SCIENTIFIC COMMITTEE
FIFTEENTH REGULAR SESSION

Pohnpei, Federated States of Micronesia
12-20 August 2019

Data Preparation for Southeast Pacific Blue and Shortfin Mako Sharks

WCPFC-SC15-2019/SA-IP-14

Quiroz. J. and Hoyle, S.

Data preparation for Southeast Pacific blue and shortfin mako sharks

Juan Carlos Quiroz [1] and Simon Hoyle [2]

Introduction

This study involves collaborative work between the National Institute of Water and Atmospheric Research (NIWA, New Zealand) and the Fisheries Development Institute (IFOP, Chile), funded by the Western and Central Pacific Fisheries Commission (WCPFC) under the ABNJ Tuna Project. The main goal of the ABNJ project is to develop a Southern Hemisphere pelagic shark stock assessment for management purposes, in which fishing data collected by the Chilean government plays a relevant role. This project builds on previous collaborative work between NIWA and IFOP, also funded by the ABNJ Tuna Project (Hoyle *et al.* 2017a).

Fishery

The fishery for pelagic sharks in the south-eastern Pacific is conducted mainly by longline and gillnet fleets from Chile, but distant water fleets from various countries are also involved. The Chilean pelagic shark fishing fleets comprise industrial and artisanal vessels, which have historically been part of swordfish fishery (*Xiphias gladius*). Swordfish catches have been reported in Chile since the early 1960s. The industrial longline fleet operates between 100 and 800 nautical miles from the coast, overlapping with the fishing zones of large longline artisanal vessels. The small artisanal component (small longline and gillnet) operates within 40 nautical miles from the coast mainly because of its low autonomy and fishing power. Annex 1 contains a description of these fleets and vessels.

Commercial targeting

Historically, pelagic shark catches have been treated as by-catch of the swordfish fishery; however, over the last eight years, deliberate targeting has been identified, representing a multispecies fishery for pelagic sharks, with fins sold in Asian markets (Hernandez *et al.* 2008). Recent fishing reports, delivered by the IFOP, show that blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) are heavily targeted in most fishing sets. Similarly, the porbeagle shark (*Lamna nasus*) has become relevant in the operations of reported fisheries in southern Chile, and lastly, at least 10 other shark species are caught occasionally in much of the fishery area. Hoyle *et al.* (2017a) report significant numbers of sharks in swordfish catches over 10 years, which agree with recent swordfish fishery reports indicating that the catch proportion (in number) of the principal shark species exceeds the swordfish catch, due to greater artisanal fleet targeting during the last eight years.

Indicators for stock assessment

The Swordfish Observer and Monitoring programs, developed by the Fisheries Development Institute (IFOP) in Chile, aim to maintain adequate sampling coverage for the principal pelagic shark species. This study uses both catch/effort records and biological samples collected under these programs to explore spatial and temporal patterns of shark life history, and to develop indicators that support the development of conceptual dynamic population models of pelagic sharks, which

[1] IFOP, Valparaiso, Chile
[2] NIWA, Nelson, New Zealand. simon.hoyle@niwa.co.nz.

would facilitate integration of these indicators into quantitative models for management purposes in the Pacific Ocean.

Methods

Fishing data

Several sets of historical data were used in this study. Most data were obtained under the framework of the Scientific Observer Program from commercial fishing vessels. For some analyses these were complemented by fishing logbook records from vessels without observers, compiled after the fishing trip. However due to suspected trends in the reliability of reporting of shark catches in the logbook data, only observer records were used for CPUE standardization. Analyses were carried out separately for industrial and artisanal longline fleets between 2001 and 2018. Due to operational differences, the records of the artisanal longline fleet were separated by strata of vessels longer or shorter than 12 meters. Table 1 shows the total number of fishing trips, coverage by scientific observers, and the number of participating vessels.

Due to the sparse observer and logbook coverage for the small artisanal vessels, only simple analyses were carried out for this fleet, with most analyses focusing on the large artisanal and industrial fleets.

Two data types were integrated in this study: (a) catch data (kg and number) and effort (number of hooks, number of sets by stratum) for blue sharks and shortfin mako sharks, together with operational characteristics of the fishing set such as date, registered position in degree-minute-second, depth, and fishing area; (b) individual biological samples with information on length (cm, curve fork lengths), sex, and weight (kg). Lunar illumination ('moon') and moon phase ('phase') were determined from the set date using the R package *lunar* (Lazaridis 2014).

Models

Several types of generalised additive model (*gam*) were implemented to predict variables of interest such as catch number, catch success, average length of sharks, individual spatial length distribution, and gender spatial segregation. The analyses were implemented for strata that combined type of longline fleet (industrial, major artisanal, minor artisanal), species under study (blue shark, shortfin mako), and sex (male, female). Prior to analysis, the data were prepared with checks for errors and outliers. We selected predictors based on goodness of fit and sensitivity analysis.

The categorical response variables catch success (probability of non-zero catch) and sex ratio (probability of presence of males) were modelled assuming a binomial distribution with the following variables as predictors: temporal (year, month), spatial (longitude, latitude, fishing zone), operational (depth of hooks), and environmental (relative lunar illumination and moon phase, determined from the set date).

Model 1: P(**y**) **~ year_bin + predlist**, family **= binomial**,

where `P` is the probability of catch success or presence of males at given year and `predlist` comprises the selected predictors.

The continuous variables catch (number or kg) per non-zero set and catch per unit of effort (CPUE) were modelled using *gam* with a lognormal distribution. Log-scale transformation of the response variable (`y`) was performed to normalise the residuals, following the model:

Model 2: log(**y**) **~ year_pos + predlist**, family **= Gaussian**.

All analyses were performed in R (R Core Team 2018) using packages *mgcv* (Wood 2011), *mgcViz* (Fasiolo *et al.* 2019), *ggplot2* (Wickham 2016), and *tidyverse* (Wickham 2017).

Finally, a delta-generalized linear model (*dglm*) was fitted to catch and effort data for each shark species and used to construct standardised annual indices for blue shark and shortfin mako. The delta approach decomposes the catch rate into the probability of positive catch (encounter probability) and the non-zero catch rate (Lo *et al.* 1992; Hoyle & Maunder 2005), therefore the *dglm* was specified as:

Model 3: y ~ b(**year_bin**) ***** exp(**year_pos**),

where `year_bin` is the logit-linked annual linear predictor of the binomial model (`Model 1`) and `year_pos` is the log-linked annual linear predictor for the non-zero catch (`Model 2`).

Best models were selected from a set of model candidates using as criteria the lowest log-likelihood value, Wald-like tests (Wood 2013), Akaike information criteria (AIC, Akaike 1973) and degrees of freedom criteria. Model differences were reported as delta AIC, which is the absolute difference in the AIC values.

Results

Fishing data

Data from a total of 47,619 fishing sets collected between 2001 and 2018 (32.1% Industrial Fleet, 10.5% Artisanal Large Fleet, and 57.4% Artisanal Small Fleet) were included in the analyses. The fishing logbooks show that during the study period the industrial and large artisanal fleets deployed an average of 1,219 hooks per fishing set. For the small artisanal fleet, the low scientific observer coverage (see Table 1) led to uncertainty about the number of hooks per fishing set, so the number of sets reported at the end of the fishing trip was used as the unit of effort. For this fleet, 5.2 sets per fishing trip were deployed on average, with a maximum of 24 sets. Annex 1 provides details on the fishing effort deployed by the fleets for the period 2001-2018.

