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Comparative analysis of three bait types in deep-set pelagic longline gear in the Equatorial Atlantic Ocean

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ABSTRACT

The choice of bait is one of the fisheries tactics used to increase selectivity for particular target species. The performance of three bait types (mackerel, sardine, squid) was evaluated with a commercial vessel operating in the Equatorial Atlantic Ocean using the deep-set pelagic longline deployment method to target large yellowfin and bigeye tunas. The effect of different factors and covariates on the Capture per Effort Unit - CPUE was evaluated through Generalized Linear Models (GLM). In 121 experimental sets using three bait types, 2385 individuals of the two target species were captured, 1166 yellowfin tuna and 1219 bigeye tuna. The results suggest a preference between bait types for each target species, with the yellowfin tuna being mostly caught by the hooks using squid and bigeye tuna with fish bait mackerel. Stratifying the results for three depth ranges of the hooks, the combination of bait and depth for yellowfin tuna resulted in an increase of catch probability in the intermediary depth layer using mackerel. For bigeye tuna, using mackerel in the intermediary layer resulted in a reduction in the catch rate. Bycatch represented around 11.15% of total captures. These results will provide important information to choosing the most efficient bait for the pelagic longline fishing operation and will help future decisions of fisheries management.

Keywords: Bigeye tuna; bycatch; GLM; selectivity; Yellowfin tuna.

Análise comparativa de três diferentes tipos de isca utilizados no espinhel pelágico de profundidade no Oceano Atlântico Equatorial

RESUMO

A escolha da isca é uma das estratégias utilizadas para aumentar a seletividade para espécies-alvo com espinhel pelágico. O desempenho de três tipos de isca (cavala, sardinha e lula) foi avaliado em um barco de pesca comercial, operando no Oceano Atlântico Equatorial usando o espinhel pelágico de profundidade para captura de tunídeos. O efeito de diferentes fatores e covariáveis sobre a Captura por Unidade de Esforço - CPUE das espécies-alvo foi avaliado por meio de Modelos Lineares Generalizados (GLM). Em 121 lances de espinhel usando os três tipos de isca, foram capturados 2385 indivíduos das espécies-alvo de atum, 1166 albacora laje e 1219 albacora bandolim. Os resultados sugerem uma preferência entre os tipos de isca para cada espécie-alvo. Com a albacora laje sendo principalmente capturada pelos anzóis utilizando lula e a albacora bandolim pelos anzóis utilizando com isca de cavala e sardinhas. As capturas acidentais representaram em torno de 11,15%. A combinação de isca e profundidade para albacora laje resultou em um aumento de captura utilizando cavala em profundidade intermediária. No caso da albacora bandolim resultou em uma redução de captura utilizando cavala em profundidades intermediarias. Esses resultados fornecerão informações importantes para a escolha da isca mais eficiente para a operação de pesca com espinhel pelágico de profundidade e auxiliarão nas decisões futuras de gestão pesqueira.

Palavras-chaves: Albacora bandolim; *Bycatch;* GLM; seletividade; Albacora laje.

INTRODUCTION

The success of any fishing operation depends on several components inherent to the fishing gear, each of which affects its selectivity (Løkkeborg and Bjordal, 1992). Among the tactics used to increase the selectivity of hook-and-line fishing gears, changing the bait used has always been one of the simplest and most efficient (Løkkeborg et al., 2014). Although the efficiency of the pelagic longline gear is determined by several interrelated factors, including type and size of hook, the spacing between hooks, configuration, and direction of the fishing gear setting, the most important of them still is the kind and size of the bait used (Løkkeborg and Bjordal, 1992; Løkkeborg and Pina, 1997). The choice of good bait may result in more efficient fishing activities, producing higher economic returns.

According to Løkkeborg and Pina (1997) the catches of the longline are directly affected by technical factors related to the fishing gear, to the biology of the species and to the environment. Bait is considered one of the most important factors influencing the success of longline fishing operations (Coelho et al., 2012; Løkkeborg et al., 2014; Kumar et al.,2016). The sort of bait used in a given fishing operation is often chosen based on the presumed dietary habits of the target species (Løkkeborg et al., 2014). Chub mackerel (*Scomber japonicus* Houttuyn, 1782), longfin inshore squid (*Loligo paeli* Lesueur, 1821) and sardine (*Sardinella* spp. Valeciennes, 1847) are the main baits used in pelagic longline fishing in Brazil (Foster et al., 2012; Santos et al., 2012; Løkkeborg et al., 2014, Kumar et al., 2016).

