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Biodiversity and distribution of istiophorid (Billfishes) in the Eastern Pacific Tropical tuna purse-seine fishery

Distribución y biodiversidad de istiofóridos (picudos) en pesquería cerquera del atún Tropical del Pacífico Oriental

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ABSTRACT

In the Eastern Pacific Ocean (EPO), Billfish species caught incidentally in the tuna fishery varied spatially depending on the associated purse seine set type. This aims to a) delimit the spatial and/or temporal bycatch distribution of six billfish species in the EPO; b) determine the differences between the annual catches by month, type of set, stock, and fishing areas; and c) estimate the biodiversity indices of six billfish species associated with tuna purse-seine fishing in the EPO. The results showed a variety of patterns which indicated that the distribution and diversity of billfish species depended on the conditions (seasons) that prevailed in certain areas of the EPO. This model reflects a displacement of the potential habitat species to regions that are currently considered marginal. Analysis results of multiple comparisons (Dunn's p.) between the groups found that the purse seine sets associated with dolphins presented significant differences from the remaining comparisons for the fishing indicators. It indicated that the distribution of six billfish species is more homogeneous in association with the dolphins because the greater effort of the set was made mainly on the larger pelagic fish. Global warming trends could increase the temperature of the currently hottest areas in the EPO if the thermal tolerance of these species could be exceeded it would affect the extension of its habitat to the most temperate zones shortly.

Keywords: Bycatch, Database, Dummy variables, IATTC, Tropical Tuna.

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RESUMEN

En el Océano Pacífico Oriental (OPO), las especies de peces picudos capturados incidentalmente en la pesquería de atún variaron espacialmente dependiendo del tipo de lance de cerco asociado. El objetivo fue a) delimitar la distribución espacial y/o temporal de la captura incidental de seis especies de picudos en el OPO; b) determinar las diferencias entre las capturas anuales por mes, tipo de lance, stock y zonas de pesca; y c) estimar los índices de biodiversidad de seis especies de istiofóridos asociadas con la pesca atunera de cerco en el OPO. Los resultados mostraron una variedad de patrones que indicaron que la distribución y diversidad de especies de peces picudos dependía de las condiciones (estaciones) que prevalecían en ciertas áreas del OPO. Este modelo refleja un desplazamiento de las especies de hábitat potencial hacia regiones que actualmente se consideran marginales. Los resultados del análisis de comparaciones múltiples (Dunn's p.) entre los grupos encontraron que los lances de cerco asociados con delfines presentaron diferencias significativas con respecto al resto de las comparaciones para los indicadores de pesca. Indicó que la distribución de seis especies de istiofóridos es más homogénea en asociación con los delfines porque el mayor esfuerzo del lance se realizó principalmente sobre los peces pelágicos de mayor tamaño. Las tendencias del calentamiento global podrían aumentar la temperatura de las zonas actualmente más cálidas del OPO, si se pudiera superar la tolerancia térmica de estas especies se afectaría la extensión de su hábitat a las zonas más templadas en breve tiempo.

Palabras clave: Atunes tropicales, Base de datos, Captura incidental, CIAT, Variables ficticias.

INTRODUCTION

Istiophorid Billfishes are part of a pelagic group of tropical and subtropical species characterized by their extremely long, beak-like upper jaw. Some fisheries in the Eastern Pacific Ocean (EPO) and the Atlantic Ocean (AO) target billfish, such as in some tropical countries off the coast of Africa and the Western Central Atlantic, including Venezuela, which together take a significant percentage of the total billfish catch, to supply part of the food demand (Arocha 2015). In Mexico, billfish species are constrained to sport fishing within a 50 nautical miles coastal strip (Correia-Aguiar 2015). Meanwhile, billfishes are incidentally caught in the EPO as non-target species (bycatch) in some tuna longline and purse seine fishing operations. And this could contribute to their decline because there are no appropriate management strategies to mitigate the impact on potential geographic species distribution (Bonanomi *et al.* 2022).

The most important current system called the equatorial current is located in the Eastern Pacific Ocean (EPO), which divides the north from the south of the EPO (Kessler 2006). This ocean is divided between two large currents, in the northern region, the California Current, and to the south, the Peru Current, these systems influence an important climatic variation known in oceanography studies as El Niño and La Niña, which play an important role in the fishery and the global carbon cycle of the EPO (Fiedler and Talley 2006, Fiedler and Lavin 2006, 2017).

