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Update on standardized catch rates for blue shark (*Prionace glauca*) in the 2006-2022 Mexican Pacific longline fisheries based upon a shark scientific observer program

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SUMMARY

Abundance indices for blue shark (*Prionace glauca*) in the northwest Mexican Pacific for the period 2006-2022 were estimated using data obtained through a pelagic longline observer program, for two partially overlapping fisheries. Individual longline set catch per unit effort data, collected by scientific observers, were analyzed to assess effects of environmental factors (such as sea surface temperature, mean-SST anomalies), time-area factors (Year, quarter, distance to the nearest point on the coast including islands), and fishing strategy (nocturnal vs diurnal fishing sets). Standardized catch rates were estimated by applying generalized linear models (GLMs) to data from two fleets (Ensenada and Mazatlán). Sea surface temperature, mean SST anomalies, distance to the coast, latitude, year, quarter and catch of swordfish in the fishing set were all significant factors included in the model. The results of this analysis show a relatively stable trend in the standardized abundance index in the period considered for the Ensenada fleet (operating mainly above 25° N) and a descending trend in the last years of the time series for the Mazatlán fleet (operating mostly below 25° N). These trends could be explained in terms of the different fishing strategies of the fleets involved.

INTRODUCTION

The presence of more than 100 species of sharks in Mexican waters has allowed the historical development of commercial fisheries in both coastal and oceanic waters (Castillo-Géniz *et al.*1998). The main Mexican shark fisheries are the coastal artisanal fishery (along the coasts of both Pacific and Gulf of Mexico coastlines) and the pelagic longline fisheries using medium size vessels in the northern Pacific region (Castillo-Géniz *et al*.2008).

Mexico is one of the top shark producers in the world according to Musick and Musick (2011). The Mexican average annual shark production (including small sharks, "cazones") from 1976 to 2023 was 27,653.41 t. In 2023 the total domestic shark production reached 46,211t, (2.1% of the total national fisheries production), with a market value of more than 1,287 million pesos. The average annual shark production in the Mexican Pacific for 2014-2023 was 29,870.8 t. In 2023 the Pacific shark production reached 35,718 t which comprised 77.3% of the total Mexican shark production (CONAPESCA, 2023).

Pelagic shark fisheries in the Mexican Northwest Pacific began in the mid 80's with the creation of an industrial fishing fleet. Stimulated by the successful driftnet fishery in California, in 1986 a small fleet of driftnet vessels appeared in northern Baja California, Mexico. This fishery was stimulated both by the reduction in longline permits and by the local abundance of swordfish and other marketable by-catch products, including several species of large pelagic sharks. These vessels were fiberglass or steel built, with an overall length of 18-25 m and a fish hold capacity of 50-70 t.

From twenty medium size vessels in 1990, the fleet expanded to 31 vessels in 1993 (Sosa-Nishizaki *et al.*1993). This fleet targets sharks, swordfish, tuna, and other pelagic fish. Sosa-Nishizaki *et al.*(1993), Holts *et al*.(1998), Ulloa-Ramírez *et al.(*2000), and Sosa-Nishizaki *et al*.(2002) described in detail the origin and growth of swordfish and sharks fishery along the west coast of Baja California (BC).

During the first 20 years, this fleet used surface gillnets as its primary fishing gear. The Mexican Official Standard NOM-029-PESC-2006 banned driftnets in medium-size vessels (10-27 m length). By the end of 2009, all vessels switched to longlines and the operational dynamics of the fleet changed drastically. The main shark species caught were blue (*Prionace glauca*), short-fin mako (*Isurus oxyrinchus*) and thresher (*Alopias vulpinus*) sharks.

Among the studies conducted on shark fisheries in the West BC coast, included studies focused in blue shark catches and biology, are the works of Miranda-Vázquez (1996), Furlong-Estrada (2000), Reyes-González (2001) and Guerrero-Maldonado (2005).

Shark fisheries management

Shark fisheries in Mexican waters are managed mainly through three instruments: 1) The Mexican Official Standard NOM-029-PESC-2006. Shark and Ray Responsible Fisheries. Specifications for Their Exploitation; 2) The National Fisheries Chart (Carta Nacional Pesquera, CNP) and 3) The Shark and Ray Fishery Closure Agreements for both coastlines. The NOM-029 established numerous regulations for shark and ray fisheries in order to achieve sustainability, among them the establishment of specific fishing zones according to vessel characteristics, refuge zones, specifications for fishing gears, mandatory participation in the satellite vessel tracking program (Vessel Monitoring System, VMS), the banning of gillnets on medium size boats and the implementation of a scientific observer program on a voluntary basis.

The CNP includes the description and the current status of shark populations as well as their availability in Mexican waters. At present, all shark fisheries are considered to be fully exploited (Diario Oficial de la Federación, DOF 2010). Finally, the fisheries authority has established closed seasons for shark and ray fisheries in the Pacific and for sharks only in the Gulf of Mexico, with the aim of protecting the main reproductive season for most species (DOF 2012 and 2014). Those closed periods include shark by-catch in other fisheries. The closed season in the Mexican Pacific was established between May 1st and July 31st.

Blue shark Pacific catches

Based on the analysis of 683 fishing logbooks from the Ensenada longline fleet reported between 2011 and 2015, Godínez-Padilla et al. (2016) reported a specific catch composition of 18 shark species. The species with the highest numerical catch were: blue shark, *P. glauca* (89.25%); and the shortfin mako shark, *I. oxyrinchus* (7.77%). With a lower proportion the thresher shark, *A. vulpinus* (1.06%); silky shark, *Carcharhinus falciformis* (0.63%); smooth hammerhead shark, *Sphyrna zygaena* (0.56%); pelagic thresher, *A. pelagicus* (0.19%); the big-eye thresher, *A. superciliosus* (0.02%); and other species that represented 0.52% of the total numerical catch.

Corro-Espinosa (unpublished data) conducted an analysis of the commercial logbooks from the Mazatlan longline fleet for years 2009-2012. Corro-Espinosa documented a total catch of 182,482 sharks from 11 species, caught in 8,447 sets. Blue shark (*P. glauca*) 64.6%, thresher (*A. vulpinus)* 9.4%, bigeye thresher (*A. superciliosus*) 9.3%, pelagic thresher (*A. pelagicus*) 7.7% and mako (*I. oxyrinchus*) 1.7% were the most frequently caught pelagic sharks. With a similar approach, Ortega-Salgado *et al*. (unpublished data) examined the commercial logbooks of 124 fishery trips and 1,404 longline sets from the swordfish and shark fleet of Ensenada conducted during 2001-2013. The logbooks reported a capture of 42,814 sharks belonging to six shark species, with blue (86.5%), mako (11.9%) and thresher (0.73%) sharks being the most abundant species (Figure 1).

The blue shark, *P. glauca* is the most abundant shark species in pelagic longline catches in the Northwestern Mexican Pacific (Sosa-Nishizaki *et al*.2008; Vögler *et al.*2012). Sosa-Nishizaki (2011) estimated the Pacific total blue shark landings in 66,221 t for the years 1976-2011. The largest catches were reported by BC (43.4%), followed by BCS with 30% and Sinaloa (10%) (Sosa-Nishizaki 2011).

The Mexican National Aquaculture and Fisheries Commission (CONAPESCA 2023) reported an average catch of blue shark of 2,862t for the period 2001-2023 for the Mexican Pacific. In 2023, Baja California Sur(BCS) accounted for 23.8% of the total catch, followed by Sinaloa (23.6%) and Chiapas (16.9%). According to those official figures, the total annual catch of blue sharks in the Mexican Pacific has shown a consistent growth (Figure 2).

The commercial longline fishing sector in northwestern Mexico faced a severe decline in domestic demand for blue shark meat, forcing vessels to reduce the number of fishing trips made in 2020. The cancellation of the subsidy for the Marine diesel for the fishing industry and the low cost of blue shark meat also influenced the decrease in fishing activity, which was reflected in low levels of blue shark production (Miguel Chaidez, representative of the Mexican National Chamber of the Fishing Industry, pers. comm., October 2021)

The blue shark is caught all year long on the west coast of the Baja California Peninsula and in the central Pacific (off Colima and Nayarit states) (Guerrero-Maldonado 2005, Cartamil *et al*.2011, Santana-Hernandez and Valdez-Flores 2014). *P. glauca* individuals of a relatively young age (0-3 years) were reported in the catch of the shark fisheries in BC (Guerrero-Maldonado 2005).

In artisanal fisheries blue sharks are fully recruited at age 1, while in the offshore fishery, using medium size boats, individuals are recruited at the age of 2 and 3 years. In BCS artisanal fisheries, blue shark individuals were caught at relatively older ages (4 years and older on the west coast and 5 years and older on the east coast), compared to blue sharks fished in similar vessels landed at San Carlos, in Western BCS (0-7 years old). Guerrero-Maldonado (2005) also reviewed catches of blue shark landed by the Manzanillo longline fleet in Colima. This fleet caught *P. glauca* in areas off BCS at ages between one to six years old but this author reports that individuals were recruited to the fishery at age three in that region.

In the Ensenada longline fleet (for the 2006-2014 period), female blue shark catches range 35-400 cm in total length (TL) with an average of 165.1 ± 0.3 cm TL (n = 14,822 females), while range in males is 40-400 cm TL with an average of 169.3 ± 0.3 cm TL (n = 20,857 males). The female blue shark catches from the Mazatlán fleet (from the same period) were comprised by individuals with a range of 30-400 cm TL and an average of 207.1 ± 0.3 cm TL (n = 13,064 females). Males showed a length interval of 50-400 cm TL with a mean of 195.5 ± 0.1 cm TL (n = 47,003 males). Apparently, both fleets catch immature individuals with a small proportion of adults (Figure 3).

