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Experimental Mixed Gillnets Improve Catches of Narrow-Barred Spanish Mackerel (*Scomberomorus commerson*)

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Abstract: A new gillnet made from multiple mesh sizes ranging from 125 to 180 mm of stretched mesh (experimental gillnet) was tested under commercial fishing conditions to compare the fishing performance with that of conventional gillnets with a 125 mm mesh opening (control gillnet). Catch efficiency and size selectivity between the two gillnet types were evaluated throughout one year of fishing in three different locations in the waters of Vietnam. Experimental gillnets caught narrow-barred Spanish mackerel (*Scomberomorus commerson*), spotted mackerel (*Scomberomorus guttatus*), and wahoo (*Acanthocybium solandri*) in comparable amounts to the control gillnets, with the moon phase, month, and depth explaining some of the variation in the catch per unit effort (CPUE). An analysis of the size-dependent catch comparison rates and selectivity parameters showed that the experimental gillnets captured a wider range of narrow-barred Spanish mackerel sizes, but with a substantial proportion of individuals larger than those caught by the control gillnets. This is of higher weight per unit effort, and fishing enterprises therefore could improve their economic benefits by using modified gillnets with multiple mesh sizes. Our findings also support the biological and environmental benefits of the modified gillnet size selection, which might also extend to other species.

Keywords: mesh size; seasonal effect; moon phase; Vietnamese fisheries; catch comparison

Key Contribution: Experimental mixed gillnet capture the same amounts as the traditional gillnets, but catch larger size fishes, resulting in increasing the weight per unit effort and thus improve the economic benefits for the fishing enterprises, as well as contributing to the maintenance of the narrow-barred Spanish mackerel stock.

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1. Introduction

Gillnets have wall net configurations and are a passive stationary fishing gear, where capture depends on fish actively having physical contact with the gear during their natural diel movement, foraging movement, or seasonal migration [1]. Gillnets are one of the most commonly used fishing gears in the world, harvesting multiple species by commercial and artisanal fleets in both inland and marine capture fisheries [2,3]. In some fisheries, gillnets are considered an essential component for the maintenance of especially coastal fisheries, local value chains, and employment systems in fisheries-dependent areas because of the low initial cost and operational cost to commercial fisheries, contributing to the extension of the fishing season [4]. However, despite the popularity of gillnet fisheries, there is the potential for a low-quality fish catch if the nets soak for long periods in the water [5]. Like other fishing gears, gillnets are not 100% selective for the target species [6,7], and they also catch unwanted bycatch species, such as seabirds, sea turtles, and marine mammals [8–11]. "Ghost fishing" produced by lost, abandoned, and/or discarded gillnets, which is the continuous catching of target and nontarget species, represents another impact of gillnets on the marine environment and ecosystem [3,4,12]. To promote sustainable harvesting, ideal gillnets would fish across appropriate spatiotemporal scales that maximize catches of the permitted species and eliminate unwanted species and sizes.

The narrow-barred Spanish mackerel (*Scomberomorus commerson*) is an epipelagic species belonging to the family Scombridae and is distributed throughout the tropical-temperate Indo–Pacific [13–15]. The species can weigh as much as 70 kg at a 240 cm fork length (FL) and live about 22 years [16]. The global landings of narrow-barred Spanish mackerel have increased from 83,324 t in 1980 to >294,997 t in 2020 [17]. In Vietnam, various kinds of fishing gears are used, such as set-net [13], purse seine [18], and stick-held falling net [19], but most of the total catch is harvested using gillnets [20,21]. The narrow-barred Spanish mackerel resource is exploited year-round with 10 days break each month (typically from the 11th to 19th of the lunar month) to avoid low catch rates during the full moon phases on fishing grounds within 150 m depth [22–25]. In 2021, landings in Vietnam were 36,000 t accounting for USD 12.5 million in landed value. However, the resource of the narrow-barred Spanish mackerel has shown a sign of decline as revealed by catch rates of key fisheries decreasing over time [13,21–23,26]. The sizes of narrow-barred Spanish mackerel caught by Vietnamese gillnets typically range from 23.5 to 104 cm FL [22,24]. Increasing fish size selection through the use of larger mesh sizes could improve the ecological benefits and contribute to sustainable fisheries development [27–29].

Historically, Vietnamese fishers have used different lengths and heights of gillnets made of polyethylene (PE) or monofilament nylon with variable mesh sizes ranging from 61.2 to 200 mm with stretched mesh openings [23,24,30], which are deployed vertically in the water column by having weights along the bottom and floats along the top. As an important commercial species, several studies on catch rates and selectivities of gillnets targeting narrow-barred Spanish mackerel have been published [22–25], but these reports have failed to describe the spatiotemporal scales for the catch rate, size selectivity, and distribution of narrow-barred Spanish mackerel. The effects of environmental and biological factors that can influence the catch efficiency of gillnets have not been documented [31]. These are critical indices because a small change could affect the size selection and result in catch rate variations.

In addition to fish occurrence, density, mobility, and environmental conditions, which are considered critical factors for gillnet catch efficiency [1,15,32–35], technical factors, such as net length [1], hanging ratio [36], twine size and material [37,38], and mesh size, also affect catch rates [15,22]. The objective of the present study was to compare the catch rates and size selectivity of the control gillnets versus the new gear designed with mixed gillnets with larger mesh sizes across the entire fishing year in different locations incorporating various environmental and biological influences. In principle, larger mesh sizes could likely improve the capture sizes of the target species. However, they could also reduce catch rates, resulting in a negative impact on fishing efficiency and economic profits of fishing enterprises.