The EPO includes several productive systems characterized by cold waters and high concentrations of nutrients (Kessler 2006), oceanographic processes such as those associated with the Costa Rica Dome, and coastal upwellings generated seasonally by jet currents throughout Central America and particularly on the coasts of Mexico, where large amounts of nutrients are concentrated and influence the abundance and distribution of marine organisms (Fiedler and Talley 2006, Fiedler and Lavin 2016). Along the coast of Peru and the Galapagos Islands, upwelling zone systems generally present high seasonal productivity (Lezama-Ochoa *et al.* 2017), and with its large concentrations of pelagic fish, among which istiophorids stand out, species belonging to the Family Istiophoridae, known as billfish and marlins or needle fish (Arocha 2015).

Some fisheries in the OPO and AO have as their objective the capture of billfish, in some tipical countries on the coast of Africa and the Central Western Atlantic, among which is Venezuela, which as a whole extract a significant percentage of the total catch of billfish from the Atlanctic, which at a given time will supply the food demand (Arocha 2015), as Sosa-Nichizaki (1998) pointed out that billfish species are highly valued as food due to the excellent quality of their meat and its high index of edible meat with respect to its body weight (Eslava-Vargas *et al.* 2013).

To analyze the composition of the species community in any ecosystem, numerous indices have been proposed to characterize species richness and fairness (Lloyd and Ghelardi 1964, Monge-Najera and Moreno 2001, Magurran 2004). In a community, the total number of species can be counted and the relative abundance of these species can be calculated using simple indices (Carmona-Galindo and Carmona 2013), such as those proposed for Shannon's species diversity (Spellerberg and Fedor 2003), the richness of Margalef (Carmona-Galindo and Carmona 2013) and Pielou's equity (Lloyd and Ghelardi 1964), among others. In billfish studies, (Garibaldi and Busilacchi 2002) recorded the listing of the main species to analyze statistics for fishing purposes for this group of fish.

Arocha (2015) pointed out that some countries such as Venezuela are making efforts aimed at the conservation and fishing of billfish through the Intensive Research Program on Billfish in coordination with the International Commission for the Conservation of Atlantic Tunas, obtaining statistical information on catches of billfish species and the fishing effort, tagging and life history. Lezama-Ochoa *et al.* (2018) analyzed the diversity and ensemble habitat characteristics of tuna bycatch with two different types of fisheries in the EPO using additive models. These researchers used indicators related to bycatch and its habitat, obtaining results for a better development with an ecosystem approach for its fishing order in tuna fishing.

This research aims to a) delimit the spatial and/or temporal distribution of bycatch of six billfish species on the eastern Pacific Ocean (EPO); b) determine the differences between the annual catches by month, type of set, stock, and fishing areas of six billfish species; and c) estimate the biodiversity indices of six billfish species associated with tuna purse-seine fishing in the EPO.

MATERIAL AND METHODS

Study area and data collection. The study area includes the places of fishing grounds in the EPO, where the different fleets of tuna seiners had operated between 2005 to 2018, in a geographical zone located between latitudes 35° North and 25° South and the meridians 70° West and 150° West, known as the Convention Area of the Inter-American Tropical Tuna Commission (IATTC) (Fig. 1). For statistical analysis within the Convention Area (Fig. 2), one hundred one geographic quadrats were chosen. Among them, 98 quadrants followed the 5°x5° latitude/longitude format, while three quadrants arbitrarily had different fishing boundaries, which were defined based on fishing activity during the study period. Being identified as quadrat 1, delimited on the 25° North parallel and within the 125° West meridian. Quadrat 13 is bounded on the 15° North parallel and within the 100° West meridian. Quadrat 101 corresponds to all positions data below the parallel 15° South and 150° West.

Bycatch of billfishes files were compiled from the public domain database of IATTC (2023). The files contain data from tuna seiners with over 363 metric tons of carrying capacity, which operated in the EPO with observers on board, whose information was verified by the IATTC members' governments.

Data analysis. The space/time distribution of billfish species caught incidentally in the multispecific tuna purse-seine fishery in the EPO, the positive records of the database were grouped in positions of 1°X1° latitude/longitude, delimited according to fishing activities that included data on the number of individuals per set, combined by year, month and type of set between 2005 to 2018 within the IATTC fishing area (IATTC 2012). The system described by Garibaldi and Busilacchi (2002) was used to classify and code billfish species. After estimating their Biodiversity Indices using quadrats, a statistical comparison was carried out using dispersion matrices, histograms, and Spearman correlation values with a significance level of $p<0.05$ (Zar 2009). The free software R (version 3.4.1) was used to perform the statistical analysis.