The trends in the capture of blue and shortfin mako sharks differed among fleets (Figure 1). On the one hand, the industrial longline fleet's capture of blue sharks has steadily declined due to a reduction in fishing effort. For the artisanal components, the small artisanal fleet shows clear indications of targeting both shark species, with marginal catches of swordfish throughout the study period. For the large artisanal fleet, shark catches increase while swordfish catches are very variable, with some decline. Their catches represent on average (for all years and both species) about 13% of the catches of the small artisanal fleet (Table 2).

Biological patterns

Patterns in standardized sex ratio data showed a degree of spatial separation for both species. The figures that illustrate these patterns are most reliable in central areas with more data. Surface splines can extrapolate trends unrealistically at the edges, which should be viewed with caution.

Blue sharks show spatial patterns in sex ratio with similar patterns in data from both the large artisanal and the industrial fleets. Females are more commonly caught closer to the coast and further south (Figure 2). There is also significant variation through the year, with more males caught in the first half of the year, and the proportion of females peaking in September- October. There is a small amount of interannual variation, but it has much less influence than the other effects.

For shortfin mako sharks the trends are also similar between fleets, although there are some differences probably due to both relative sample sizes and uncertainty in edge areas with sparse data (Figure 3). However, shortfin makos show quite a different spatial pattern from blue sharks, with males more common than females closer to the coast and further south. Seasonal effects are relatively minor as are interannual effects.

Given the differing spatial distributions of males and females, and the tendency for sharks to distribute separately by size class, maturity state, and sex, we explored size distributions separately by sex. For male blue sharks there was a strong pattern of larger sharks being caught in the northwest of the area fished (Figure 4). There was also strong seasonality with larger sharks caught from December to May, and the smallest sharks caught from August to October. There was also significant interannual size variation, but this varied somewhat between fleets.

Female blue sharks also tended to be smaller closer to the coast and larger in the northwest (Figure 5). However, seasonal variation was limited and inconsistent among fleets. There was also some interannual size variation, but this too was inconsistent among fleets.

For shortfin mako sharks, males tended to be larger in the south and west, and smaller in the northeast (Figure 6). There is a suggestion of smaller sizes in the far south-west, but it is based on very low sample sizes, and on the edge of the plot where estimates are least reliable. They also showed seasonal size variation, with the largest sharks caught from March to May. Sizes were variable through time, but with a suggestion of smaller sizes recently. Female size patterns were unclear but not inconsistent with patterns observed for males. They appear to be larger in the south and west, apart from a suggestion of small sizes in the far southwest based on sparse data. They are also largest from February to May (Figure 7). There also appeared to be some decline in mean size through time. Length frequency distributions by year for each fleet are provided in Annex 1, in Figures A2.1, A2.2, A2.3, and A2.4.

CPUE standardization

Catch and effort data were standardized for each species and fleet using a delta lognormal approach. Both Poisson and lognormal distributions were trialled for the positive component and lognormal fitted the data very well (Figure 8), much better than the Poisson.

For both the probability of non-zero catches and the distribution of non-zero catches, the factors year, month, and vessel were statistically significant in almost all cases (Table 3). The smoothers s(lat, lon) and s(nhooks) were statistically significant in all cases but two (Table 4): the smoother for number of hooks was marginally significant for nonzero catch rates of both blue sharks and shortfin mako sharks caught by the artisanal fleet. Lunar effects were significant in all cases. Lunar illumination was the most parsimonious catch rate predictor in most cases, except for catches of shortfin mako by the industrial fleet, where moon phase was a better predictor in both the binomial and positive components.

Spatial patterns of blue shark probability of non-zero catch rates were similar for artisanal and industrial fleets, with higher proportions of non-zero catches in the east and south (Figure 9). Higher non-zero catch rates (Figure 10) were also apparent for the artisanal fleet in the east and south, whereas for the industrial fleet the distributions were similar but less clear. For shortfin mako sharks, catch rates were generally higher in the south, but patterns were less clear than for blue shark (Figures 11 and 12).

Standardized catch rate indices for blue shark in the artisanal fleet show a variable but decreasing trend (Figure 13). Indices for the industrial fleet are also very variable, but neither increase nor decline (Figure 14).

For shortfin mako sharks the proportions of nonzero catches by the artisanal fleet increase strongly to reach nearly 90% in 2010 (Figure 15). After 2009 the proportions of nonzero catches stabilises but the catch rates in positive sets continue to rise. The resulting combined index increases substantially across the time series. As for blue sharks, in the industrial fleet the proportions of nonzero sets increases over the time series, in this case starting at less than 40% in 2001 and then increasing to reach 90% in 2010 (Figure 16). The combined CPUE shows a strong increasing trend. Indices are provided in Tables 5 and 6.

Discussion

This analysis has successfully standardized size, sex ratio, and CPUE data, and identified patterns in spatial and seasonal distribution among different parts of the population. Sharks are well-known for their tendency to separate by sex and size class (Springer 1967; Wearmouth & Sims 2008).

Spatial variation in sex ratio was apparent for both blue sharks and shortfin makos. For blue sharks, males were found further north, in warmer waters, and away from the coast. Nakano & Nakasawa (1996) also found spatial distribution differences by sex for blue sharks, with males caught at warmer temperatures on average than females. Nakano (1994) developed a general model for male and female blue shark distribution in the north Pacific, with more segregation between sexes at the nursery and subadult stages than for adults.

For shortfin makos, males were more common close to the coast with females more common in oceanic waters. In the central south Pacific, strong sexual segregation was found with more female shortfin makos to the east of -140 degrees and more males to the west (Mucientes *et al.* 2009).

Blue sharks showed strong size patterns for both males and females, much larger to the west and in warmer waters further north than near the coast. Similarly, in longline surveys east of Japan, both sexes of blue sharks tended to be caught at larger sizes in warmer waters (Ohshimo *et al.* 2016). For males in the current study there was a seasonal size pattern, with larger sharks caught early in the year, but no such pattern was apparent for females.

Shortfin makos showed some spatial size patterns but not very strongly, with a suggestion of larger males to the west. There was clear seasonality for both sexes, with larger sharks caught early in the year. In the western North Pacific, most hotspots for “immature” shortfin mako occurred in the coastal waters of Japan, while hotspots for “subadult and adult” occurred in the offshore or coastal waters of Japan (Kai *et al.* 2017).

The standardized proportions of non-zero sets for both blue sharks and shortfin makos increased at the beginning of the industrial fleet time series. This may be due to increased targeting of sharks, which has not been accounted for in this analysis. Further work would be useful to explore changes in targeting, which has also been reported to be increasingly focused on sharks (author pers. obs). Cluster analysis of species composition (He *et al.* 1997; Hoyle *et al.* 2015) would be a useful tool for exploring the available data.

Further work would also be useful to explore reporting rates in the logbook data, though they were not used in the CPUE analyses. This issue could be important in interpreting differing reporting rates between observers and logbooks, or increasing reporting rates in logbooks due to increased targeting. Observers started covering the large artisanal longline fleet in 2007 and coverage increased thereafter (Table 1). In future it would be useful to compare catch rates between observer records and vessel logbooks, and to estimate reporting reliability for vessels as done for shark reporting by the Japanese fleet (Hoyle *et al.* 2017b).