Shark Observer Program (Programa de Observadores de Tiburón, POT)

The shark observer program began operations on several shark fishing fleets along the Northern West coast of Mexico in August 2006 (as established in the NOM-029-PESC-2006 official standard). Participation in the POT is voluntary so fishing trips with observer onboard are conducted according to the availability and willingness of fishing companies. The POT has been one of the most important research tools in Mexico's shark fisheries, providing data for monitoring the main shark species caught on the Mexican Pacific coast (Tovar-Ávila *et al.*2011). Observers gather data during a fishing trip, including catches by set or haul, species composition and size and sex of a sample of individuals.

Detailed POT operating statistics for the period 2006-2014 have been described previously by *Castillo-Géniz et al.*2014 (ISC / 14 / SHARWG-3/02). Figure 4 shows the fishing sets recorded for different shark fishing fleets that operated during 2006-2020. The POT operated from 2006 to 2022 on board of the longline fleets of Ensenada (BC) and Mazatlán (Sinaloa), which represent the largest pelagic longline fishing effort in the northwest Mexican Pacific.

Catch rate standardization

Stock assessments may involve the use of several indices of stock abundance derived from commercial fisheries data, observer data from fisheries, and scientific surveys (McDonald *et al.*2001). The primary indices of abundance for many of the world's valuable and vulnerable species are based on catch and effort. These indices, however, should be used with care because changes over space and time in catch rates can occur because of factors other than real changes in abundance (Gavaris 1980, Walters 2003, Maunder and Punt 2004, Campbell 2015). Nominal catch rates obtained from fishery statistics or observer programs require standardization to correct for the effect of factors not related to regional fish abundance but assumed to affect fish availability and vulnerability, usually by using statistical regression methods (Bigelow *et al.*1999, Ortiz and Arocha 2004).

Generalized Linear Models (GLM, Nelder and Wedderburn 1972, McCullagh and Nelder 1989) are the most common method for standardizing catch and effort data and their use has become standard practice because this approach allows identification of the factors that influence catch rates and calculation of standardized abundance indices, through the estimation of the year effect (Goñi *et al*.1999, Maunder and Punt 2004, Brodziak and Walsh 2013). GLMs are defined mainly by the statistical distribution for the response variable (in this case, catch rate) and the relationship of a linear combination of a set of explanatory variables with the expected value of the response variable. Its use is based upon the assumption that the relationship between a function of the expected value of the response variable and the explanatory variables is linear. A variety of error distributions of catch rate data have been assumed in GLM analyses (Lo *et al.*1992, Bigelow *et al.*1999, Punt *et al.*2000, Goñi *et al.*2004, Maunder and Punt 2004).

MATERIAL AND METHODS

As commented above, driftnet operations were banned in 2009, while longline fishing has prevailed through the years of operation of the scientific observer program. This study is focused on the longline component of the shark fishery with medium size vessels in the northwest region of the Mexican Pacific from June 2006 to December 2022.

Data were subjected to a preliminary analysis, looking for missing values, incomplete information and inconsistencies. Original data contained fishing sets from within the Gulf of California and in the southeastern Mexican Pacific, where no blue sharks were caught in the years contained in the time series. Data from these zones were excluded from the analysis. 7,804 sets were retained to be used in the analysis (2,751 for the Ensenada fleet and 5,053 for the Mazatlán fleet). The proportion of zero-catch sets was around 4.18% for the Ensenada fleet, and the probability of obtaining a positive catch being close to 1 (0.9582). The corresponding numbers for the Mazatlán fleet are 17.43% and 0.8258 (Figure 5).

After an initial exploratory analysis, factors which were considered as having a possible influence on the RESPONSE variable, catch rate (CTCHRATEbs), were selected to be included in a “maximum model” for the analyses.

The factors selected for inclusion in the analysis were the following:

Mean Sea Surface, Temperature (MEANTEMP as a three level factor, H, M and L for “high”, “medium” and “low”), calculated for each set as the average of temperature data measured *in situ*, at the beginning and the end of both gear setting and retrieval. MEANTEMP levels were defined as L<=21°C, 21<M<=25, and H>25°C, on the basis of the mean sea surface temperature in all validated sets.

Mean Sea Surface Temperature Anomaly (MEANSSTANOM) was defined as a three level factor, MEANSSTANOMML (<=-1), MEANSSTANOMMM (>-1,<+1), MEANSSTANOMMH (>=+1) for “low”, “medium” and “high” mean SST anomaly. Data on this factor were obtained from the Multi-scale Ultra-high Resolution (MUR) SST Analysis Anomaly fv04.1, Global, 0.01°, 2002-present, Daily, Lon0360 data base, available in the ERDDAP data server

(https://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST41anom1day_Lon0360.html) using the rerddapXtracto R package (Mendelssohn 2021).

The proportion of night hours in the fishing set for sets being carried out mostly in daylight or at night (PNH, a two level factor, “DAY” < 0.5 and “NIGHT” >=0.5) was calculated using the data from each fishing set and calculating the time of dawn and sunset for the corresponding dates and coordinates, using the suncalc R package (Thieurmel and Achraf 2022).

Fraction of the Moon Illuminated (MP, a three level factor, “NEW”<0.3, “PART”>=0.3 <=0.7, and “FULL” >0.7), were calculated for the dates of the fishing sets , using the suncalc R package (Thieurmel and Achraf 2019).

Distance to the nearest coastline, including islands, (DIST as a two level factor, N for “near” for distances less than 200 km and F for “far” from the coast for distances above that number), was calculated using the raster R package (Hijmans 2019).

The variable CTCHRATEposswo indicates if swordfish was caught (1) or not (0) in the fishing set.

Time-area factors such as YEAR, QUARTER and fishing area were included. Three fishing areas (LATF) were defined, NORTH above the 25° parallel, CENTRAL between 21° and 25° of latitude and SOUTH below 21°. 82% of the fishing sets of the Ensenada fleet occur above 25° N while 91% of the fishing sets of the Mazatlán fleet are below that latitude (Figure 6). The levels of the above mentioned factors were selected matching approximately the inflexion points of a LOESS smoother on a scatterplot of catch rate against the values of the corresponding variable. The fishing areas were defined based on that LOESS – scatterplot procedure and on observed fleet operations patterns.

Catch rates were modeled as a function of these factors and some two-way interactions: QUARTER:DIST, LATF:DIST, MEANTEMP:MEANSSTANOM and PNH:MP.

Although we are conscious that inter annual variations in spatial or temporal patterns could occur (*v. gr.* the species and/or effort distribution, seasonal changes in temperature or other factors among years), we preferred not including interactions involving the factor YEAR at this stage of the analysis with fixed effects models. Including interactions involving the factor YEAR, as well as treating it as a random factor by using Generalized Linear Mixed Effects Models (GLMM) as suggested by Maunder and Punt (2004) and Campbell (2015), could be considered at later stages of the analysis.

The formula of the maximum (initial) model was:

CTCHRATEbs~YEAR+QUARTER+LATF+DIST+MEANTEMP+MEANSSTANOM+PNH+CTCHRATEposswo +MP+QUARTER:DIST+LATF:DIST+MEANTEMP:MEANSSTANOM+PNH:MP

Two error structures were considered: Poisson and negative binomial (both with log link functions). The model that best described the data was selected using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) (Burnham and Anderson 2002), followed by an analysis of residuals for validation purposes.

The significance of the included variables and interactions was assessed through tests of hypothesis, using one-term deletion tests in order to prevent the potential effects of collinearities, as described by Crawley (2007) The effect of the term was determined to be significant at least at the alpha = 0.05 level based on a Chi squared test.

The Generalized Variance Inflation Factor was calculated to detect collinearities among the predictors in the model (Fox, 2019). A partial pseudo R2 analysis was performed to quantify the contribution of individual predictors to the model (Agresti, 2015). The alleffects() function from the effects package in R was used to compute the marginal effect estimates for all predictors in the model (Fox, 2003, Fox & Weisberg, 2019). A hanging rootogram to assess the fitting of the models was produced using the topmodels package (Kleiber and Zeileis, 2016; Zeileis, 2023)

The estimated marginal means and their standard errors for the YEAR factor (the standardized abundance indices) were obtained by using the emmeans routine contained in the emmeans R package (Lenth, 2022).

RESULTS AND DISCUSSION

Table 1 shows the values of the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) for the maximum models tried. Based on the AIC and BIC, the model with the Negative Binomial error distribution and the log link was selected for simplification with one-term deletion tests.

The final ("minimum adequate") model was:

For the Ensenada Fleet:

CTCHRATEbs ~ YEAR + QUARTER + LATF + DIST + MEANTEMP + QUARTER:DIST

For the Mazatlán Fleet:

CTCHRATEbs ~ YEAR + QUARTER + LATF + DIST + MEANTEMP + MEANSSTANOM + CTCHRATEposswo + QUARTER:DIST + LATF:DIST + MEANTEMP:MEANSSTANOM

The Generalized Variance Inflation Factor showed no evidence for collinearities among predictors in both models (Table 2).

Figure 7 shows the pseudoR^2, partial pseudoR^2 and the significance of the variable deletion tests for both models. The high contribution of the YEAR factor is noticeable. Figure 8 shows the hanging rootogram for both models. For the Mazatlán fleet, the lack of fit of the model to the proportion of zero and low values (1 to around 10-15) is evident. Figure 9 shows the effects plots for the models.

The results of the estimated marginal means procedure, the standardized abundance indices for the blue shark (2006-2020) from the models are shown in Table 3. The re-scaled values of the estimated indices are shown in table 4. Figure 10 show the estimated values of the relative index and their 95% confidence intervals, together with the nominal catch rates for years 2006-2022.

Figure 11 shows the histogram and QQplot of the residuals of the Negative Binomial GLM as well as the marginal-residual plots for each factor. The residuals for the Negative Binomial GLM for the Ensenada fleet are closer to normal than those for the Mazatlán fleet. Although the variability of residual is higher in the last years of the series, this is quite more marked for the Mazatlán fleet. The histogram and QQplot for this latter fleet also show clearer signs of a positive skew.

Figure 12 show the spatial distribution of residuals (positive residuals in green and negative ones in red). There are clear spatial patterns that should be taken in consideration, in particular the negative ones on the mouth of the Gulf of California.