Estimation of the index of bycatch of fish associated with the tuna fishery. The bycatch index per set (BIPS) was the average number of billfish individuals retained in the net bag in each set (Hall and Román 2013). In

Figure 1. The Convention Area of the Inter-American Tropical Tuna Commission. (IATTC 2012).

this case, it was used as a proportional indicator of the species to establish comparisons between the different zones of the EPO. The effort (E) was expressed as the number (N) of sets for the purse-seine vessels that, due to their carrying capacity, are classified according to the IATTC, as belonging to class 6 (>323 m^3). The BIPS was estimated according to the equation adapted from Correia-Aguiar (2016), using the following equation:

$$BIPS = \frac{\sum CI_{z,y,m,s}}{\sum E_{z,y,m,s}}$$

Where:

BIPS= Incidental catch per set.

CI = Number of organisms caught incidentally.

E = Number of total sets made (Effort).

z = Fishing Quadrant.

y= Year.

m = Month.

s = Fishing indicator.

The fishing indicators were the types of purse-seine sets in the tuna fishery that were made in the EPO, such as sets associated with dolphins (DEL), floating objects (OBJ), or unassociated free schools (NOA).

Dummy variables analysis. A generalized linear model (GLM) was run based on the dummy variables method modified by Quinn and Deriso (1999). The basis of

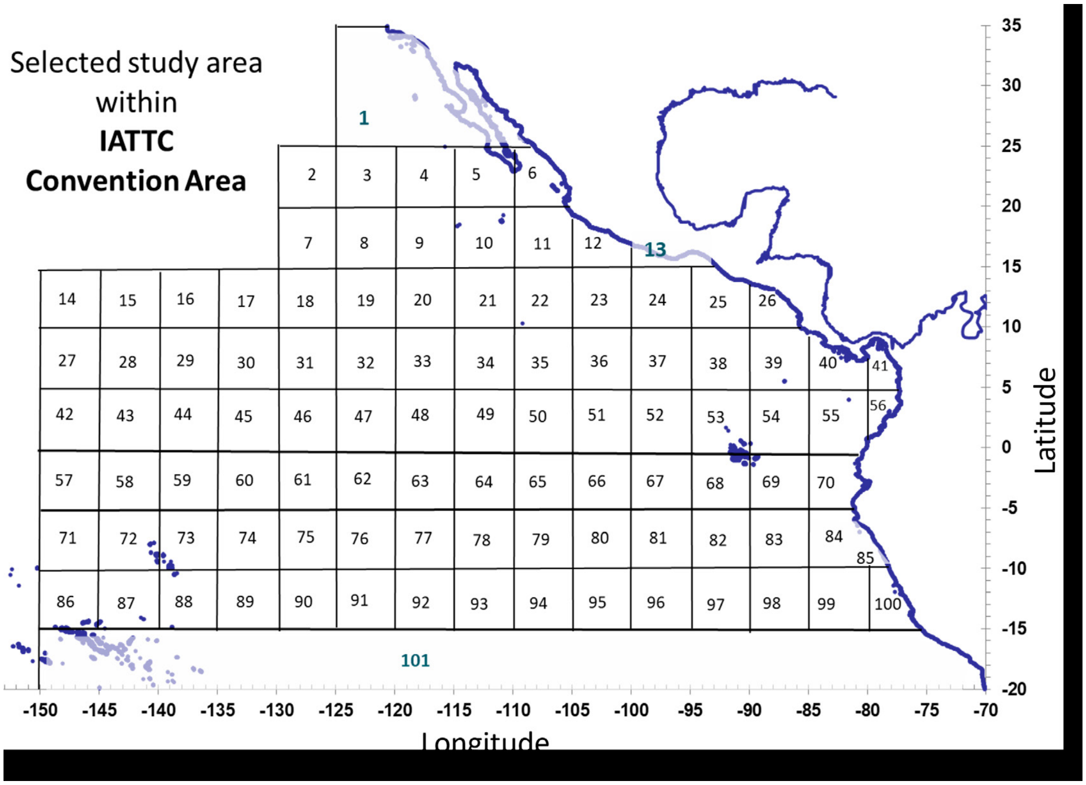

Figure 2. Selected study area within the Convention Area of the Inter-American Tropical Tuna Commission (IATTC 2012).

this analysis was to include categorical information in a mathematical model, considering the effect of variables of a characteristic or condition, such as response variables, contrasted with another set of variables also of any nature, which in this case were the explanatory variables (Arriaza-Balmón 2006).

