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Short Communication

Enjoy the darkness: Forsake partially nocturnal sets provides a good opportunity to improve profits and sustainability in the southern Brazil longline fishery

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ABSTRACT

Pelagic longline fishing globally raises concerns for adverse interactions with non-target species, prompting the need for sustainable practices and effective mitigation. Adherence to bycatch measures varies globally, driving efforts to find cost-effective alternatives sustaining target species catch while minimizing bycatch. Our study, based in a previous research in southwestern Atlantic Ocean, confirms that fully nocturnal sets (FNS) are more effective in capturing target species (e.g. swordfish, tunas) and reducing bycatch of mako shark and loggerhead turtle compared to partially nocturnal sets (PNS). Extending the analysis to warm and cold seasons, FNS consistently outperforms PNS. In terms of profitability, trips with more FNS are generally more profitable than those with more PNS. Adopting only FNS in pelagic longline fishing seems to be viable, efficient in capturing target species, minimize bycatch, and potentially increasing profits—a promising solution for sustainable and economically viable pelagic longline fishing in southern Brazil.

1. Introduction

Pelagic longline fishing is an economic practice prevalent in all global ocean basins, primarily targeting tunas, billfish and pelagic shark species. While tunas and some billfishes stocks have shown recovery signs to fishing practices [12], significant global concerns have been raised due to adverse interactions with non-target species, including declining populations of sharks and sea turtles [10,12,21]. Such interactions can have profound ecological repercussions since fisheries represents additional mortality sources to slow recovery k-strategy species, characterized by longevity and limited reproductive rates [1,5,15,16]. These unintended consequences underscore the need for sustainable fishing practices and effective mitigation measures to minimize the impact on non-target species and maintain the overall health of marine ecosystems. Therefore, balancing economic interests with conservation imperatives is crucial for the long-term viability of pelagic longline fishing.

The escalating concern over bycatch in global fisheries has spurred a heightened interest in implementing mitigation measures Hall et al. [9,21]. Recognized as effective practices, these measures encompass the use of operational modifications to prevent unintended captures of sea turtles, sharks, and seabirds [7–9,21]. However, adherence to bycatch mitigation varies across fleets and countries, influenced mainly by socio-political factors. Ongoing efforts seek alternatives that address implementation difficulties, with an emphasis on solutions that minimally disrupt fishing activities, incur low costs, and sustain efficient

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target species catch. Furthermore, the adoption of such practices can be enhanced by demonstrating to stakeholders that fishing activities can be optimized (through the increase or maintenance of profits per trip), while avoiding the capture of non-target species.

In a previous investigation, we conducted a study to examine the optimal setting time for fishing as a readily applicable alternative to mitigating incidental catch in the longline fishery operating in southern Brazil [20]. In general, the outcomes of this investigation indicated that fully nocturnal sets (initiated between 16:00 and midnight) have higher probabilities to catch target species and diminish non-target species compared to partially nocturnal sets (initiated between midnight and 04 h). Those findings are ascribed to the behavior of the fishers in their operational activities and the behavior of the species in their daily vertical migration cycles [20]. However, in the aforementioned study, we advised readers that there were limited observations of partially nocturnal sets throughout each season of the year. Furthermore, we did not provide interested parties with information on the anticipated financial implications of discontinuing partially nocturnal sets. In this context, our current study aims to: 1) reanalyze the phenomena observed in an extended dataset comparing along warm and cold seasons, and 2) estimate profits during trips by correlating them with the frequency of utilizing fully nocturnal sets.

2. Methods

2.1. Data acquisition

We investigated the longline fishery operating in southern Brazil over the Southwestern Atlantic Ocean (SWAO; defined as between 22–55°S and 40–70°W). The main target species of this fishery are the swordfish *Xiphias gladius*, the albacore tuna *Thunnus alalunga*, the yellowfin tuna *Thunnus albacares*, the bigeye tuna *Thunnus obesus*, blue shark *Prionace glauca* and the escolar *Lepidocybium flavobrunneum* [4]. Mako shark *Isurus oxyrinchus* and loggerheard turtle *Caretta caretta* are the main bycatches of this fishery and represent a relevant 10 % of total reported catch [4]. All the aforementioned species comprise approximately 90 % of reported species by fishers [4]. Similarly to previously published by Rodrigues et al. [20] we accessed the logbooks reported by fishers to obtain information about the trip such as: setting time, date, vessel, effort (in number of hooks) and the amount of individuals captured by species. It yielded 4255 reported sets from 2018 to 2023, of which 4224 were retained after missing necessary information was cleaned. In the case of mako shark we used 4024 sets due to the landing prohibition after May, 2023 in Brazil and reduced reliability in logbooks data for this species after such date. Setting time was combined in fully nocturnal sets (FNS) when started between 16 h and midnight and partially nocturnal sets (PNS) when started between midnight and 04 h. We assumed that most of the effective catch takes place between 1 and 5 h after the setting time based on studies with hook timers [18,19,22]. We were prevented to classify FNS/PNS based on setting and haul back time – this latter information scarce in our database. Such approach implicates in absence of sunlight during catches by FNS and presence of sunlight during catches by PNS. For example, if a set started at 16 h, the effective catch will take place between 17 h and 21 h, a time window of dusk and night which target species are mostly starving, ascending or already reached to sea surface layer. By the other hand, if the set started at midnight, the effective catch will take place between 1 h and 5 h, a time window of night and dawn, which target species are mostly full or diving to deeper layers. Also, the months October to March were combined as ‘warm’ season, while April to September were combined as ‘cold’ season in the southern hemisphere. Finally, we accessed how many sets of each trip have performed as FNS or PNS.

