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ASSESSMENT OF THE EFFECT OF HOOK SHAPE ON FISHING MORTALITY OF MULTI-TAXA FISH SPECIES USING EXPERIMENTAL LONGLINE OPERATION DATA

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SUMMARY

To evaluate the effect of circle hooks (C-hooks) on fishing mortality of fish species (blue shark, shortfin mako, striped marlinand swordfish) other than sea turtles in experimental longline operations, Bayesian estimation using statistical models was used to examine whether there were differences in haulback mortality rate, CPUE, mortality per unit effort (MPUE), and hooking position between 3.8 sun tuna hooks and size-different C-hooks. The results showed that the haulback mortality rate, CPUE, and MPUE did not improve with either size of C-hook, but rather tended to worsen. In addition, the use of the C-hook did not reduce the hook swallowing which can lead to post-release mortality. In addition, the mortality rate may be greatly influenced by environmental factors such as soak time and water temperature. These results suggest that it is necessary to consider the trade-off between the effects on sea turtles and on multi-taxa fish species when discussing the use of C-hooks.

RÉSUMÉ

Pour évaluer l'effet des hameçons circulaires (hameçons en forme de C) sur la mortalité par pêche d'espèces de poissons (requin peau bleue, requin-taupe bleu, makaire rayé et espadon) autres que les tortues de mer dans des opérations expérimentales palangrières, une estimation bayésienne utilisant des modèles statistiques a été utilisée pour examiner s'il y avait des différences dans le taux de mortalité par remontée, les CPUE, la mortalité par unité d'effort (MPUE) et la position de l'hameçon entre les hameçons thoniers de 3,8 sun et les hameçons en forme de C de tailles différentes. Les résultats ont montré que le taux de mortalité à la remontée de l'engin, les CPUE et les MPUE ne s'amélioraient pas avec les différentes tailles d'hameçons en forme de C, mais avaient plutôt tendance à s'aggraver. En outre, l'utilisation de l'hameçon en forme de C n'a pas réduit l'avalage de l'hameçon qui peut entraîner une mortalité après la remise à l'eau. En outre, le taux de mortalité peut être grandement influencé par des facteurs environnementaux tels que le temps de mouillage et la température de l'eau. Ces résultats suggèrent qu'il est nécessaire de prendre en compte le compromis entre les effets sur les tortues marines et sur les espèces de poissons multi-taxons lorsque l'on discute de l'utilisation de l'hameçon en forme de C.

RESUMEN

Para evaluar el efecto de los anzuelos circulares (anzuelos C) sobre la mortalidad por pesca de especies de peces (tintorera, marrajo dientuso, marlín rayado y pez espada) distintas a las tortugas marinas en operaciones experimentales de palangre, se utilizó la estimación bayesiana usando modelos estadísticos para examinar si existían diferencias en la tasa de mortalidad en la virada, en la CPUE, en la mortalidad por unidad de esfuerzo (MPUE) y en la posición de enganche del anzuelo entre anzuelos de túnidos de 3,8 sun y anzuelos circulares de diferentes tamaños. Los resultados demostraron que la tasa de mortalidad de la virada, la CPUE y la MPUE no mejoraban con diferentes tamaños de azuelo en forma de C, sino que más bien tendían a empeorar. Además, el uso de anzuelos circulares no reducía el que los peces se tragaran el anzuelo, que puede dar lugar a mortalidad posterior a la liberación. Asimismo, la tase de mortalidad podría estar muy influida por factores medioambientales como el tiempo de inmersión y la temperatura del agua. Estos resultados sugieren que es necesario considerar la compensación entre los efectos sobre las tortugas marinas y sobre especies de peces de múltiples taxones a la hora de discutir el uso de anzuelos circulares.

KEYWORDS

Billfishes, Bycatch, Fishing gear, Longlining, Research vessels, Sharks, Tuna fisheries

1. Introduction

In recent years, effectiveness of circle hooks (hereafter referred to as C-hooks) for tuna longline fisheries has been continuously discussed in ICCAT. There are concerns about the negative/positive effects on the haulback mortality on fish species other than sea turtles, especially sharks, and billfishes.

Currently, there are several issues that need to be addressed: 1) does the use of C-hooks reduce fishing mortality which contains mortality rate and catch rate, 2) does operational environment affect haul-back mortality, and 3) does the use of C-hooks reduce fatal hooking (i.e., gut hooking due to hook swallowing). Although many studies on these topics have been published in scientific papers (e.g., Watson et al. 2005; Diaz et al. 2008; Carruthers et al. 2009; Ward et al. 2009; Sales et al. 2010; Afonso et al. 2011; Coelho et al. 2012; Domingo et al. 2012; Huang et al. 2016), the results have not been consistent. A meta-analysis has also shown that C-hooks reduce the catch rate of sharks but increase mortality rate (Gilman et al. 2016; Reinhardt et al. 2017) hence conclusions about the effectiveness of C-hooks in reducing fishing mortality have yet to be drawn.

The weaknesses of the studies conducted so far include: (i) heterogeneity in operating conditions, fishing gear and environment in the data due to the collection of data from various commercial vessels; (ii) "bite-off" by sharks without using wire leaders; (iii) the confounding effect of soak time and water temperature on mortality rate; and (iv) the failure to consider the number of dead catches as an indicator, only comparing mortality and catch rates. These problems may be attributed to the fact that the effectiveness of C-hooks has not been quantitatively evaluated.

Therefore, we attempted to verify the above four points by using data from the experimental longline operations designed for scientific surveys in the Northwest Pacific Ocean. The data from the 612 operations used in this analysis were conducted under almost the same conditions (operation season, shallow set, use of wire leaders, bait type, and nighttime soaking), making it easy to conduct quantitative comparisons and evaluations.

