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EQUIVALENCE IN EFFICIENCY PER HOOK BETWEEN THE TRADITIONAL MULTIFILAMENT AND MONOFILAMENT SURFACE LONGLINE STYLES USED BY THE SPANISH FLEET TARGETING SWORDFISH (*XIPHIAS GLADIUS*) IN THE SOUTH EAST PACIFIC [*]

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SUMMARY

*A total of 143 sets (281000 hooks) were observed on board two Spanish surface longliners targeting swordfish (*Xiphias gladius*) during fishing operations in the South East Pacific. Each vessel used a surface longline type (monofilament or multifilament style), including several hook and bait types, previously designed to provide an identical configuration in both vessels. Standardized catch rates were obtained by the Generalized Linear Model using a Delta-lognormal approach and observations were restricted to those areas and time periods where the fishing operations of the two gear types overlapped. 'Gear' and 'area' were the most important factors able to explain both the proportion of positive sets and the catch rates of most of the species captured. Given the special characteristics of this experiment, equivalences between the efficiency of the two longline styles are provided for each of the species under consideration. The monofilament longline showed an efficiency per hook of 1.7, 1.9, 1.3 and 2.0 greater than the multifilament longline for swordfish, blue shark, shortfin mako and billfish, respectively, when their standardized catch rates were considered.*

RÉSUMÉ

*Un total de 143 opérations (281.000 hameçons) a été observé à bord de deux palangriers de surface espagnols qui ciblaient l'espadon (*Xiphias gladius*) lors d'opérations de pêche dans le Pacifique Sud-Est. Chaque navire a utilisé un type de palangre de surface (style monofilament ou multifilament), y compris plusieurs types d'hameçons et d'appât, antérieurement conçus pour fournir une configuration identique chez les deux navires. Des taux de capture standardisés ont été obtenus par le modèle linéaire généralisé en utilisant une approche delta-lognormale et les observations se sont limitées aux zones et périodes temporelles où les opérations de pêche des deux types d'engin se sont chevauchées. L' « engin » et la « zone » étaient les facteurs les plus importants capables d'expliquer à la fois la proportion d'opérations positives et les taux de capture de la plupart des espèces capturées. Compte tenu des caractéristiques spéciales de cet essai, les équivalences entre l'efficacité des deux styles de palangre sont fournies pour chacune des espèces à l'étude. La palangre monofilament a montré une efficacité par hameçon de 1,7, 1,9, 1,3 et 2,0 supérieure à la palangre multifilament pour l'espadon, le requin peau bleue, le requin-taupe bleue et les istiophoridés, respectivement, lorsque leurs taux de capture standardisée ont été examinés.*

RESUMEN

*Se observaron un total de 143 lances (281.000 anzuelos) a bordo de dos palangreros de superficie españoles dirigidos al pez espada (*Xiphias gladius*) durante las operaciones de pesca en el Pacífico suroriental. Cada buque utilizó un tipo de palangre de superficie (monofilamento o multifilamento), lo que incluye varios tipos de anzuelos y cebo, diseñados previamente para proporcionar una configuración idéntica en ambos buques. Las tasas de captura estandarizadas se obtuvieron mediante un modelo lineal generalizado utilizando un enfoque delta lognormal y las observaciones se restringieron a aquellas zonas y periodos en los que las operaciones de pesca de los dos tipos de artes se solaparon. "Arte" y "zona" fueron los factores más importantes para explicar tanto la proporción de lances positivos como las tasas de captura de la mayor parte de las especies capturadas. Dadas las características especiales*

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de este experimento, se facilitan las equivalencias entre la eficacia de los dos tipos de palangre para cada especie considerada. El palangre monofilamente tuvo una eficacia por anzuelo 1,7; 1,9; 1,3 y 2,0 veces superior al palangre multifilamento para el pez espada, la tintorera, el marrajo dientuso y los marlines, respectivamente, cuando se consideraron las tasas de captura estandarizadas.