To adjust the model, the response variable was considered to be the value of the natural logarithm (ln) of the BIPS of each record with the presence of at least one species of billfish, and each of the explanatory variables (year, month, type of sets, billfish species, classified quadrats) were replaced by a mathematical artifice, with binary categorical predictors; coded zero (0) if data were absent, and one if data were present (Quinn and Deriso 1999).

With the confirmation of the indicator or fictitious variables, the differential effects of an initial indicator variable contrasted at the different levels of factors were analyzed in a spreadsheet (Table 2). They were classified statistically and it was determined if there were significant differences in the catch of the different species of billfish between the years (interannual), months (inter monthly) and in the three types of sets as indicators of fishing (sets associated with dolphins (DEL), sets associated with floating objects (OBJ) and in free or unassociated schools (NOA), and the quadrats demarcated in the geographic polygon in the EPO.

When analyzing the relationships between the fictitious factors (year, month, type of set, billfish stocks, and quadrat) referring to the lnBIPS, it's required for each record the presence of at least one billfish species.

Biodiversity índices. The diversity by area 5°X5° latitude/longitude of the different species of billfish were considered about their abundance based on the three types of fishing indicators: DEL, OBJ, and NOA.

Shannon index. This index calculation determines the average level of uncertainty in identifying a species of a randomly chosen individual in a specific geographic area. A higher index indicates greater habitat species diversity:

$$H'_{Shannon} = -\sum_{i=1}^{S} pi \ x \ ln(pi)$$

Where:

S= number of species (species richness).