Another issue that should be addressed in future work is to develop separate indices for sharks of different size and sex classes. This may be particularly important for blue sharks, which appear to show more segregation by size.

Observer coverage in the industrial fleet dropped from its previous very high levels to just below 10% as of 2014. While this lower level of observer coverage is still high compared to many fisheries around the world, it results in greater uncertainty in the year effects for 2015-2018 in the form of wider confidence intervals on the estimates.

Acknowledgments

Thanks to the ABNJ Tuna Project for providing funding for the project, to NIWA Nelson for hosting JCQ during the analyses, and to Shelley Clarke for reviewing the manuscript.

References

Akaike, H. (1973) Information theory and an extension of the maximum likelihood principle.

Fasiolo, M., Nedellec, R., Goude, Y., Wood, S.N. (2019) Scalable visualisation methods for modern Generalized Additive Models. *Journal of computational and Graphical Statistics*(just-accepted): 1-16.

He, X., Bigelow, K.A., Boggs, C.H. (1997) Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. *Fisheries Research*, 31(1-2): 147-158.

Hernandez, S., Haye, P., Shivji, M.S. (2008) Characterization of the pelagic shark-fin trade in north-central Chile by genetic identification and trader surveys. *Journal of Fish Biology*, 73(10): 2293-2304.

Hoyle, S.D., Maunder, M.N. (2005) Standardisation of yellowfin and bigeye CPUE data from Japanese longliners, 1975-2004. IATTC Working Group on Stock Assessments, 2006.

Hoyle, S.D., Okamoto, H., Yeh, Y.-m., Kim, Z.G., Lee, S.I., Sharma, R. (2015) IOTC–CPUEWS02 2015: Report of the 2nd CPUE Workshop on Longline Fisheries, 30 April – 2 May 2015, IOTC–2015–CPUEWS02–R[E]: 126.

Hoyle, S.D., Quiroz, J.C., Zarate, P., Devia, D., Azocar, J. (2017a) WCPFC-SC13-SA-IP-17. Population indicators for porbeagle sharks in the Chilean swordfish fishery. *WCPFC Scientific Committee 13*.

Hoyle, S.D., Semba, Y., Kai, M., Okamoto, H. (2017b) Development of porbeagle shark stock abundance indicators using Japanese data. *New Zealand Fisheries Assessment Report 2017/07.*,

Kai, M., Thorson, J.T., Piner, K.R., Maunder, M.N. (2017) Spatiotemporal variation in size-structured populations using fishery data: an application to shortfin mako (Isurus oxyrinchus) in the Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences*, 74(11): 1765-1780.

Lazaridis, E. (2014) lunar: Lunar Phase & Distance, Seasons and Other Environmental Factors (Version 0.1-04). Available from http://statistics.lazaridis.eu. http://statistics.lazaridis.eu

Lo, N.C.H., Jacobson, L.D., Squire, J.L. (1992) Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences*, 49(12): 2515-2526.

Mucientes, G.R., Queiroz, N., Sousa, L.L., Tarroso, P., Sims, D.W. (2009) Sexual segregation of pelagic sharks and the potential threat from fisheries. *Biol Lett*, 5(2): 156-159. 10.1098/rsbl.2008.0761

Nakano, H. (1994) Age, reproduction and migration of blue shark [Prionace] in the north Pacific ocean. *Bulletin-National Research Institute of Far Seas Fisheries (Japan)*.

Nakano, H., Nakasawa, K. (1996) Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. *Fisheries Science*, 62(6): 860-865.

Ohshimo, S., Fujinami, Y., Shiozaki, K., Kai, M., Semba, Y., Katsumata, N., Ochi, D., Matsunaga, H., Minami, H., Kiyota, M. (2016) Distribution, body length, and abundance of blue shark and shortfin mako offshore of northeastern Japan, as determined from observed pelagic longline data, 2000–2014. *Fisheries Oceanography*, 25(3): 259-276.

R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Springer, S. (1967) Social organization of shark population. *Sharks, skate and rays*: 149-174.

Wearmouth, V.J., Sims, D.W. (2008) Sexual segregation in marine fish, reptiles, birds and mammals: behaviour patterns, mechanisms and conservation implications. *Advances in Marine Biology*, 54: 107-170.

Wickham, H. (2016) *ggplot2: elegant graphics for data analysis*. Springer.

Wickham, H. (2017) The tidyverse. *R package ver. 1.1*, 1.

Wood, S.N. (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 73(1): 3-36.

Wood, S.N. (2013) On p-values for smooth components of an extended generalized additive model. *Biometrika*, 100(1): 221-228.

Tables

Table 1: Number of fishing trips, presence of scientific observer by trip, and number of vessels participating in the fishery, by type fleet.

	Industrial Longline			Large Artisanal Longline			Small Artisanal Longline		
	n Trip	With Obs	n Vessel	n Trip	With Obs	n Vessel	n Trip	With Obs	n Vessel
2001	86	85	12	--	--	--	--	--	--
2002	82	81	13	21	0	6	755	0	105
2003	84	84	13	32	0	7	807	0	109
2004	58	45	10	37	0	7	704	0	126
2005	58	43	10	35	0	6	622	0	131
2006	42	37	7	33	0	5	722	0	123
2007	40	30	8	26	4	5	683	0	128
2008	29	29	5	11	2	2	541	0	112
2009	43	31	6	9	5	1	418	0	120
2010	54	44	7	9	5	1	339	8	103
2011	32	30	4	13	12	2	420	9	105
2012	40	31	6	20	18	3	531	8	109
2013	27	17	6	22	9	3	558	9	98
2014	14	12	3	16	14	2	678	10	114
2015	66	6	1	10	10	2	569	8	101
2016	77	7	1	20	17	2	359	8	73
2017	77	7	1	17	16	2	249	9	66
2018	55	5	1	9	9	2	259	8	57

Table 2: Annual average catch of sharks by fleet type between period 2001-2018.

Fleet	Specie	average	max	min
Industrial	Blue shark	9985	36420	1558
Industrial	Shortfin mako	2962	5526	801
Industrial	Swordfish	11164	26881	1057
Large artisanal	Blue shark	1306	2440	270
Large artisanal	Shortfin mako	933	2305	117
Large artisanal	Swordfish	2988	4651	1160
Small artisanal	Blue shark	8794	17651	1972
Small artisanal	Shortfin mako	8287	15095	2167
Small artisanal	Swordfish	112	331	2

*Table 3: Generalized additive model results for the three factors fitted for each species, fleet, and distribution. Results comprise degrees of freedom, Chi squared, and p value estimates. I = industrial fleet, A = large artisanal fleet. P values are highlighted by * (< 0.05) or ** (< 0.01).*