KEYWORDS

Longline, CPUE, swordfish, sharks, billfish

1. Introduction

The equivalence between the fishing effort exerted by the different fishing gears or between the different styles of a particular gear is an ongoing debate in many fisheries. The number of hooks set has traditionally been used to measure nominal fishing effort in surface longliners targeting highly migratory fish species. However, in order to convert this to effective fishing effort, a number of other important elements may be involved, such as the technology and gear configuration used, including baits, hooks, soaking time as well as fishing area-time, skipper skill, boat type, -among other possible factors- (Hilborn and Ledbetter 1985; Squires and Kirkley 1999; Vega and Licandeo 2009; Ward 2008). Some of the problems that arise owing to the standardization or equivalence between different gears or styles of surface longline have generally been resolved by applying models (Venables *et al.* 2004) or other approaches for the standardization of the catch rates yielded. The modeling process would also include the factors and their interactions considered to be important or significant in each case taken from data recorded in the logbooks or obtained during surveys. However, abundance surveys are very scarce in open ocean using longlines because of the high cost and the complexity in obtaining representative samples for species with broad spatial and temporal variability (Ward 2008). As regards the surface longliners targeting swordfish or other highly migratory species, this problem has become more evident on a global scale since the introduction of new drifting surface longlines styles based on the so-called “Florida style” developed in the 1980s (Hoey *et al.* 1989). This type of longline style tends to use a smaller number of hooks per set and is more highly mechanized with clips, a polyamide monofilament mainline and other technological improvements which replace the traditional multifilament longlines.

The Spanish surface longline fishery targeting swordfish has traditionally used the multifilament longline style with “J” or derivative hook shapes, soaked at night, and the predominant bait has generally been mackerel. However, with the introduction of the mechanized surface monofilament longline style in recent times, squid has been a frequent bait type, and there have been other changes in hook types and gear configuration. The shift from the multifilament gear to the monofilament style took place very quickly in the Spanish fleet at the end of the last century. Moreover, the spatial and temporal overlapping of the observations was limited, especially in some geographical regions. The monofilament style –also so called the “American style”- used in a large number of fleets regularly targeting swordfish, yields higher catch rates per hook than the multifilament style (Ortiz *et al.* 2010; Tserpes and Peristeraki 2010; Vega and Licandeo 2009, Ward and Elscot 2000).

Several experiments testing alternative hooks, baits and other factors have recently been carried out on board European surface longline fleets targeting tuna and tuna-like species, covering several oceans. Significant decreases in the catch rates of the main or target fish species were regularly obtained in most of these experiments when alternative hooks-baits were introduced. The combination of squid as bait seems to increase the hooking rates of sea turtles, regardless of the hook type used (Anon. 2008, Ariz *et al*. 2005, García-Cortés *et al.* 2009, Mejuto *et al*. 2008). In the Mediterranean Sea, where the interaction with sea turtles was found to be somewhat higher than in other areas surveyed, factors other than hook type were significant and more important in terms of reducing the interaction of the fishing activities with sea turtles and swordfish juveniles, such as the longline style and bait type (De la Serna *et al.* 2006, 2008). However the overall goal of most of these experiments cited was mainly to test alternative “G” hooks and bait types to minimize incidental sea turtle bycatch.

The preliminary results obtained during an experiment developed in South East Pacific areas by two commercial Spanish longline vessels fishing over the similar time periods and areas with two different longline styles (multifilament and monofilament) also suggested much higher nominal catch rates per hook for the monofilament style than for the multifilament style. This is in keeping with what was reported by several authors for other areas. Factors such as 'hook' and 'bait', and statistical significance largely depended on the fish species caught. However their interactions were not significant in most cases (García-Cortés *et al.* 2009).

The goal of this study was to expand upon the most recently cited experiment performed in the South East Pacific areas and specifically, to compare the efficiency of the two longline styles used in the Spanish fishery, on the target species (swordfish) as well as on the main bycatch fish species, selecting the observations carried out in overlapping 5ºx5º squares areas where both longline styles were operating during the same period and taking advantage of standardized protocols among boats.

2. Material and methods

Vessels / gears: Two long distant commercial vessels belonging to the Spanish surface longline fleet targeting swordfish, which regularly fish in these areas, were involved in this experiment. The mean characteristics of the boats were as follows: 38.9m in length, 224.5 GRT and 634 HP. One of the boats used a mean number of 2688 hooks per set with the multifilament longline type (used as a reference –Ref.-) and the other boat used 1184 hooks per set with the monofilament longline. During the sets, each vessel maintained the characteristics of the gear, without making any changes in the flotation line length, the section/length of the steel wire, the length and type of the gangions, or the distance between them, etc. The experiment was based on the use of the most regular and standardized gear configuration possible within each vessel. Three hook and two bait types were used in both vessels-gears and kept constant throughout the experiment (**Table 1**). A single skilled skipper per boat was maintained throughout the experiment.

*Fishing area / time_*: The observations selected were restricted to those where both boats had been fishing in the South East Pacific Ocean during the same months (March to July, 2007) within overlapping areas (4 squares of 5ºx5º) labeled as z1, z2, z3 and z4, respectively (**Figure 1**).

