.97	99	5.323	OK	1.81E-01	Normal	4.97	99
Size_DblN_descend_se_Gill_Net_1(1)	5.504	OK	4.05E-01	Normal	5.13	99	5.487	OK	4.42E-01	Normal	5.13	99	5.485	OK	4.39E-01	Normal	5.13	99
Size_DblN_end_logit_Gill_Net_1(1)	-2.260	OK	7.28E-01	Normal	-2.00	99	-2.066	OK	7.27E-01	Normal	-2.00	99	-2.061	OK	7.18E-01	Normal	-2.00	99
Size_DblN_peak_LongLine_2(2)	167.129	OK	2.40E+00	Normal	170.00	15	169.892	OK	2.32E+00	Normal	170.00	15	170.288	OK	2.33E+00	Normal	170.00	15
Size_DblN_ascend_se_LongLine_2(2)	7.029	OK	1.06E-01	Normal	7.00	99	6.982	OK	9.18E-02	Normal	7.00	99	6.978	OK	9.29E-02	Normal	7.00	99
Size_DblN_peak_Sport_4(4)	163.562	OK	1.73E+00	Normal	160.30	99	164.483	OK	1.86E+00	Normal	160.30	99	164.962	OK	1.83E+00	Normal	160.30	99
Size_DblN_ascend_se_Sport_4(4)	5.522	OK	1.70E-01	Normal	5.70	99	5.527	OK	1.72E-01	Normal	5.70	99	5.533	OK	1.65E-01	Normal	5.70	99

Table 2. Derived quantity values and standard deviations for the three models under consideration.

Quantity	Group_0		Group_1		Group_2	
	Value	Std. Dev	Value	Std. Dev	Value	Std. Dev
F_2023 (end)	0.252	0.079	0.468	0.148	0.163	0.059
Bratio_2024 (begin)	0.923	0.329	0.413	0.153	1.190	0.426
SSB_unfished	8,690	720	7,707	541	7,252	419
Totbio_unfished	20,851	1,727	18,495	1,298	17,401	1,006
SmryBio_unfished	20,818	1,725	18,465	1,296	17,373	1,004
Recr_unfished	239	20	212	15	199	12
SSB_MSY	2,605	374	2,095	299	1,816	229
SPR_MSY	0.431	0.038	0.377	0.037	0.338	0.031
annF_MSY	0.200	0.029	0.249	0.037	0.290	0.037
Dead_Catch_MSY	1,441	47	1,481	44	1,533	36
Ret_Catch_MSY	1,441	47	1,481	44	1,533	36
B_MSY/SSB_unfished	0.300	0.019	0.272	0.020	0.250	0.017

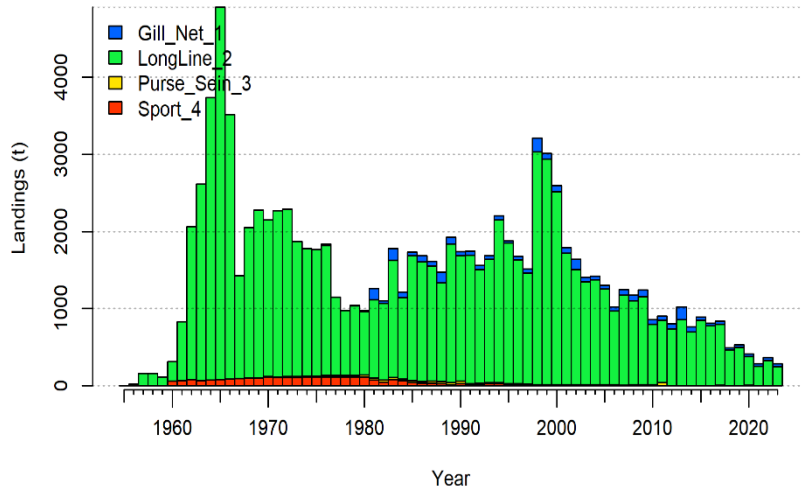


Figure 1. Landings of white marlin and spearfish by year and gear.