In addition to logbooks, interviews with vessel captains during landings were also considered. Through these interviews, the amount of catch (in kg), ex-vessel price ($/kg) for each species and variable cost were reported by trip. The income for each trip was calculated by multiplying the ex-vessel price for each species by its amount of catch (in kg) and then adding them all up. The profit was calculated as the income minus the variable cost.

2.2. Data analysis

We conducted Bayesian Generalized Linear Mixed Models (BGLMM) in order to assess the probability of catch by set, along setting time (two levels, FNS or PNS), season (two levels, warm or cold) and the interactions between them. We also incorporate in BGLMMs the random effects *trip* (478 trips), *year* (6 years) and *vessel* (32 vessels) which can be described as:

$$Y_i \sim NegBin(p_i, r)$$

$$p_i = \frac{r}{(r+\pi_i)}$$

$$\log(\pi_i) = \eta_i$$

$$\eta_i = offset(\log[effort_i]) + \beta_0 + \beta_1 SettingTime_i + \beta_2 Season_i + \beta_3 SettingTimeSeason_i + Z_{trip_i} + Z_{year_i}$$

$$\beta_0 \sim Normal(0, 0.001)$$

$$\beta_1 \sim Normal(0, 0.001)$$

$$\beta_2 \sim Normal(0, 0.001)$$

$$\beta_3 \sim Normal(0, 0.001)$$

$$Z_{trip_i} \sim Normal(Z_{vessel_i}, \sigma^2_{trip_i})$$

$$Z_{year_i} \sim Normal(0, \sigma^2_{year_i})$$

$$Z_{vessel_i} \sim Normal(0, \sigma^2_{vessel_i})$$

$$\sigma^2_{trip_i} \sim Unif(0, 100)$$

$$\sigma^2_{year_i} \sim Unif(0, 100)$$

$$\sigma^2_{vessel_i} \sim Unif(0, 100)$$

$$r \sim Gamma(0.01, 0.01)$$

where, Y_i is the response variable, p_i is the parameter of interest, and $\log(\pi_i)$ is the link function of parameter p_i, η_i is the linear predictor, $\log[effort_i]$ is the component of effort in number of hooks for each set *i*. and $\beta_p x_p$ are the parameters of the linear predictor for each *p* explanatory variable, including the interactions. *r* is the shape parameter for the Negative Binomial distribution. Weakly-informative prior probability distributions were used to maximize data information in inference. Monte Carlo Markov Chains were computed ($n.chains = 3$, $n.burnin = 3000$, $n.thin = 3$, $n.iter = 5000$) in order to estimate posterior parameters of interest. The convergence of MCMC procedure and, therefore, the quality of simulated posterior distributions were evaluated by standard diagnostic plots. Posterior distributions of parameters were used to estimate the number of animals by setting time and season. When comparing, we considered as a strong evidence in favor of a difference, whenever the 90 % credibility intervals had no overlap [17].

We also built a Bayesian Quantile Regression (BQR) in order to estimate the effect of the frequency of FNS in trips over its profits. Quantile regressions are required when the heteroscedasticity in data is evident and because it can assess various rates of change across the spectrum of minimum to maximum response, offering a more comprehensive understanding of the relationships between variables that may not be as