Experimental design: Both longline styles were configured in sections and a combination of the hook-bait was placed within each section. Each vessel tried to set out the same number of hooks of each type by set, dividing the total number of hooks per set of their configuration by three. The position of each hook on the longline was rotated and these positions were alternated –in a chain effect– every 3 sets. Similar to the alternating combination by hook type, the two bait types were combined in balanced amounts. The position of the bait varied in combination with each type of hook, in an attempt to prevent its position from affecting the catch obtained. The purpose of this approach was to prevent the interference of elements such as the changing drift of the longline sections, the varying duration of the soaking time among sections or other uncontrolled factors related to the position of the respective combinations within the gear, as well as the varying availability of the fish depending on the position of each section within the set (García-Cortés *et al.* 2009, Mejuto *et al.* 2008).

Species: The dressed weight (DW kg), including live releases and dead discards, of the most prevalent fishes (swordfish, *Xiphias gladius*; blue shark, *Prionace glauca*; shortfin mako, *Isurus oxyrinchus* and billfish, Istiophoridae (species combined) was considered.

Catch rates and analysis: The nominal effort was measured in number of hooks. The nominal catch rates per thousand hooks were obtained for each observation considered in the analyses based on the addition of the catch and the effort of the sections configured with the same type of hook and bait in each set. The two levels of longline styles (gear), the three levels of hooks (hook) and the two levels of bait types (bait) were tested (**Table 1**) as well as the four areas (area), which were all considered as main factors. Their interactions were also tested. Therefore, the gear factor means, in this case, the two levels of longline styles which have been configured using the same hook and bait types within their respective configurations.

The statistical methods used to evaluate the significance (α=5%) of the variables tested in the standardization of the catch rates of each species were the same as previously documented (García-Cortés *et al.* 2009). Generalized Linear Model procedures (Robson 1966, Gavaris 1980, Kimura 1981, Venables and Dichmont 2004) were used. A Delta-lognormal model error distribution was assumed for the analysis of all species due to the characteristics of the analyzed data (zero- catch records and real-value catch rates with positive data). Delta models describe separately the probability of a non-zero catch, typically modeled assuming a binomial error distribution, and the probability of a positive catch, which can be modeled based on different error distributions (lognormal, gamma, Poisson, negative binomial, *inter alia*) depending on the nature of the response variable (Minami *et al.* 2007, Ortiz and Arocha 2004, Stefansson 1996). Since the recorded catch data was fish weight, a lognormal error distribution was assumed for modeling catch rates of the observations with a positive catch. The proportion of positive observations (observations with at least one individual) was the result of ***s*** successful observations of a total ***n*** number of observations, with each one representing the execution of an independent *Bernouilli* process, and modeled assuming a binomial error distribution. The selection of factors affecting both the probability of a non-zero catch and catch rate for observations with positive catch data was based on an analysis of deviance tests. Deviance tables were constructed in a stepwise manner starting with a minimal model, which included only the overall mean, sequentially adding explanatory factors. The difference in the deviance between two models that differ only in one explanatory variable follows a chi-squared distribution with degrees of freedom equal to the number of additional estimated parameters minus one (McCullagh and Nelder 1989). Only factors significant at the 5% level were kept in the final models. In the event that there was a significant interaction between factors, the corresponding main factors were included in the model, even if they were not significant (hierarchy principle). Standardized catch per unit of effort values were calculated from the final models as the product of the expected probability of non-zero catch and the expected conditional catch rate for observations with a positive catch. Both the expected probability of non-zero catch and the expected conditional catch rate were based on the adjusted means of the gear factor for the final fitted models (Lo *et al.* 1992; Stefansson 1996, Ortiz and Arocha 2004).

The ratio (%) between the standardized catch rates was understood to be the increment in the monofilament standardized catch rates in relation to the standardized catch rates obtained using the multifilament traditional style selected as a reference (ref): Ratio%= ((value – value of reference) / value of reference) * 100. Therefore this ratio (%) represents an empirical estimate of the proportion in incremented catchability between both longline styles used during this experiment. Assuming equal abundance and availability (B) in the fishing areas selected for both boats (1 and 2), relative standardized catch rates could provide an approximation to the proportionality in efficiency or catchability (q) between the two longline styles: $CPUE_1 = q_1*B$; $CPUE_2=q_2*B$ or the equivalent $CPUE_2/CPUE_1 = q_2/q_1$ (Gulland 1983, Hilborn and Walters 1992, Sparre and Venema 1997) or $\Delta q = CPUE_2/CPUE_1$ (Ward 2008). On the basis of the latter formulation, also presented are values that define the equivalence between the efficiency of the two longline types for each species under consideration.