2. Materials and Methods

2.1. Data Collection

The comparative fishing experiments were conducted on board commercial fishing vessels (NĐ2790TS, NT0555TS, and BV94035TS) from 6 November 2008 to 30 October 2009 in the three different locations, namely the Gulf of Tonkin and center and south of Vietnam (Figure 1). Fishing locations in each study site were decided by the captain following traditional fishing practices. Both traditional gillnets, herein called control nets, and mixed gillnets, herein called experimental nets, were deployed and retrieved at the same time within each day and left at sea for the same period of time (soaking time) for comparative purposes (Figure 1). Control nets were constructed with 1.5 mm diameter dark green PE twine and had a 125 mm mesh opening size with a 0.59 hanging ratio (Figure 2). Experimental nets had similar configurations to those of the control nets, but with multiple mesh sizes ranging from 125 to 180 mm and variable hanging ratios (0.59–0.7) (see Figure 2 for details). Each gillnet consisted of 100 net webbings (sections), for a total length of 4500 m.

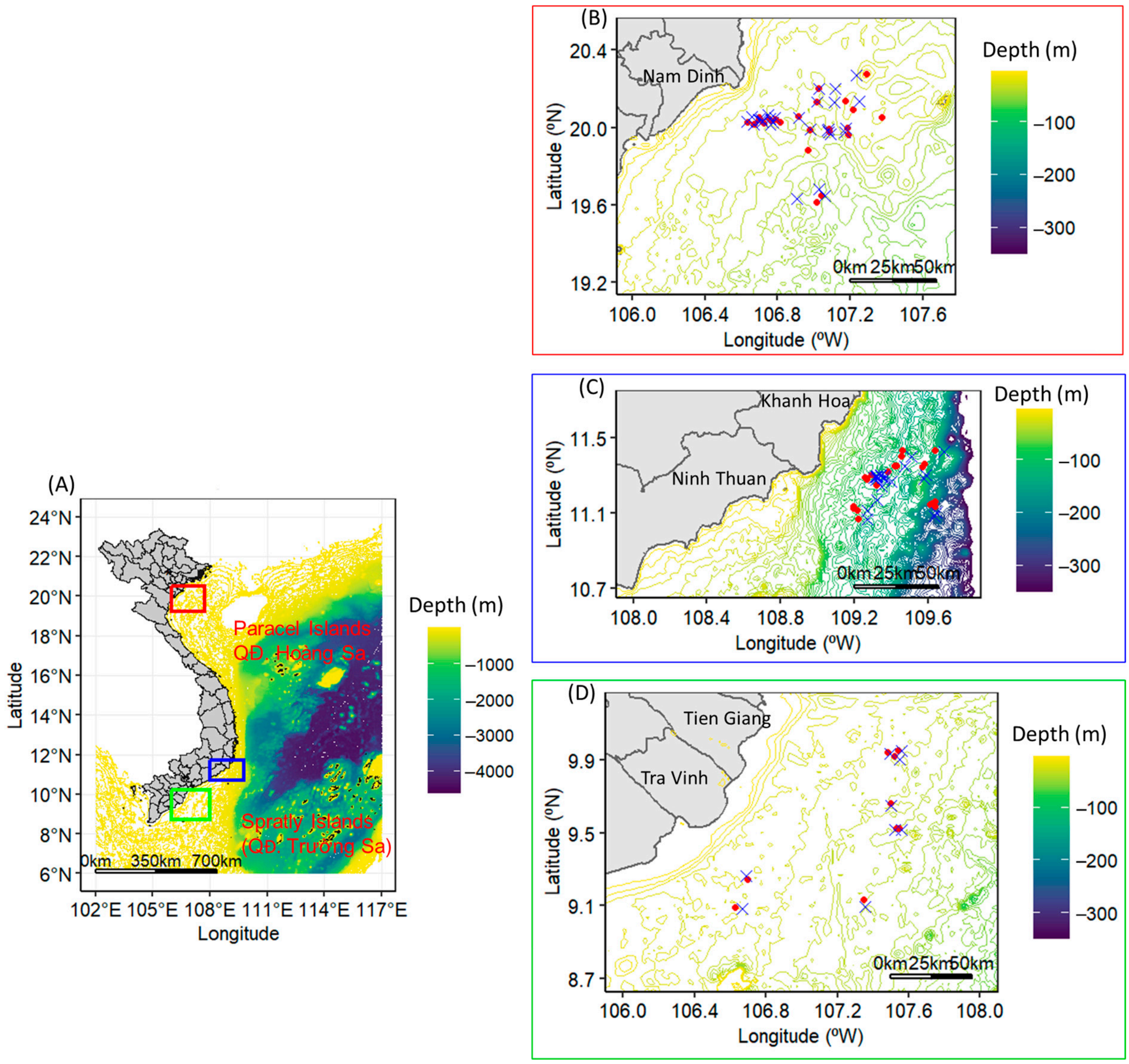

Figure 1. Map of Vietnam (**A**) including Gulf of Tonkin (red rectangular), center (blue rectangular), and south (green rectangular) study sites, and insets zoomed in on right (**B**–**D**) represent those study sites, respectively. Each blue x and red dot in the right panels indicates the location of a set of control gillnets and experimental gillnets, respectively, that were deployed during the study.

Gillnets were set in the seabed during the night. For each haul and deployment of gear, captains provided the date, time, soak time, sea depth, and location (coordinates). After each deployment, all individuals captured were separated by species level, counted, and recorded as the catch rate per gillnet by scientists. As the main target species, the total lengths of all narrow-barred Spanish mackerel caught by control gillnets and experimental gillnets were measured to the nearest mm using a measurement board. Other species were recorded in number, but the lengths were not measured.