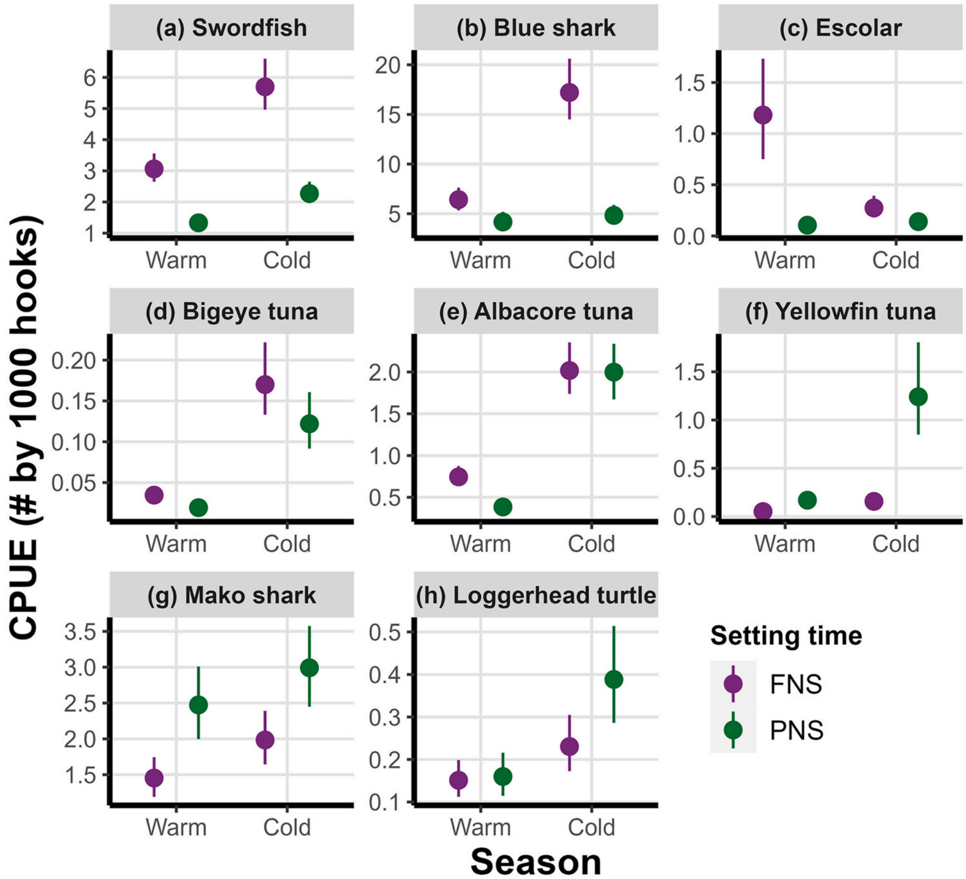

Fig. 1. Posterior distributions estimated for capture per unit effort (CPUE) (2000 values) among setting time (FNS or PNS), season (warm or cold) and species (a–h) in longline fishery of the southwestern Atlantic Ocean (SWAO). Dots are the median and lines the 25 % and 75 % quantiles.

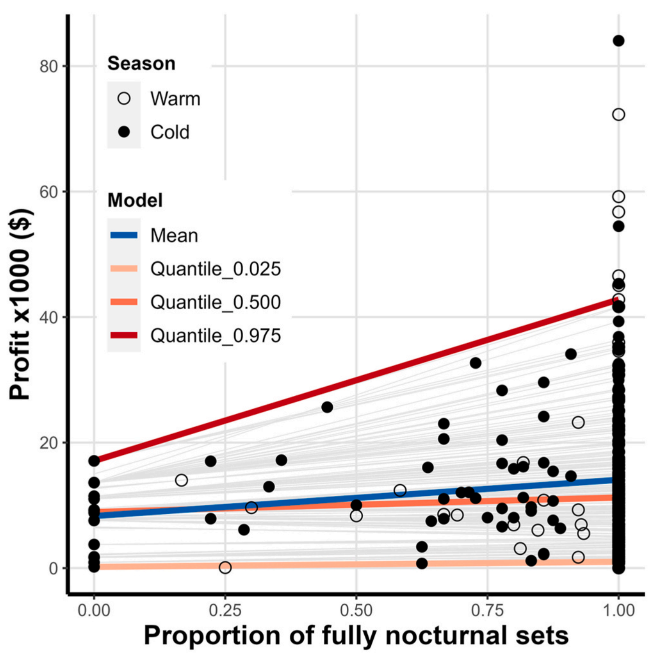

Fig. 2. Relation between profits for each trip and the proportion of fully nocturnal sets in longline fishery of the southwestern Atlantic Ocean (SWAO). Standard and quantile regressions are showed in colored lines. Other quantiles between 0.025 and 0.975 in grey.

evident with alternative regression techniques [3]. Mean and quantiles of 0.025, 0.500 (median) and 0.975 were chosen. Similarly as aforementioned we chose weakly-informative reference priors and set the MCMC with the same conditions as previously described. All analysis and plots were built in R language through the *brms* v2.19.0 [2] and *ggplot2* v3.4.4 [23] packages.