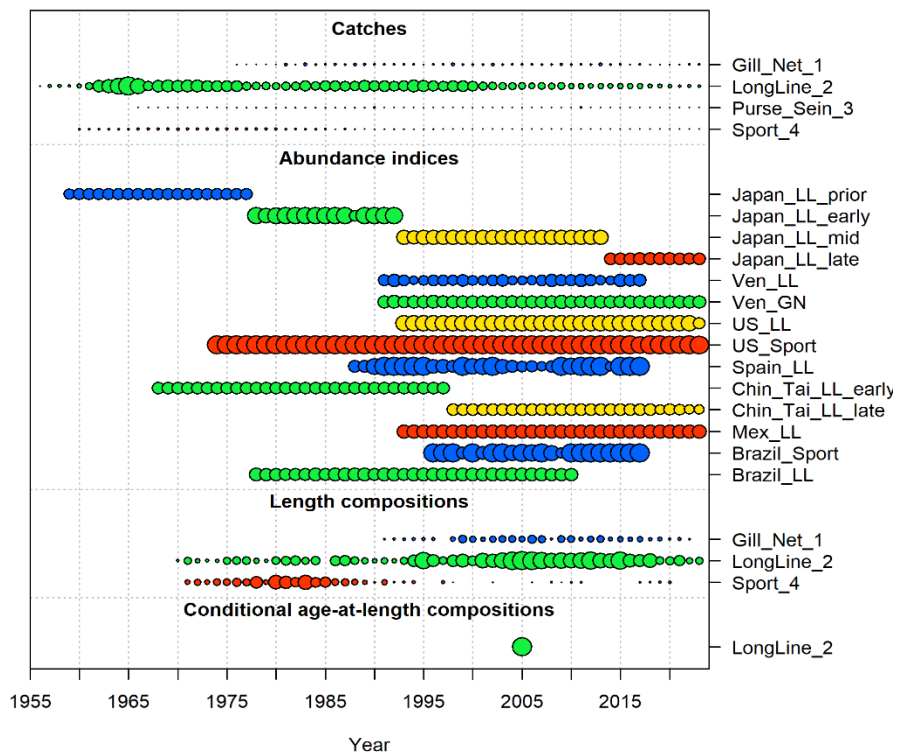


Figure 2. Data sources by year used in the Stock Synthesis models.

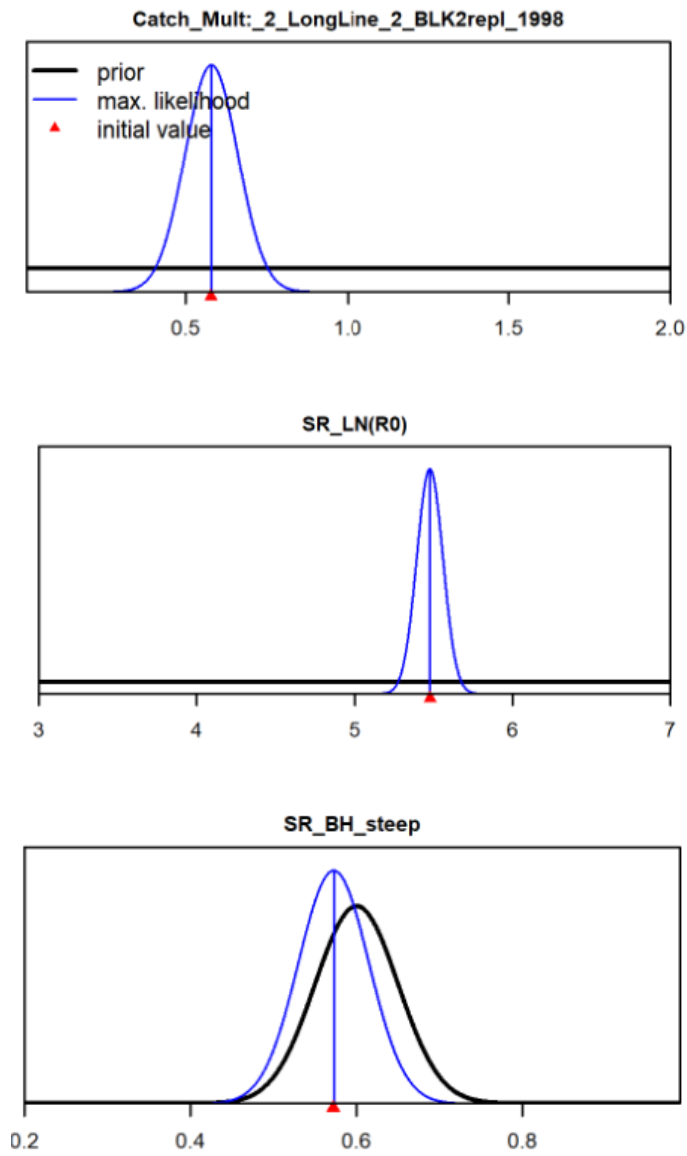


Figure 3. Distribution of prior and parameter estimates and initial starting value of (top) catch multiplier, (middle) virgin recruitment (R_0) and (bottom) steepness (h) for model Group_0.

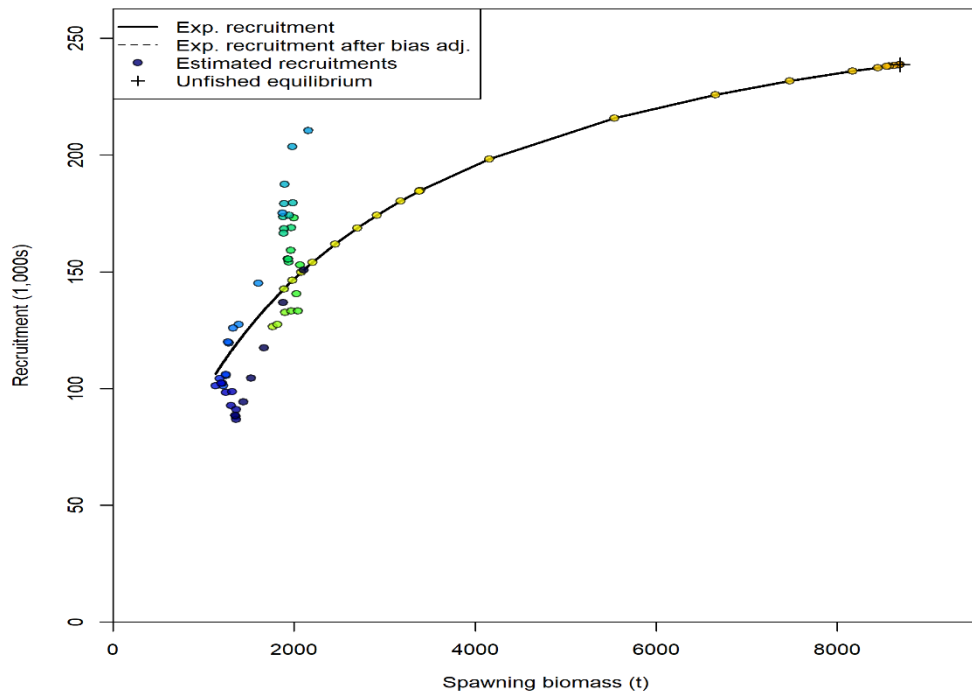


Figure 4. Estimated stock-recruitment relation for model Group_0.