From 2010 to 2013, several Japanese-flagged pelagic longline fishing vessels targeting tunas operated in the Equatorial Atlantic Ocean through a chartering arrangement with a Brazilian fishing company. These chartered vessels mainly directed their fishing efforts to target yellowfin tuna (*Thunnus albacares* Bonnaterre, 1788) and bigeye tuna (*Thunnus obesus* Lowe, 1839), with the purpose of exporting the tuna product to foreign markets. In this context, the present study investigated the efficiency of three different types of baits (chub mackerel, longfin inshore squid, and sardine) commonly used by pelagic longline vessels regarding the catches of the two main target species of yellowfin tuna and bigeye tuna.

MATERIALS AND METHODS

Fishing Operations

The pelagic longline vessel was *Taiwa Maru Nº 88*, 56.70 m of length overall (LOA). Fishing operations were conducted from January to May 2012. A total of 121 experimental sets were done in the Equatorial South Atlantic Ocean ranging from 04°30'S to 04°50'N and from 25°20'W to 31°00'W (Figure 1).

The pelagic longline used had a mainline length of about 120 km, operating in the mesopelagic region, at depths ranging between 103 and 451 m. Estimated hook depths were calculated using the catenary equation developed by Yoshihara (1951, 1954). The mainline was composed of a polyamide multifilament cable (8 mm diameter), divided into 170 baskets, each one composed of 18 branch lines, with 40 m between lines, ending with stainless steel tuna hooks size 3.6 sun. Light-sticks were placed on the fourth branchline of each basket. Once the fishing area was selected, operations began with the setting of the longline at 05:30 h. Haulback started around in the late afternoon between 15:00 and 16:00 h. Sets contained an average of 3060 hooks.

During the experimental trials, three different types of bait were used: chub mackerel, inshore longfin squid, and sardine; the average individual weight of each bait was 120 g, 300 g, and 120 g respectively. The order of baiting in the hooks was intercalated, following repeating pattern of mackerel, squid, and sardine. Sardines and mackerels were baited on the dorsal region, while squids were placed on the hook by putting the barbed point through the fleshy posterior region and then doubling this point back again through the mantle. All baiting methods were commonly used by the Japanese pelagic longline vessels during the experimental period.

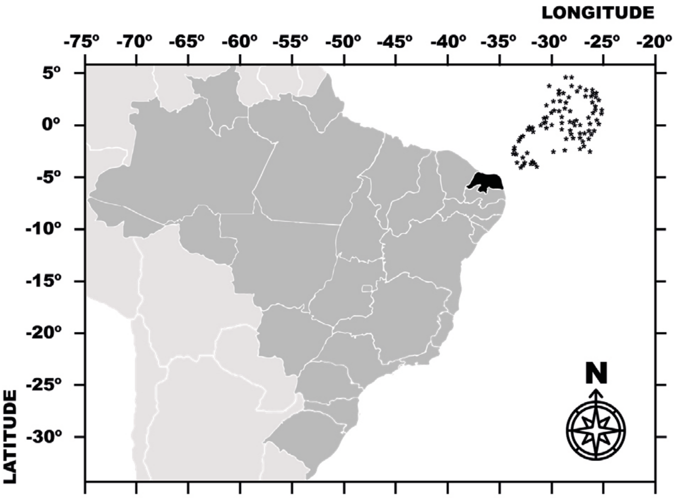

Figure 1. Location and spatial distribution of the experimental pelagic longline sets during 2012, indicated by black dots. The black highlight identifies the state of Rio Grande do Norte, where the vessel's departure port is located.