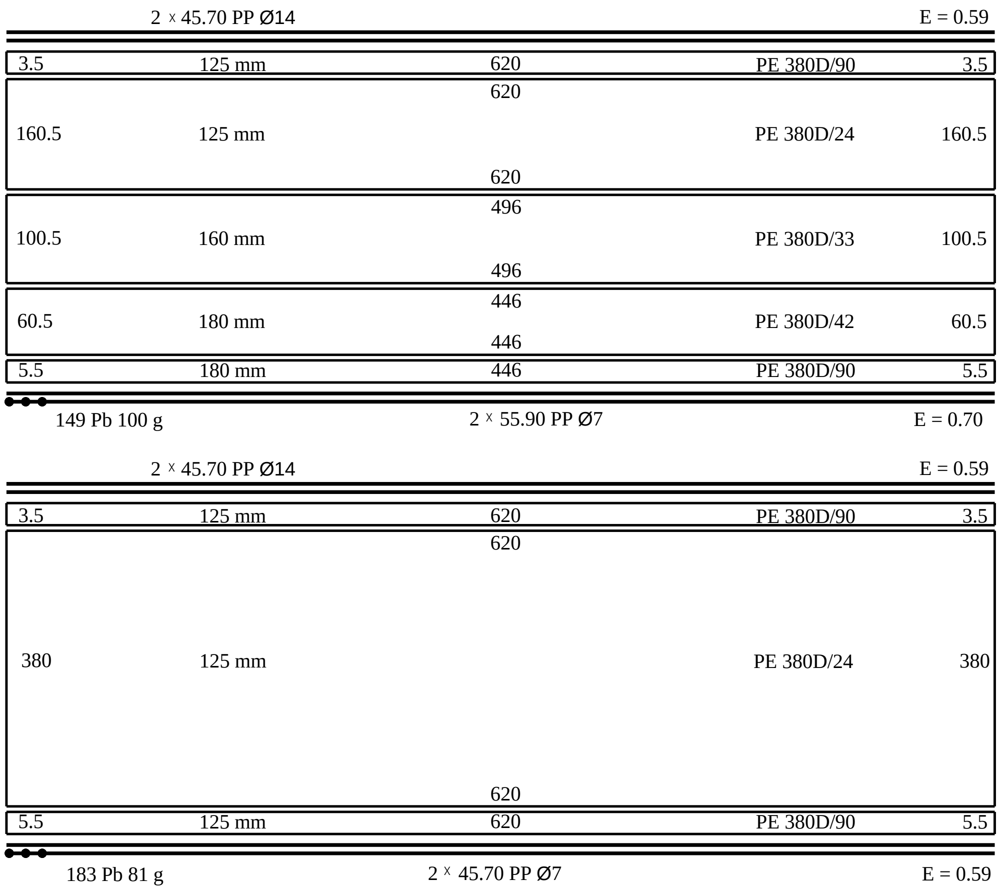

Figure 2. Schematic representation of the experimental (top panel) and control (bottom panel) gillnets tested during the fishing trials. Pb—Plumbum is lead; PP and PE are polypropylene and polyethylene, respectively; Ø is diameter; D is denier; and E is hanging ratio.

2.2. Statistical Analysis

We prepared the data, conducted the analyses, and produced figures using R (V4.1.2) Statistical Software [39]. Generalised Additive Models (GAMs) were used to compare the catch per unit effort (CPUE) between the control gillnets and experimental gillnets, where the catch was calculated as the number of individuals caught per hour for each gear type, and effort was a section (net webbing) of gillnet. GAMs were used because the shape of the relationship between the response variable (CPUE) and predictor variables (moon phase, deployment month, and depth) was unknown. GAMs included smoothers, which are algorithms that attempt to generalize data into smooth curves by local fitting to subsections of the data [40]. We estimated the variation of CPUE, while including potentially confounding moon phases, time series, and depth variables. In this model, we incorporated the moon phase variable because the catch, as a factor in our analysis, was known to be influenced by lunar rhythm and natural light, which is typical for most pelagic fisheries [13,18,19,41]. Moon phase was a continuous variable ranging from 0 to 1 corresponding to the new moon and full moon, respectively. Fishing month and depth were also continuous variables. The candidate model was as follows:

$$Log(CPUE) = \alpha + Trm + Loc + s(Moonphase) + s(month) + s(depth) + \varepsilon \quad (1)$$

where α is the intercept; *Trm* is the experimental treatment (control gillnets vs. experimental gillnets); *Loc* is the fishing locations (Gulf of Tonkin, center, and south of Vietnam); *s* is a thin-plate smoothing spline function; and ε is an error term as defined above. Because of the potential nonlinear relationships of CPUE with moon phase and month, cyclic cubic regression spline smoothers were applied, which forces the response to have the same startand endpoint that was handled to smooth the predictors. The depth variable was treated using a thin-plate smoothing spline with an automatic penalizing function that adopted zero values to exclude the effect of the independent variable from the model. We tested and found that the best model fit was produced using a gamma error structure with a link log. To obtain spatially relevant responses and to avoid overfitting the models [42,43], we set the number of knots for each of the smoothers to 4 (k = 4), allowing the smoother to divide the response from each explanatory variable into three parts. Models were visually inspected for spatial autocorrelation by plotting smoothed correlograms of model residuals, deviance residuals vs. linear plots, and deviance residuals vs. fitted plot [44]. Analyses were conducted separately for each species.