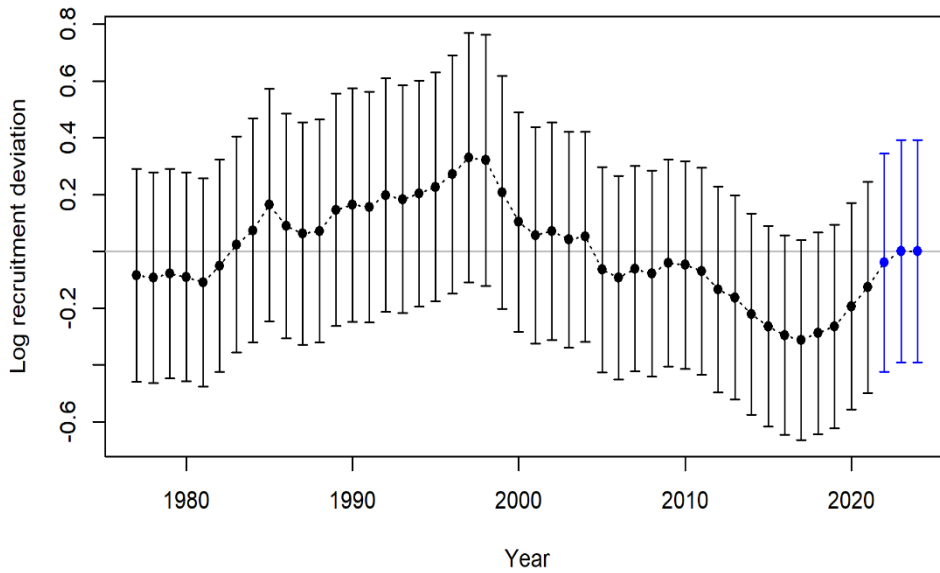


Figure 5. Annual recruitment deviations for model Group_0.

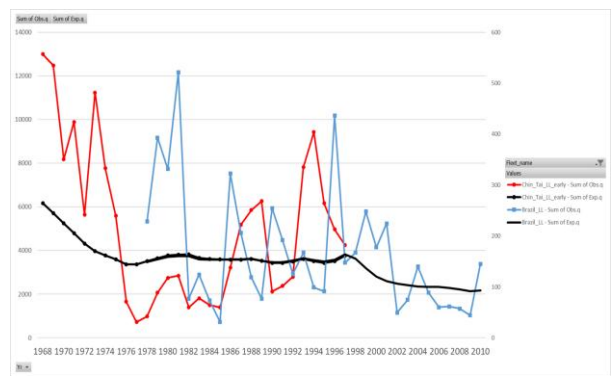
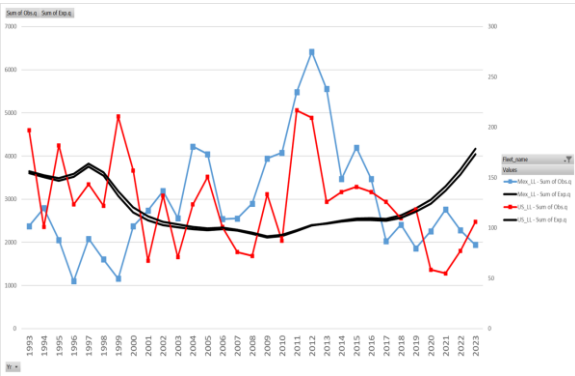
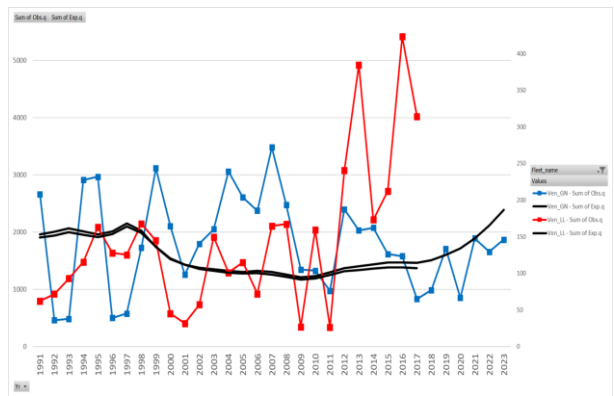
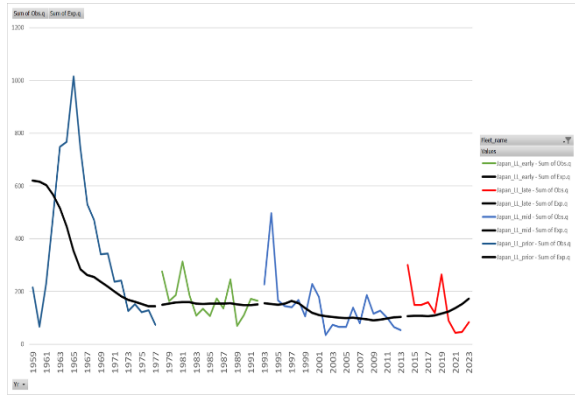


Figure 6. Fit to indices of abundance for model Group_0. Indices are grouped by geographic proximity or by fleet.

