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CPUE standardization for striped marlin caught by the Japanese longliners in the western and central North Pacific from 1977 to 2023[1]

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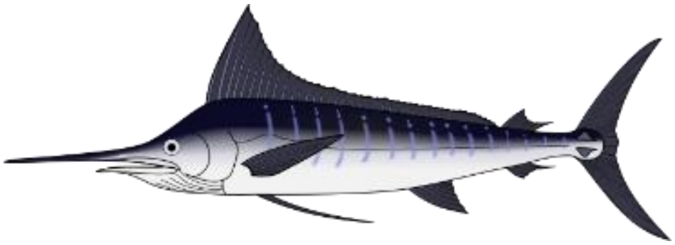

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Abstract

The nominal CPUE for striped marlin (*Kajikia audax*) caught by the Japanese coastal and distant water longline fisheries operating in the western and central North Pacific Ocean was standardized using a GLM with logbook data spanning the period from 1977 to 2023. Four explanatory variables—year, season, area, and fishing gear clusters—were used as main effects, along with their two-way interactions. Model selection revealed that a negative binomial model outperformed a Poisson model. According to AIC, the best model was the full model incorporating all combinations of two-way interactions, while BIC favored a full model excluding two-way interactions involving the year. Model diagnostics suggested that the best models fit the data adequately. For the AIC best model, the annual CPUE exhibited an upward trend until 1995 with significant annual fluctuations, followed by a downward trend until 2009, and then an increasing trend until 2022. For the BIC best model, the annual CPUE maintained a high level with significant annual fluctuations from 1977 to 1995, then showed a decreasing trend until 2010, followed by a slight increase, but remained at a low level until 2023. This study applied a simple method as a first step towards comprehensive CPUE standardization. It will be necessary to advance this work using more sophisticated methods in the future.

Introduction

A benchmark stock assessment of striped marlin (*Kajikia audax*) in the western and central North Pacific (WCNPO MLS) was conducted using Stock Synthesis (SS3) with fishery data from 1977-2020 by the ISC Billfish Working Group (BILLWG or WG) in 2023 (ISC 2023a). The stock status indicated that the stock was overfished ($SSB_{2018\text{-}2020}/20\%SSB_{(F=0)} = 0.37$) and was likely subject to overfishing ($F_{2018\text{-}2020}/F_{20\%SSB(F=0)} = 1.09$) relative to the dynamic 20-year $20\%SSB_{(F=0)}$-based reference points, where $SSB_{F=0}$ is the average of the dynamic B_0 over the last 20 years (2001-2020). However, the WG recognized substantial uncertainties, including the stock structure, the catch and CPUE (i.e., catch per unit effort) data, the life history parameters such as growth and maturity, and the initial equilibrium conditions, among others. To improve confidence in future WCNPO MLS stock assessments, the ISC 23 Plenary had determined to seek the opinions of experts through an external peer review (ISC 2023b), and the WG conducted the in-person review meeting in 2024 (ISC 2024). The review panel submitted a single consensus report to the ISC 24 Plenary. In the report, the reviewer recommended to standardize the Japanese longline CPUE series without splitting the periods before and after 1994.

The main purpose of this working paper is to standardize the nominal CPUE (catch per hook) for striped marlin caught by the Japanese offshore and distant water longliners operating in the western and central North Pacific Ocean using the full time series of data between 1977 and 2023.

Materials and Methods

Data

Logbook data reported by the Japanese coastal and distant water longline fisheries was used. To remove mis-reporting and spurious data, the following data filtering was carried out: 1) removed set-by-set data located on land, 2) removed set-by-set data other than the number of hooks between 500 and 4,500, 3) removed set-by-set data outside the northwestern Pacific Ocean (i.e., north of the equator and west of 150°W; WCNPO) which was the area used in the previous stock assessment in 2023 (Fig. 1), 4) removed set-by-set data other than the number of hooks between floats (hbf) from 3 to 23 according to the catch records for striped marlin. In addition, the three-month seasons were defined as winter (JAN-MAR), spring (APR-JUN), summer (JUL-SEP), and autumn (OCT-DEC). The WCNPO area was divided into four regions: northwest, northeast, southwest, and southeast, using the 20°N and 160°E lines (Fig. 1). The gear configuration (the number of hooks between floats, hbf) was categorized into three classes, 3~4, 5~14, and 15~23, based on hierarchical cluster analysis of species composition ratios by the number of hbf (Fig. 2). The set-by-set data were finally pooled by year, season, area, and fishing gear cluster (gear; hbf) to reduce computational cost and facilitate model convergence.

CPUE standardization

The nominal CPUE was standardized using a generalized linear model (GLM), assuming a negative binomial or Poisson distribution for the data. Four explanatory variables: year, season, area, and fishing gear clusters were used as main effects, and a two-way interaction of these explanatory variables were used as well.

Model selection

Model selection was carried out using AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion), respectively.

Model diagnostics

Model diagnostics was conducted using Pearson residuals and QQ plots.

Results

Data filtering

After data filtering, the number of set-by-set data items was reduced from 4,785,687 to 2,592,999. By pooling the data, the number of set-by-set data items was further reduced to 1,794.

Model selection

As a result of model selection, negative binomial models were found to be better than Poisson models. The full model including all combinations of two-way interactions was chosen as the best model by AIC (Table 1 and see the equation below), whereas a full model without two-way interactions in terms of year was chosen by BIC (Table 2; see also equations below).

AIC best model: Negative binomial (theta = 3.676)
striped_mar ~ yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear + qt:Area + qt:gear + yr:qt + Area:gear

BIC best model: Negative binomial (theta = 1.779)
striped_mar ~ yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear + Area:gear

Model diagnostics

The model diagnostics indicated that the fit the best models fit the data adequately (Figs. 3, 4, 5, and 6). In both models, the effect of changes in each explanatory variable on the CPUEs was strongest for the year, followed by season, area, and fishing gear cluster (Table 1, 2, Figs. 7, and 8).