3. Results and discussion

A total of 143 fishing sets were used in this analysis (74 with the multifilament style and 69 with the monofilament style), corresponding to 281 000 hooks set (198 200 with the multifilament and 82 800 with monofilament gear) in the four areas considered in this analysis (**Table 1**, **Figure 1**). Total catches in weight and the nominal catch rates per thousand hooks are summarized in **Table 2**.

Table 3 reports a qualitative summary of the deviance analyses for factors affecting the catch rates of positive sets and the proportion of positive sets for each species considered, respectively, for the models tested. The 'gear' factor affected both the catch rates and the proportion of positive sets in all the species of fish except swordfish when the proportion of positive observations was considered. The interaction of factors analyzed - 'gear*hook', 'gear*bait' and 'gear*area'- did not prove to be significant in any case, except for the billfish "gear*area" as regards the positive catch rates and 'gear*bait' for blue shark in terms of the proportion of positive sets (**Tables 4-5**). **Table 6** reports the final models selected for the standardization of the catch rates by species. The results of the standardized mean catch rates by fish species and for the principal factor 'gear' indicate important yield gains per hook (ratio%) for the monofilament longline type versus the multifilament style, within an interval of 32%-101% according to the species considered (**Table 7**).

Ideally, the equivalence between the catch rates of the two types of longline should be computed on the basis of standardization processes using a broad sampling of vessels of both types, covering spatial and temporal strata with the greatest possible similarity and with the observations of the different styles having a high degree of overlap (Hilborn and Walters 1992). This ideal scheme, however, is not always feasible in the practices of many commercial fisheries targeting highly migratory large pelagic fishes, especially when rapid changes take place in fishing gears or there are different spatial and temporal patterns in the different styles used in addition to other possible data limitations. In such cases, so as not to lose sight of our retrospective view of catch rate trends, it might be useful to look for alternative methods to obtain the proxy equivalence between gears-styles on the basis of experiments carried out specifically as is regularly implemented in demersal fisheries.

A general linear modeling (Delta-lognormal) was recently run for the standardization of swordfish catch rates including surface longline fleets of different countries using mono or multifilament styles and covering very broad areas of the North Atlantic during a long historical period. The standardized catch rates by fleet and style suggested that the monofilament style produced higher standardized catch rates per hook than the multifilament style in all the fleets analyzed. The equivalence between efficiency per hook of both styles was estimated for the swordfish between 1.4 and 2.4 in favour of the monofilament styles (Ortiz *et al*. 2010). Therefore the value of 1.7 obtained in this experiment was within the interval observed for North Atlantic areas. Another experiment was recently conducted in the Chilean longline fleet also in areas off the South East Pacific. Despite the fact that only 37 sets (82 thousand hooks) were observed in two areas and a different methodological approach was used, a value of 2.6 between the nominal catch rates of both longline styles was had for swordfish (Vega and Licandeo 2009). This was identical to the value obtained in this experiment when the nominal catch rates were also considered, but different when the mean standardized catch rate was compared.

The mean equivalence in efficiency obtained between the monofilament and the multifilament styles was 1.9, 1.3 and 2.0 for blue shark, shortfin mako and billfish when their respective standardized catch rates are considered. Values of 1.9, 1.0 and 0.8 were obtained between their respective nominal catch rates for the same species. It does not seem appropriate to carry out a comparison of the results among authors for the bycatch species. Among experiments, the use of different types of gangions, some made entirely of polyamide and others constructed partially with steel wire, made it difficult to make comparisons in the case of sharks. In some of the experiments polyamide gangions were assumed to favour the release of some sharks hooked and reduce their catch rates (Vega and Licandeo 2009, Ward *et al.* 2008). Other factors, however, may also result in major differences in the catch rates recorded for these bycatch species in the different experiments. Moreover, owing to the low prevalence of billfish in these regions of the South East Pacific, their catch rates are relatively low. For certain longline bycatch species such as the istiophorids and other low-prevalence bycatch species, the conclusions and significance of the factors analyzed may depend largely on the sampling size used and on the spatial-temporal coverage of the experiment (Ortiz and Arocha 2004).

Certainly many of the factors may contribute to the variability observed in the catch rates of the longline vessels targeting swordfish (Ward 2008). The gear type and its configuration, the fishing practices, along with the spatial and temporal variations and associated oceanographic factors may play an important role in most of the fleets under examination. Other factors such as vessel type, its fishing history in the zone and skipper are other variables that must be taken into account in some cases (Squire and Kirkley 1999). However, on rare occasions do we have access to information about all of the factors that we would like to analyze, with the exception of strictly controlled experiments, which is highly unlikely when dealing with data from commercial longline vessels. The targeting criteria or skipper's preference for a particular species (Ortiz *et al.* 2010) and the experimental area-time design itself (Ortiz and Arocha 2004) could also be important factors in this type of fisheries.