Using the above data, the current study will examine whether C-hooks reduce (1) haulback mortality rate, (2) CPUE, (3) mortality per unit effort (MPUE; Afonso et al. 2011), and 4) incidence rate of hook swallowing for four fish species.

2. Methods

2.1 Experiments and data

For this analysis, data from 200,588 hooks of 612 experimental longline operations conducted by the R/V Taikei No. 2 (196 GT) chartered from April to June of each year from 2002 to 2010 were used. The area of the operations for each year is shown in **Figure 1**. Most of the operations were conducted off Sanriku and east of the Izu Islands. The style of operation and fishing gear were the same as those of Yokota et al. (2006), and the longline operation consisted of a nighttime soaking shallow set targeting for swordfish, with setting in the evening and hauling in the early morning. The hooks per basket was 4, and the distance between buoys was approximately 23 m.

The configuration of the branchline was also that of a typical Japanese longline operation for swordfish. It was 15 meters long, made of polyester line and nylon monofilament, with a wire leader attached to the 2.5 meters of the branchline. The length of the float line was 8 meters, and the depth of the hooks was approximately 40-90 meters.

Tuna hooks (3.8-sun) were used for the control group and C-hooks were used for the experimental group. Because the C-hooks used varied in size, the hook size categories were simplified by the expedient of that those equal to or larger than 18/0 were categorized as *Large* C-hooks and those smaller than 18/0 as *Small* C-hooks (**Table 1**). The offset of all hooks was just smaller than 10°. Multiple experimental sections were set up for the sequence of longlines, and tuna hooks and C-hooks were used alternately in each section. (Yokota et al. 2006).

We used whole frozen Japanese flying squid *Todarodes pacificus* as bait and thawed them completely before using them. Frozen mackerel were also used as bait in some operations but were excluded from the analysis due to the small number of samples using this bait in the C-hook. For all catches that could be identified, we recorded fate at capture, hooking position, time of catch, and branchline sequential number. In this study, we selected the data of blue shark *Prionace glauca*, shortfin mako *Isurus oxyrinchus*, striped marlin*Kajikia audax* and swordfish *Xiphias gladius* (**Table 2**), which were caught in substantial numbers, for the analysis.

The data used in the statistical model in the next section are the year of operation, setting location (latitude), surface water temperature at the start of each operation, catches and effort by hook type as information related to the operation, and the captured species, fate at hauling, hooking position (mouth, swallow, body), and soak time of the branchline (calculated from buoy casting time and hauling time) as information on each catch (**Table 2-4**).

2.1 Statistical model

All analyses were performed using parameter estimation with a hierarchical Bayesian model. The model structure is shown in **Figure 2**. The model is divided into two parts, one to estimate haulback mortality rate in each hook type based on the latent Dirichlet allocation model (Blei et al. 2003) and the other to estimate standardized CPUE based on GLM. By multiplying the parameters estimated by both parts, the mortality per unit effort (MPUE) is calculated.

In general, standardized CPUE calculations mainly examine the effects of time scales such as year and season, but it should be noted that the effects of hook types were examined here to evaluate the effects of hook-induced mortality. In the estimation, we initially included the factor of body size as a candidate parameter explaining haulback mortality, but finally excluded it because it had little effect on the results for all species.

Parameter estimation using the Bayesian approach was performed using Stan (rstan 2.21.2), and all analyses other than Bayesian estimation were performed using R 4.0.3. All estimates were done by MCMC (NUTS) sampling (4 chains, 2000 iterations, 1000 warmups, no shinning). Since Bayesian estimation does not allow for significance testing of parameters, the difference between groups was conventionally determined by the median of one estimated parameter being outside the 95% Bayesian credible interval of the other (Krusche 2014).

3. Results

All the parameter estimates by MCMC converged, and the Rhat of all the estimated parameters was less than 1.1, indicating that the estimation results were sufficiently robust.

3.1 Haulback mortality rate

Haulback mortality rate by hook type is shown in **Figure 3**. There was no clear difference in haulback mortality rate by hook type among the fish species. In particular, the mortality rate of blue shark was very low regardless of the hook type, while that of striped marlin and swordfish was high in any hook types.

3.2 CPUE and MPUE

Figure 4 shows the standardized CPUE by hook types, and **Figure 5** shows the MPUE, the expected value of fishing mortality calculated based on CPUE and haulback mortality rate. Uncertainty was slightly higher for shortfin mako, but the standardized CPUE and MPUE of sharks tended to be lower for tuna hooks and higher for C-hooks. A similar trend was observed for billfishes, but the differences were not as clear as for sharks.

3.3 Environmental factors on mortality rate

The effects of soaking time and water temperature (SST) on mortality are shown in **Figure 6** and **7**, respectively. Although there was a great uncertainty overall, the mortality rate increased with prolonged soaking time, which was consistent among the four species. However, with the single exception of striped marlin, in which the increase was very gradual.

The response to water temperature differed among the species, with sharks and swordfish showing a tendency for mortality to increase with higher water temperatures. In the case of striped marlin, the haulback mortality rate was higher at lower water temperatures.

3.4 Composition of hooking position at hauling

Figure 8 shows the hooking position composition when the fish were caught. The composition of hooking position differed among species: two shark species swallowed nearly 50% of hooks, striped marlins mostly hooked in the mouth, and swordfish had a composition intermediate between sharks and striped marlins. Expedient *Small* C-hooks tended to be hooked in mouse more frequently for shortfin mako and swordfish, while expedient *Large* C-hooks and tuna hooks showed no clear difference in hooking composition for all species.

4. Discussion

Regarding the effects of C-hooks on fishing mortality other than sea turtles, the results of this analysis showed that MPUE of sharks and billfishes tended to be worsened with both expedient *Large* and *Small* C-hooks (**Figure 4-6**). In the case of billfish, the mortality rate was similar level for *Large* and *Small* C-hooks, but in the case of sharks, fishing mortality was higher for *Small* C-hooks. The reason for the worsening of MPUE may be due to the difference in CPUE, as haulback mortality rate did not differ among hook types.