Annual trends in CPUEs

For the AIC best model, the annual CPUE showed an upward trend with notable fluctuations until 1995, followed by a downward trend until 2009, and then an upward trend until 2022 (Fig. 9). For the BIC best model, the annual CPUE remained high with significant fluctuations from 1977 to 1995, then exhibited a downward trend until 2010, followed by a slight increase, but stayed at a low level until 2023 (Fig. 10). The effect of seasons showed high CPUEs in winter and spring, while low CPUEs were observed from summer to autumn for both models (Fig. 11). The CPUE was higher north of 20°N and east of 160°E compared to respective north-south and east-west areas for both models (Fig. 12). The effect of fishing gear tended to be highest for hbf 5-14 in both models (Fig. 13).

Discussions

Our study standardized the nominal CPUE for striped marlin caught by the Japanese coastal and distant water longline fisheries using a GLM with logbook data over a long time period 1977-2023. Although CPUE standardization has been conducted using methods such as GLM and GLMM in the past (Ichinokawa and Yokawa, 2006; Ijima and Kanaiwa, 2019a; Ijima and Kanaiwa, 2019b; Ijima and Koike, 2021; Yokawa 2004, 2005, 2006; Yokawa and Clark 2005; Shono et al., 2005; Kanaiwa et al., 2005), it has never been estimated as a continuous index from 1977 onwards (i.e., about 50 years).

The format of Japanese logbook data forms changed around 1975 and 1992. The amount of available information increased with these format changes. For example, since 1975, ‘the number of hooks between floats’ have been available, and since 1992, ‘sharks’ have been recorded by species. Additionally, records included the branch line length and material, main line material, and whether sharks or billfish were targeted. On the other hand, due to reporting issues following the format changes, data from the first two post-change years have often been discarded, and analyses generally started from 1977 or 1994. Additionally, the introduction of monofilament in the late 1980s and early 1990s is believed to have improved the catch efficiency of tuna species (Satoh et al. 1990). In the 1970s and 1980s, shallow-set gears were frequently used to target billfish, albacore, and yellowfin tuna. However, due to high market demand, stock fluctuation, and advancements in freezing and fishing gear technology, the targets gradually shifted to bigeye tuna. Consequently, the use of deep-set gear increased significantly after the 1990s. For the reasons mentioned above, CPUE standardization has been conducted separately for the periods ‘1977–1993’ and ‘1994–the most recent year’.

The 2023 stock assessment showed a clear change in the estimated recruitment levels around the mid-1990s. One of the possible reasons for this is the division of CPUE in 1994 (ISC 2024) as noted by the stock-assessment reviewers: *“[...]the current base case model estimated the population scale during the early period (1977-1993) largely independently of the late period (1994-) due to splitting the Japanese longline CPUE index before and after 1994”.* Based on this, the panel recommended developing a single CPUE index covering the assessment period. Therefore, this study attempted to standardize CPUE using data from 1977 to 2023.

As the amount of data increases, the model faces convergence issues. We therefore pooled the data according to explanatory variables and developed a simple GLM using a minimal set of important explanatory variables, demonstrating that CPUE standardization is possible even with long-term data. An important drawback is that reducing the amount of data decreases estimation accuracy and results in wider confidence intervals. Additionally, further examination of explanatory variables is warranted; for example, the WCNPO area is arbitrarily divided into four regions. The clusters of hooks between floats (hbf) based solely on species composition do not seem to reflect the actual longline fishing practices. In the future, complementary approaches to CPUE standardization should also be considered, including the application of GAM and spatiotemporal statistical models.

Pooling data reduces the variation available for standardizing the CPUE index. In addition, verifying the impact of targeting is critical for standardization, and set-by-set data is recommended for such analyses (Hoyle et al., 2007). Future standardizations should address how to handle operational-level data. Previous standardizations of abundance indices revealed large seasonal and spatial differences in catch size, indicating that the age composition reflected in the indices varies by season and location. As a result, abundance indices were standardized for specific seasons and locations to better align catch data with abundance estimates in the SS3 model. Addressing how to account for catch size in abundance indices remains a key challenge.

Two best models were selected based on AIC and BIC, but cross-validation (Shono and Tsubaki 2006) could be used as a method to pinpoint a single best model. The BIC best model does not include interaction terms containing the year, potentially failing to sufficiently standardize the spatial distribution of CPUE (which varies greatly by year), or the changes in CPUE due to changes in target (e.g., number of hooks between floats). From this perspective, it may be more desirable to use the AIC best model for the stock assessment.

References

Ichinokawa, M., Yokawa, K. 2006. Standardized CPUE of striped marlin caught by Japanese distant water longliners using set-by-set data in the north Pacific. ISC/06/MARWG&SWOWG-2/06.

ISC. 2023a. Stock Assessment Report for Striped Marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2020. ISC23 plenary report Annex 14, 12-17 July 2023 Kanazawa, Japan.

ISC. 2023b. Report of the 23rd meeting of the international scientific committee for tuna-like species in the North Pacific Ocean. ISC23 plenary report, 12-17 July 2023 Kanazawa, Japan.

ISC. 2024. Western and Central North Pacific Ocean Striped Marlin Assessment Consensus Peer Review. ISC24 plenary report Annex 11, 19-24 June 2024 Victoria, Canada.

Hoyle, S.D., Bigelow, K.A., Langley, A.D., Maunder, M.N., 2007. Proceedings of the pelagic longline catch rate standardization meeting. WCPFC-SC3-2007-ME-IP-1 (http://www.wcpfc.int/doc/me-ip-1/proceedings-pelagic-longline-catchrate-standardization-meeting, last accessed 3, November 2010).Ijima, H., Kanaiwa, M. 2019a. Size-dependent distribution of Pacific Striped Marlin (*Kajikia audax*): The analysis of Japanese longline fishery logbook data using the finite mixture model. ISC/19/BILLWG-1/09.