A generalized linear mixed-effect model (GLMM) was used to compare the length of the captures from the catch between treatments in each length class [45–47]. The logit catch proportion retained ((experimental/(experimental + control)]) of the catches-at-length was estimated by low-order polynomial GLMMs (i.e., constant, linear, quadratic, cubic, and quartic) to fit the proportions at each length class retained in experimental treatments. In this model, the logit of the retained catch proportion per length class was considered as a response variable, and length class was the explanatory variable, and the random effect was set on the intercept. A polynomial GLMM was applied to fit curves for the expected proportions of catch at a given length class using the glmer function from the *lme4* package [48]. The best model fit was determined based on the minimum Akaike information criterion (AIC) using the function AICctab from the bblme package [49]. Our data were fit with a binomial distribution. We fit the following model:

$$logit(y) = \alpha + \beta_1 + \beta_2 + \beta_3 + \beta_4 + b + \varepsilon \quad (2)$$

where y is the catch proportion retained between treatments as defined above. α is the intercept. β_1–β_4 is the modeled polynomial (i.e., linear, quadratic, cubic, and quartic) coefficients. b is a random factor (where $b \sim N\,[0, \sigma^2]$). ε is the error term. In this analysis, a proportion of 0.5 indicated no difference in catch between the two treatments at the given length, whereas a proportion greater than 0.5 indicated that more fish were captured by experimental gillnets than by control gillnets and vice versa. For example, if the catch proportion equaled 0.7, 70% of the analyzed species in the specific length class were captured by experimental gillnets and 30% by control gillnets, and if the proportion was 0.3, 30% of fish at given length class were caught by experimental gillnets and 70% by control gillnets. The significance between treatments was determined by confidence intervals (CIs); if the CIs overlap by 0.5, there is not any significant difference in catch-at-length between experimental and control gillnets at the given length class [45].

3. Results

Over the course of the study period (6 November 2008 to 30 October 2009), we conducted 67 nights of fishing and successfully deployed a total of 133 sets of nets (67 control net sets and 66 experimental sets). The fishing depths (mean ± 1 SD, in m) were 53.7 ± 5.1, 84.3 ± 17.8 m, and 66.7 ± 5.6 m for the Gulf of Tonkin, center, and south of Vietnam, respectively. The effective fishing time (i.e., time that gillnets deployed onto the sea bed) ranged from 2.2 to 11.8 h (mean of 6.9 h) for both types of nets. There was a variation of the soak time between seasons and locations due to the weather, fish abundance, and fishing habits.

As is usually the case in tropical fisheries, diverse groups of species were caught during the study. Control and experimental gillnets caught 27 and 28 species, respectively (Table 1). The main target species included narrow-barred Spanish mackerel (*Scomberomorus commerson*), spotted mackerel (*Scomberomorus guttatus*), and wahoo (*Acanthocybium solandri*). Together, these three species comprised 73.9% and 84.3% of the total catch of all species captured by the control and experimental gillnets (Table 1), and only these three species were included in the catch analysis. Length analysis was carried out on narrow-barred Spanish mackerel. Specifically, the control gillnets captured 55.7, 1.6, and 16.7%, while experimental gillnets captured 66.0, 1.6, and 16.8% narrow-barred Spanish mackerel, spotted mackerel, and wahoo, respectively (Table 1).

Table 1. Summary of all species captured during the fishing experiment for control and experimental gillnets.

Species	Scientific Name	Species Captured by Net Type in Number	
		Control	Experimental
Target species (retained)			
Narrow-barred Spanish mackerel	*Scomberomorus commerson*	32,000	29,900
Spotted mackerel	*Scomberomorus guttatus*	900	700
Wahoo	*Acanthocybium solandri*	9600	7600
Byproduct (retained)			
Tripletail	*Lobotes surinamensis*	299	199
Barramundi	*Lates calcarifer*	98	100
Pilotfish	*Naucrates ductor*	299	0
Black pomfret	*Formio niger*	500	498
Bronze croaker	*Otolithoides biauritus*	201	0
Bullet tuna	*Auxis rochei*	1501	1599
Cobia	*Rachycentron canadum*	0	100
Daggertooth pike conger	*Muraenesox cinereus*	98	199
Dogtooth tuna	*Gymnosarda unicolor*	299	199
Frigate tuna	*Auxis thazard thazard*	903	598
Giant catfish	*Arius thalassinus*	1501	100
Great barracuda	*Sphyraena barracuda*	299	299
Largehead hairtail	*Trichiurus lepturus*	98	100
Yellow-spotted skate	*Raja hollandi*	98	199
Indian threadfin	*Polynemus indicus*	3301	399
Japanese scad	*Decapterus maruadsi*	0	299
Longtail tuna	*Thunnus tonggol*	201	100
Common dolphinfish	*Coryphaena hippurus*	299	100
Red bigeye	*Plectorhynchus hamrur*	98	199
Crimson snapper	*Lutjanus erythropterus*	0	100
Shortfin scad	*Decapterus macrosoma*	201	0
Silver pomfret	*Pampus argenteus*	98	100
Elongate ilisha	*Ilisha elongata*	98	100
Spottail shark	*Carcharhinus sorrah*	1898	598
Small spotted dart	*Trachinotus bailloni*	903	199
Swordfish	*Xiphias gladius*	1501	399
Talang queenfish	*Scomberoides commersonianus*	201	0
White-spotted grouper	*Epinephelus caeruleopunctatus*	0	199
Yellowfin tuna	*Thunnus albacares*	0	100