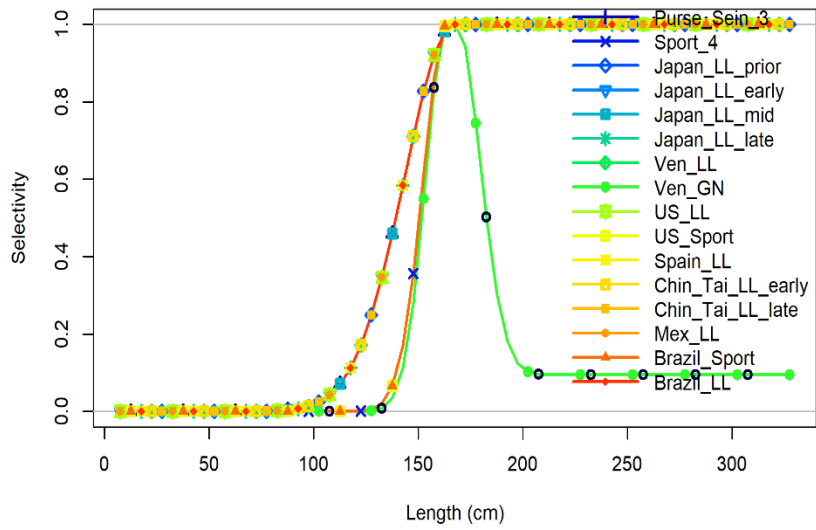


Figure 7. Selectivity at length for the four fleets and associated CPUE tie series.

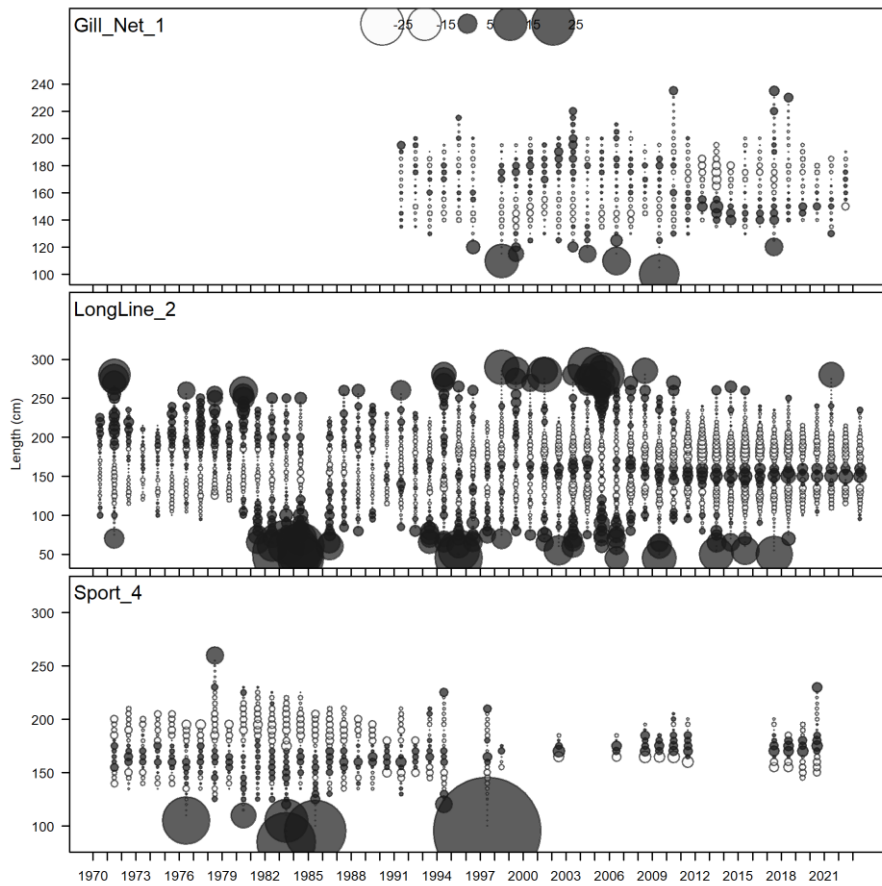


Figure 8. Pearson residuals, comparing across fleets. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