Ijima, H., Kanaiwa, M. 2019b. Japanese longline CPUE of the striped marlin (*Kajikia audax*) in the WCNPO. ISC/19/BILLWG-1/07.

Ijima, H, Koike, H., 2021. CPUE Standardization for Striped Marlin (*Kajikia audax*) using Spatio-Temporal Model using INLA.

Kanaiwa, M., Takeuchi, Y., Saito, H., Shono, H., Yokawa, K. 2005. Striped marlin CPUE standardization of Japanese longline fishery in North Pacific Ocean using a statistical habitat model. ISC/05/MARLIN-WG-05.

Shono, H., Yokawa, K., Clarke, S., Takeuchi, Y., Kanaiwa, M., Saito, H. 2005. Preliminary analysis for area stratification and CPUE standardization of striped marlin caught by Japanese longline fishery in the north Pacific using tree regression models (TRM). ISC/05/MARLIN-WG/06

Shono, H, Tsubaki, H. 2006. Fish Population Analysis by Neural Networks-Attempts for CPUE Prediction and Factorial Experiment. Japanese Journal of Biometrics. 27. 35-53. 10.5691/jjb.27.35.

Yokawa, K. 2004. Standardizations of CPUE of striped marlin caught by Japanese offshore and distant water longliners in the north-west and central Pacific. ISC/04/MARLIN-WG-02.

Yokawa, K. 2005. Standardizations of CPUE of striped marlin caught by Japanese coastal longliners in the northwest Pacific. ISC/05/MARLIN-WG-04.

Yokawa, K., Clark, S. 2005. Standardizations of CPUE of striped marlin caught by Japanese offshore and distant water longliners in the north Pacific. ISC/05/MARLIN-WG-03.

Yokawa, K. 2006. Update of CPUE standardizations of striped marlin caught by Japanese coastal longliners in the northwest Pacific. ISC/06/MARWG&SWOWG-2/04.

Table 1. Summary of model selection by AIC

	formula	Family(θ)	k	n	deviance	ΔD	AIC	ΔAIC
0	striped_mar~offset(log(hooks))	Negative Binomial (0.6851)	2	1794	24940.55	3213.66	24944.55	2327.66
1	striped_mar~yr + offset(log(hooks))	Negative Binomial (0.7793)	48	1794	24660.28	2933.39	24756.28	2139.39
2	striped_mar~yr + qt + offset(log(hooks))	Negative Binomial (0.8231)	51	1794	24544.55	2817.66	24646.55	2029.66
3	striped_mar~yr + qt + Area + offset(log(hooks))	Negative Binomial (1.1444)	54	1794	23908.63	2181.74	24016.63	1399.74
4	striped_mar~yr + qt + Area + gear + offset(log(hooks))	Negative Binomial (1.2064)	56	1794	23794.07	2067.18	23906.07	1289.18
5	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area	Negative Binomial (1.4363)	194	1794	23408.40	1681.51	23796.40	1179.51
6	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear	Negative Binomial (1.5728)	286	1794	23223.62	1496.73	23795.62	1178.73
7	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear + qt:Area	Negative Binomial (2.1795)	295	1794	22620.11	893.22	23210.11	593.22
8	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear + qt:Area + qt:gear	Negative Binomial (2.5373)	301	1794	22362.00	635.11	22964.00	347.11
9	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear + qt:Area + qt:gear + yr:qt	Negative Binomial (3.0307)	439	1794	22047.36	320.47	22925.36	308.47
10	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + yr:Area + yr:gear + qt:Area + qt:gear + yr:qt + Area:gear	Negative Binomial (3.6757)	445	1794	21726.89	0.00	22616.89	0.00

Table 2. Summary of model selection by BIC

	formula	family	k	n	deviance	ΔD	BIC	ΔBIC
0	striped_mar~offset(log(hooks))	Negative Binomial (0.6851)	2	1794	24940.55	1901.7	24955.53	1339.78
1	striped_mar~yr + offset(log(hooks))	Negative Binomial (0.7793)	48	1794	24660.28	1621.43	25019.91	1404.16
2	striped_mar~yr + qt + offset(log(hooks))	Negative Binomial (0.8231)	51	1794	24544.55	1505.7	24926.65	1310.9
3	striped_mar~yr + qt + Area + offset(log(hooks))	Negative Binomial (1.1444)	54	1794	23908.63	869.78	24313.21	697.46
4	striped_mar~yr + qt + Area + gear + offset(log(hooks))	Negative Binomial (1.2064)	56	1794	23794.07	755.22	24213.63	597.88
5	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area	Negative Binomial (1.5393)	65	1794	23327.98	289.13	23814.97	199.22
6	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear	Negative Binomial (1.6623)	71	1794	23196.1	157.25	23728.05	112.3
7	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear + Area:gear	Negative Binomial (1.7787)	77	1794	23038.85	0	23615.75	0

8	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear + Area:gear + yr:qt	Negative Binomial (2.081)	215	1794	22744.05	-294.8	24354.87	739.12
9	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear + Area:gear + yr:Area	Negative Binomial (2.4979)	215	1794	22399.86	-638.99	24010.68	394.93
10	striped_mar~yr + qt + Area + gear + offset(log(hooks)) + qt:Area + qt:gear + Area:gear + yr:gear	Negative Binomial (2.1582)	169	1794	22674.94	-363.91	23941.13	325.38