Spatiotemporal heterogeneity in the marine environment is believed to greatly affect the biology, dynamics, and availability of fish stocks, as well as their vulnerability to fishing gear, thus introducing a source of variability in nominal catch rates (Bigelow *et al.*1999). Sea surface temperature is one of the most important physical factors because it modifies the geographical and vertical aggregation patterns of fishes, through its effect on feeding, reproductive and migratory behavior, and body thermoregulation (Fonteneau 1998). The blue shark is highly migratory, with complex movement patterns related to water temperature, reproduction, and the distribution of prey (Nakano 1994; Nakano and Seki 2003; Stevens 2010).

The results of this analysis show a relatively stable trend of the standardized abundance indices from 2006 to 2022 for the Ensenada fleet. For the Mazatlán fleet, the standardized abundance indices show lower levels in the last years of the series (Figure 10).

It should be noted that the period 2013-2016 registered the occurrence of two unusual and consecutive warming events known as The Blob (TB2013–2015) and the 2015–2016 El Niño (Jiménez-Quiroz *et al.*2019). The observed decrease in CPUE for the Ensenada fleet during this period could be caused by the blue shark leaving the area included in this analysis or moving to deeper waters, rather than by an actual decrease in local abundance. It is suggested to compare the results of this analysis with those performed on the contiguous colder zone off California. Adams *et al.*(2016) report lower blue shark CPUEs at positive values of the MEI off the coast of Peru. Cavole *et al.*(2016) comment that research surveys during the summer of 2015 reported unusual sightings of blue shark in the Gulf of Alaska and that those reports suggested that tropical invertebrates such as tuna crabs were followed northward by their predators, tuna, which were in turn followed by their predators, sharks. According to Compagno (1984), in the tropics the blue shark shows submergence and occurs at greater depths there. In the tropical Indian Ocean the greatest abundance of blue sharks occurs at depths of 80 to 220 m, with temperatures about 12° to 25° C.

Variability in nominal catch rates can also be related to other physical, chemical, and biological processes or factors in the ocean (e.g. water transparency, circulation patterns, frontal zones, salinity, plankton, nekton), which together with temperature define the identity, structure, and interaction of water masses and can affect the availability of potential prey and the capture efficiency of predatory fishes (Laurs *et al.*1984, Bigelow *et al.*1999).

Fishery-related factors like hook size and type, fishing depth or bait type were not included in this analysis, even as they could feasibly show a relationship with CPUE, as data on these factors were not available in the data set we used but could be available in the observer data base.

However, the inclusion in the model of terms like CTCHRATEposswo was aimed at assessing the effect of an apparent shift to fishermen looking for species other than sharks, like swordfish (*Xiphias gladius*). This change in fishing strategy is apparently related to the shift to night sets in some specific areas (in particular, the mouth of the Gulf of California) where the operations of the Mazatlán fleet have been concentrated in the last years.

Figure 13 shows the fraction of fishing sets for the Mazatlán fleet, where the shift to operating at night results evident. Figure 14 contains the fractions of positive sets for swordfish and blue shark by year in the available data set, in the Mazatlán fleet. A clear upward trend in the fraction of fishing sets for swordfish coincides with a downward one for blue shark. Figure 15 shows the ratio of blue shark/swordfish (numbers per fishing set) in the Mazatlán fleet. The change in the proportion of the species is clear and marked.

The present study represents part of a work in progress on attempting to merge fishery and environmental information from the distribution range of the blue shark in the Mexican Pacific, that includes adding other predictor variables to the ones in the present model and adopting other modeling approaches (like GAMs and BRTs) and standardization methods as well as investigating the relationships with the catch of other species. Our results clearly point to the need to adopt modeling frameworks that explicitly include spatio-temporal components.

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Table 1. Values of the Akaike and Bayesian Information Criterions for the maximum models tried.

Ensenada fleet

	df	AIC	BIC
Poisson (log link)	**42**	**138,012.88**	**138,261.51**
Negative binomial (log link)	**43**	**26,328.61**	**26,583.16**

Mazatlán fleet

	df	AIC	BIC
Poisson (log link)	**40**	**128,340.44**	**128,607.54**
Negative binomial (log link)	**41**	**44,846.06**	**45,119.84**

Table 2. Generalized Variance Inflation Factor for the Ensenada and Mazatlán models.

Ensenada fleet

	GVIF	Df	GVIF^(1/(2*Df))
YEAR	2.88	16	1.03
QUARTER	3.31	3	1.22
LATF	1.82	2	1.16
DIST	2.29	1	1.51
MEANTEMP	2.72	2	1.28
QUARTER:DIST	2.53	3	1.17

Mazatlán fleet

	GVIF	Df	GVIF^(1/(2*Df))
YEAR	6.15	16	1.06
QUARTER	7.06	3	1.38
LATF	2.50	1	1.58
DIST	5.65	1	2.38
MEANTEMP	81.58	2	3.01
MEANSSTANOM	230.61	2	3.90
CTCHRATEposswo	1.62	1	1.27
QUARTER:DIST	10.13	3	1.47
LATF:DIST	2.78	1	1.67
MEANTEMP:MEANSSTANOM	3672.92	4	2.79

Table 3. Standardized abundance indices (estimated marginal means for the YEAR factor) from the Negative Binomial model fit, their standard errors (SE), coefficient of variation (CV) and lower and upper asymptotic 95% confidence intervals, FOR THE Ensenada and Mazatlán fleets models.

Ensenada fleet:

YEAR	Index	SE	CV	asymp.LCL	asymp.UCL
2006	20.23	3.82	0.19	13.97	29.30
2007	19.82	3.11	0.16	14.57	26.96
2008	24.02	4.11	0.17	17.18	33.58
2009	8.73	1.65	0.19	6.04	12.64
2010	12.87	2.33	0.18	9.03	18.35
2011	10.58	1.94	0.18	7.39	15.16
2012	19.37	4.81	0.25	11.90	31.52
2013	23.09	4.13	0.18	16.26	32.77
2014	12.11	2.08	0.17	8.64	16.96
2015	9.87	1.72	0.17	7.02	13.89
2016	13.90	2.49	0.18	9.78	19.75
2017	6.13	1.09	0.18	4.33	8.69
2018	13.21	2.61	0.20	8.98	19.45
2019	10.24	1.97	0.19	7.03	14.93
2020	21.34	4.58	0.21	14.01	32.51
2021	12.64	2.64	0.21	8.40	19.02
2022	18.88	4.66	0.25	11.63	30.64

Mazatlán fleet:

YEAR	Index	SE	CV	asymp.LCL	asymp.UCL
2006	37.14	3.29	0.09	31.22	44.18
2007	35.55	1.94	0.05	31.95	39.56
2008	40.83	2.42	0.06	36.36	45.85
2009	34.40	2.48	0.07	29.86	39.63
2010	27.83	1.50	0.05	25.04	30.93
2011	24.13	1.56	0.06	21.26	27.38
2012	42.11	6.59	0.16	31.00	57.22
2013	38.25	2.86	0.07	33.03	44.29
2014	37.32	2.76	0.07	32.29	43.14
2015	35.42	4.14	0.12	28.16	44.55
2016	34.35	3.43	0.10	28.24	41.77
2017	28.91	2.19	0.08	24.91	33.54
2018	25.66	2.10	0.08	21.86	30.12
2019	20.28	1.55	0.08	17.46	23.55
2020	18.62	1.78	0.10	15.45	22.45
2021	4.26	0.42	0.10	3.52	5.16
2022	13.06	1.01	0.08	11.23	15.20

Table 4. Re-scaled values of the estimated indices for the Negative Binomial model and their 95% confidence intervals for both models.

Ensenada fleet:

YEAR	Re-scaled abundance index	L CI 95%	U CI 95%
2006	1.34	0.92	1.94
2007	1.31	0.96	1.78
2008	1.59	1.14	2.22
2009	0.58	0.40	0.84
2010	0.85	0.60	1.21
2011	0.70	0.49	1.00
2012	1.28	0.79	2.08
2013	1.53	1.08	2.17
2014	0.80	0.57	1.12
2015	0.65	0.46	0.92
2016	0.92	0.65	1.31
2017	0.41	0.29	0.57
2018	0.87	0.59	1.29
2019	0.68	0.46	0.99
2020	1.41	0.93	2.15
2021	0.84	0.56	1.26
2022	1.25	0.77	2.03

Mazatlán fleet:

YEAR	Re-scaled abundance index	L CI 95%	U CI 95%
2006	1.27	1.07	1.51
2007	1.21	1.09	1.35
2008	1.39	1.24	1.56
2009	1.17	1.02	1.35
2010	0.95	0.85	1.06
2011	0.82	0.73	0.93
2012	1.44	1.06	1.95
2013	1.31	1.13	1.51
2014	1.27	1.10	1.47
2015	1.21	0.96	1.52
2016	1.17	0.96	1.43
2017	0.99	0.85	1.14
2018	0.88	0.75	1.03
2019	0.69	0.60	0.80
2020	0.64	0.53	0.77
2021	0.15	0.12	0.18
2022	0.45	0.38	0.52

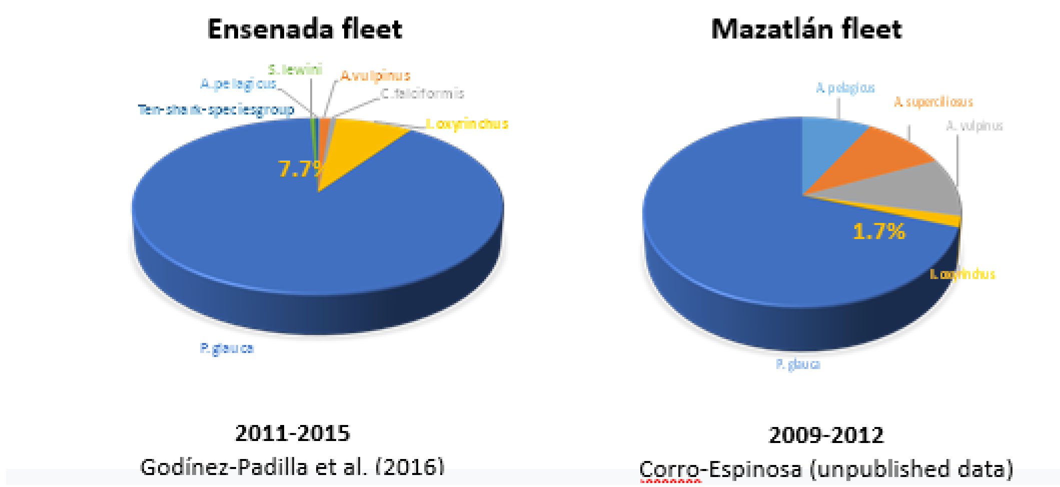


Figure 1.- Sharks catch composition of the Mexican Pacific coast.