Among all of the factors that might have a greater or lesser effect on longline catchability in most of the studies carried out on swordfish, the most relevant appear to be spatial and temporal factors and the associated variations in oceanographic conditions. This empirical knowledge held by fisherman has been used as the foundation on which many of the fleets have operated over the course of decades to maximize their catch rates. However, the catchability of swordfish and other epipelagic species is also contingent upon the availability of the individual specimens according to their distribution by depth. Recent studies using pop-up tags in South East Pacific areas report that, during the day the swordfish, are often found at 900 m depth and in some cases, down to 1136 metres (Abascal *et al.* 2009). Similar behaviour was described for the North Atlantic swordfish (Loefer *et al.* 2007, Neilson *et al.* 2009). In keeping with these studies, swordfish tend to remain in the deeper waters during the day, swimming up to the mixed layers at night, where they are more vulnerable to surface longline gears. This vertical migration pattern –long known to fishermen using longlines targeting this species- has traditionally determined the fishing practices of the longline vessels fishing this species with night sets. This behaviour was also considered by both of the vessels-skippers involved in this experiment. They assumed the behaviour of the swordfish to be similar in the areas-times of the experiment and that the availability of swordfish and other species was identical in the epipelagic layers where the two vessels were operating.

In this experiment it was our intent to minimize the effects of some of the factors which, in practice, are hard to control in longline fishing activity. In order to do this, the fishing protocols of the two vessels were previously standardized, with the exception of the longline styles used. The time variable, which was not considered in this analysis, is linked to the area variable, since the experiment was carried out with consecutive sets in the different areas-months. Hence, the spatial effect is in this case a combined spatial-temporal effect related to its respective oceanographic variables. The variable boat/skipper skill was minimized as much as possible by using vessels and skippers with a lot of experience in the fishing zone where they sought to maximize the capture of swordfish. In any event, the possible effect of skipper skill, which is assumed to be negligible in this case, would be evidenced in the variability of the gear factor. The variables related to the fishing practices were reduced since a similar soaking time was used in the gears on both vessels during the sets. This approach is only one of many different possibilities.

The special characteristics of this experiment have made it possible to reduce some of these potential effects of factors that could influence the catch rate estimates in this type of gear-species. A similar methodological approach was carried out to compare the efficiency of wire and monofilament gangions in the configuration of the Canadian surface longline (Stone and Dixon 2001). Another study was conducted to discuss the estimate of the variations in the catchability of the longline over time, taking into consideration the potential effect of several complex factors that underwent some change during the period analyzed (Ward 2008). Other similar experiments using both types of surface longline styles have been performed in the Aegean Sea where higher catch rates per hook were also reported for the monofilament style (Tserpes and Peristeraki, 2010). But very rarely does the opportunity arise where, as is the case at hand, we have information that has been scientifically verified in which two surface longline styles previously standardized in fishing protocols have been operating simultaneously in such restricted overlapping areas-times.

The results show that the monofilament longline is more efficient per hook in catching all the species analyzed when the standardized catch rates are considered. On the basis of the values obtained, it might be possible to gain insight into the empirical equivalence (proxy) between the two longline styles fishing in these areas with a view to its future application as an approach towards converting the swordfish catch rates of the Spanish multifilament traditional longline fishing in theses areas to their equivalent value in terms of the monofilament longline, or vice versa, when other more desirable standardization alternatives are not feasible.

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Table 1. General characteristics and operational differences between the multifilament longline and the monofilament types monitored.

Characteristics	*Multifilament style*	*Monofilament style*
Mainline material	Polyethylene multifilament	Polyamide monofilament
Mainline length (Km)	114.4	111.1
Floatline (m)	16/20	18
#Floats per set	260	225
Gangion length (m)	14	17
Distance between gangions (m)	43	94
Steel wire	Yes	Yes
Hook size, type, (offset)	16/O J(10º), 17/O G(8º), 17/O G(0º)	16/O J(10º), 17/O G(8º), 17/O G(0º)
#Hooks per set (mean)	2688	1184
#Hooks between floats	8-10	5
#Hooks per hook type	J(10º)= 66008	J(10º)= 27600
	G(8º)= 66264	G(8º)= 27600
	G(0º)= 65928	G(0º)= 27600
#Total hooks	198200	82800
Light sticks	Chemical light-sticks and electralumes	Chemical light-sticks and electralumes
#Light sticks per set	1344	1184
Baits	mackerel/squid	mackerel/squid
Line shooter	No	Yes
#Total sets	74	69
Set start time	17:00	17:00
Set duration (h)	7	7
Haul start time	06:00	06:00
Haul duration (h)	10	10

Table 2. Summary of the nominal catches (kg dressed weight) and nominal catch rates (kg per thousand hooks) of each species on the multifilament and monofilament gear types, respectively.