Species	Distri-bution	Fleet	Factor	DF	Chi.squared	p.value
Blue shark	bin	I	year	17	394.7	2.43E-73**
Blue shark	bin	I	month	10	241.7	2.96E-46**
Blue shark	bin	I	vessel	16	873.1	1.54E-175**
Blue shark	bin	A	year	11	65	1.10E-09**
Blue shark	bin	A	month	11	15.2	0.175
Blue shark	bin	A	vessel	2	21.7	1.94E-05**
Blue shark	pos	I	year	17	41.5	1.12E-134**
Blue shark	pos	I	month	10	225.5	0.00**
Blue shark	pos	I	vessel	16	114.1	0.00**
Blue shark	pos	A	year	11	12	1.02E-21**
Blue shark	pos	A	month	11	16.5	7.49E-31**
Blue shark	pos	A	vessel	2	7.7	0.000456**
Shortfin mako	bin	I	year	17	987.3	4.79E-199**
Shortfin mako	bin	I	month	11	373.6	2.45E-73**
Shortfin mako	bin	I	vessel	16	625.9	7.32E-123**
Shortfin mako	bin	A	year	11	58	2.13E-08**
Shortfin mako	bin	A	month	11	104.8	1.95E-17**
Shortfin mako	bin	A	vessel	2	4.7	0.0961
Shortfin mako	pos	I	year	17	64.7	1.30E-210**
Shortfin mako	pos	I	month	11	34.4	9.31E-73**
Shortfin mako	pos	I	vessel	16	38.4	2.29E-116**
Shortfin mako	pos	A	year	11	18.8	1.84E-35**
Shortfin mako	pos	A	month	11	15.7	3.15E-29**
Shortfin mako	pos	A	vessel	2	5.3	0.0051**

*Table 4: Generalized additive model results for the three smoothers (location, number of hooks, and either lunar illumination ("moon") or moon phase ("phase")) fitted for each species, fleet, and distribution. Results comprise effective degrees of freedom, Chi squared, and p value estimates. I = industrial fleet, A = large artisanal fleet. P values are highlighted by * (< 0.05) or ** (< 0.01).*

Species	Distribution	Fleet	Smoother	Effective DF	Chi.sq	p.value
Blue shark	bin	I	te(lon,lat)	45.18	252	1.90E-34**
Blue shark	bin	I	s(moon)	0.8	3.6	0.0322*
Blue shark	bin	I	s(nhooks)	8.51	97.8	3.46E-18**
Blue shark	bin	A	te(lon,lat)	47.39	110.2	1.34E-05**
Blue shark	bin	A	s(moon)	0.84	4.7	0.0154*
Blue shark	bin	A	s(nhooks)	8.71	14.8	0.0798
Blue shark	pos	I	te(lon,lat)	59.52	30.6	0.00**
Blue shark	pos	I	s(moon)	2.35	5.5	1.37E-12**
Blue shark	pos	I	s(nhooks)	7.2	9.1	2.86E-16**
Blue shark	pos	A	s(lon,lat)	32.29	4.7	8.93E-37**
Blue shark	pos	A	s(moon)	2.29	1.1	0.00455**
Blue shark	pos	A	s(nhooks)	2.38	1.3	0.00179**
Shortfin mako	bin	I	te(lon,lat)	63.85	378.3	3.20E-44**
Shortfin mako	bin	I	s(nhooks)	6.69	81.7	6.06E-17**
Shortfin mako	bin	I	s(phase)	4.93	141.7	4.44E-33**
Shortfin mako	bin	A	te(lon,lat)	23.07	52.1	0.00741**
Shortfin mako	bin	A	s(moon)	1.44	24	4.03E-07**
Shortfin mako	bin	A	s(nhooks)	1.63	3.8	0.0823
Shortfin mako	pos	I	te(lon,lat)	63.15	9.9	1.79E-97**
Shortfin mako	pos	I	s(nhooks)	5.31	13.1	3.90E-27**
Shortfin mako	pos	I	s(phase)	5.24	16.8	9.44E-35**
Shortfin mako	pos	A	te(lon,lat)	39.92	4.6	2.45E-21**
Shortfin mako	pos	A	s(moon)	1.08	8.3	1.95E-18**
Shortfin mako	pos	A	s(nhooks)	1.42	0.8	0.0094**

Table 5: Delta lognormal CPUE indices for the large artisanal fleet, for blue shark (left) and shortfin mako (right), with 95% confidence intervals.

	Blue shark			**Shortfin mako shark**		
year	**Estimate**	**2.5%**	**97.5%**	**Estimate**	**2.5%**	**97.5%**
2007	1.069	1.069	1.069	0.298	0.298	0.298
2008	1.523	1.046	1.561	-0.257	-0.073	-0.480
2009	1.088	0.891	1.105	0.155	0.025	0.456
2010	1.587	1.405	1.604	0.990	0.733	1.061
2011	1.320	1.030	1.366	0.687	0.543	0.731
2012	0.622	0.199	0.870	0.627	0.383	0.739
2013	1.091	0.640	1.200	0.682	0.390	0.827
2014	1.233	0.865	1.306	1.064	0.758	1.179
2015	0.630	0.177	0.904	1.104	0.717	1.262
2016	0.245	0.048	0.509	1.662	1.344	1.751
2017	0.584	0.140	0.914	2.666	2.454	2.699
2018	1.010	0.328	1.320	2.321	1.652	2.486

Table 6: Delta lognormal CPUE indices for the industrial fleet, for blue shark (left) and shortfin mako (right), with 95% confidence intervals.

	Blue shark			**Shortfin mako shark**		
year	**Estimate**	**2.5%**	**97.5%**	**Estimate**	**2.5%**	**97.5%**
2001	1.050	1.050	1.050	0.298	0.298	0.298
2002	0.812	0.784	0.836	-0.257	-0.073	-0.480
2003	0.398	0.365	0.428	0.155	0.025	0.456
2004	0.743	0.706	0.773	0.990	0.733	1.061
2005	0.802	0.763	0.833	0.687	0.543	0.731
2006	1.089	1.065	1.107	0.627	0.383	0.739
2007	1.293	1.263	1.313	0.682	0.390	0.827
2008	0.995	0.967	1.014	1.064	0.758	1.179
2009	0.891	0.851	0.920	1.104	0.717	1.262
2010	1.291	1.252	1.317	1.662	1.344	1.751
2011	1.341	1.310	1.359	2.666	2.454	2.699
2012	0.693	0.670	0.708	2.321	1.652	2.486
2013	0.811	0.763	0.840	1.003	0.945	1.039
2014	1.715	1.651	1.740	1.241	1.168	1.287
2015	1.219	0.932	1.299	1.195	1.054	1.282
2016	1.010	0.788	1.070	1.831	1.655	1.926
2017	0.538	0.376	0.619	2.577	2.335	2.661
2018	1.309	1.023	1.354	2.239	2.088	2.285

Figures

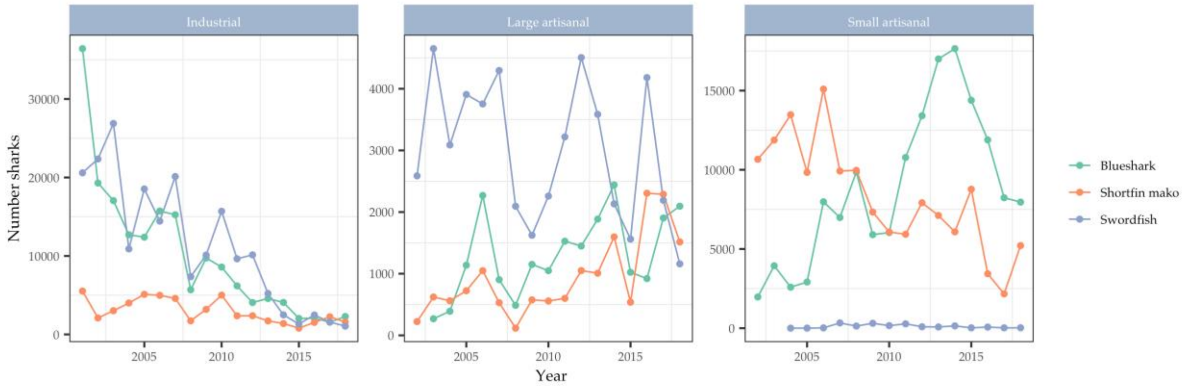

Figure 1: Catch time series of blue shark, shortfin mako and swordfish by type fleet.