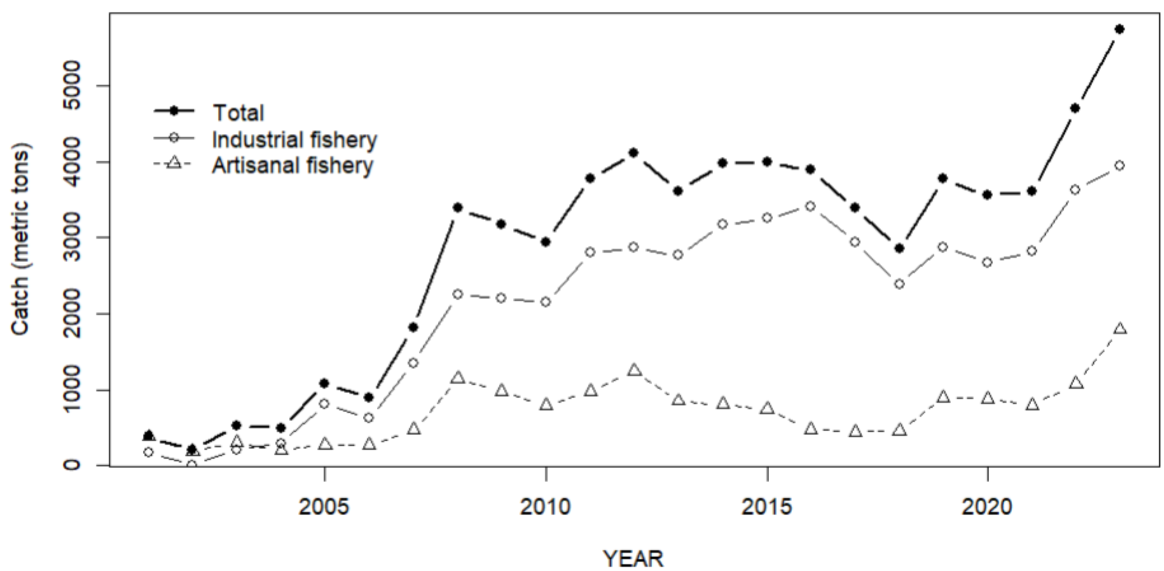


Figure 2. Total, industrial and artisanal catch of blue shark from the Mexican Pacific, 2001-2023. Source: CONAPESCA 2023.

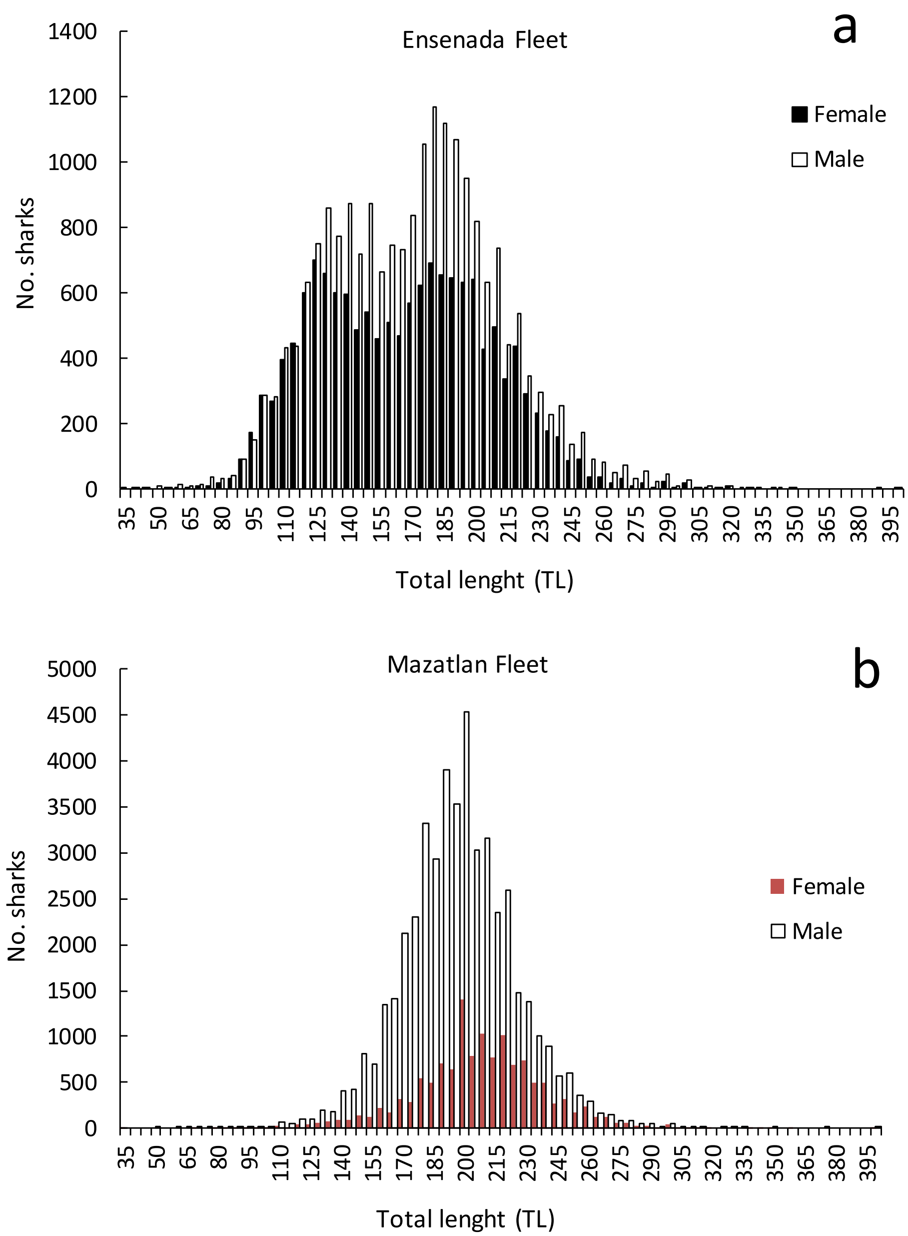


Figure 3. Size frequency structure of blue shark longline catches by sex and fleet in the northern Mexican Pacific in 2006-2014.

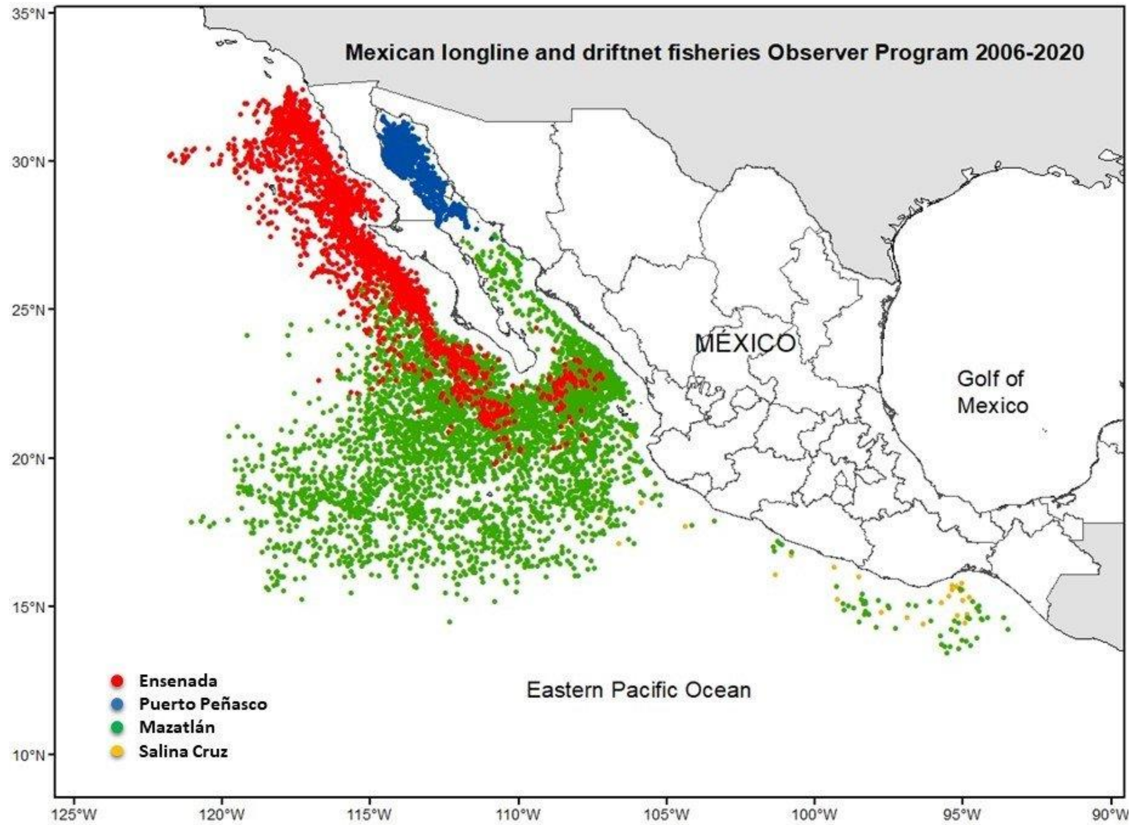


Figure 4. Observer effort in the different Mexican shark pelagic fisheries during 2006-2020.