		Total catch (kg)		*Nominal catch rate (kg)*	
Common name	*Scientific name*	*Multifilament*	*Monofilament*	*Multifilament*	*Monofilament*
Swordfish	*Xiphias gladius*	45704	10026	230.6	599.1
Blue shark	*Prionace glauca*	12880	10026	65.0	121.1
Shortfin mako	*Isurus oxyrhinchus*	11508	5030	58.1	60.7
Billfish	Istiophoridae	2001	692	10.1	8.4

Table 3. Qualitative results of the statistical significance (α=5%) of deviance analyses by species for factors affecting the catch rates (in kg) of positive sets for each species (upper table) and the proportion of positive sets (lower table) (yes= factor considered to be significant, no= factor not considered to be significant). Interaction between factors is indicated with "*".

Factor / Species	*Swordfish*	*Blue shark*	*Shortfin mako*	*Billfish*
Gear	yes	yes	yes	yes
Hook type	yes	no	no	yes
Bait type	yes	no	yes	no
Area	yes	yes	yes	no
Gear*hook	no	no	no	no
Gear*bait	no	no	no	no
Gear*area	no	no	no	yes
Hook*bait	yes	no	no	no
Hook*area	no	no	no	yes
Bait*area	yes	no	yes	no

Logged catch rates (in kg)

Factor / Species	*Swordfish*	*Blue shark*	*Shortfin mako*	*Billfish*
Gear	no	yes	yes	yes
Hook type	no	no	No	yes
Bait type	no	no	yes	yes
Area	no	no	no	yes
Gear*hook	no	no	no	no
Gear*bait	no	yes	no	no
Gear*area	no	no	no	no
Hook*bait	no	no	no	no
Hook*area	no	no	no	yes
Bait*area	no	no	no	no

Response proportion positive sets

Table 4. Deviance table analysis for swordfish (SWO) and blue shark (BSH). Response variable: logged catch rates (kg dressed weight), upper panel; proportion of positive sets, lower panel. df, degrees of freedom; % of total deviance refers to that for the null model; *p- value* refers to consecutive models; in shaded and tagged with (*), statistically significant factor at α = 5%.

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
SWO	NULL	1	320.39				
(*) SWO	GEAR	1	227.02	93.37	29.14	29.14	2.20E-16
(*) SWO	GEAR HOOK	2	222.43	4.59	1.43	30.58	1.03E-02
(*) SWO	GEAR HOOK BAIT	1	216.93	5.50	1.72	32.29	9.40E-04
SWO	GEAR HOOK BAIT AREA	3	210.39	6.54	2.04	34.33	4.62E-03
SWO	GEAR HOOK BAIT AREA GEAR*HOOK	2	209.93	0.46	0.14	34.48	6.29E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	208.90	1.03	0.32	34.80	1.51E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	207.98	0.92	0.29	35.09	6.02E-01
(*) SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	204.13	3.84	1.20	36.28	2.15E-02
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	201.42	2.71	0.85	37.13	4.86E-01
(*) SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	197.17	4.25	1.33	38.46	3.68E-02

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
SWO	NULL	1	22.50				
SWO	GEAR	1	22.49	0.01	0.03	0.03	9.31E-01
SWO	GEAR HOOK	2	21.43	1.06	4.71	4.75	5.88E-01
SWO	GEAR HOOK BAIT	1	18.36	3.07	13.65	18.39	7.98E-02
SWO	GEAR HOOK BAIT AREA	3	15.39	2.97	13.19	31.58	3.97E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK	2	10.85	4.54	20.20	51.78	1.03E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	9.32	1.53	6.79	58.58	2.16E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	5.75	3.57	15.85	74.42	3.12E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	1.82	3.93	17.49	91.91	1.40E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	0.00	1.82	8.09	100.00	9.35E-01
SWO	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	0.00	0.00	0.00	100.00	1.00E+00