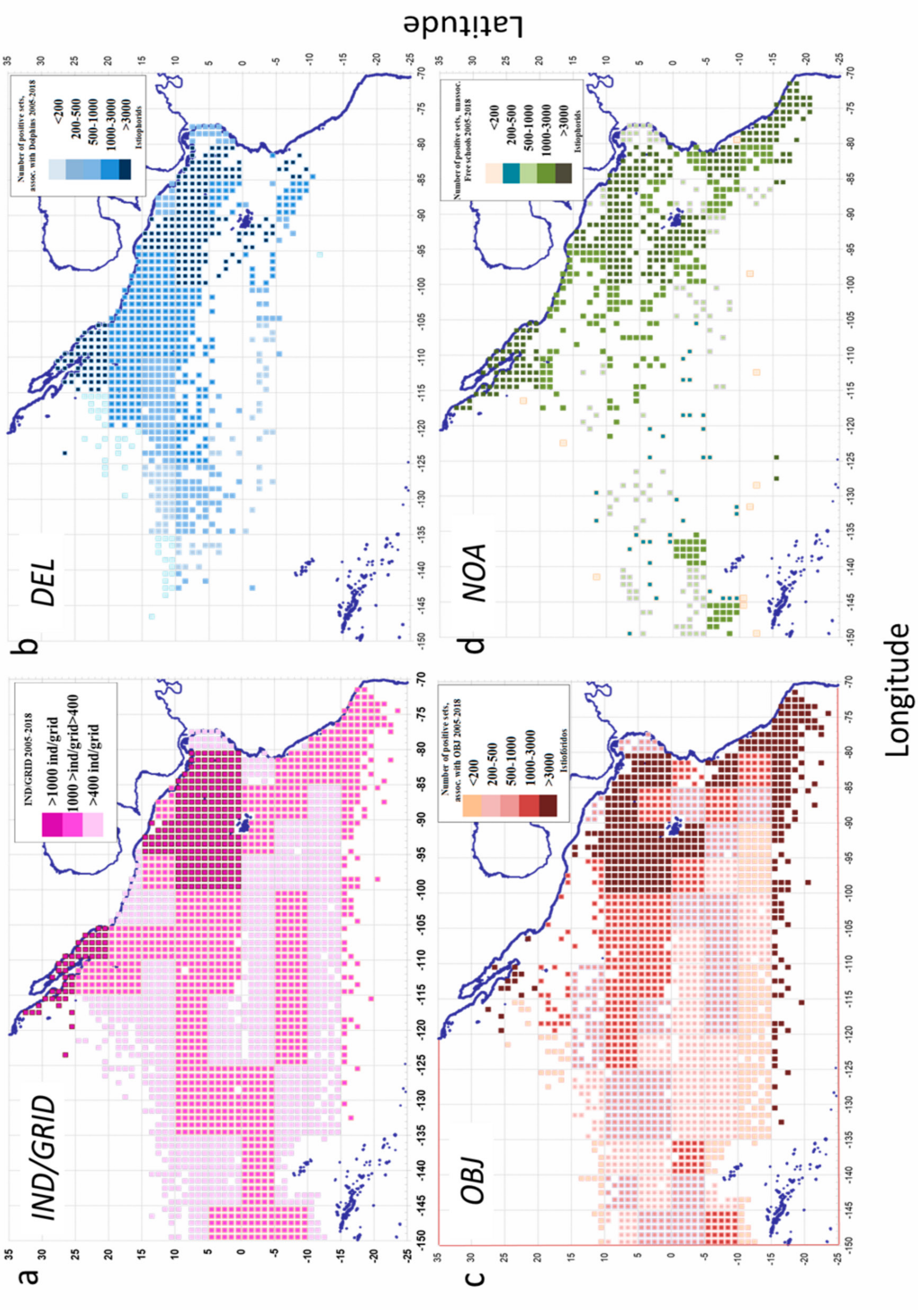

Figure 3. Georeference distribution of the bycatch of Billfish in the tuna purse-seine fishery: a) distribution of individuals caught by 1°x1° latitude/longitude charts, b) dolphin-associated sets (DEL), c) sets associated with floating objects (OBJ), and d) sets of unassociated free schools (NOA).