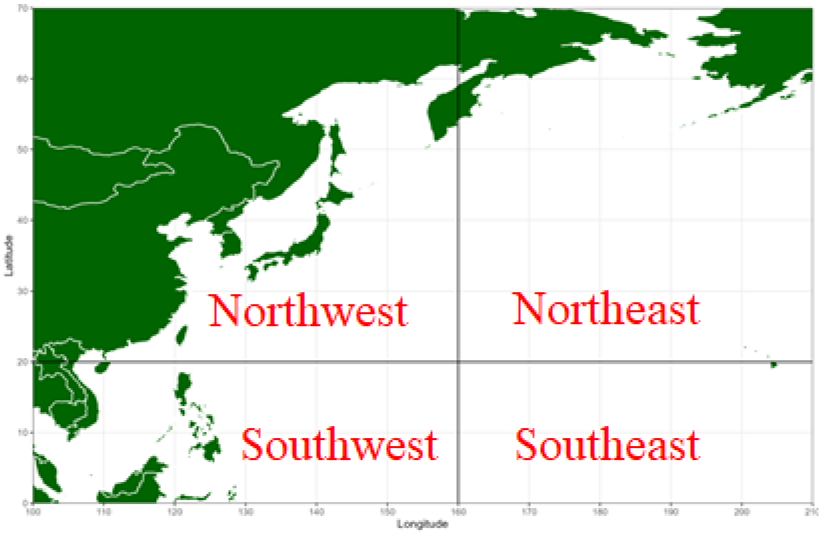

Fig1. Area definition used in the CPUE standardization. Four regions were defined as northwest, northeast, southwest, and southeast.

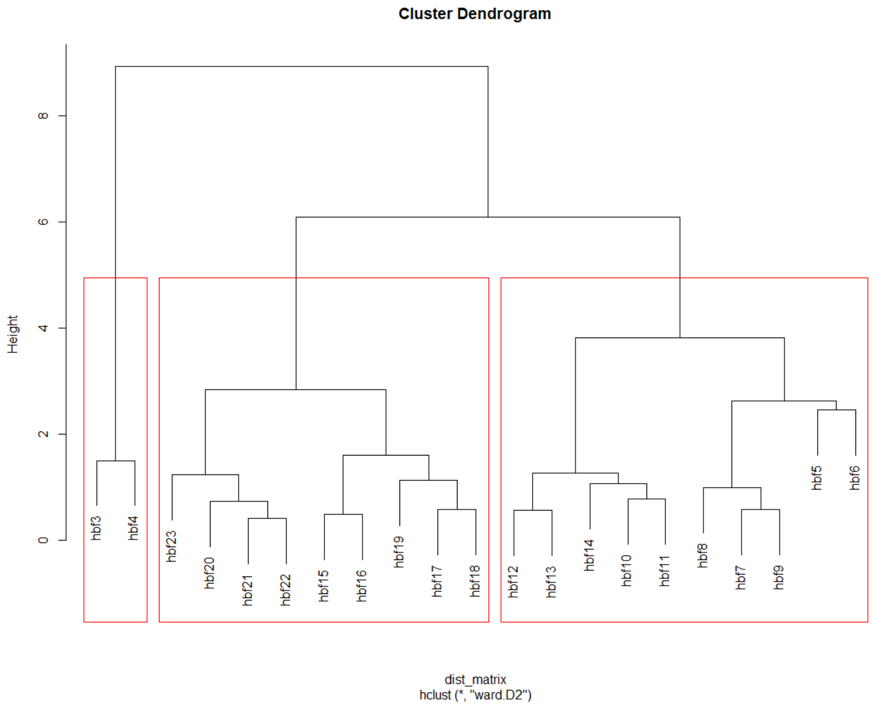

Fig2. Dendrogram for the cluster analysis based on hbf (hooks between floats) and species compositions ratios. Gear was defined as three classes of hbf: 3~4, 5~14, and 15~23.

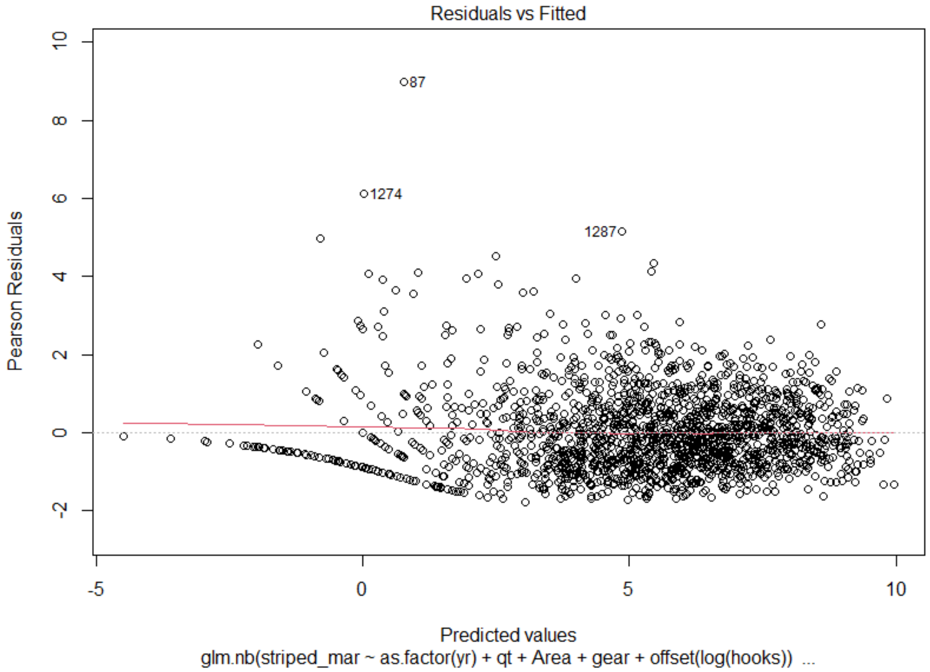

Fig. 3 Pearson residuals plot for the best model chosen by AIC.