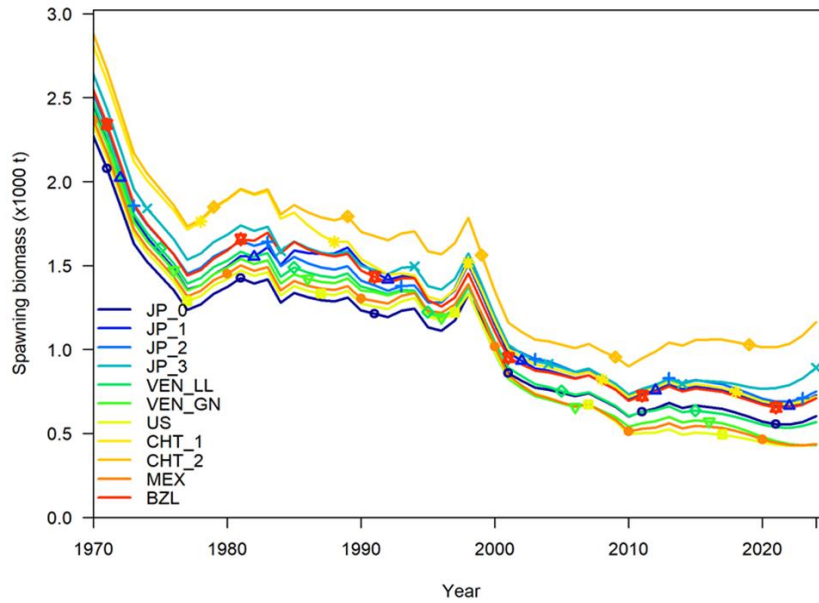


Figure 9. Jack-knife analysis where each CPUE decided upon at the Data Preparatory meeting is removed from the model Group_0. The ChT_2 time series was ultimately removed per the decision of the Technical Team.

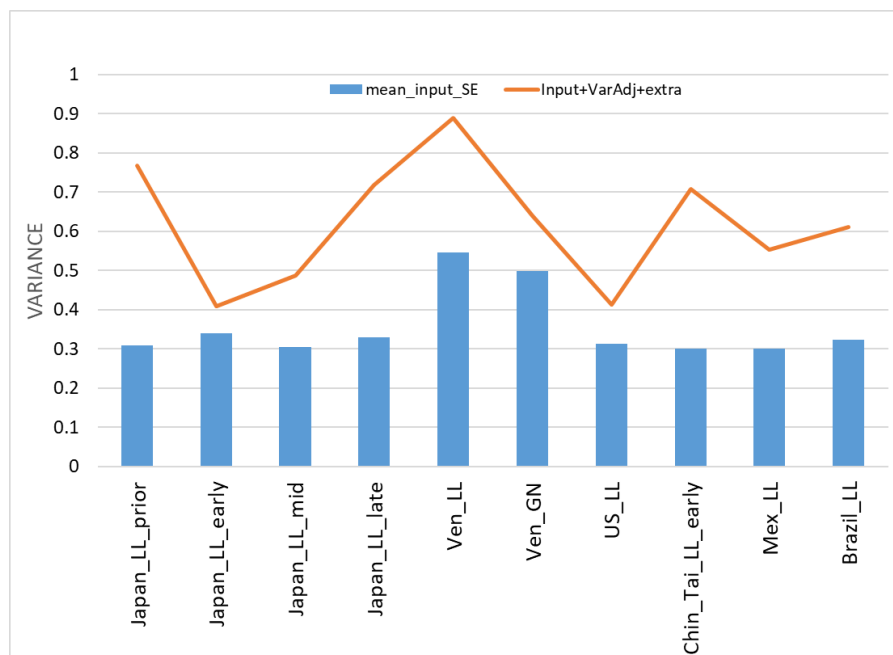


Figure 10. Input and Input + added variance for CPUEs for model Group_0.

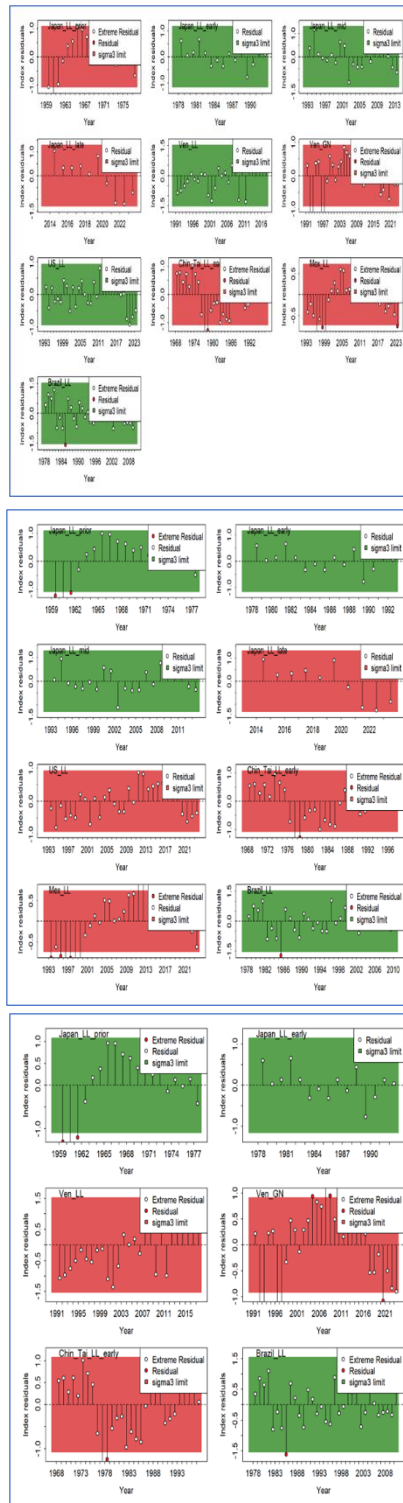


Figure 11. Run tests on fits to CPUE for (top) Group_01, (middle) Group_1, and (bottom) Group_2. Green background indicates no evidence ($p > 0.05$) to reject the hypothesis of a randomly distributed time-series of residuals. Red background indicates failure of test.