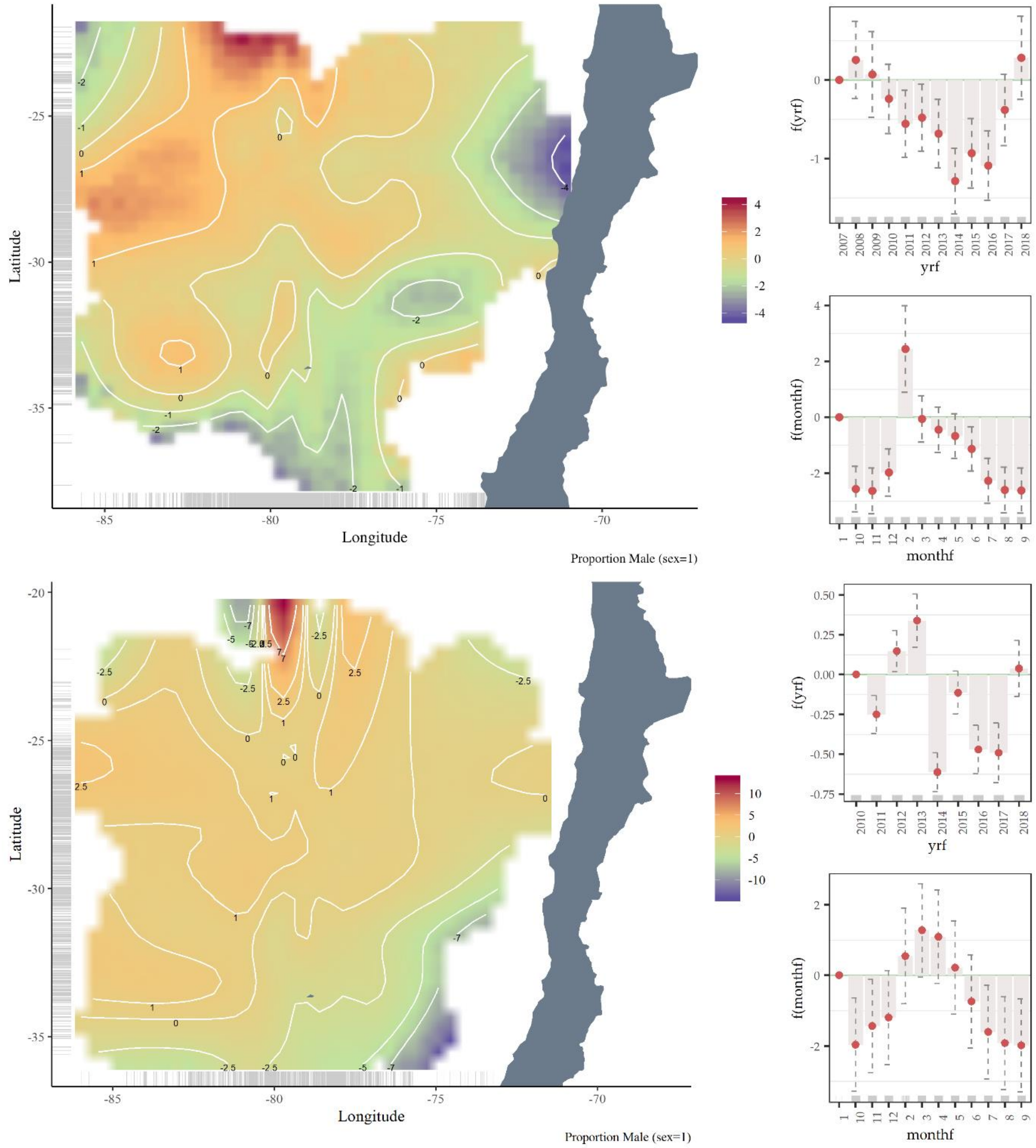

Figure 2: Sex ratios of blue sharks in catches by large artisanal (above) and industrial (below) longliners, by latitude and longitude (left), and by year (above right) and month (below right), as predicted from a generalized additive model. Higher proportions of males are represented by warmer colours. The rug components of the plot show the distribution of the data.