Because the experimental operations used in this analysis used wire leaders for branch lines, the problem of bite off by sharks, which has been an issue in the past discussion, was almost avoided. Therefore, we consider that we have been able to make a reasonably accurate assessment of the C-hook effect on fishing mortality in this analysis. In fact, in the case of swallow hooking, which is prone to bite off in the operation using branch line other than wire leaders, surviving individuals are no longer observable due to bite off, so if data from operations that do not use wire leaders are used, the fishing mortality rate is likely to be overestimated. It is difficult to verify and evaluate the true effects without considering methods to complement the effects of bite off, and it is necessary to establish extrapolation methods such as comparing catches under the same operating conditions.

As for the effects on billfishes, although there is greater uncertainty than for shortfin makos, there is little benefit from C-hook, and in fact tuna hooks are more effective in reducing fishing mortality. However, the haulback mortality rate of billfishes was higher than that of sharks, and since mortality rates are greatly influenced by other environmental factors such as water temperature and soak time, the reducing fishing mortality of billfishes by live release may be more uncertain than for sharks.

Although there is a great uncertainty about the relationship between haulback mortality rate and environmental factors, the positive relationship between soak time and mortality rate for all species may be drawn from the effects of debilitation and respiratory distress caused by hooking. As for the relationship with water temperature, the difference between the water temperature in the depth zone and the surface water temperature may affect the physiological homeostasis of the caught fish, but this needs to be additionally examined based on the knowledge of the physiological response of the target fish to water temperature.

The frequency of swallow hooking, which can increase post-release mortality, did not differ significantly among hook types in the experimental operations, suggesting that the use of C-hooks does not improve post-release mortality. The difference in the percentage of swallowing hooks was more apparent for the fish species rather than for the hook type. This may reflect the differences in feeding methods among species. Since the feeding method may vary depending on the type of bait, it is necessary to verify the hooking position of the fish bait.

Our results indicate that C-hooks, which have been shown to be effective for sea turtle bycatch, may be ineffective or exacerbate mortality in other fish species. It is necessary to continue to accumulate cases of accurate impact assessment in the Atlantic Ocean, and then careful discussion including the trade-off of the effect among multi-taxa-species and the combination of various mitigation measure taking into consideration of the spatio-temporal overlap between fishing effort and species of concern is necessary before the introduction of C-hooks.

References

Afonso, A.S., Hazin, F.H.V., Carvalho, F., Pacheco, J.C., Hazin, H., Kerstetter, D.W., Murie, D. and Burgess, G.H. 2011. Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. Fish. Res. 108: 336–343.

Blei, D.M., Ng, A.Y. and Jordan, M.I. 2003. Latent Dirichlet allocation. J. Machine Learn. Res. 3: 993-1022.

Carruthers, E.H., Schneider, D.C. and Neilson, J.D. 2009. Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. Biol. Conserv. 142(11): 2620–2630.

Coelho, R., Santos, M. N., and Amorim, S. 2012. Effects of hook and bait on targeted and bycatch fishes in an equatorial Atlantic pelagic longline fishery. Bull. Mar. Sci. 88(3): 449–467.

Diaz, G.A. 2008. The effect of circle hooks and straight (J) hooks on the catch rates and numbers of white marlin and blue marlin released alive by the U.S. pelagic longline fleet in the Gulf of Mexico. N. Am. J. Fish. Manag. 28(2): 500–506.

Domingo, A., Pons, M., Jiménez, S., Miller, P., Barceló, C., and Swimmer, Y. 2012. Circle hook performance in the Uruguayan pelagic longline fishery. Bull. Mar. Sci. 88(3): 499–511.

Gilman, E., Chaloupka, M., Swimmer, Y., and Piovano, S. 2016. A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. Fish and Fisheries 17(3): 748–784.

Huang, H.-W., Swimmer, Y., Bigelow, K., Gutierrez, A., and Foster, D.G. 2016. Influence of hook type on catch of commercial and bycatch species in an Atlantic tuna fishery. Mar. Policy 65: 68–75.

Kruschke, J. 2014. Doing Bayesian data analysis: A tutorial with R, JAGS, and Stan. Elsevier inc.

Reinhardt, J.F., Weaver, J., Latham, P.J., Dell'Apa, A., Serafy, J.E., Browder, J.A., Christman, M., Foster, D.G. and Blankinship, D. R. 2018. Catch rate and at-vessel mortality of circle hooks versus J-hooks in pelagic longline fisheries: A global meta-analysis. Fish and Fisheries, 19(3), 413–430.

Sales, G., Giffoni, B.B., Fiedler, F.N., Azevedo, V.G., Kotas, J.E., Swimmer, Y., and Bugoni, L. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquat. Conserv. 20(4): 428–436.

Ward, P., Epe, S., Kreutz, D., Lawrence, E., Robins, C., and Sands, A. 2009. The effects of circle hooks on bycatch and target catches in Australia's pelagic longline fishery. Fish. Res. 97(3): 253–262.

Watson, J.W., Epperly, S.P., Shah, A.K., and Foster, D.G. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fish. Aquat. Sci. 62(5): 965–981.

Yokota, K., Kiyota, M., and Minami, H. 2006. Shark catch in a pelagic longline fishery: comparison of circle and tuna hooks. Fish. Res. 81(2–3): 337–341.

Table 1 Fishing effort by hook type

Hook type	Effort
Large circle hook (18/0 or more)	31872
Small circle hook (smaller than 18/0)	70882
Tuna hook 3.8 sun	97834

Table 2 Number of fish caught by species and fate at hauling

Species	Total	Alive	Dead	Unknown*
Blue Shark	8755	8009	746	148
Shortfin Mako	260	208	52	2
Striped Marlin	126	61	65	0
Swordfish	243	47	196	6

* Indicates failure to determine due to fishing loss other than bite off. Excluded from mortality estimation analysis.