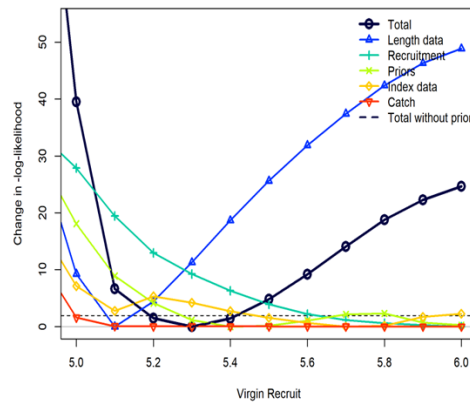
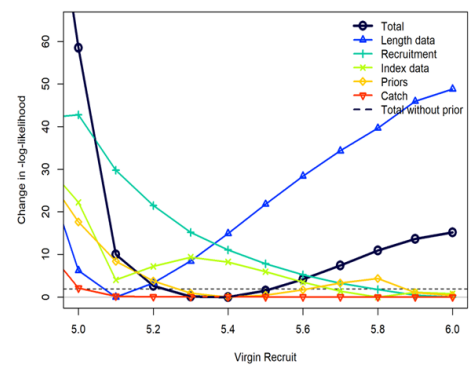
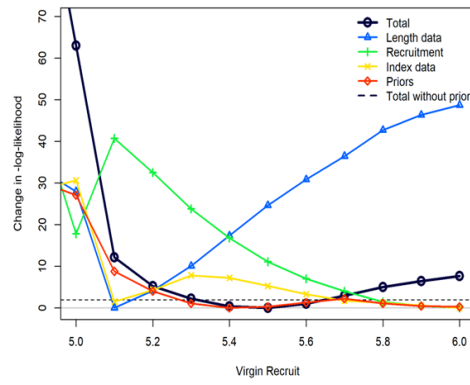


Figure 12. Profile analysis on virgin recruitment parameter (R_0) for model (top) Group_0, (middle) Group_1, and (bottom) Group_3.

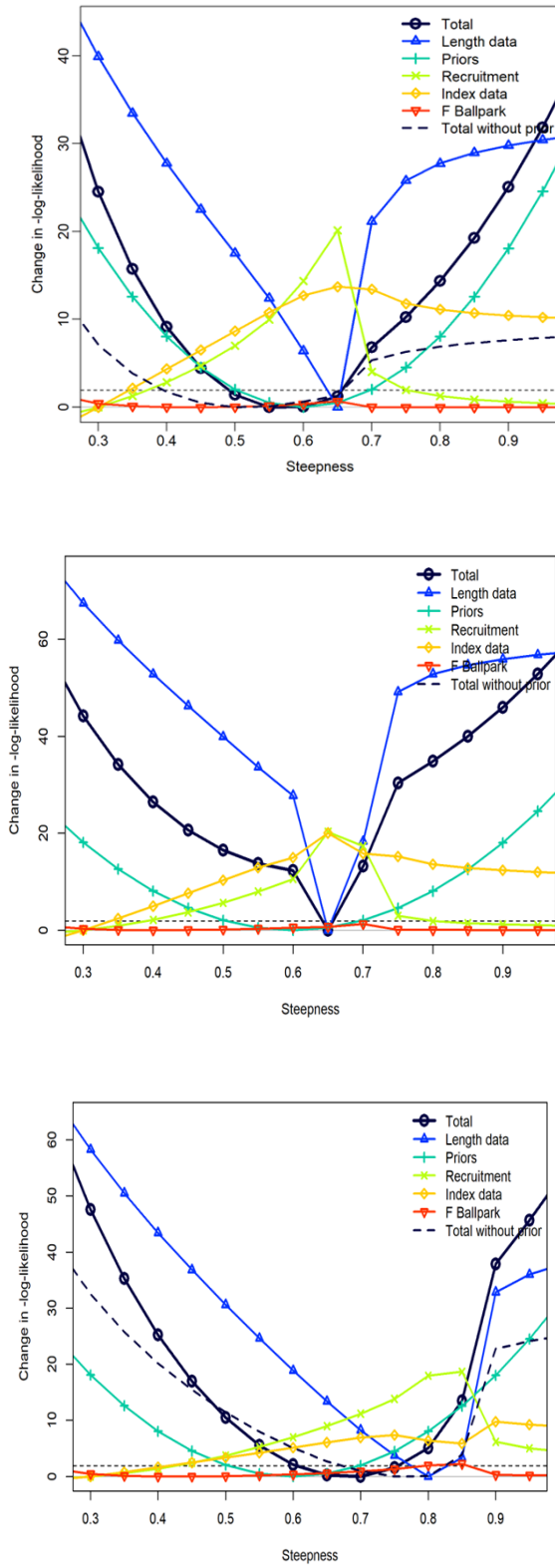


Figure 13. Profile analysis for steepness parameter (h) for model (top) Group_0, (middle) Group_1, and (bottom) Group_3.