3. Results

Our results reveals insightful patterns in the capture probabilities of different species based on the timing of fishing sets and season (Fig. 1; models' diagnostics in Supplementary Material S1–S8). Notably, the target species swordfish, blue shark, escolar and bigeye tuna demonstrate a greater probability of been captured in FNS compared to PNS during both warm and cold seasons (Fig. 1a–d). This trend is more pronounced in the first two species. Similarly, albacore tuna exhibits a higher likelihood of capture in FNS, but exclusively during the warm season (Fig. 1e). Conversely, yellowfin tuna and the bycatch specie mako shark are more likely to be captured in PNS in both seasons (Fig. 1f–g). Loggerhead turtle was more captured at PNS only during cold season (Fig. 1h).

There is a positive relationship between profits and the frequency of FNS performed by trip in quantile regression with 0.975 percentile (Fig. 2; $\beta_{0.975} = 26.9$ [CrI = 22.5–30.9]). The relationship weakens towards smaller quantiles and compared to standard linear regression (Fig. 2; $\beta_{0.025} = 0.57$ [CrI = 0.07–2.37], $\beta_{0.500} = 2.46$ [CrI = – 1.04 to 5.92]) (model' diagnostics in Supplementary Material S9).

4. Discussion

As previously demonstrated, FNS showed a significant likelihood of capturing the majority of target species with the exception of yellowfin tuna, while the bycatch species mako shark and loggerhead turtle exhibit a higher probability of been captured under PNS [20]. Going a step further, in our current research we incorporated interaction terms in the models, enabling a comparison of setting times across both warm and cold seasons. In general, the phenomena occurs in a similar way in warm and cold season; an evidence that gives us confidence to suggest the implementation of FNS for both seasons in order to efficiently catch target species and, simultaneously, avoid incidental catch. In addition, we confirmed our speculations in Rodrigues et al. [20] that escolar and bigeye tuna are more able to be captured in FNS than PNS. These observations reaffirm the previous discussions emphasizing the synergistic effects of the circadian behavior of fished species (dive depth during day and night, feeding timing, vision accuracy) and the operational behavior of fishers (the depth and time at which hooks are set) (please see Rodrigues et al. [20] for full discussion).

In addition, GPS tracking data linked to longliners—accessed through safety-designed Automatic Identification System (AIS)—indicate that sets under any level of sunlight incidence are bluntly the majority kind of set in the South Atlantic, contrasting with just 5.5 % of fully night sets [13]. Fact that raises attention not only to the species investigated here, but also to other taxonomic groups. Seabirds, for example, may be other beneficiaries in the implementation of trips performing only FNS instead of PNS due to its greater interaction with longline fisheries during light time [11,13]. Furthermore, we would like to acknowledge that performing exclusively FNS instead of PNS may not be interpreted as an advantage in every fishery nor applicable worldwide. We encourage further investigation using geographically broader data sets to confirm if our findings are valid for other fisheries' conditions It is important to remember that considering the exclusive use of FNS depends on knowledge of which and how local species behave regarding movement and feeding.

Upon examining the aforementioned patterns, a crucial inquiry emerged: "Does the profitability of catching yellowfin tuna compensate for performing PNS?" The second section of our findings addresses this query. The connection between the frequency of FNS and profits revealed that the greatest profits typically coincide with trips involving more FNS than PNS. This evidence conveys a noteworthy and significant message to stakeholders: trips focused solely on FNS in the southwestern Atlantic Ocean, aside from efficiently capturing the target species and minimizing bycatch, also have the potential to be more profitable compared to PNS. This approach we pursuit is seeking to provide a "bottom-up" change in fishers behaviors (which emanates from them), encourage multilateral cooperation from stakeholders and avoid standard bycatch managements, like "command-and-control" fishery managements [14]. Furthermore, our findings are similar to other studies. For example, in longline fishing off Argentina, the use of deterrents reduced the bait losses and seabird mortality representing win-win benefits to conservation and fishing companies [6]. It demonstrates that in many cases employing strategies to minimize bycatch not only contributes to environmentally friendly fisheries but also fosters a more profitable activity. Strengthening marine policies in order to provide information to fishers and vessel captains about such findings is essential to achieving more sustainable fishing.

5. Conclusions

In summary, our results support the notion that longline fishery trips utilizing fully nocturnal sets not only help in avoiding incidental catches while effectively capturing the majority of target species [20] but it also works similarly in warm and cold seasons and has the potential to yield greater profits. Forsake trips with partially nocturnal sets seems to be a viable alternative for reducing incidental captures without adversely affecting fishing incomes.

CRediT authorship contribution statement

Lucas Rodrigues: Investigation, Formal analysis, Conceptualization, Data curation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Paul Gerhard Kinas:** Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. **Vinni Santos Thykjaer:** Data curation, Formal analysis, Methodology, Validation, Writing – review & editing. **Luis Gustavo Cardoso:** Writing – review & editing, Validation, Conceptualization, Funding acquisition, Project administration, Resources, Supervision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used https://chat.openai.com/ in order to improve English grammar and reading—none of coauthors are English native speaker. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

The authors do not have permission to share data.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106149.

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