Table 3 Hooking position by fish type

Species	Body	Mouth	Swallowed	Unknown*
Blue shark	65	2608	2270	3960
Shortfin mako	17	68	66	111
Striped marlin	8	80	12	26
Swordfish	17	118	59	55

* Indicates failure to determine due to fishing loss due to fishing error other than bite-off or lack of survey. Excluded from mortality estimation analysis.

Table 4 Number of fish caught by hook type

Species	*Large* C	*Small* C	Tuna hook
Blue shark	1119	3158	4626
Shortfin mako	23	113	126
Striped marlin	22	49	55
Swordfish	39	102	108

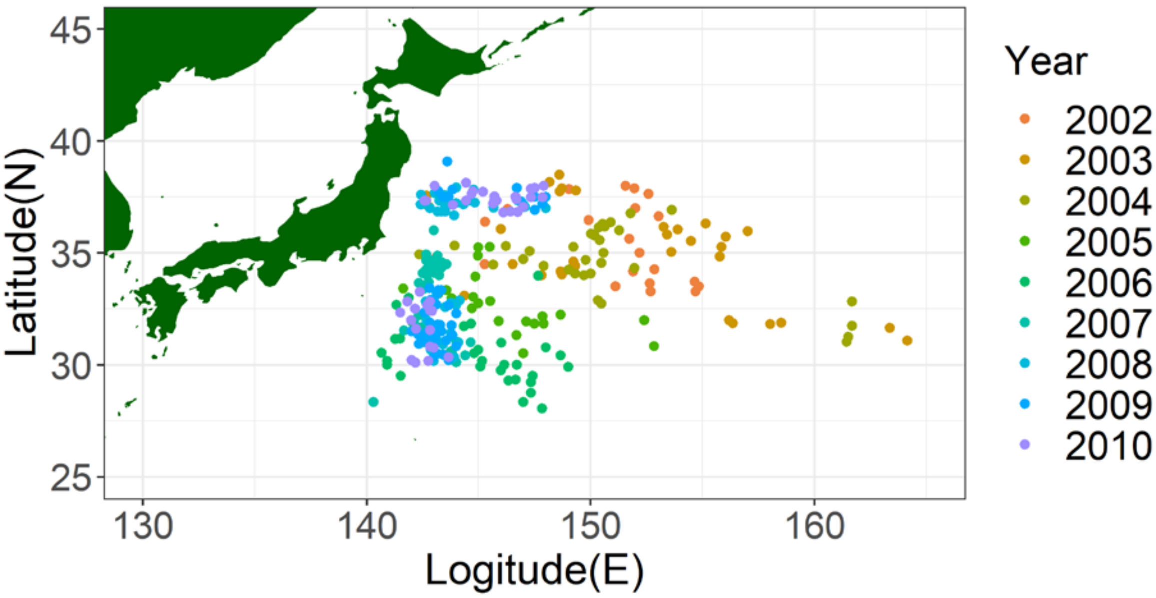

Figure 1 The longline operation area where the experiment was conducted.

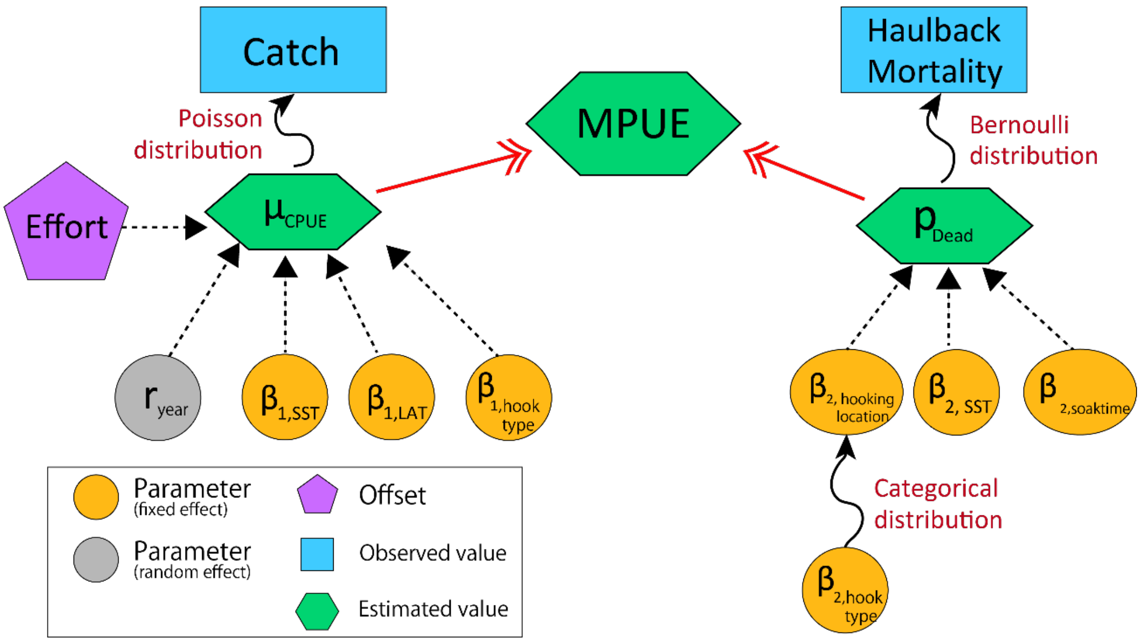

Figure 2 Overview of the Bayesian statistical model created to estimate the MPUE.