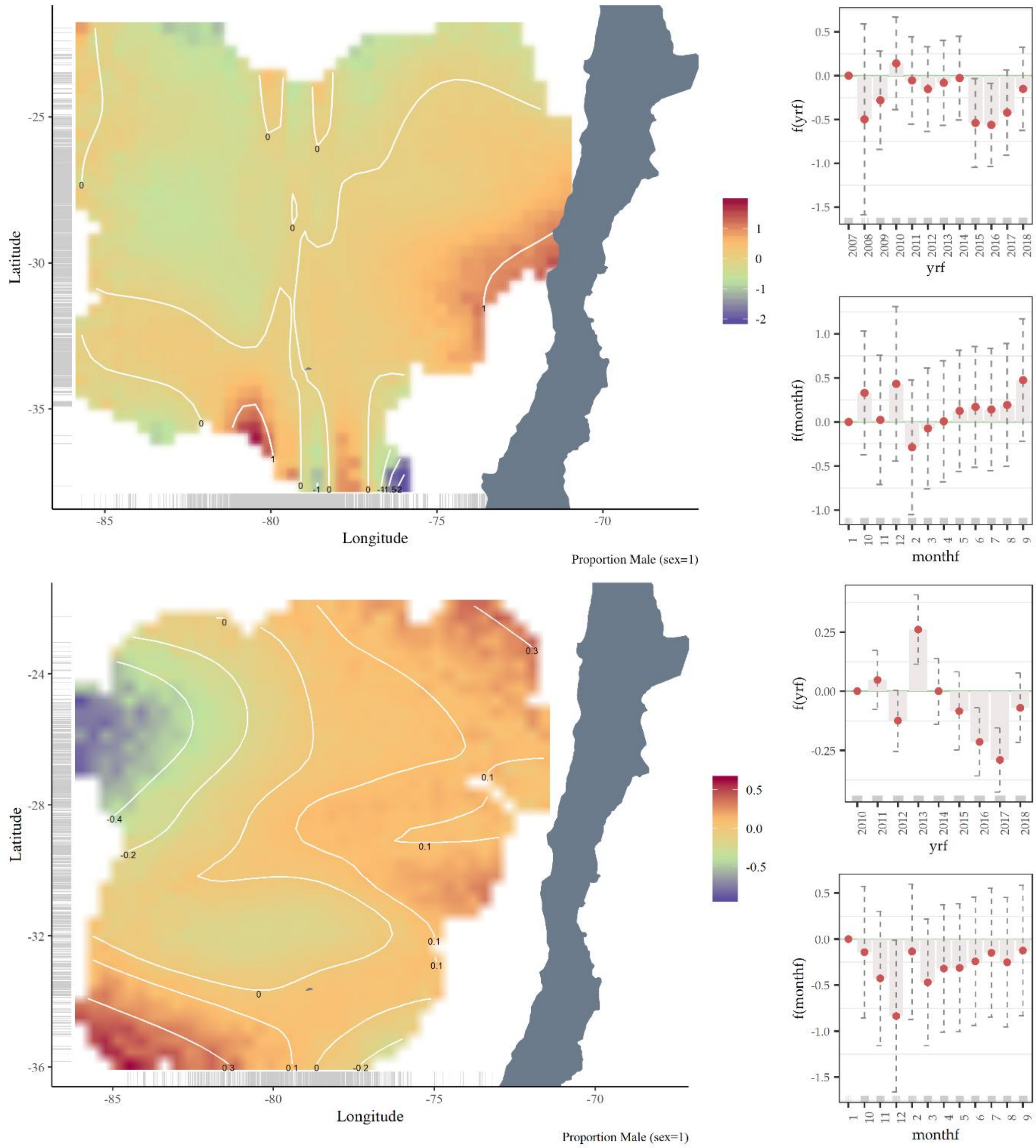

Figure 3: Sex ratios of shortfin mako sharks in catches by large artisanal (above) and industrial (below) longliners, by latitude and longitude (left), and by year (above right) and month (below right), as predicted from a generalized additive model. Higher proportions of males are represented by warmer colours. The rug components of the plot show the distribution of the data.

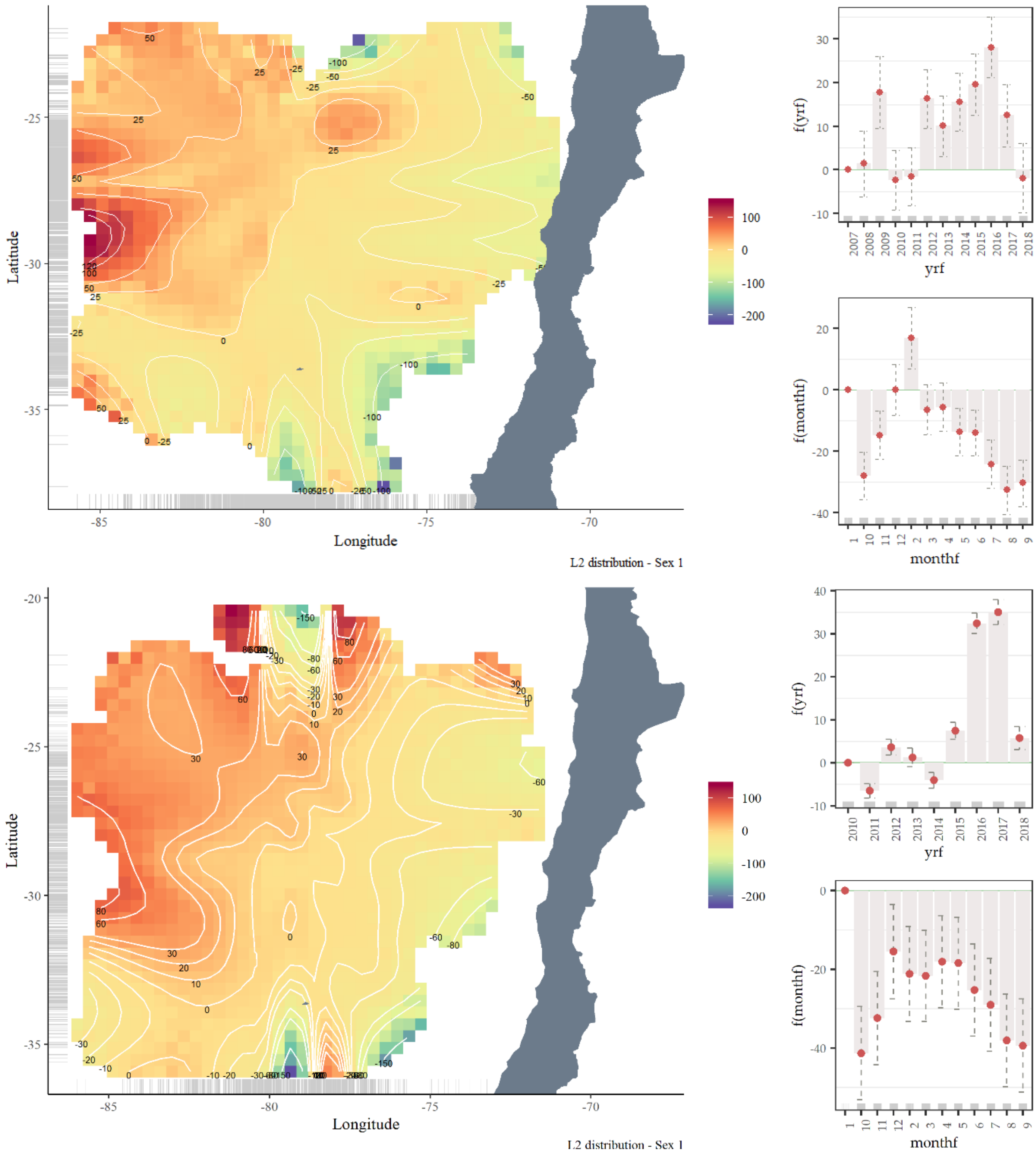

Figure 4: Blue shark male size distributions in large artisanal (above) and industrial (below) fisheries.Larger sizes are represented by warmer colours. The rug components of the plot show the distribution of the data.