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
BSH	NULL	1	240.76				
(*) BSH	GEAR	1	203.45	37.32	15.50	15.50	1.74E-14
BSH	GEAR HOOK	2	202.84	0.61	0.25	15.75	5.91E-01
BSH	GEAR HOOK BAIT	1	202.26	0.59	0.24	15.99	3.14E-01
(*) BSH	GEAR HOOK BAIT AREA	3	184.83	17.43	7.24	23.23	2.30E-06
BSH	GEAR HOOK BAIT AREA GEAR*HOOK	2	184.82	0.02	0.01	23.24	9.86E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	184.51	0.31	0.13	23.37	4.65E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	183.04	1.47	0.61	23.98	4.67E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	183.03	0.01	0.00	23.98	9.93E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	180.03	3.00	1.24	25.22	5.18E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	178.34	1.70	0.70	25.93	4.01E-01

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
BSH	NULL	1	60.42				
(*) BSH	GEAR	1	56.34	4.08	6.76	6.76	4.34E-02
BSH	GEAR HOOK	2	52.84	3.50	5.79	12.55	1.74E-01
BSH	GEAR HOOK BAIT	1	52.68	0.16	0.26	12.81	6.92E-01
BSH	GEAR HOOK BAIT AREA	3	49.12	3.57	5.90	18.71	3.12E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK	2	47.06	2.06	3.40	22.11	3.58E-01
(*) BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	41.23	5.83	9.65	31.76	1.58E-02
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	37.31	3.93	6.50	38.25	2.70E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	35.78	1.53	2.53	40.78	4.66E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	34.58	1.20	1.98	42.77	9.77E-01
BSH	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	32.04	2.55	4.21	46.98	4.67E-01

Table 5. Deviance table analysis for shortfin mako (SMA) and billfish (BIL). Response variable: logged catch rates (kg dressed weight), upper panel; proportion of positive sets, lower panel. df, degrees of freedom; % of total deviance refers to that for the null model; *p- value* refers to consecutive models; in shaded and tagged with (*), statistically significant factor at α = 5%.

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
SMA	NULL	1	115.09				
(*) SMA	GEAR	1	109.03	6.06	5.26	5.26	2.13E-04
SMA	GEAR HOOK	2	108.96	0.07	0.06	5.33	9.20E-01
(*) SMA	GEAR HOOK BAIT	1	106.66	2.30	2.00	7.32	2.12E-02
(*) SMA	GEAR HOOK BAIT AREA	3	97.77	8.89	7.72	15.05	1.77E-04
SMA	GEAR HOOK BAIT AREA GEAR*HOOK	2	96.28	1.49	1.29	16.34	1.78E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	95.92	0.36	0.31	16.65	3.60E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	94.92	1.00	0.87	17.52	5.04E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	94.02	0.90	0.78	18.30	3.51E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	91.66	2.36	2.05	20.35	4.79E-01
(*) SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	88.25	3.42	2.97	23.32	4.86E-02

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
SMA	NULL	1	86.32				
(*) SMA	GEAR	1	78.99	7.33	8.49	8.49	6.79E-03
SMA	GEAR HOOK	2	74.83	4.16	4.82	13.30	1.25E-01
(*) SMA	GEAR HOOK BAIT	1	50.50	24.33	28.19	41.49	8.11E-07
SMA	GEAR HOOK BAIT AREA	3	47.30	3.20	3.71	45.20	3.62E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK	2	44.39	2.92	3.38	48.58	2.33E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	43.08	1.31	1.51	50.09	2.53E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	37.21	5.87	6.80	56.89	1.18E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	36.51	0.70	0.81	57.70	7.06E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	29.43	7.08	8.20	65.90	3.13E-01
SMA	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	27.92	1.52	1.76	67.66	6.79E-01

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
BIL	NULL	1	43.52				
(*) BIL	GEAR	1	36.86	6.66	15.31	15.31	1.27E-03
(*) BIL	GEAR HOOK	2	33.29	3.57	8.19	23.50	4.96E-02
BIL	GEAR HOOK BAIT	1	33.00	0.29	0.66	24.16	4.74E-01
BIL	GEAR HOOK BAIT AREA	3	29.96	3.04	6.99	31.15	1.55E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK	2	29.07	0.90	2.06	33.21	4.48E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	28.30	0.77	1.77	34.98	2.43E-01
(*) BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	22.61	5.69	13.08	48.05	2.57E-02
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	22.01	0.60	1.37	49.42	5.84E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	20.64	1.37	3.14	52.56	6.48E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	20.23	0.41	0.94	53.51	6.89E-01