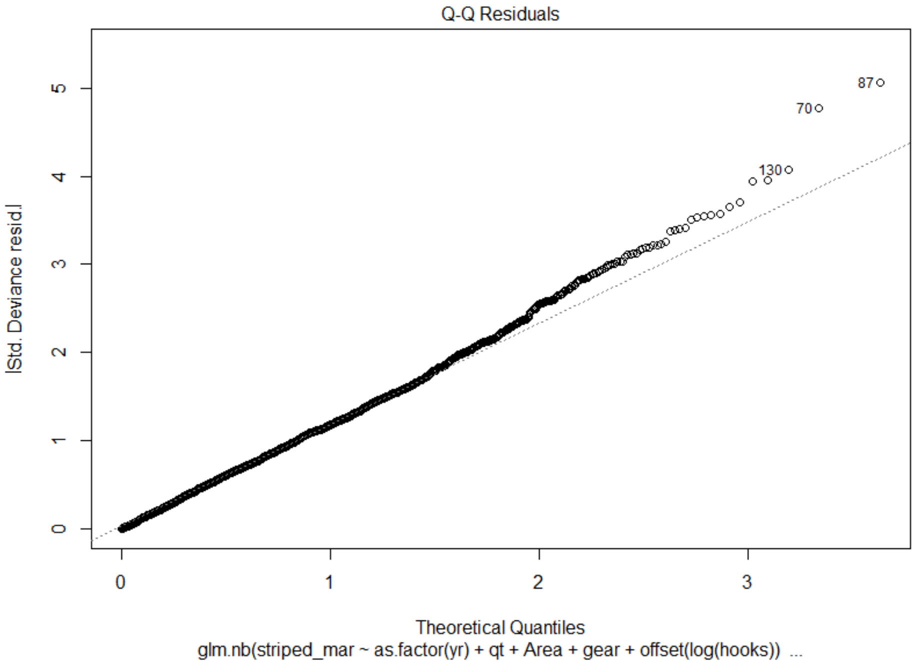

Fig 4. QQ plot for the best model chosen by AIC.

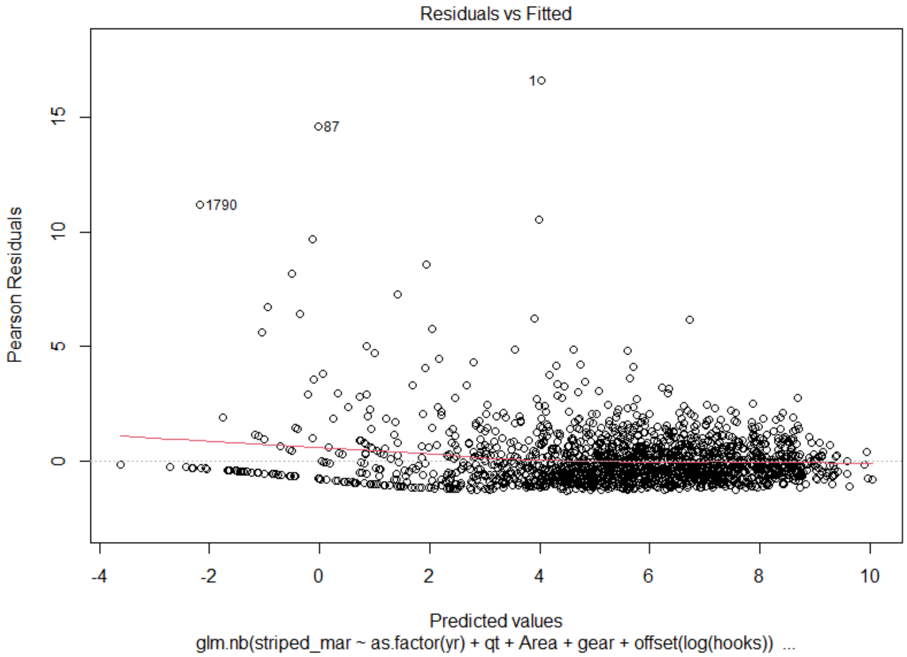

Fig 5. Pearson residual plot for the best model chosen by BIC.

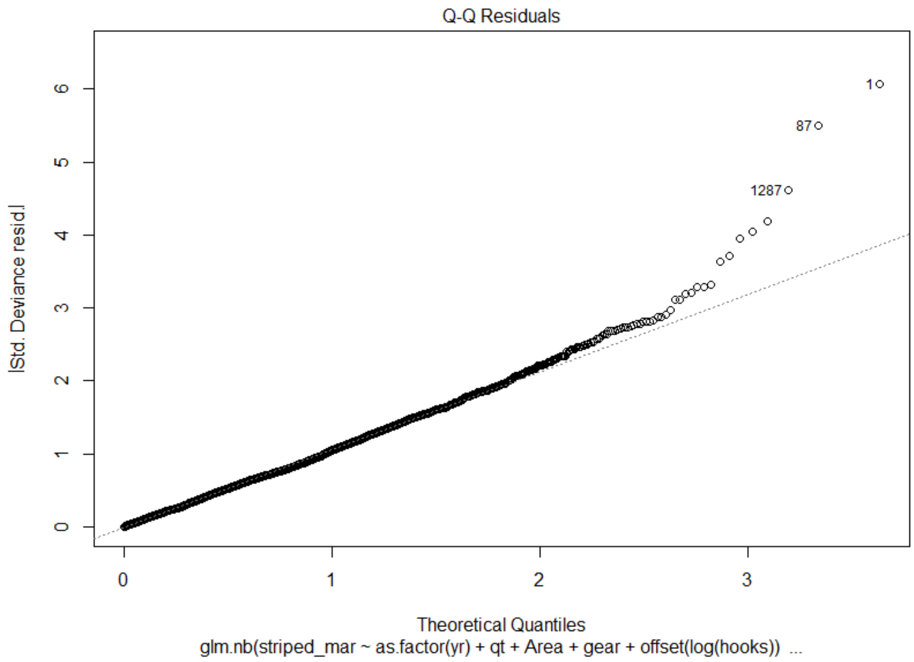

Fig 6. QQ plot for the best model chosen by BIC.