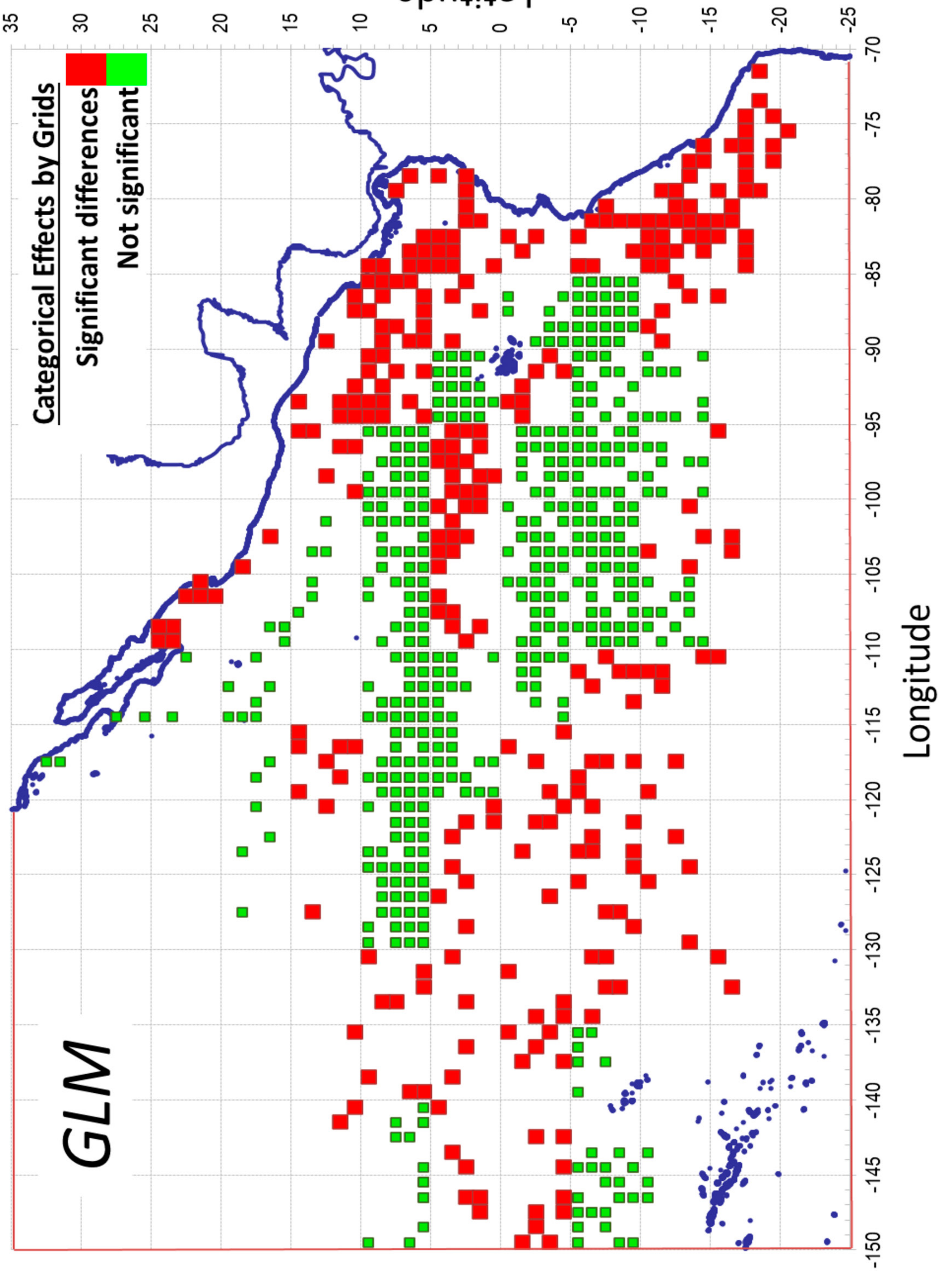

Figure 4. Referential geographic distribution considering all the differential effects contrasted with InBIPS in the tuna purse-seine fishery in the EPO, from 2005 to 2018. In red, are quadrats with significant differences according to GLM results with dummy variables.

Table 1. List of Standard Codes Used for Billfish Species Incidentally Caught by IATTC Purse-seine Vessels in the Antigua Convention Area.

Family/Specie	Common name	COD
Istiophoridae, Xiphiidae	Marlins, Sailfishes, Spearfishes	BIL
Istiompax indica (Cuvier, 1832)	Black Marlin	BLM
Makaira nigricans Lacepède 1802	Blue Marlin	BUM
Kajikia audax (Philippi ,1887)	Striped Marlin	MLS
Istiophorus platypterus (Shaw, 1792)	Indo-Pacific sailfish	SFA
Tetrapturus angustirostris Tanaka, 1915	Shortbill Spearfish	SSP
Xiphias gladius Linnaeus, 1758	Swordfish	SWO

pi= ni/N, proportion of individuals of species i with respect to the total number of individuals (that is, the relative abundance of species i).

ni= Number of individuals of species i.

Analyzing the data from the Shannon diversity indices for the different fishing indicators (DEL, OBJ, NOA), billfish species caught incidentally in the EPO did not present a normal distribution ($p<0.05$), deciding on an analysis of unifactorial variance by Kruskal-Wallis test with Dunn's post correction was applied (Zar 2009).

Margalef Species Richness Index. It corresponded to the number of species that were detected during a sampling area (Eslava-Vargas 2013).

R= (S-1)/lnN

Where:

S = total number of species in a collection.

N= total of individuals of all collections. It is considered a simple expression of the species based on the logarithm of the extension of the sample (Carmona-Galindo and Carmona 2013).

Pielou index. It is a measure of relative abundance, it represented the proportion of observed diversity about the maximum expected diversity (its estimated value is zero to one so that one corresponded to situations where all species are equally abundant):

$$J' = \frac{H'}{H'max}$$

Where:

H' = Shannon diversity index.

H'max= lnS.

S= number of species (species richness).

RESULTS

In the tuna fishery, the incidental catch of billfish species varied depending on the type of associated set. According to (Fig. 3), the total catch was 54 175 billfishes, out of which 32 854 fish were caught in sets associated with floating objects, 14 307 in sets associated with dolphins, and 7014 individuals in sets unassociated and free tuna schools, as shown in (Table 3).

Comparing the annual lnBIPS with all the grouped variables, no significant differences were found between the years 2005, 2006, and 2007. However, there were statistical differences between the years 2008 to 2018 (Fig. 4). While between January, April, May, June, August, September, and December, no significant differences were found.

The results of the biodiversity indices are indicated in (Fig. 5) for the different PPICOS species about their abundance based on the three fishing indicators (DEL, OBJ, NOA) for the tuna purse-seine fleet operating in the EPO (Fig. 5a).

Table 2. Factor levels of explanatory variables are considered in the standardization model to obtain the fictitious or indicator variables.

Level	Year (Y)	Month (M)	BILLFISCHES (Code)	Fishing indicators	Quadrat
1	2005	January (M1)	BIL	DEL	1
2	2006	February (M2)	BLM	NOA	2
3	2007	March (M3)	BUM	OBJ	3
4	2008	April (M4)	MLS		4
5	2009	May (M5)	SFA		5
6	2010	June(M6)	SSP		6
7	2011	July (M7)	SWO		7
8	2012	August (8)			8
9	2013	September (M9)			9
10	2014	October (M10)			10
11	2015	November (M11)			11
12	2016	December (M12)			12
13	2017				13
14	2018				14
					.
					.
101					101

A Kruskal-Wallis ranges (Zar 2009), indicating significant differences according to the type of set H=27.326 (p=0.001), later the analysis of multiple comparisons (Dunn's p.) between the groups, it was found that the sets associated with dolphins presented significant differences to the remaining comparisons for the fishing indicators (Table 4).