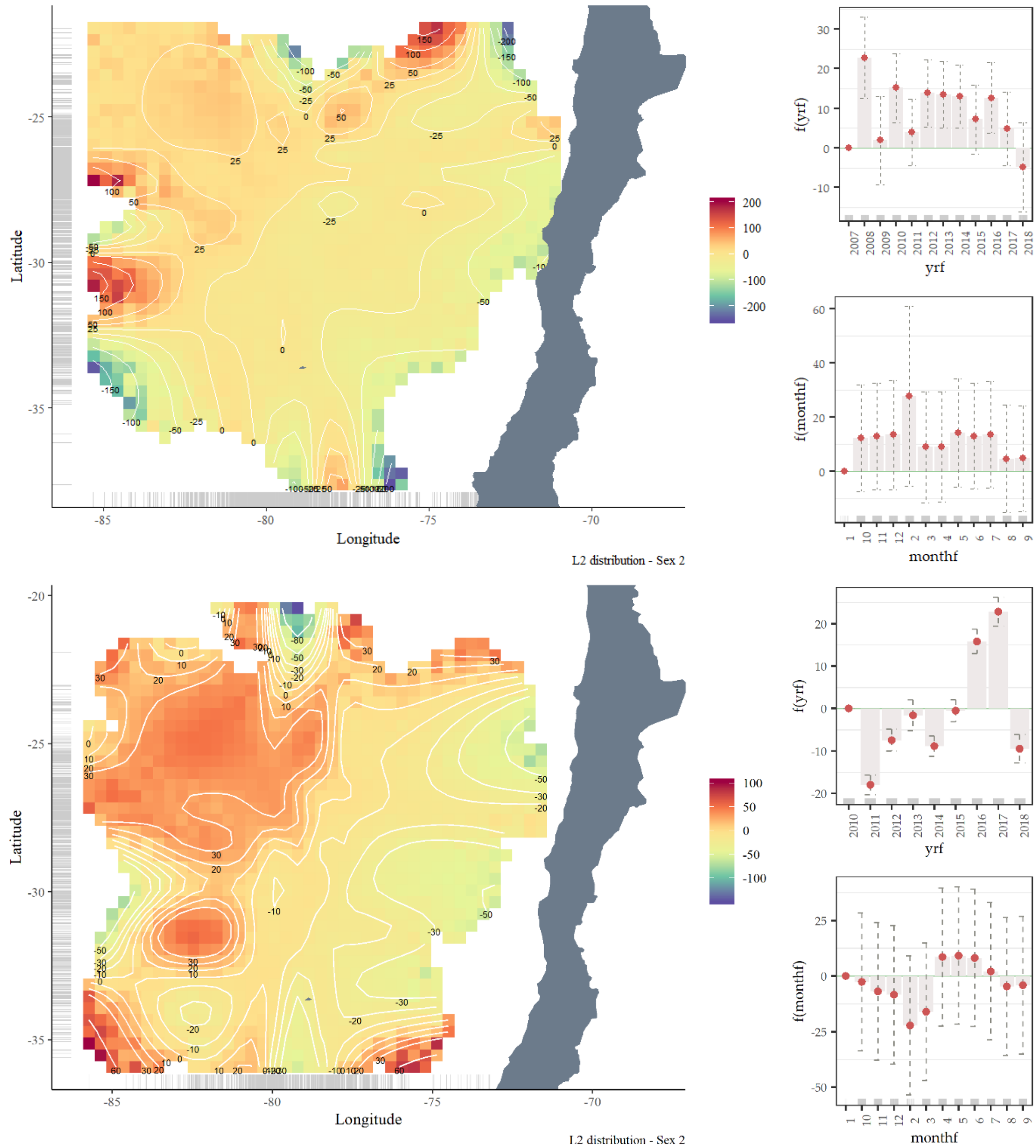

Figure 5: Blue shark female size distributions in large artisanal (above) and industrial (below) fisheries. Larger sizes are represented by warmer colours. The rug components of the plot show the distribution of the data.

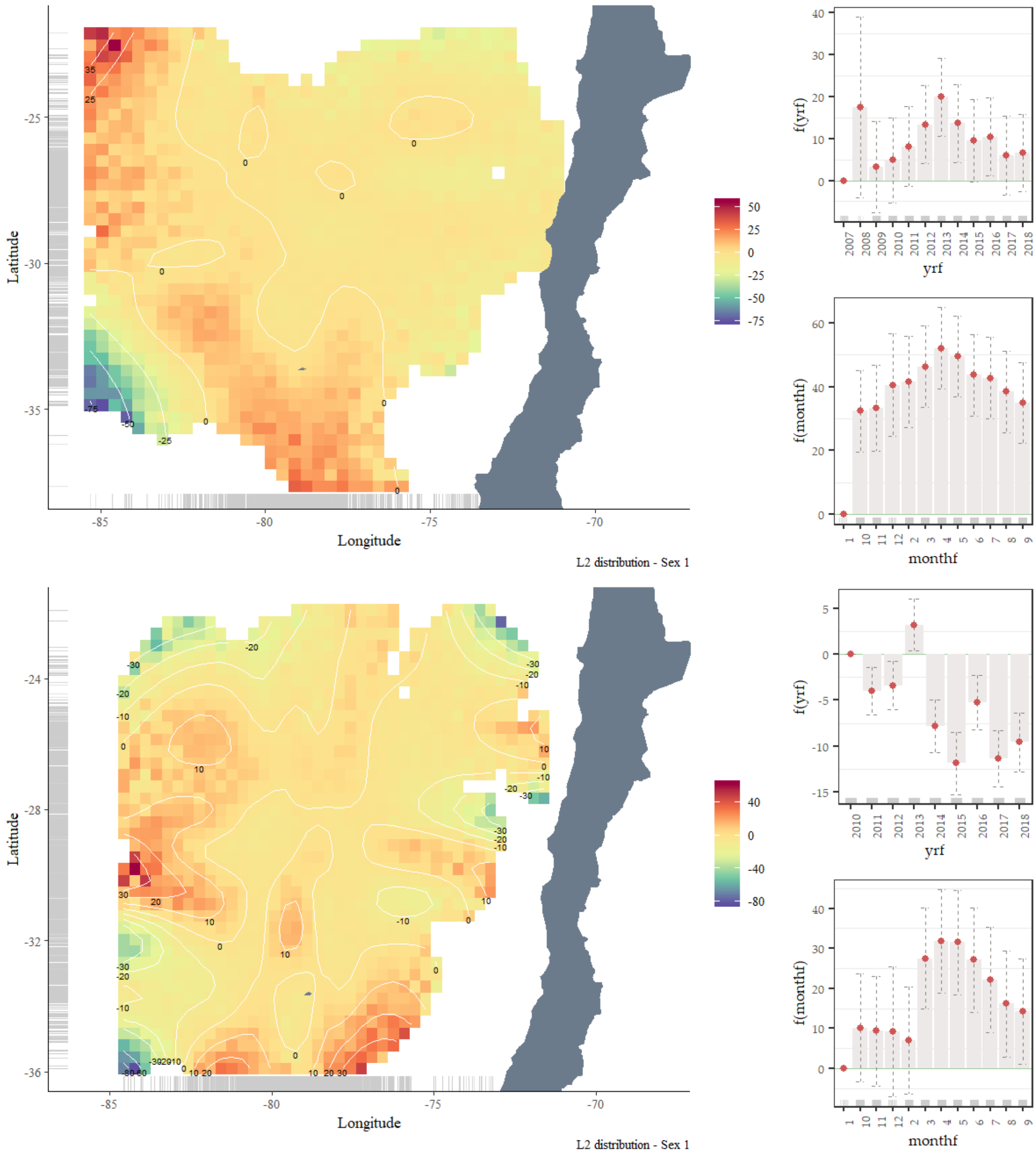

Figure 6: Shortfin mako shark male size distributions in large artisanal (above) and industrial (below) fisheries. Larger sizes are represented by warmer colours. The rug components of the plot show the distribution of the data.