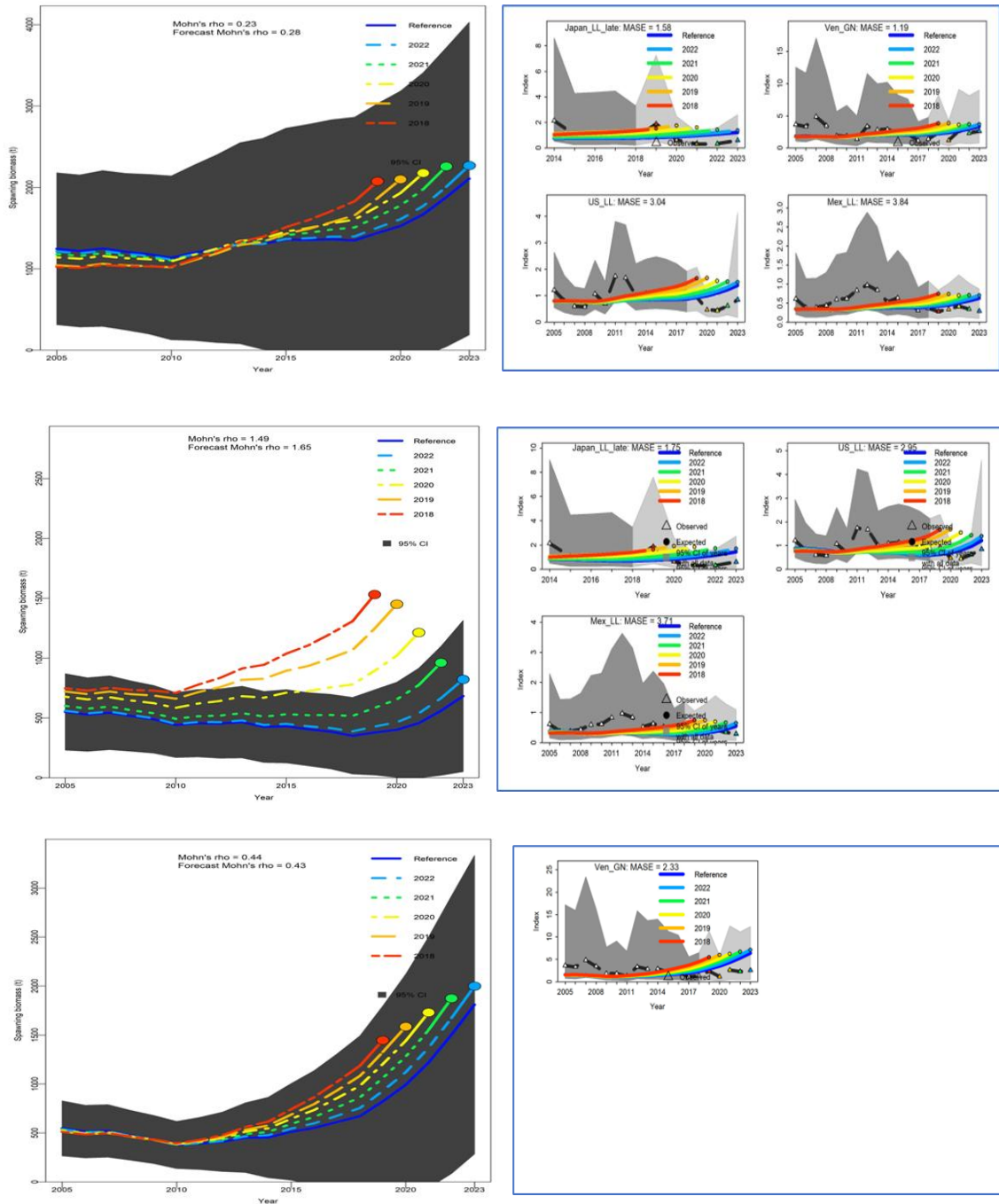


Figure 14. Retrospective analysis for Model_1 (top), Model_2 (middle) and Model_3 (bottom) for spawning stock biomass. The Mohn's rho statistic was calculated for a 5 year "peel".