Analyses

A Generalized Linear Model (GLM) was utilized to assess the different factors and variables that might influence the CPUE of the target species (Nelder and Wedderburn, 1972). For the statistical analysis, the fishing gear was divided in three different depth layers (DL1 = 103-137 m, DL2 = 186-293 m, DL3 = 334-451 m), to ensure that all bait types would have been used in all three depth layers. The final models were chosen based on Akaike Information Criterion (AIC; Akaike, 1974). Statistical analysis was performed using the statistical program R® version 4.1.2 (R Core Team, 2021), we used the R packages (reshape, reshape2, coefplot, questionr, effects, sjplot, dplyr, car, plyr, stargazer). All results were considered statistically significant at 95% ($p = 0.05$)

RESULTS

Catches

During the study, 2385 individuals of the two target species were caught: 1166 yellowfin tunas and 1219 bigeye tunas. Of the yellowfin tunas, 330 were caught with mackerel bait, 527 with squid, and 309 with sardine; of the bigeye tunas, 461 were caught with mackerel, 325 with squid, and 433 with sardine. On the first layer, it was caught 715 bigeye tunas and 219 yellowfin tunas. At the second layer it was caught 427 yellowfin tunas and 397 bigeye tunas. In addition to at the third layer it was caught 439 yellowfin tunas and 188 bigeye tunas.

Bycatch represented around 11.15% of total captures and included 91 blue shark (*Prionace glauca* [Linnaeus 1758]), 38 istiophorid billfishes, 52 wahoo (*Acanthocybium solandri* [Cuvier in Cuvier and Valenciennes, 1832]), 30 skipjack tuna (*Katsuwonus pelamis* [Linnaeus, 1758]), 23 common dolphinfish (*Coryphaena hippurus* Linnaeus, 1758), eight ocean sunfish (*Mola* sp. Kölreuter, 1766), seven crocodile shark (*Pseudocarcharias kamoharai* [Matsubara, 1937]), seven shortfin mako (*Isurus oxyrhinchus* Rafinesque, 1810), three thresher shark (*Alopias* sp. Rafinesque, 1810), and seven sea turtles.

The fishing efforts were 3000 hooks day^{-1} for 121 days. Totalizing 363000 hooks/fishing trials. CPUE of target-species, yellowfin tuna 3.07 per 1000 hooks, and bigeye tuna 3.36 per 1000 hooks. To bycatch CPUE were 0.732 per 1000 hooks. In more specifically, we had 0.25 blue shark, 0.10 billfishes, 0.14 wahoo, 0.08 skipjack tuna, 0.06 common dolphinfish, 0.02 ocean sunfish, 0.019 crocodile shark, 0,019 shortfin mako, 0.008 thresher shark, and 0.019 sea turtles per 1000 hooks.

Analyses

The final GLM Models that explained the largest proportion of the variance were:

i) YF_TUNA<-glm(YFTprop)~BAIT+DL+BAIT: DL, (family=binomial);

ii) BE_TUNA<-glm(BETprop)~BAIT+DL+BAIT: DL, (family=binomial);

where: YFTprop represents the catches of yellowfin tuna; BETprop represents the catches of bigeye tuna; BAIT the type of bait used; and DL the 3 different depth layers.

For the yellowfin tuna, the probability of catch was significantly higher when squid was used as bait. The catch rate for this species with mackerel was about 45% lower, when compared to squid, and 25% lower when sardine was used (Table 1).

For the bigeye tuna, the results showed an opposite trend, with the use of squid as bait resulting in a significantly less probability of the species being caught, while its catch rate increased by 59%, with the use of mackerel, and by around 18% (Table 2) when sardine was used as bait.

Table 1. Summary of the results of the binomial models on catchability yellowfin tuna showing the summary effect size (odds ratio, OR) and 95% confidence interval (CI).

BAIT	Odds Ratio	2.5%	97.5%	P-value
MACKEREL	0.55	0.39	0.76	2.85 e^{-04}
SARDINE	0.77	0.57	1.02	7.93 e^{-02}
DEPTH 02 (186-293)	1.81	1.43	2.30	1.07 e^{-06}
DEPTH 03 (334-451)	2.17	1.73	2.74	4.86 e^{-11}
INTERA. MACKEREL x D.02	1.48	1.00	2.18	4.68 e^{-02}
INTERA. SARDINE x D.02	0.73	0.50	1.06	9.94 e^{-02}
INTERA. MACKEREL x D.03	0.90	0.61	1.33	5.87 e^{-01}
INTERA. SARDINE x D.03	0.64	0.44	0.93	1.82 e^{-02}

Table 2. Summary of the results of the binomial models on catchability bigeye tuna showing the summary effect size (odds ratio, OR) and 95% confidence interval (CI).