DISCUSSION

Even though most sets of dolphins were observed north of the Equator, most catches were observed between areas near the Costa Rica Dome (Costa Rica) and Northeast Galapagos (Ecuador). Free schooling sets (NOA) were observed in areas overlapping with the other two indicators (OBJ and DEL), showing considerable catches towards the Gulf of California, Mexico. Sets on floating objects were observed in the equatorial counter-current zone. Most of the species were caught in sets on floating objects, except for the swordfish *Xiphias gladius* Linnaeus, 1758, which was caught in greater proportion in sets of free-roaming tuna, and the sailfish *Istiophorus platypterus* (Shaw, 1792) in sets associated with dolphins. However, worldwide the tuna purse-seine fleet is associated with two types of behavior, a) associated with floating objects derived from men actions, and b) objects on unassociated with tuna (Lennert-Cody *et al.* 2023).

The response variables used for all the fishing indicators of the generalized linear model (GLM) were the values of the natural logarithm (ln) of the BIPS of each record of the presence of at least one species of billfish contrasted in this exercise with the explanatory variables (fictitious) obtained by year, month, hauls, areas and billfish species from the first time the black marlin *M. nigricans* (Lacepède 1802) (main species) was captured in this study, corresponding to the BIPS: the year 2005, January, DEL set and area 1. For the black marlin, blue marlin, and unidentified stocks, no significant differences were found