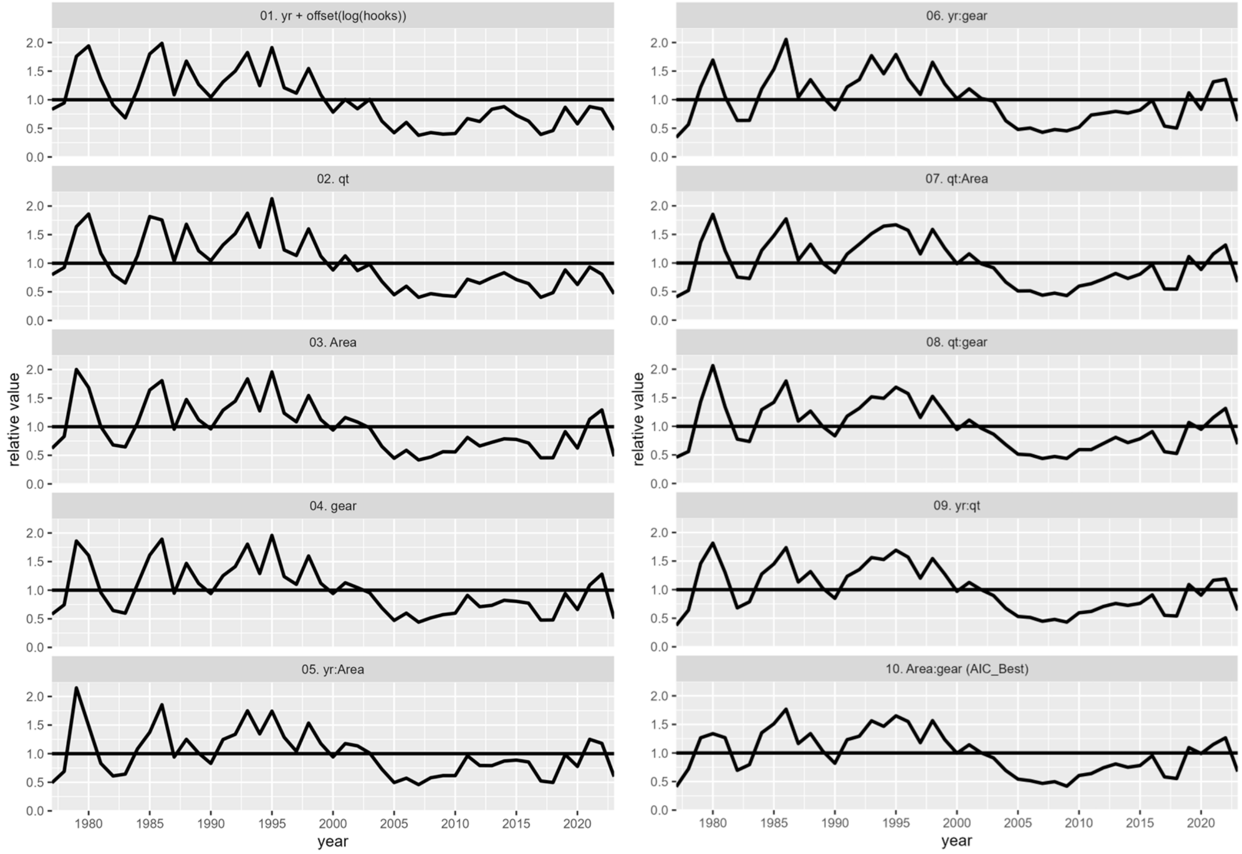

Fig 7. Influence plot for the best model chosen by AIC. Explanatory variables and two-way interactions are sequentially added to the base model (year only model).

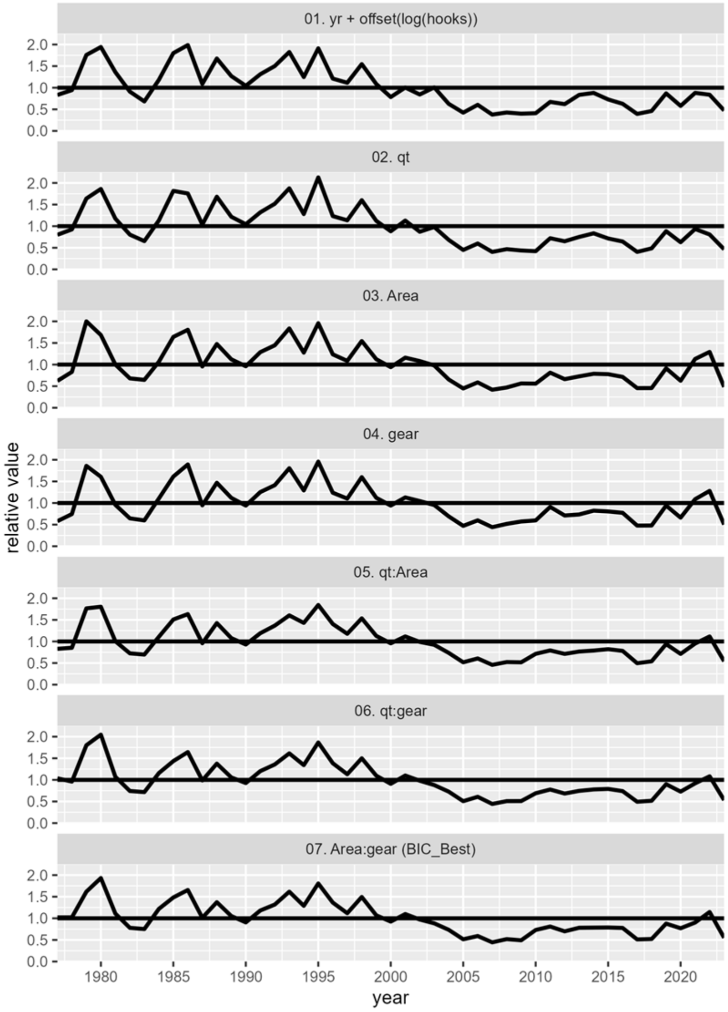

Fig 8. Influence plot for the best model chosen by BIC. Explanatory variables and two-way interactions are sequentially added to the base model (year only model).