BAIT	Odds Ratio	2.5%	97.5%	P-value
MACKEREL	1.59	1.29	1.97	1.22 e^{-05}
SARDINE	1.18	0.95	1.48	1.41 e^{-01}
DEPTH 02 (186-293)	0.77	0.59	0.99	3.86 e^{-02}
DEPTH 03 (334-451)	0.31	0.22	0.44	1.33 e^{-11}
INTERA. MACKEREL x D.02	0.81	0.59	1.13	2.18 e^{-01}
INTERA. SARDINE x D.02	1.28	0.93	1.78	1.34 e^{-01}
INTERA. MACKEREL x D. 03	0.98	0.64	1.50	9.09 e^{-01}
INTERA. SARDINE x D. 03	1.60	1.05	2.46	3.03 e^{-02}

Regarding the depth of the longline hooks, the catches of yellowfin tuna were about 80% higher in the hooks located in the second layer and 117% higher in the third layer, in comparison to the first layer (Table 1). In the case of the bigeye tuna, again, an opposite behavior was observed, with a catch rate 23% lower in the second layer and 69% lower in the 3rd depth layer, in comparison to the first layer (Table 2).

When the interactions are considered, the combination of "Bait" and "Depth" for yellowfin tuna resulted in a 47% increase in its catch probability with the use of mackerel, in the second depth layer, when compared to squid and the first layer. The combination of sardine and the second depth layer resulted in a reduction of the catch probability of yellowfin tunas of about 27%. In the third depth layer, the use of sardine and mackerel lowered the catch probability for the species by 36% and 11%, respectively, in relation to the use of squid in the first layer (Figure 2).

In the case of bigeye tuna, the interaction of the factors "bait" and "depth" resulted in a reduction in the catch rate, when using mackerel, in the second layer, by 19%, in comparison to squid in the first layer. When sardine was used in the second depth layer, there was an increase in catch probability of about 28%. In the third depth layer, the use of mackerel resulted in a drop of about 3% compared to squid, while the use of sardine as bait in the same layer increased the catch probability by 59% (Figure 3).

DISCUSSION

The results demonstrated a clear difference in bait preference by each target species. For any bait, or combination of baits, to be successful in catching fish, it is reasonable to assume that it must stimulate both olfactory and gustatory responses. This is probably the reason why pelagic longline vessels use more than one type of bait in commercial fisheries (Jacobsen and Joensen, 2004). According to Løkkeborg e Bjordal (1992), if two types of baits are used in the longline, they have a synergistic effect, meaning that the use of two different baits together increases the probability to catch fish when compared to the use of only one kind of bait. Chemical and physical properties of water make it an excellent solvent, facilitating the propagation of chemical substances that attract the prey's attention (Jacobsen and Joensen, 2004). However, there is no defined understanding on which substances provoke an olfactory response and those that induce a gustatory response (Kasumyan and Døving, 2003), nor at what distances these responses may be generated in pelagic fishes.

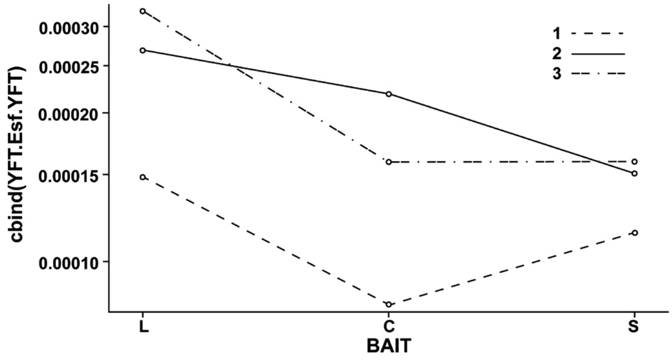

Figure 2. Effect of catch probability per bait to Yellowfin tuna by the Japanese vessel *Taiwa Maru* nº 88, which operated in Brazil in the year of 2012. Where, LS1 represents different depth layers (1, 2 and 3); L represents squid; C represents mackerel; and S represents sardine.