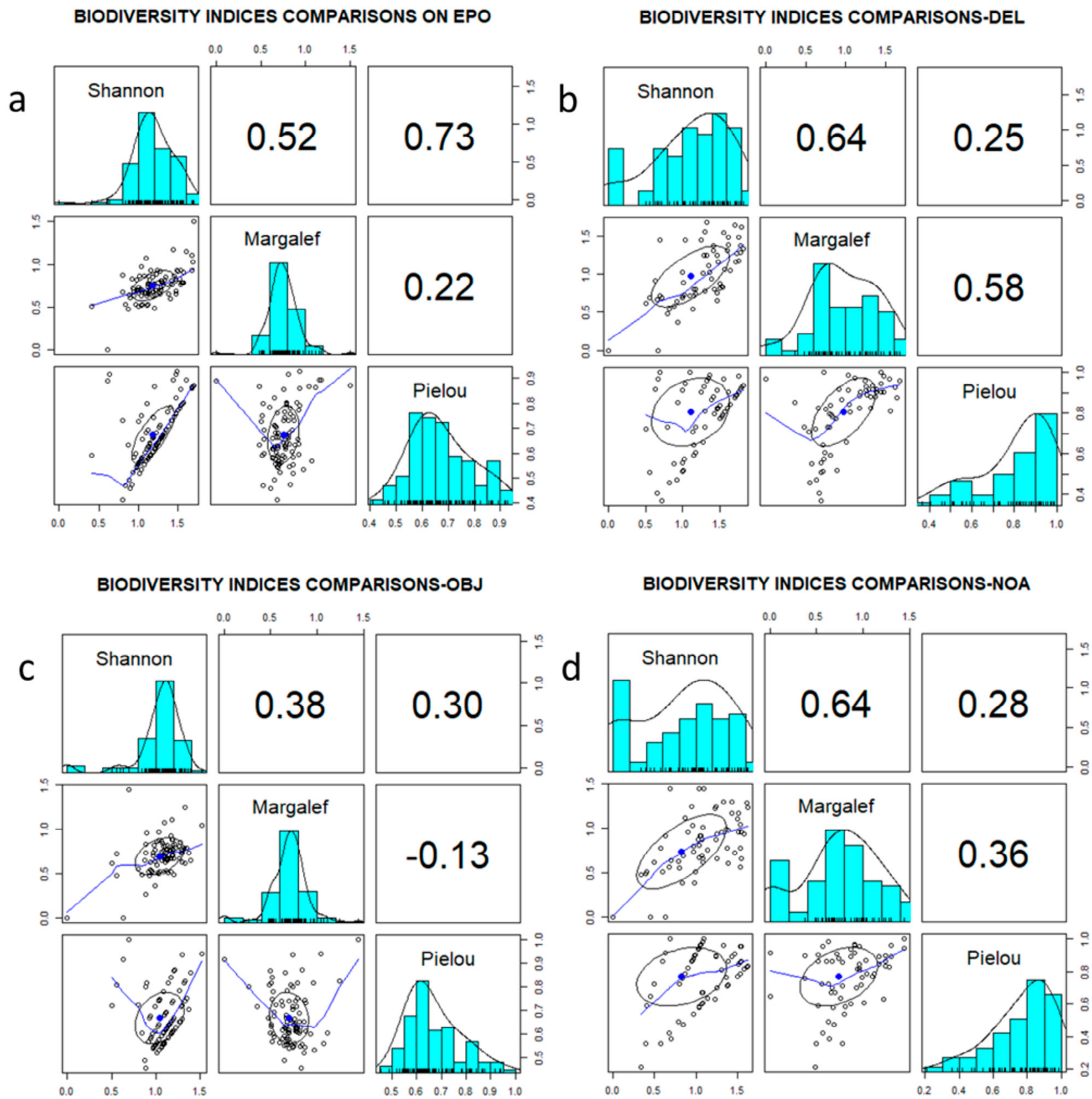

Figure 5. Comparison of biodiversity indices of billfish species by fishery indicator using Spearman's correlation test presented as dispersion matrices, histograms, and correlation values, p<0.05 (Zar 2009): a) Comparisons on EPO; b) Comparisons on dolphin-associated sets (DEL), c) Comparisons on sets associated with floating objects (OBJ), and d) Comparisons on sets of unassociated free schools (NOA).

between them, and it can be deduced that possibly some of the unidentified marlins belonged to either of the two species (Bernard *et al.* 2014, Williams *et al.* 2018).

The results showed a variety of diversity patterns depending on the year (season) species and capture area, in addition, new characteristics of the habitat of billfish species were observed in the EPO. Furthermore, this coincided with Lezama-Ochoa *et al.* (2017) indicating that the billfish species and the capture area presented different oceanographic conditions in the EPO, which indicated that the distribution and diversity of billfish species depended to a large extent on the conditions (seasons) that prevailed in certain areas of the EPO.

Table 3. The abundance of billfish species caught incidentally in sets associated with the different fishing indicators (OBJ, NOA, and DEL) in the EPO from 2005 to 2018.

Species	OBJ	NOA	DEL	Ind/species	Records
Istiophoridae, Xiphiidae	3725	729	1394	5848	3123
Istiompax indica	7008	775	940	8723	5279
Makaira nigricans	18629	1182	1220	21031	11657
Kajikia audax	1718	1031	1365	4114	2396
Istiophorus platypterus	1357	3017	9055	13429	2956
Tetrapturus angustirostris	259	56	120	435	325
Xiphias gladius	158	224	213	595	460
Total	32854	7014	14307	54175	26199

Based on these results, the sets associated with dolphins presented the highest Shannon index concerning the other fishing indicators. This indicated that the distribution of the billfish species, is more homogeneous in associations with the dolphins because the greater effort of the set was made mainly on the larger pelagic fish. Therefore, the floating objects sets should have a greater dominance (greater number of individuals of one or two species), as observed by *M. nigricans*. Unassociated free schools or not associated with dolphins recorded a better diversity in the community, which is considered important because it means that some istiophorid species are more attracted by floating objects than other species, at least, presented different habitats in the distribution area of the objects, which coincided with that indicated by other authors (Hall and Román 2013, Lezama-Ochoa *et al.* 2017). This behavior was statistically corroborated when comparing the averages of the Shannon index by fishing indicator and by the trend line.

Table 4. Analysis of multiple comparisons by pairs (Dunn's p.).

Comparison	Range difference	Q	P<0.05
H_OPO vs H_NOA	71.14	4.68	Si
H_OPO vs H_OBJ	43.21	2.96	Si
H_OPO vs H_DEL	6.78	0.43	No
H_DEL vs H_NOA	64.36	3.89	Si
H_DEL vs H_OBJ	36.43	2.28	No
H_OBJ vs H_NOA	27.93	1.83	No

This model reflects a displacement of the potential habitat species to regions that are currently considered marginal. Global warming trend could increase the temperature of the currently hottest areas in the EPO (Lezama-Ochoa *et al.* 2017). The thermal tolerance of this species could be exceeded and it would affect the extension of its habitat to the most temperarte zones. In addition, the results showed a variety of diversity patterns depending on the year (season) species and capture area and new characteristics of the habitat of billfish species were observed in the EPO.

CONFLICTS OF INTEREST

The authors of this study declare that there is no conflict of interest with the publication of this manuscript.

AUTHOR´S PARTICIPATION

MJCA post graduate student, RPG direction, JSRP results consulting, YGR results consulting and JFAG manuscript writing.

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