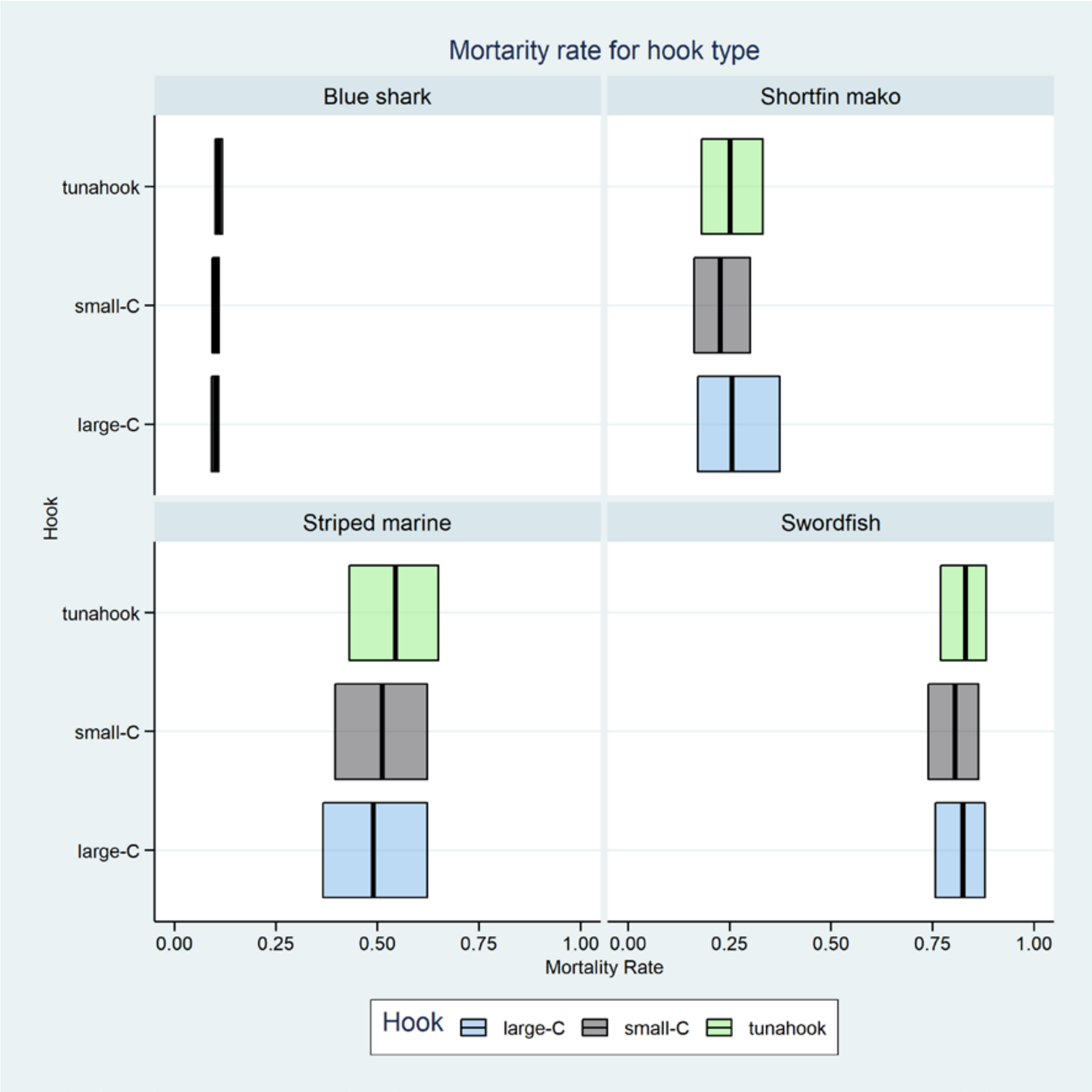

Figure 3 Estimated haulback mortality rate by hook type for each fish species. The center line of the boxplot represents the median, and the two ends represent the 95% Bayesian credible interval.