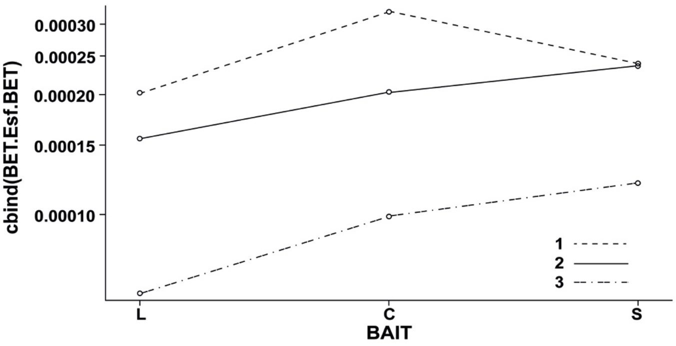

Figure 3. Effect of catch probability per bait to Bigeye tuna by the Japanese vessel *Taiwa Maru* nº 88, which operated in Brazil in the year of 2012. Where, LS1 represents different depth layers (1, e and 3); L represents squid; C represents mackerel; and S represents sardine.

Variations in tuna diets may result from occupation of different habitats, both vertically and horizontally (Bertrand et al., 2002), as well from opportunistic behavior that might vary in different regions and areas of occurrence (Jaquemet et al., 2011; Ménard et al., 2006; da Silva et al., 2019). Analyses of stomach contents, however, indicate that the main source of prey in yellowfin tuna consists of squids, followed by small teleosts, although this diet may vary according to the local availability of prey items and seasonality (Vaske Jr. and Castello, 1998; Vaske Jr. et al., 2005). The present study has demonstrated highest catch rate for this species was attained by squid, with a reduction in the probability of catch when teleost baits were used, notwithstanding three types of bait are available in equal quantities throughout the fishing gear. This finding leads us to believe that squid is the more efficient bait for this species in the pelagic longline fishery.

Similar to other tuna species, bigeye tuna exhibits a diversified diet due to the vast range of prey items. In quantitative terms, the species prefer fish, followed by cephalopods and crustaceans (Bertrand et al., 2002; Vaske Jr. et al., 2012; Duffy et al., 2017; Ohshimo et al., 2018; da Silva et al., 2019). The results presented are generally consistent with the literature, since the use of mackerel and sardine as bait resulted in a considerable increase in their catch rate over the use of squid. Although Watson et al. (2005) has found mackerel bait less effective for bigeye tuna in the western North Atlantic, a direct comparison with the present study is not entirely possible, since the size of mackerel (200-500 g) evaluated were considerably larger than those used in most tuna fisheries and in our experiment.

The correct choice of bait affects catches and thus level of profitability of a given fishery (Coelho et al., 2012; Løkkeborg et al., 2014). In this way, the choice of more efficient bait is directly related to the choice of the target species it is intended to capture. There are other potential factors that should be considered for future research on the topic, such as the geographic location of the fishing area and the prevailing environmental conditions, such as temperature and dissolved oxygen, which also have a strong influence on the efficiency of the fishing gear. The present work shows that yellowfin tuna and bigeye tuna, despite being caught in the same fishing operation, present a very different bait preference.

Tuna moves under the thermocline in the daytime to feed on deep sea scattering layer organisms, and swims back to the upper mixed layer at night (Dagorn et al., 2000; Howell et al., 2010). Therefore, the depth of thermocline directly affects the vertical distribution of tuna (Houssard et al., 2017) and is essential in tuna fishery forecasting. Several authors have studied the movement patterns of tunas in various scales. These movement patterns match, in general, the vertical movements of their prey, such as squids and mesopelagic fishes, which perform differentiated circadian movements (Bertrand et al., 1999; Dagorn et al., 2000; Marcinek et al., 2001). In Holland et al. (1990, 1992) and Dagorn et al. (2000), the large bigeye tuna occupied the upper mixed layer during the night, at depths similar to those occupied by organisms of the Sound Scattering Layer (SSL) and followed the SSL during its shifts at dawn and dusk. Although tunas are considered generalist predators, previous studies have shown that differences in vertical feeding behavior are correlated to differences in thermocline depth and/or other environmental factors. These differences in habitat could also explain inter- and intraspecific dietary differences over relatively short spatial scales (Olson et al., 2010; Williams et al., 2015, Houssard et al., 2017).