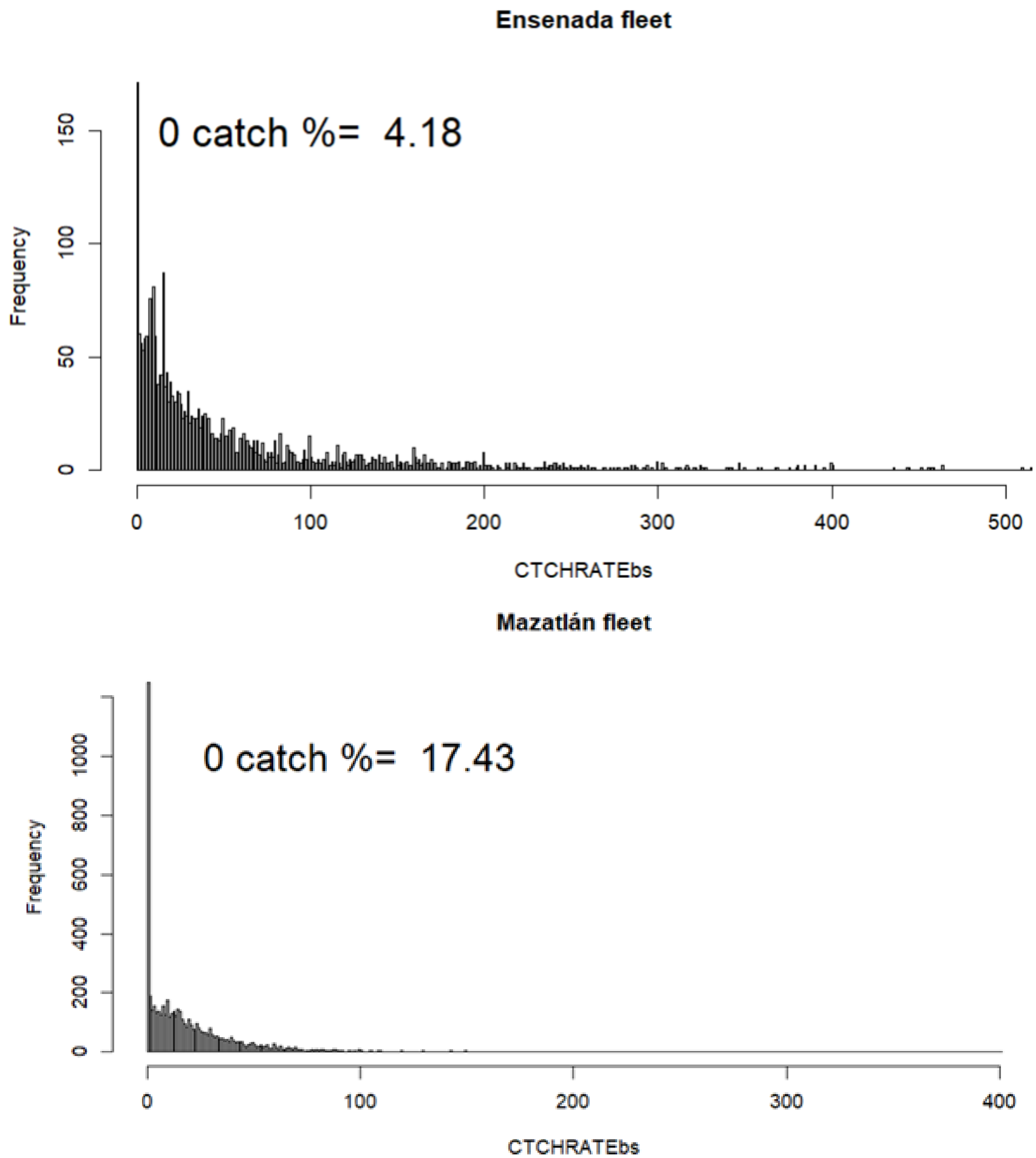


Figure 5. Histograms of catch rate for the Ensenada and Mazatlán fleets (see text).

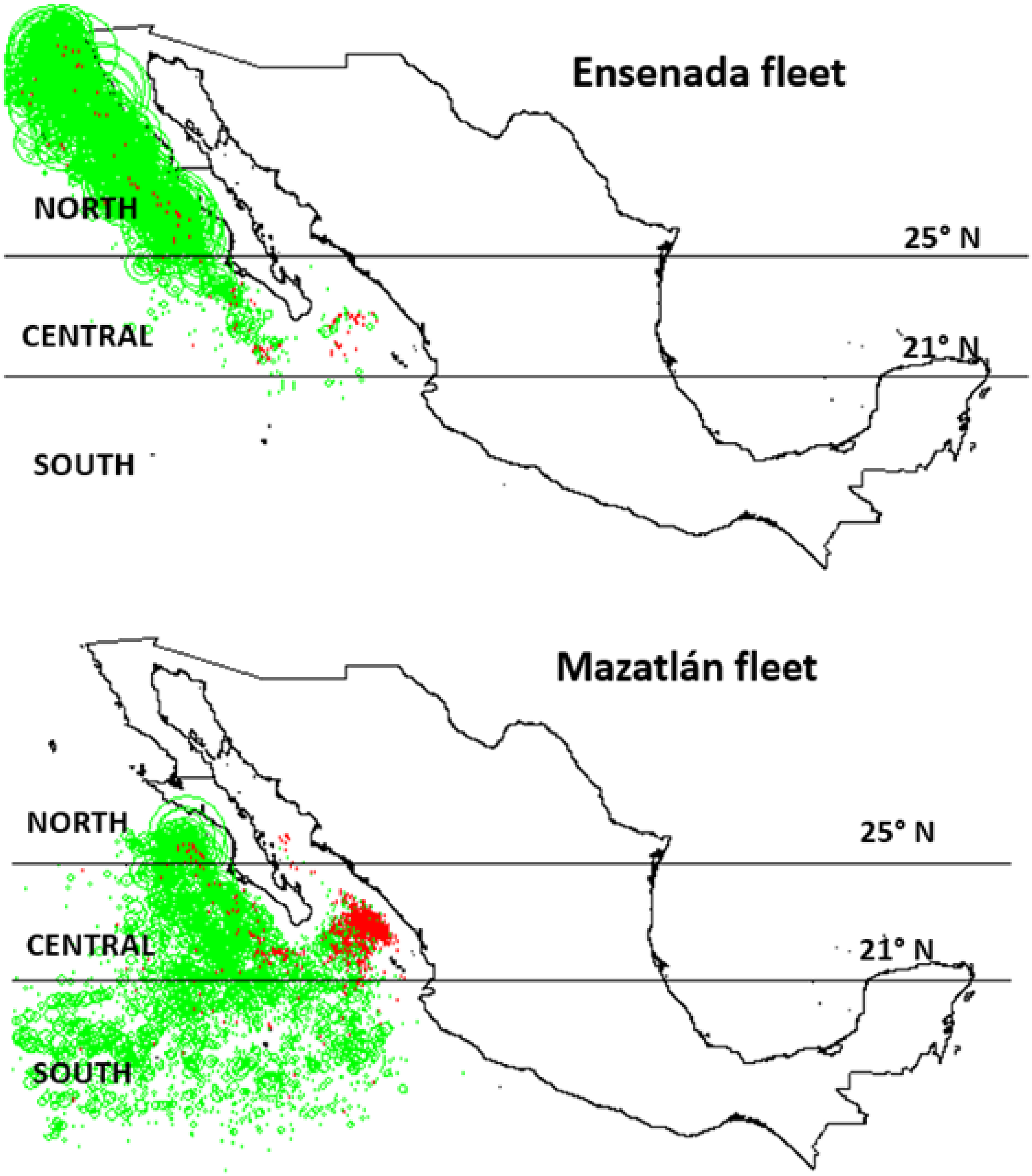


Figure 6. The zones used in the analyses. Diameter of green circles is proportional to nominal CPUE. Red dots show fishing sets with no blue shark catch (see text).