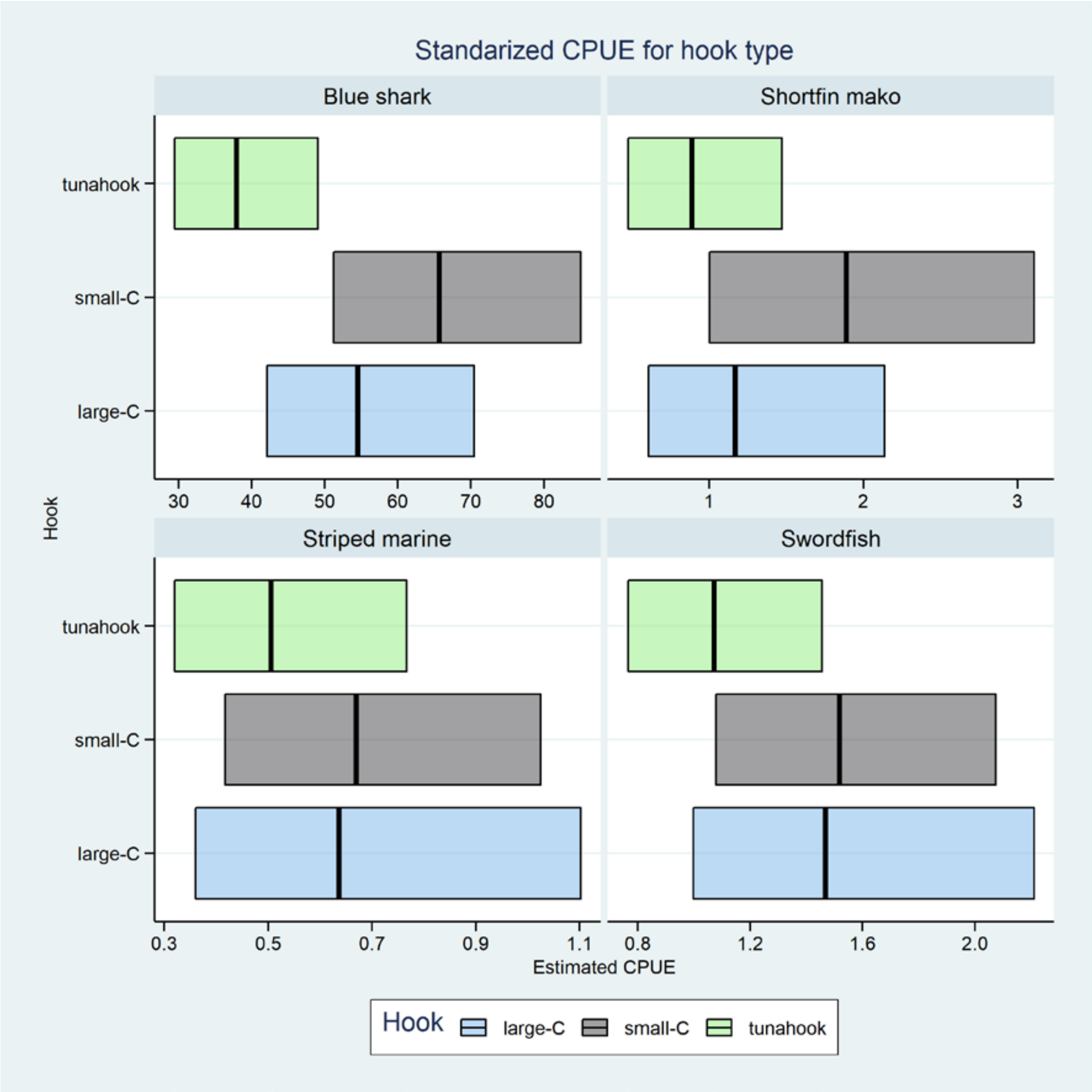

Figure 4 Standardized CPUE by hook type for each fish species. The center line of the boxplot represents the median, and the two ends represent the 95% Bayesian credible interval.

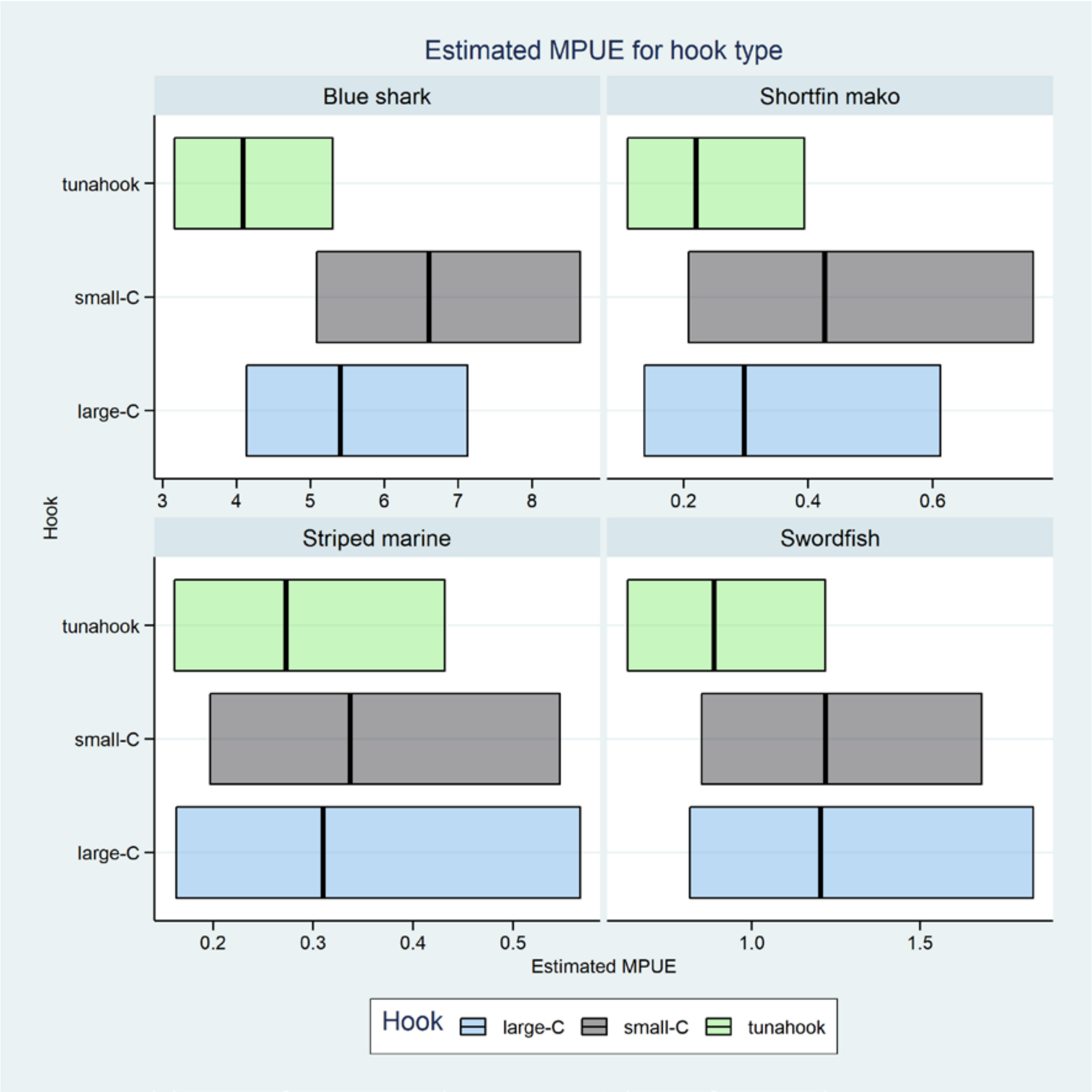

Figure 5 Expected value of Mortality Per Unit Effort (MPUE) by hook type for each fish species. The center line of the boxplot represents the median, and the two ends represent the 95% Bayesian credible interval.