The models show that there were no significant differences in the CPUE between the control and experimental gillnets for the examined species. The modelled CPUE for narrow-barred Spanish mackerel, spotted mackerel, and wahoo for the control gillnets were 0.84, 0.02, and 0.27 individuals per gillnet, respectively, compared with 0.82, 0.01, and 0.06 individuals per gillnet per hour for those species caught in experimental gillnets, respectively (Figure 3). Additionally, the models detected significant differences in the CPUE of the total examined species between locations. The CPUE of narrow-barred Spanish mackerel was the highest in the south site (CPUE: 2.11), followed by the center site (CPUE: 0.84) and the Gulf of Tonkin (CPUE: 0.48), which was statistically significant for all pairwise comparisons (Figure 4). The CPUE of wahoo was also significantly higher in the south site (CPUE: 0.68) than in the center (CPUE: <0.01) and Gulf of Tonkin (0.04) sites (Figure 4). However, there was no significant difference in the CPUE of spotted mackerel among the locations, which had a low CPUE (Figure 4).

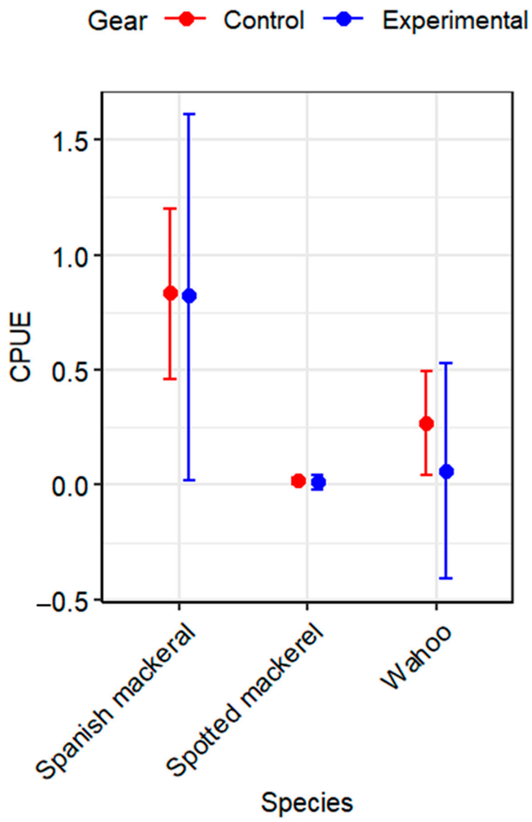

Figure 3. Mean CPUE (number of fish caught per h for webbing) of narrow-barred Spanish mackerel, spotted mackerel, and wahoo caught by control (red) and experimental (blue) gillnets. Points represent mean catch. Bars are 95% confidence intervals. Negative confidence intervals indicate that they are not statistically significant.

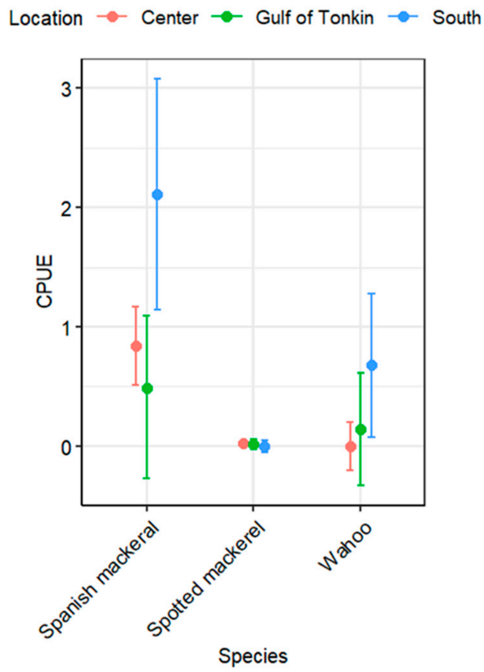

Figure 4. Mean CPUE (number of fish caught per h for webbing) of narrow-barred Spanish mackerel, spotted mackerel, and wahoo caught in the Gulf of Tonkin (green), center (red), and south (blue) of Vietnam. Points represent mean catch. Bars are 95% confidence intervals. Negative confidence intervals indicate that they are not statistically significant.

We tested different models to identify the best fit based on the selected criteria. The GAMs showed that the best explanation of the variations in the CPUE of the examined species included moonphase, month, and depth. The CPUE patterns were similar for all tested species (Figure 5). For example, the CPUE significantly decreased with the high lunar illumination levels for all species tested (Figure 5A–C). For all species, the CPUE peaked in September (Figure 5D–F). We observed a spatial variation, with peaks of CPUE at 90 m depth (Figure 5G–I).