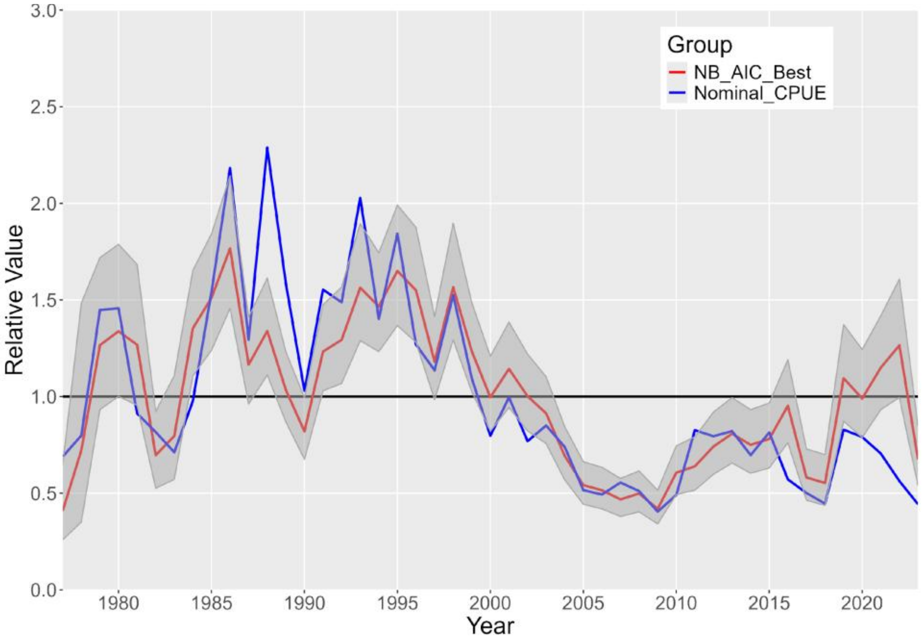

Fig 9. Annual changes in nominal CPUE (red line) and standardized CPUE (blue line) for the AIC best model. The grey shade denotes the 95% confidence interval.

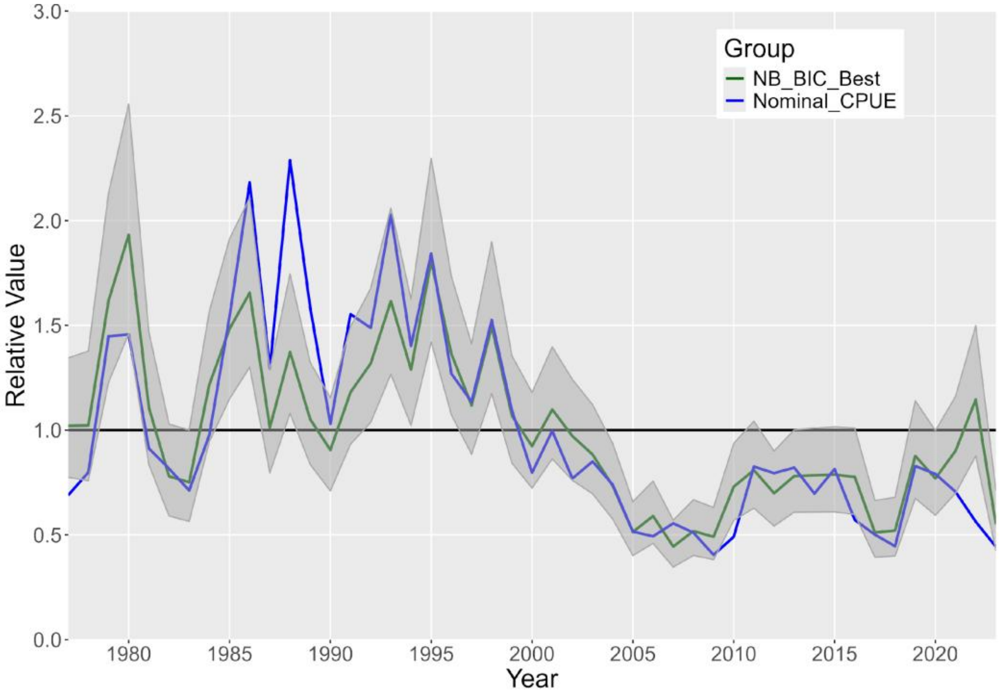

Fig 10. Annual changes in nominal CPUE (blue line) and standardized CPUEs (green line) for the BIC best model. The grey shade denotes the 95% confidence interval.