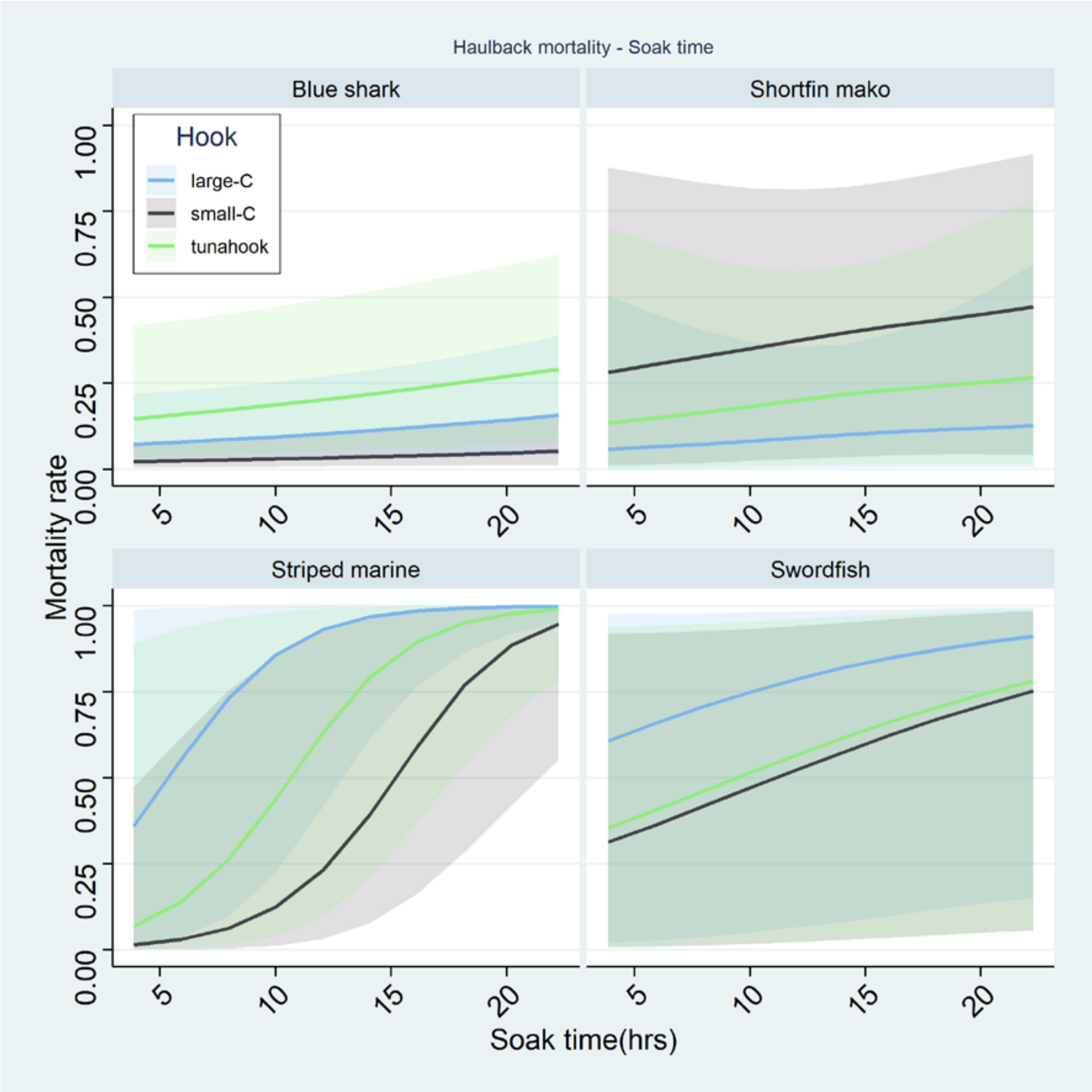

Figure 6 Variation in haulback mortality rate by species as a function of soak time. Solid lines indicate median values, masked bands indicate 95% Bayesian credible intervals.