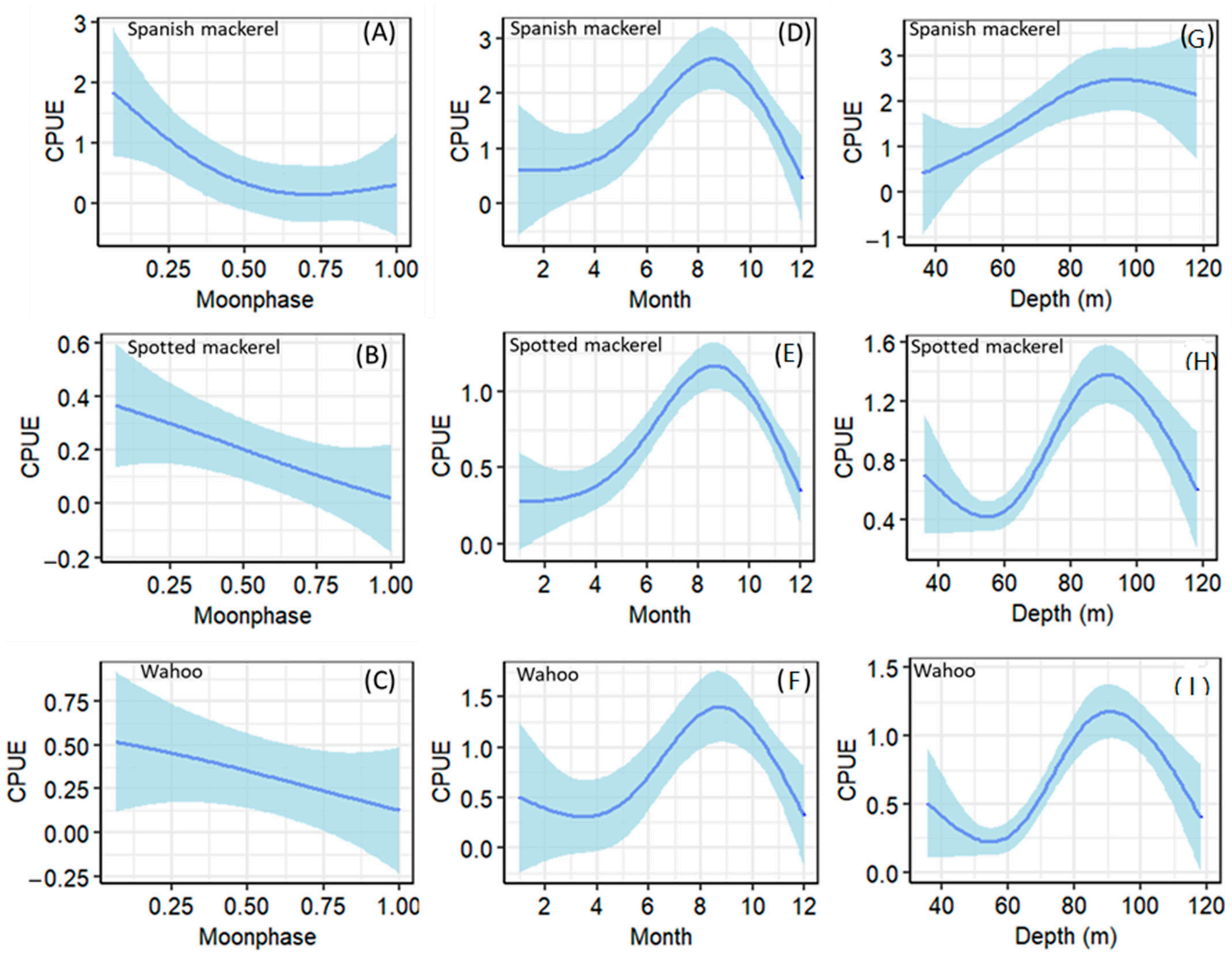

Figure 5. Predicted CPUE (number of fish caught per h for webbing) obtained from the GAMs for catch of narrow-barred Spanish mackerel, spotted mackerel, and wahoo in relation to moon phase (**A**–**C**), fishing month (**D**–**F**), and depth (**G**–**I**). Blue curves indicate mean values obtained from the models. Shaded areas represent 95% confidence intervals. Negative confidence intervals indicate that they are not statistically significant.

The total length of narrow-barred Spanish mackerel caught by the control gillnets ranged from 370 to 1250 mm, compared with that of those caught by experimental gillnets ranging from 370 to 1760 mm (Figure 6A). Most of the fish caught by both experimental gillnets were greater than the maturity size (752 mm total length). A logit cubic curve showed the best fit for the comparison, having the lowest Akaike Information Criterion (AIC) value and with all model parameters being statistically significant (Table 2). The GLMM model showed that the control gillnets caught more fish at total lengths smaller than 960 mm, while the experimental gillnets caught more individuals at total lengths larger than 1150 mm (Figure 6B). The significant differences in catch-at-length between the control vs. experimental gillnets were shown where the confidence intervals (CIs) did not overlap the 0.5 band. Contrastingly, there was no difference in size-based selectivity between the control and experimental nets for the moderate-sized fish (i.e., 450–600 mm and 960–1150 mm) based on the CI area overlap at the 0.5 band (Figure 6B).