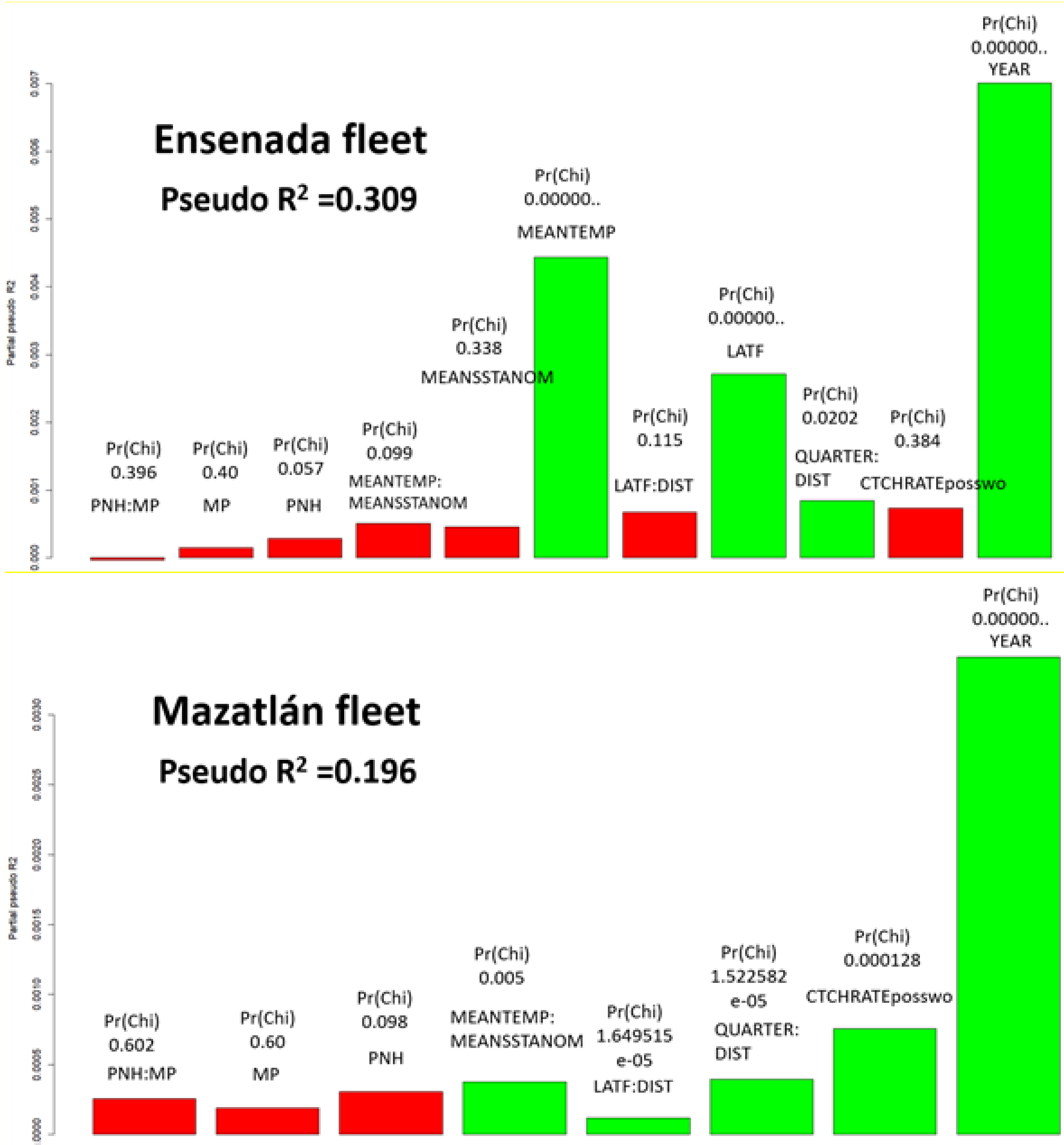
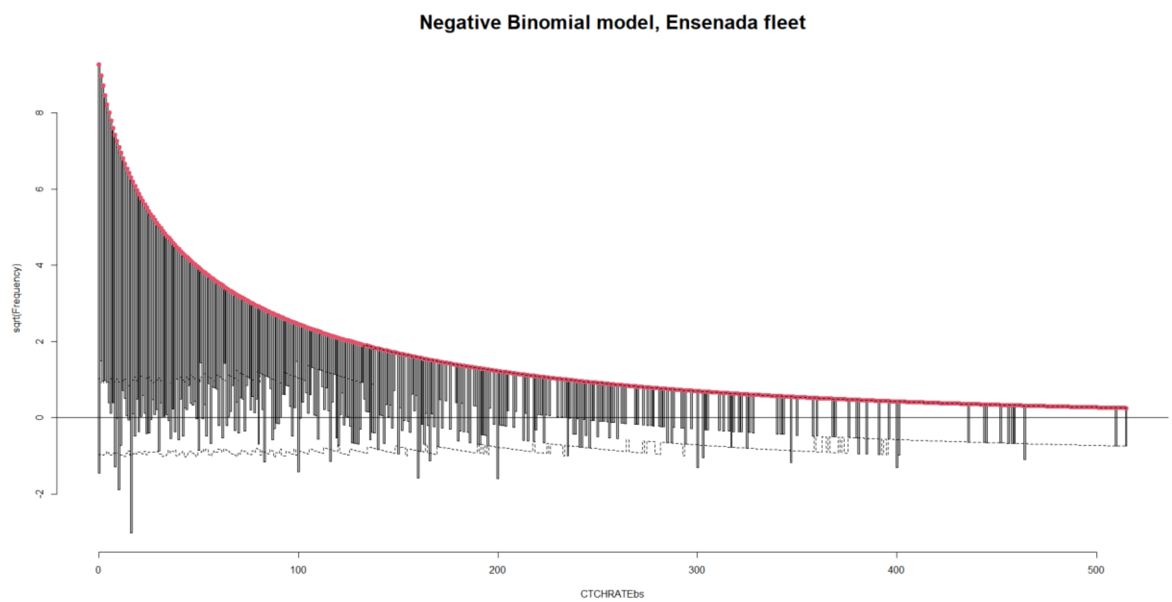


Figure 7. Pseudo R^2, Partial pseudo R^2 and the significance of the variable deletion tests for both models. (see text).



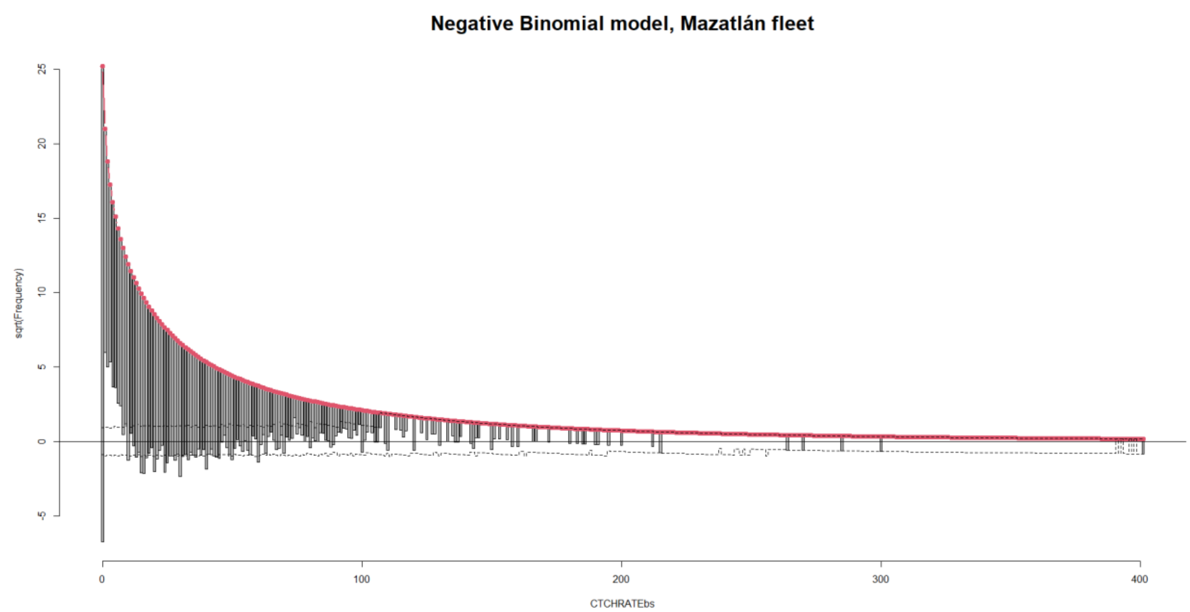
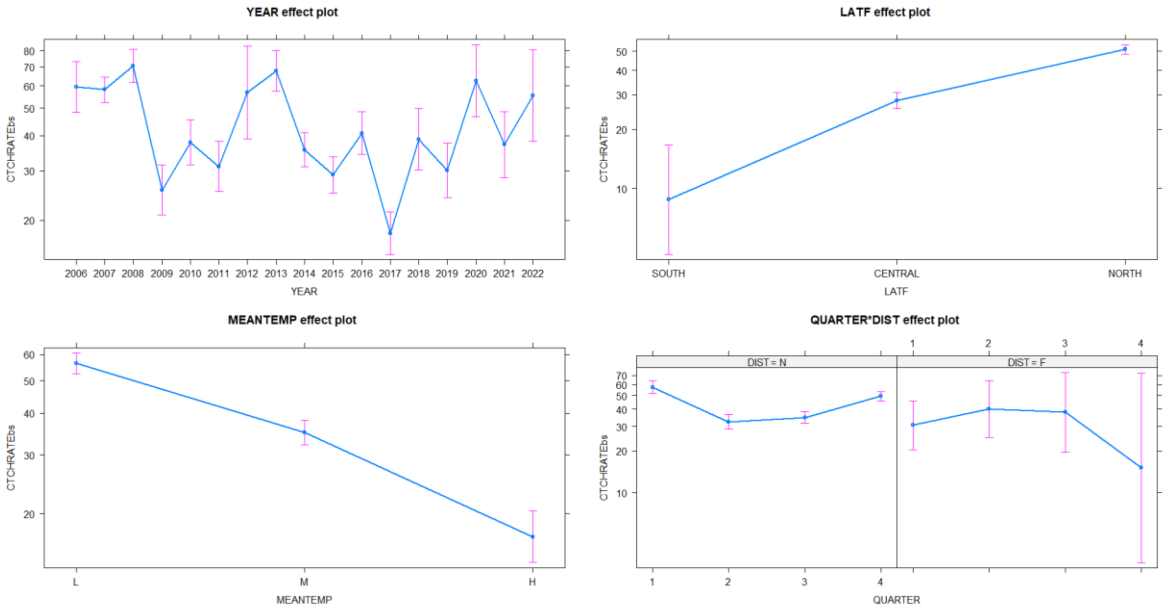


Figure 8. Hanging rootogram for both models. (see text).