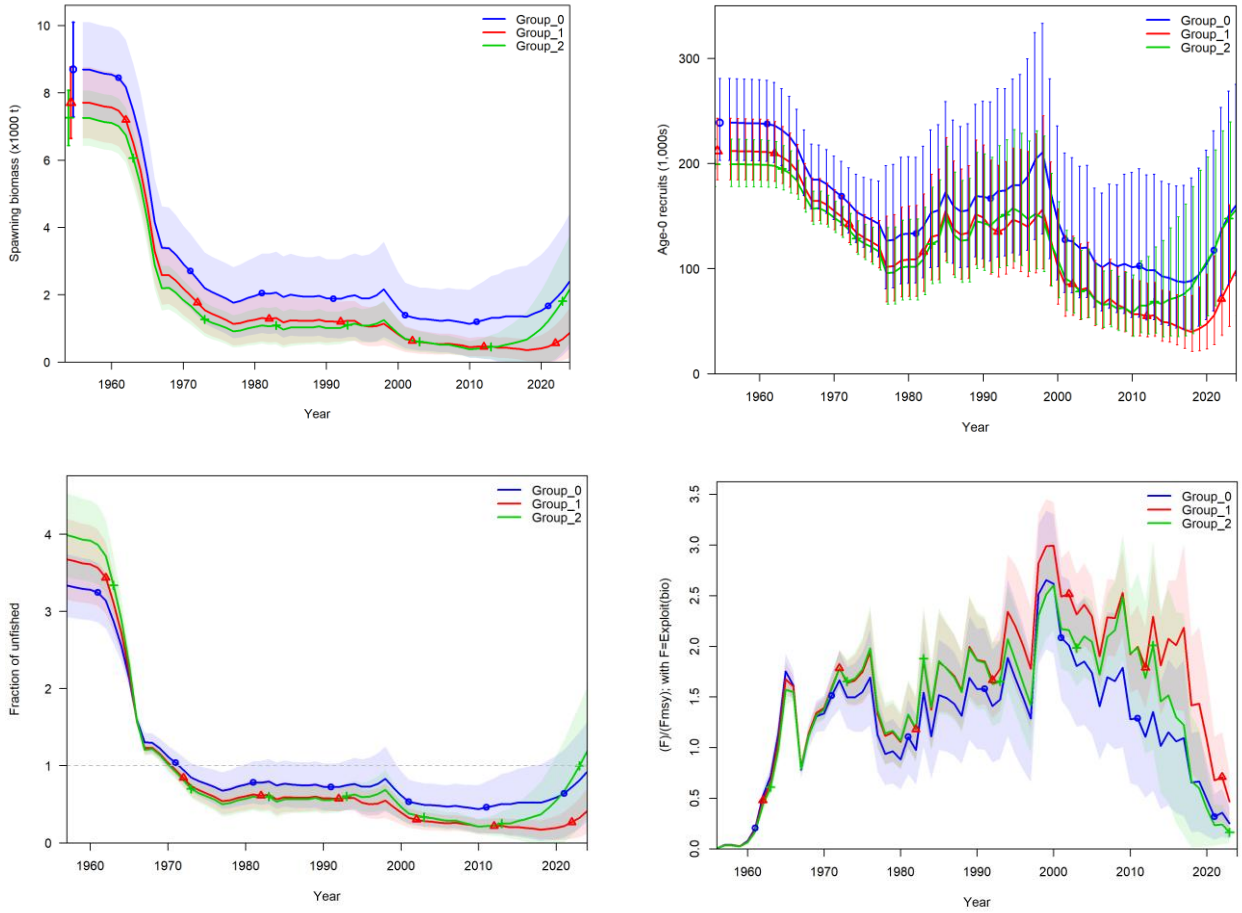


Figure 15. Estimated trends in (upper left) spawning stock biomass, (upper right) recruitment, (lower left) SSB/SSB_{MSY} and (lower right) F/F_{MSY} from the three models (Group_0, Group_1 and Group_2) under consideration.

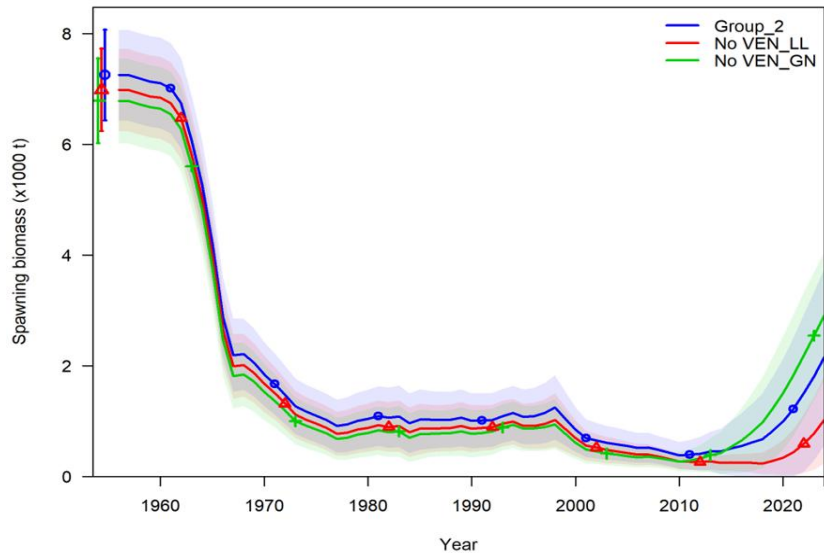


Figure 16. Estimated trends in spawning stock biomass from Group_2, Group_2 without using the VEN_LL and Group_2 not using the VEN_GN.

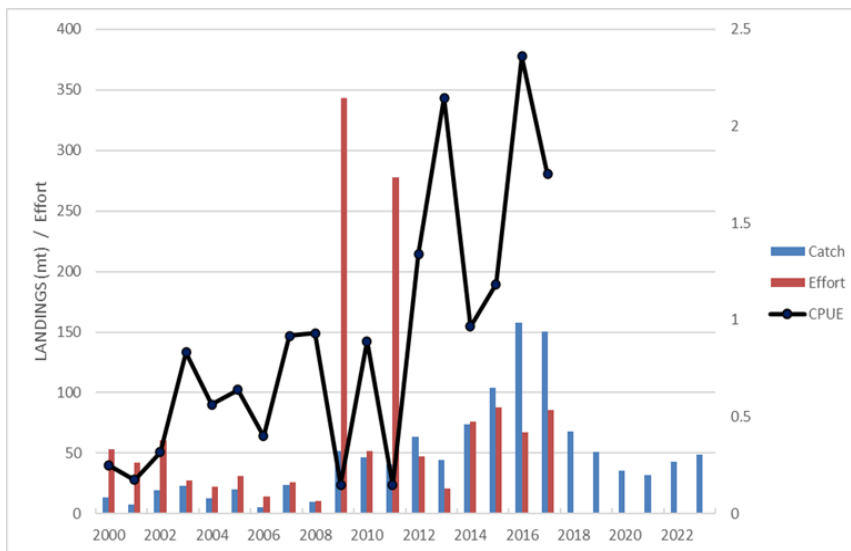


Figure 17. Catch, effort and catch per unit effort from the Venezuelan longline fishery.