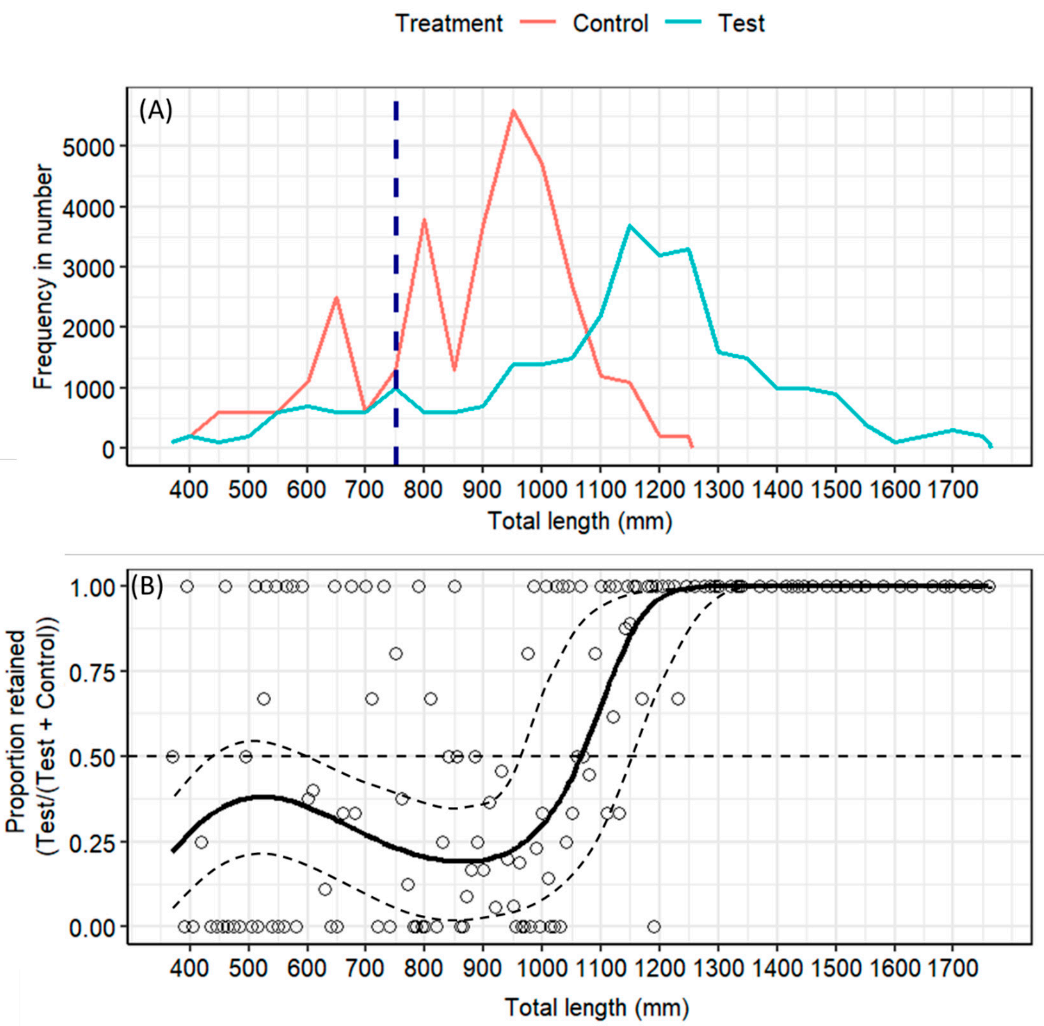

Figure 6. Length frequency curves for narrow-barred Spanish mackerel captured by the control and experimental gillnets (**A**). GLMM results for the proportion of the total catch retained by control gillnets compared with experimental gillnets (**B**). The vertical blue dashed line in the top panel indicates the maturity size of narrow-barred Spanish mackerel at 752 mm total length. The horizontal dashed line at 0.5 in the bottom panel indicates equal performance of both experimental gears. A value of 0.25 indicates the given length class where 25% of fish were captured by the experimental gillnets and 75% of fish were captured by control gillnets. Contrastingly, a value of 0.75 means that 75% of fish were caught by the experimental and 25% by the control gillnets. The solid black curve in the bottom panel models the mean total length at given size, while the gray shaded areas are the 95% confidence intervals. If confidence intervals overlap at 0.5, then there is no statistically significant difference in catch-at-length between control and experimental gillnets at the given length class.

Table 2. GLMM results for the control vs. experimental gillnet comparison. **Bold p-values** denote the selected model with the lowest AIC and the model parameters resulted in being statistically significant. SE is the standard error of the estimate.

Model	AIC	Parameter	Estimate	SE	z-Value	p
Constant	5246.4	β_0	−0.07	0.01	−8.44	<0.001
Linear	3588.3	β_0	−5.04	0.06	−105.70	<0.001
		β_1	0.01	0.05	106.60	0.53
Quadratic	2615.5	β_0	9.09	0.30	195.00	<0.001
		β_1	−0.03	0.01	−572.20	0.469
		β_2	0.70	0.02	277.80	<0.001
Cubic	2389.5	β_0	−14.40	0.05	−306.18	**<0.001**
		β_1	0.07	0.01	1279.74	**<0.001**
		β_2	3.00	0.40	−1473.23	**<0.001**
		β_3	5.70	0.70	0.72	**<0.001**
Quartic	5663.3	β_0	−21.59	0.33	−65.64	<0.001
		β_1	0.11	0.01	294.14	<0.001
		β_2	−2.40	0.67	−377.95	<0.001
		β_3	5.30	1.40	0.25	0.42
		β_4	<0.01	<0.01	0.02	0.59

4. Discussion

Modifying fishing gear is one of the few ways to assess the utility of a key technical modification on the gillnet catches of a migratory species, in order to increase captures or improve gear selectivity. In this study, we showed that the experimental gillnet with multiple mesh sizes catches narrow-barred Spanish mackerel in comparable amounts to the control net, while it selects a range of sizes extended toward larger individuals, which is reflected in the caught biomass, ultimately increasing the revenues of the narrow-barred Spanish mackerel gillnet fisheries. Like other passive gears (set-net [13], pot [50], trammel net [51], and fyke net [52]), the catch of gillnet depends on temporal (i.e., seasonal migration and natural diel movement) and spatial (i.e., depth and locations) factors. The present study shows that mixed gillnets had higher catch rates in autumn under dark conditions. Finally, this study adds further evidence to the fact that fishermen can obtain their catch with improved size selectivity through suitable modifications of fishing gear, and mixed gillnets represent an alternative to the traditional gillnets in mitigating the capture of small sizes of fish species targeted by gillnet fisheries.