Mazatlán fleet

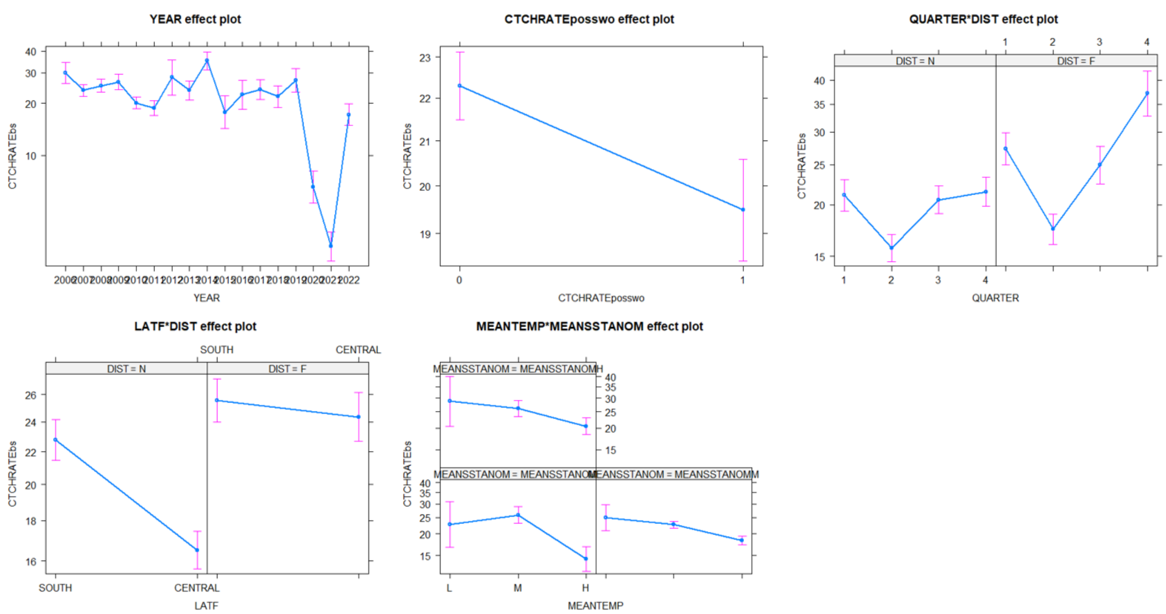
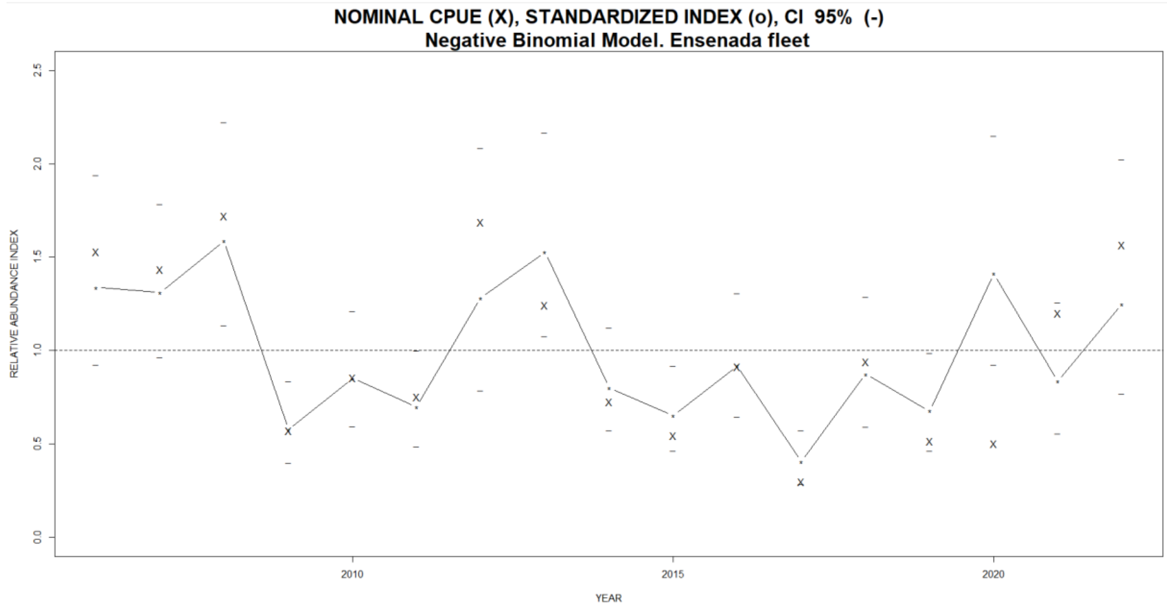


Figure 9. Marginal effects plots for both models. (see text).



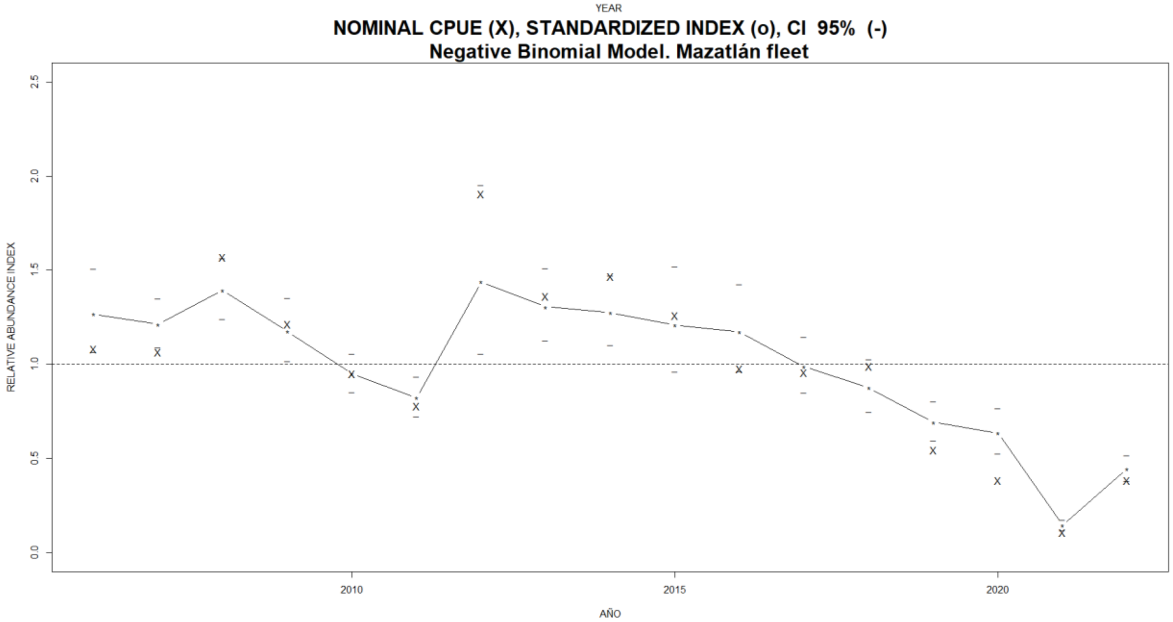
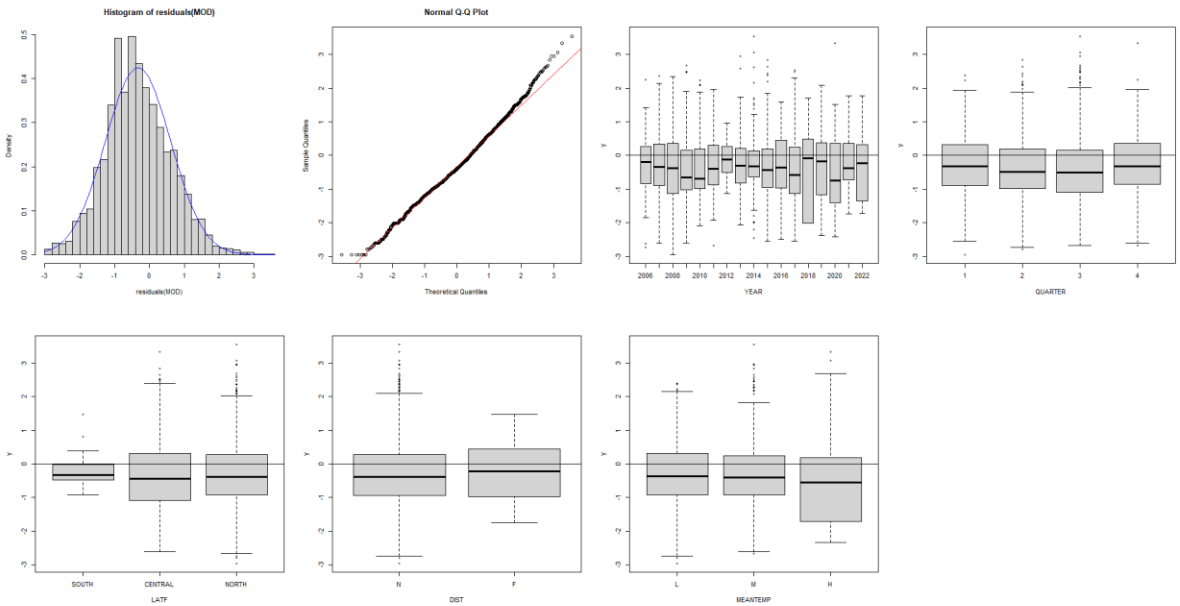


Figure 10. Relative abundance indices for the blue shark with approximate 95% confidence intervals. Negative Binomial model for years 2006-2022.