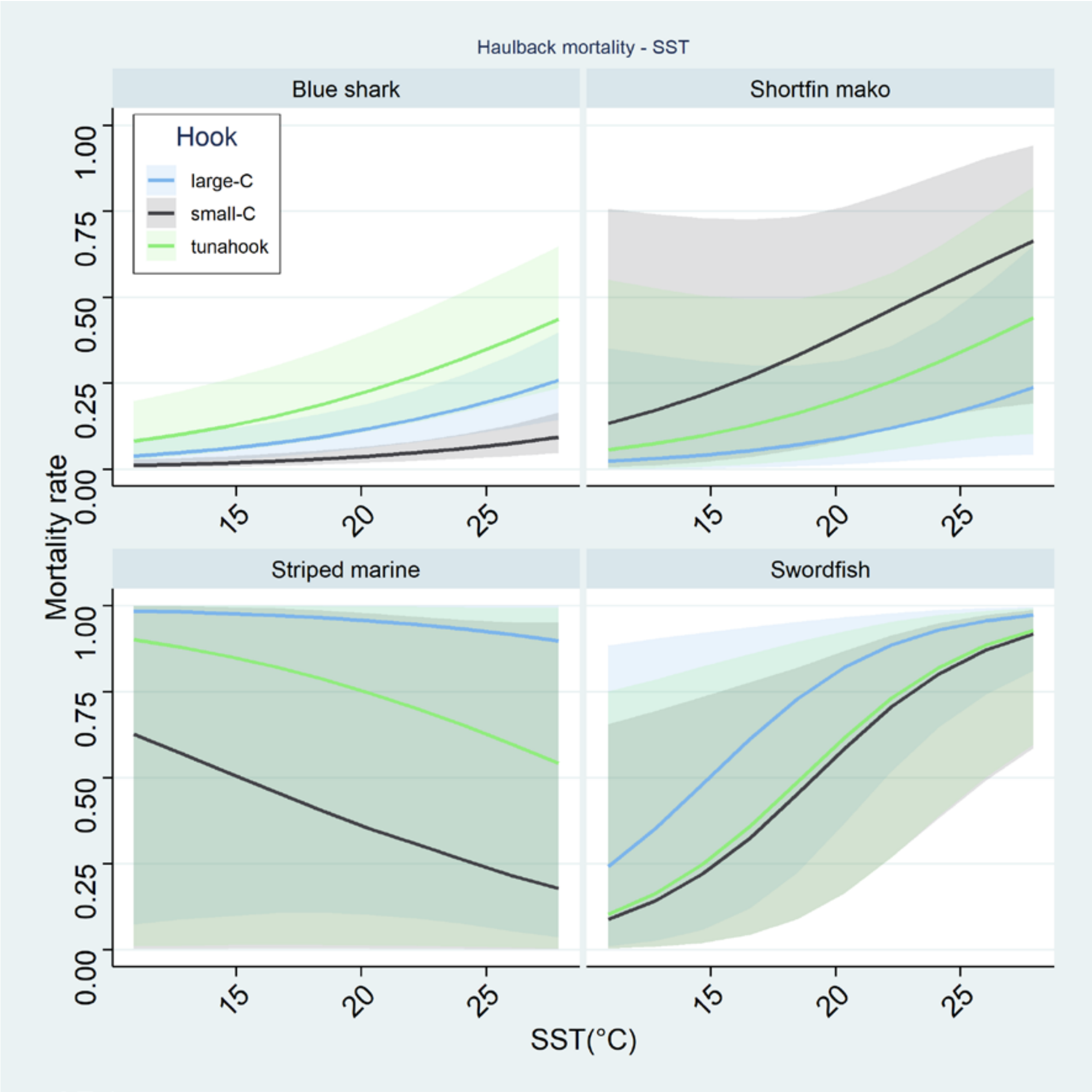

Figure 7 Variation haulback mortality rate by species as a function of sea surface temperature. Solid lines indicate median values, masked bands indicate 95% Bayesian credible intervals.

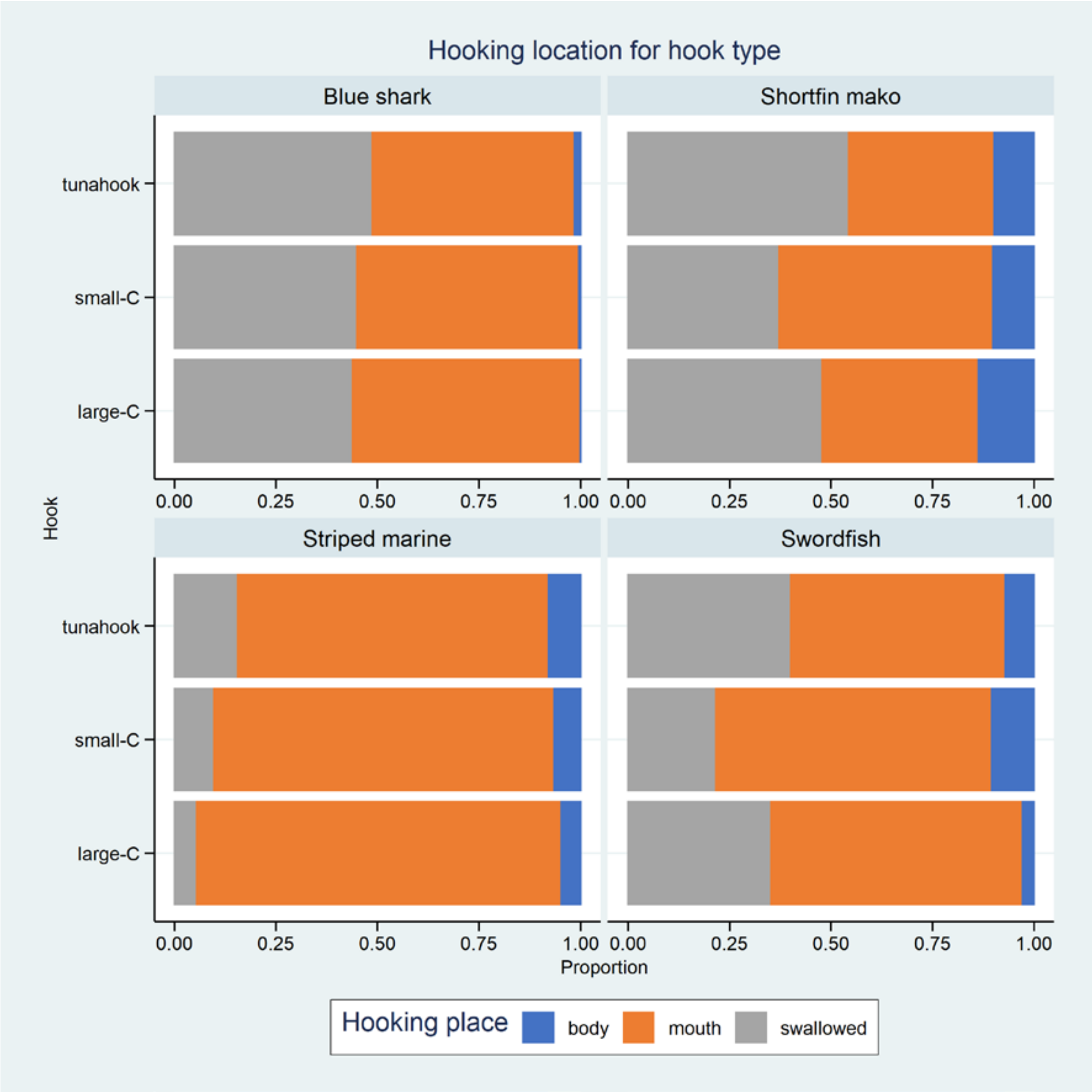

Figure 8 Estimated hooking position composition by hook type for each fish species estimated by the model.