As expected, our results show that larger narrow-barred Spanish mackerel were captured by the mixed gillnets across the entire targeted length range compared to the traditional gillnets. In other words, the mean lengths of fish increased with increasing mesh size, and this is typical for the gillnet selectivity feature [53]. A consistent feature of the gillnet fisheries is represented by the selectivity of the captured fish size along with the net mesh size [15,22,54]. Our experiment indicates that the catch of the experimental gillnets, which had larger mesh sizes in the bottom, captured larger fish compared to the single-mesh-size gillnets. This outcome is possibly related to the vertical diel migration of narrow-barred Spanish mackerel, where larger individuals aggregate near the seabed and forage food in demersal habitats, while small and young fish live in the upper water column [14,16,55]. Diel vertical migration and distribution apparently depend on the oceanographic conditions, in particular, the seasonal stratification of the water column, because diel effects on catch rates are more pronounced during the autumn when the water column is thermally stratified than during spring and winter when the water column is well mixed [56]. Seasonality also influences the catch efficiency of narrow-barred Spanish mackerel gillnets [15]. For example, [15] show that gillnets catch larger percentages of adults during autumn and winter, and catch rates significantly decrease in the spring. Our results show that the catch of mixed gillnets peaks in September.

Gillnetting is different from most other fishing methods, which commonly reduce the catch rates once increasing mesh sizes, which is not acceptable from the fishermen's perspective. The mixed gillnets used in our experiments captured the same amounts of fish as the traditional gillnets, but the substantially extended the size of the captured individuals in the upper limit of the range. This is an important contribution because fishermen can improve the weight per unit effort and sell fish at higher prices. Our mixed gillnets have an efficient catch; perhaps we chose an effective hanging ratio and materials, which made fish catching easily [15].

As other pelagic species, the catch of mackerel species in this study was influenced by the lunar phases. Moonlight reflection on the net while fishing in shallow water might potentially change the behavioral responses of the target and bycatch species to the fishing gear, resulting in a lower catch rate under high moonlight intensity. This is sustained by previous observations of other species and fisheries [19,41,57]. For example, the catch rates of pole-and-line fisheries catching yellowfin tuna (*Thunnus albacares*) during the full-moon period are one third of those in the new-moon phase [41]. Purse seine and stick-held falling nets with artificial light are often suspended during the high moonlight intensity period (i.e., 10th–20th of lunar month) [18,19]. The target species of the gillnet fisheries in this study, the narrow-barred Spanish mackerel, spotted mackerel, and wahoo, were more responsive to the nocturnal light condition. These species reportedly exhibit shallower nighttime distributions around new moons and deeper distributions when the lunar illumination is high, presumably in association with the vertical distribution of prey [55].

We measured higher catch rates of narrow-barred Spanish mackerel and wahoo in the south of Vietnam compared to the Gulf of Tonkin study site using both gear types. Other studies also showed pronounced differences in catches among fishing sites [22,23], which is not surprising for gillnet fisheries that depend on fish occurrence, density, mobility, diel movements, and seasonal migration [1]. Higher catch rates in the south of Vietnam are consistent with natural resource distribution in this area [58,59]. Additionally, Vietnamese coastal areas are known to exhibit different habitats and environmental conditions, which could also influence fishing efficiency [60].

Mixed gillnets captured the same fish species that traditional gillnets did, and both gear types captured few spottail sharks (*Carcharhinus sorrah*) and bronze croakers (*Otolithoides biauritus*), which are protected species in Vietnam [61]. Further research on gear modification and fish behavior is needed in order to avoid incidental catches of protected or otherwise undesired species. A reduction in effort in terms of either soak time or type of gears used, or both, could lead to a reduction in the catches of undesired species. Unlike for regional pole-and-line fisheries, no marine turtles were caught in the present study [41].

While the traditional gillnet with single-small-mesh sizes has become part of the social license to catch multiple species in the waters of Vietnam, some enhancements can be introduced. Fishing with mixed gillnets requires minimal vessel or equipment modifications to use the new gear. Importantly, the investment cost of the new gear is similar to that already adopted by fishermen. Although there have been several studies on the gillnet modification targeting pelagic species in Vietnam [22,23], our results show the first successful application of mixed gillnets to improve the catch efficiency by catching larger fish sizes. As a result of the findings from our study, the commercial fisheries has generally shifted to the mixed gillnet technique throughout coastal communities in Vietnam, reporting results very similar to our research findings. Mixed gillnet fisheries deserves attention in the future because of the herein reported benefits. Monitoring this modified gear to collect data on stock selectivity, measuring bycatch, and resource management is recommended.

5. Conclusions

Marine fisheries have a very important role in the socioeconomic development throughout coastal communities, because many millions of Vietnamese directly and/or indirectly rely on capturing marine fish. Although traditional gillnets show good performance of catching, modifications are available and needed. Our results show that experimental gillnets tested in this study provide a promising alternative to the single-mesh-size gillnets.

The benefit of mixed gillnets for the fishermen is to increase the weight per unit effort of the target species, and given the broad application of this gear type, the fishermen are required to make a minimal adjustment and upgrade their current nets and vessels. The new type of gear does not add extra operational costs compared to the traditional gillnets. In addition to the potential economic benefits, widespread use of mixed gillnets contributes to the maintenance of the narrow-barred Spanish mackerel stock, resulting in large fish sizes being caught.

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Data Availability Statement: The data that support the results of this study are available from the corresponding author upon reasonable request.

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