Ensenada fleet



Mazatlán fleet

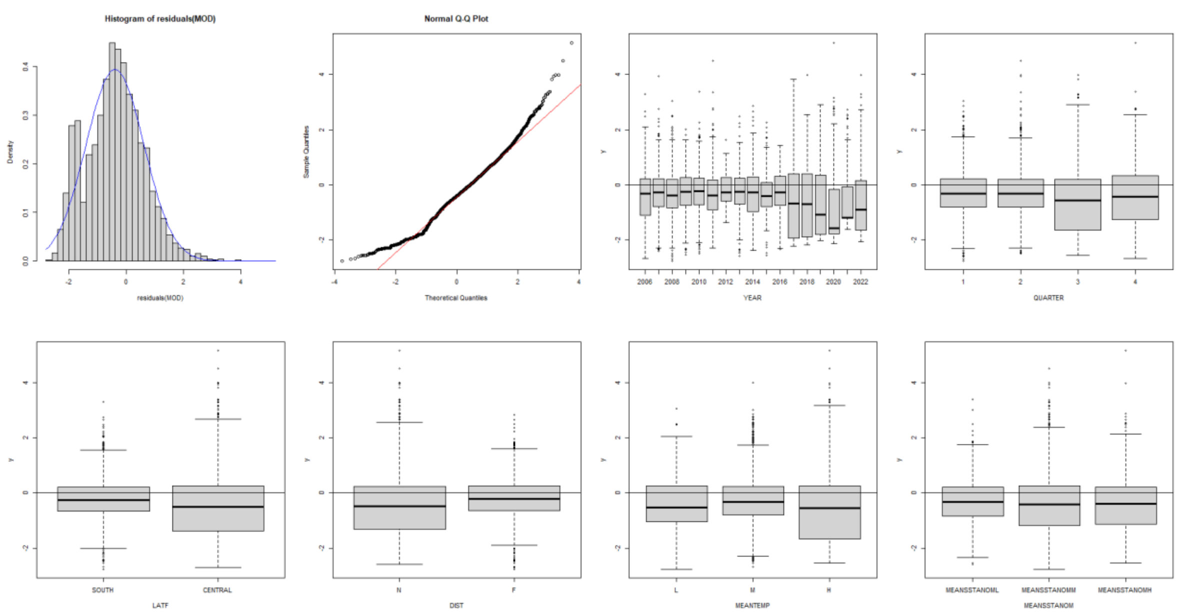
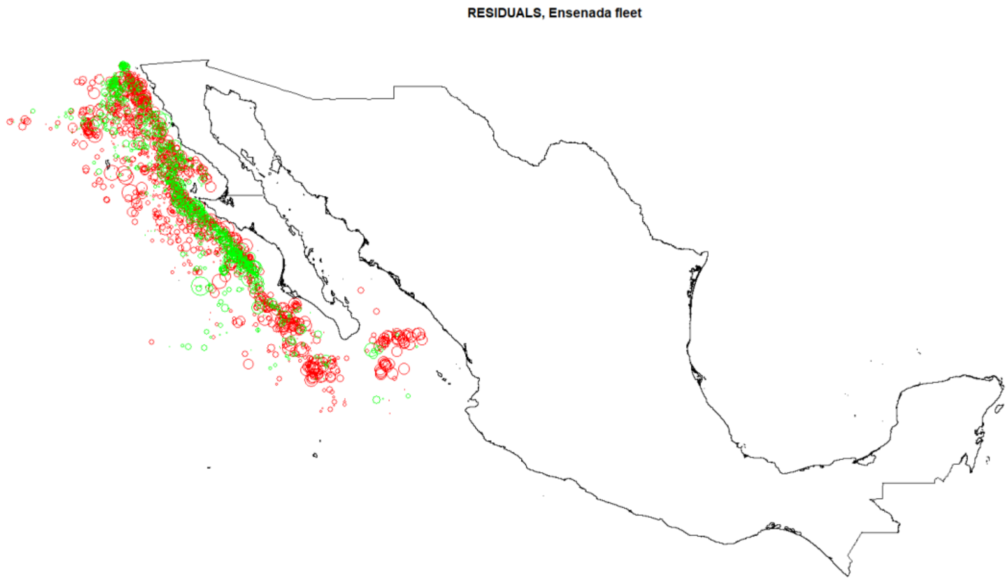


Figure 11. Histogram, QQplot of residuals and marginal-residual plots of the Negative Binomial GLM.



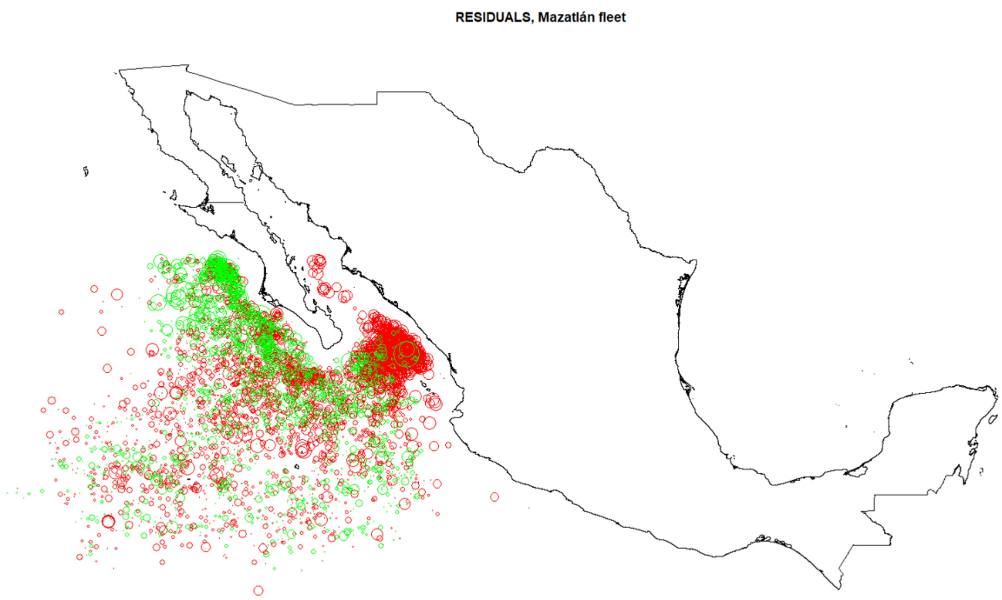


Figure 12. Spatial distribution of residuals (positive residuals in green and negative ones in red). Circle diameter is proportional to the size of the residuals.

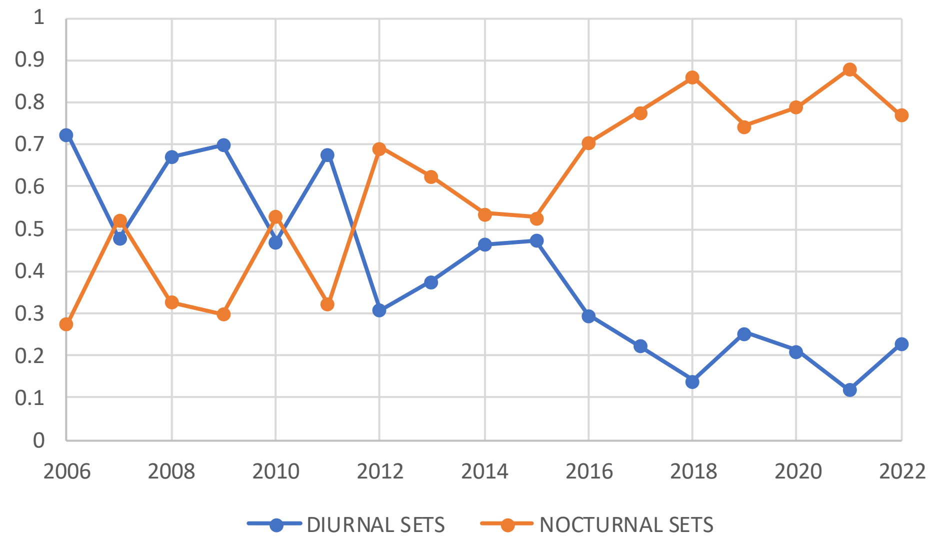


Figure 13 Fraction of diurnal and nocturnal fishing sets for the Mazatlán fleet.

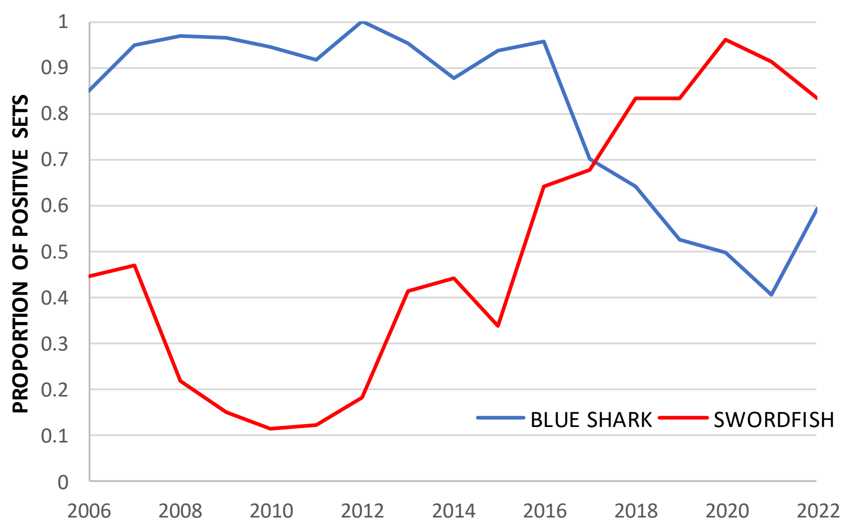


Figure 14 Fraction of diurnal and nocturnal fishing sets for the Mazatlán fleet.

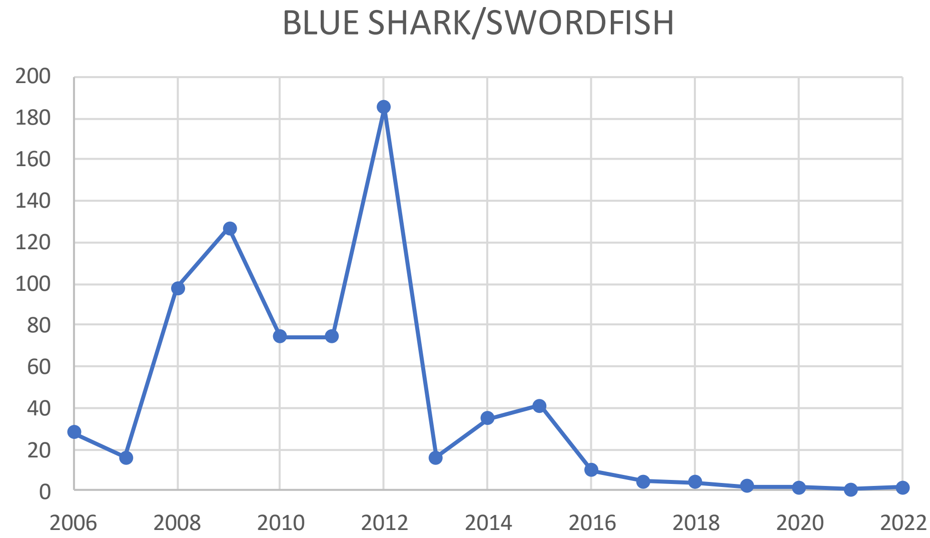


Figure 15 Ratio of blue shark/swordfish (numbers per fishing set) in the Mazatlán fleet.