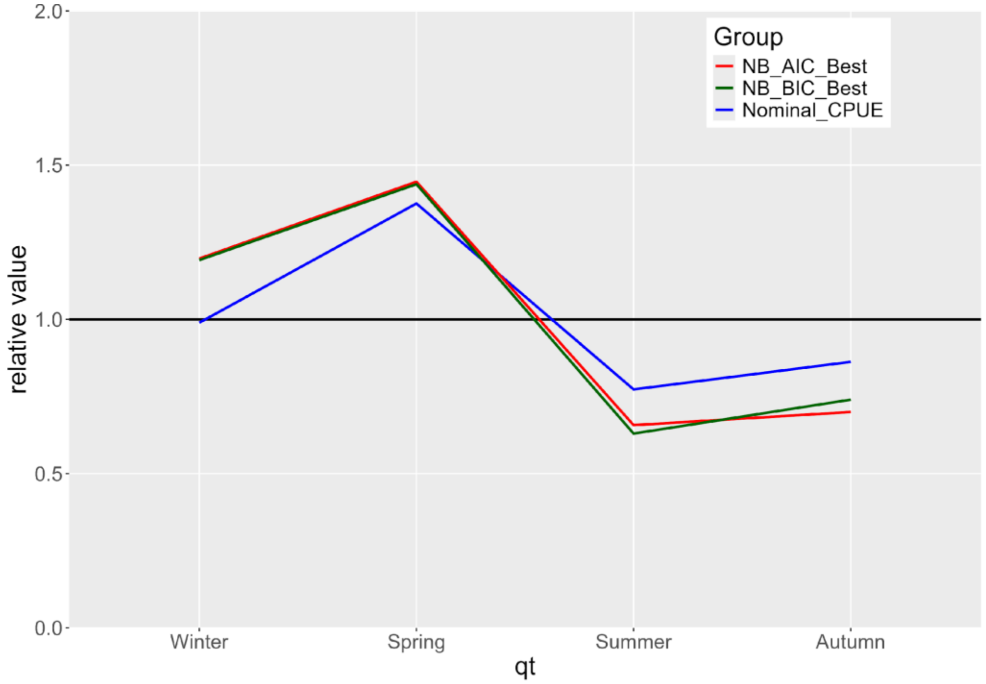

Fig 11. Seasonal changes in nominal CPUE (blue line) and standardized CPUEs for the AIC best model (red line) and the BIC best model (green line).

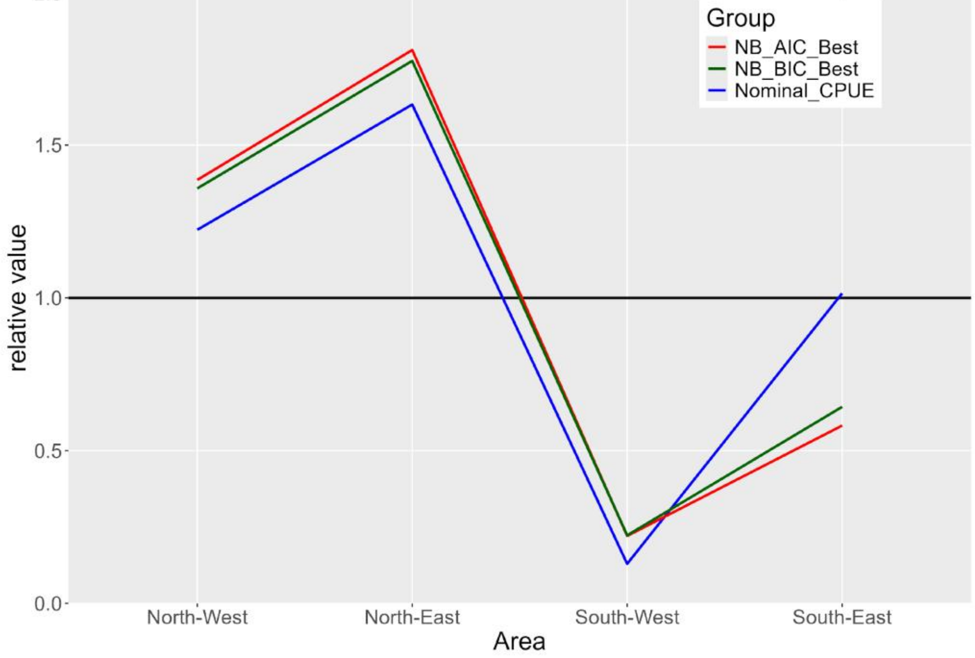

Fig 12. Spatial changes in nominal CPUE (blue line) and standardized CPUEs for the AIC best model (red line) and the BIC best model (green line).

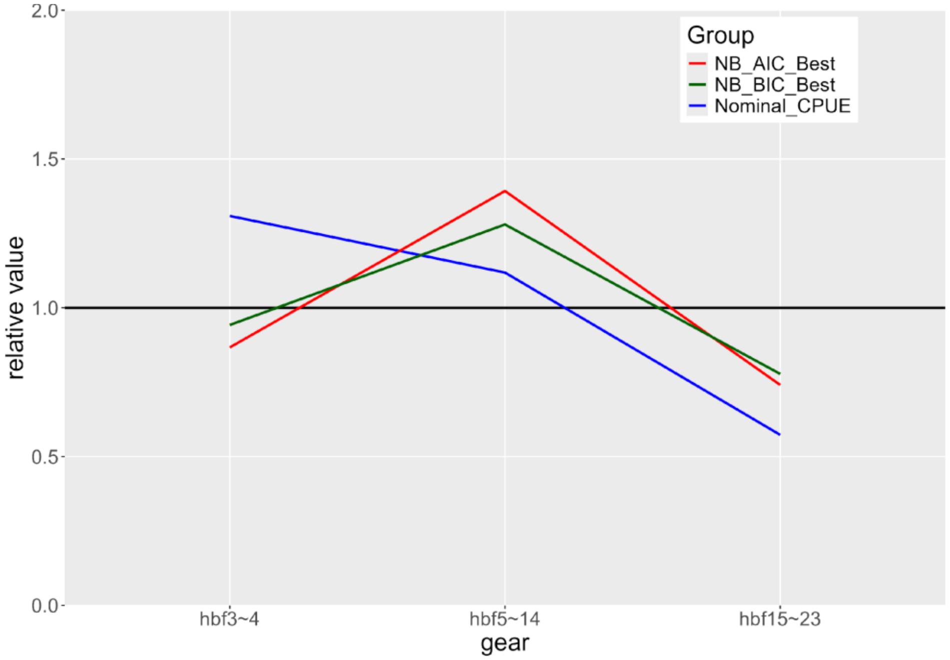

Fig 13. Gear-specific changes in nominal CPUE (blue line) and standardized CPUEs for the AIC best model (red line) and the BIC best model (green line).