Species	**Model tested**	**df**	**Resid. Dev.**	**Change in Dev.**	**% total Dev.**	**Model % Dev.**	***p- value***
BIL	NULL	1	113.97				
(*) BIL	GEAR	1	103.28	10.68	9.37	9.37	1.08E-03
(*) BIL	GEAR HOOK	2	88.11	15.17	13.31	22.69	5.07E-04
(*) BIL	GEAR HOOK BAIT	1	80.37	7.74	6.79	29.48	5.40E-03
(*) BIL	GEAR HOOK BAIT AREA	3	51.57	28.80	25.27	54.75	2.47E-06
BIL	GEAR HOOK BAIT AREA GEAR*HOOK	2	51.24	0.34	0.30	55.04	8.45E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT	1	49.98	1.26	1.10	56.15	2.62E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA	3	47.86	2.11	1.85	58.00	5.49E-01
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT	2	43.20	4.66	4.09	62.09	9.71E-02
(*) BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA	6	30.20	13.01	11.41	73.51	4.29E-02
BIL	GEAR HOOK BAIT AREA GEAR*HOOK GEAR*BAIT GEAR*AREA HOOK*BAIT HOOK*AREA BAIT*AREA	3	27.95	2.25	1.97	75.48	5.23E-01

Table 6. Final models selected by species (logged catch rates and proportion of positive observations, respectively) for the standardized catch rates.

Final fitted model

Species	*logged catch rates*
Swordfish	ln(CPUE) = Gear + Hook + Bait + Area + Hook*Bait + Bait*Area
Blue shark	ln(CPUE) = Gear + Area
Shorfin mako	ln(CPUE) = Gear + Bait + Area + Bait*Area
Billfish	ln(CPUE) = Gear + Hook + Area + Gear*Area

Species	*proportion of positive observations*
Swordfish	logit(p/(1-p)) = μ (overall mean)
Blue shark	logit(p/(1-p)) = Gear + Bait + Gear*Bait
Shorfin mako	logit(p/(1-p)) = Gear + Bait
Billfish	logit(p/(1-p)) = Gear + Hook + Bait + Area + Hook*Area

Table 7. Swordfish standardized mean catch rates (Std. catch rate) (kg dressed weight x 1000 hooks^{-1}) by gear type, standard error, 95% confidence limits (based on a normal approximation), coefficient of variation and ratio% (gains in percentage in relation to the type gear of reference (Ref.)).

Species	*Gear type*	*Std. catch rate*	*Std. Err.*	*95%upp*	*95%low*	*CV (%)*	*Ratio%*
Swordfish	multifilament	233.29	11.71	256.25	210.34	5.02	Ref.
Swordfish	monofilament	393.26	35.15	462.14	324.37	8.94	68.57
Blue shark	multifilament	55.74	3.18	61.98	49.51	5.71	Ref.
Blue shark	monofilament	106.34	7.31	120.67	92.01	6.88	90.77
Shortfin mako	multifilament	59.16	3.87	66.75	51.57	6.54	Ref.
Shortfin mako	monofilament	78.35	5.58	89.29	67.41	7.12	32.44
Billfish	multifilament	26.38	3.59	33.42	19.35	13.61	Ref.
Billfish	monofilament	53.04	9.33	71.32	34.76	17.59	101.03

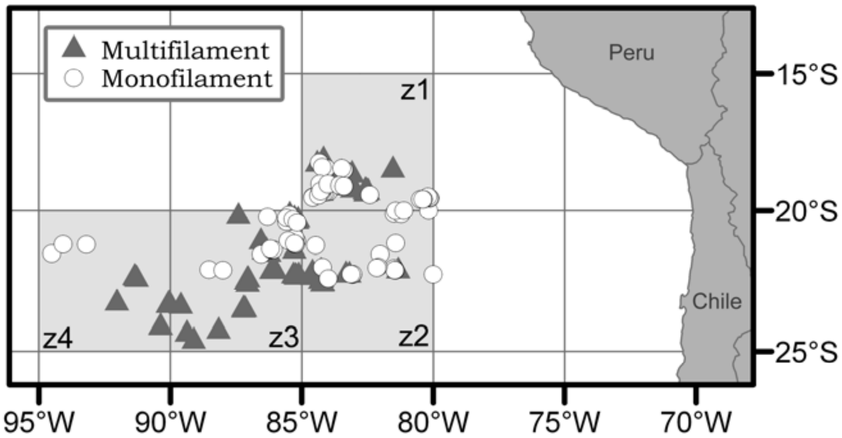

Figure 1. Map of the four fishing areas selected in the South East Pacific where the sets were carried out, the traditional multifilament type (triangles) and monofilament gear type (circles) overlapping in the same 5ºx5º squares (areas: z1, z2, z3 and z4) during the same period.