Yellowfin tuna generally spend most of their time either in the mixed layer or at the top of the thermocline (Brill et al., 1999; Dagorn, 2000). Studies have indicated vertical movements of yellowfin to be predominantly restricted to the mixed layer, but occasionally below the thermocline for short periods (Block et al., 1997; Brill et al., 1999). Moreover, in areas where the decrease of oxygen content with depth is not limiting, yellowfin tuna depth distributions are set not by a specific depth or water temperature, but by the relative change in water temperature with depth (Block et al., 1997, Brill et al., 1999). Vertical movements of yellowfin are not restricted by the depth of the thermocline, but by body temperature cooling rates and physiological performance at depths below the mixed layer (Schaefer et al., 2007). According to Flores Montes et al. (2009) the beginning of the thermocline in tropical regions is located approximately at the same depth as the base of the photic layer, in the depth range between 50 to 150 m. The fact that yellowfin tunas were caught more with squids in deeper layers, well below the mixed layer in this region, might reflect a feeding behavior by the species that would dive deeper in search of squids, increasing their catch rates by the longline during these incursions.

In contrast, bigeye tuna regularly exposes themselves to temperature changes of up 20°C (from 25°C surface layer temperature to 5°C at 500 m depth) and regions of low dissolved oxygen rate, during their daily vertical movements. The vertical habitat data demonstrated that bigeye tuna exhibit some significant and unexpected differences among length classes, where larger fish occupied shallower depths, in their daytime and nighttime depth distributions, when exhibiting non-associative and associative behavior (Fuller et al., 2015). Bigeye tuna remain near the surface at night but descend during the day, routinely to depths where water temperatures are close to 5°C, occasionally making upward excursions into the mixed layer to warm their muscles and increase its metabolism (Carey, 1990; Brill et al., 2005). According to Josse et al. (1998), the bigeye tuna in French Polynesia performs extensive diurnal vertical movements to follow organism which comprise the sound scattering layer (squids, euphausiids, and mesopelagic fishes). Therefore, while the higher catch rates of yellowfin tunas in deeper waters might reflect incursions of this species in search of squids, their preferred prey, while bigeye tuna, searching for small teleosts, could be doing the opposite, coming to shallower waters to feed on small fish and then increasing their catch rates by the hooks positioned in shallower depths.

Although there are clear instances where the depth distributions of tunas are set by the depth distribution of their prey (Block et al., 1997; Marcinek et al., 2001; Brill et al., 2005), the dichotomous depth distributions of yellowfin and bigeye tunas in the same areas implies that one or more abiotic factors are having an impact on their vertical movements. In the present case, the distribution of their CPUE in different depths would reflect much more the vertical distribution of their preferred prey, during their feeding time, than their own distribution.

CONCLUSION

Yellowfin tuna catch rates were higher with the use of squid as bait, while the catch of bigeye tuna was higher with the use of sardine and mackerel (small teleosts). Counterintuitively, the catch rate of yellowfin tuna was higher at deeper layers, the opposite behavior observed in bigeye tuna. A possible explanation is that the distribution of their CPUE is reflecting much more the vertical distribution of their preferred prey than their own putative depth distributions, especially as described from other geographic locations. These results emphasize the need for caution in the inference of the vertical distribution for pelagic species by their depth of catch in longline fisheries.

Acknowledgment

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Conflict of interests

Nothing to declare.

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Authors' Contributions

Campello, T.H.P.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Supervision Validation, Visualization Writing – Original Draft, Writing – Review and Editing Comassetto, L.E.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Software, Supervision Validation, Visualization, Writing – Original Draft. Dos Santos, J.C.P.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resource, Supervision Validation, Visualization, Writing – Original Draft, Writing – Review and Editing. Hazin H.G.: Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Software, Supervision Validation, Visualization, Writing – Original Draft, Writing – Review and Editing. Kerstetter D.: Formal Analysis, Investigation, Methodology, Project Administration, Resource, Software, Supervision Validation, Visualization, Writing – Original Draft, Writing – Review and Editing. Hazin F.H.V.: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resource, Software, Supervision Validation, Visualization, Writing – Original Draft.

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