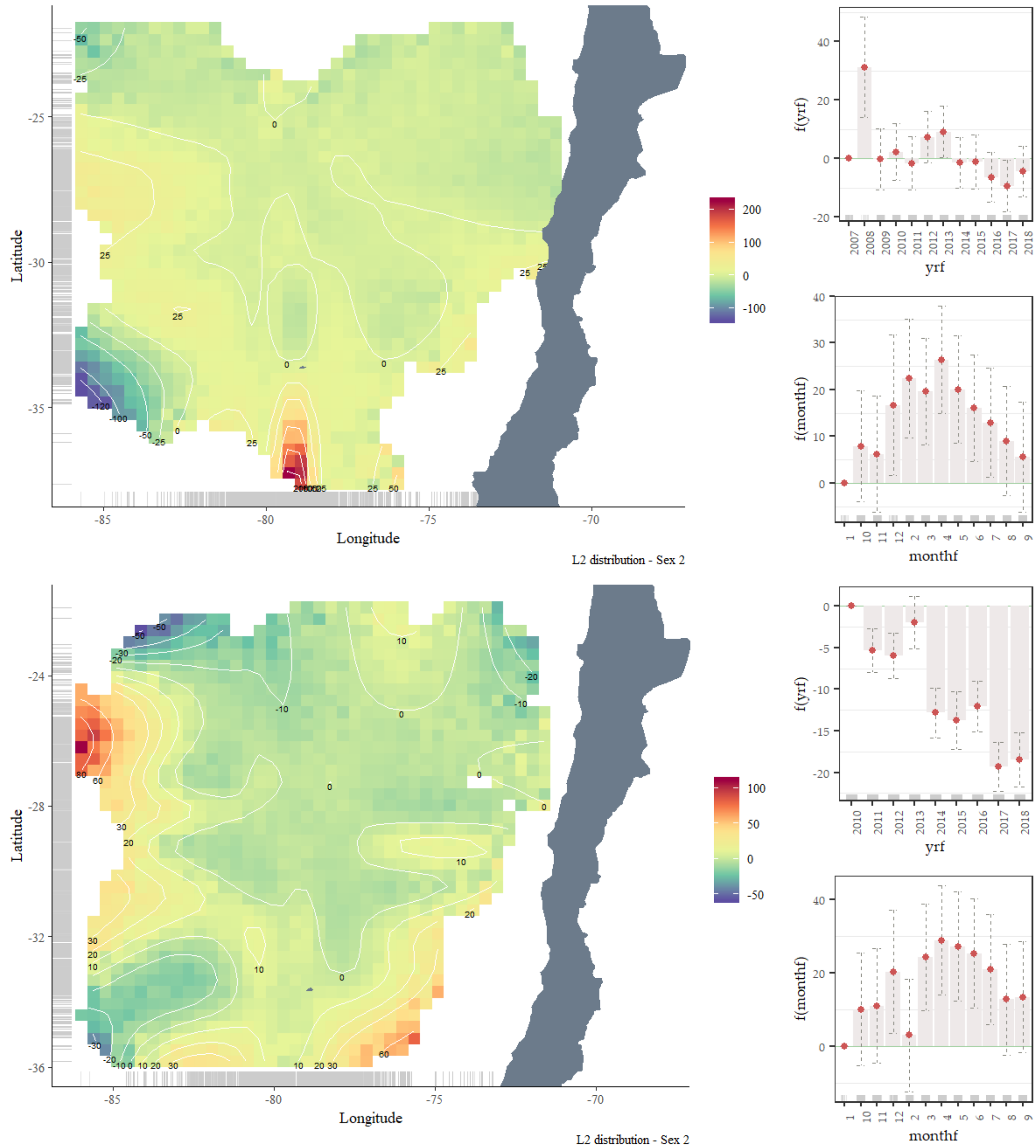

Figure 7: Shortfin mako shark female size distributions in large artisanal (above) and industrial (below) fisheries. Larger sizes are represented by warmer colours. The rug components of the plot show the distribution of the data.

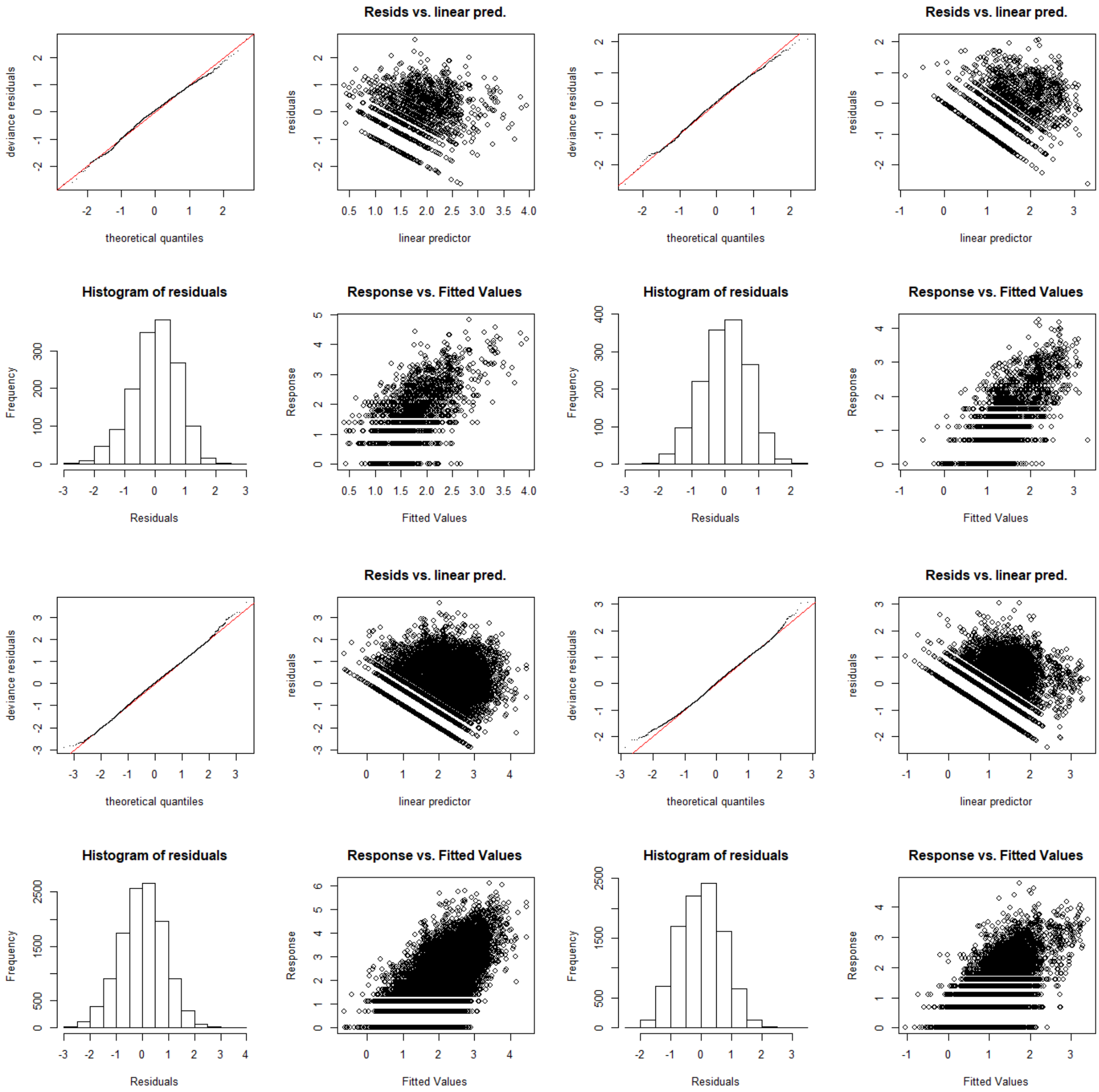

Figure 8: Residual diagnostic plots for generalized additive models of catch rates for sets with nonzero catches, assuming the lognormal distribution, fitted to data from large artisanal (above) and industrial (below) fleets, for blue sharks (left) and shortfin mako sharks (right).

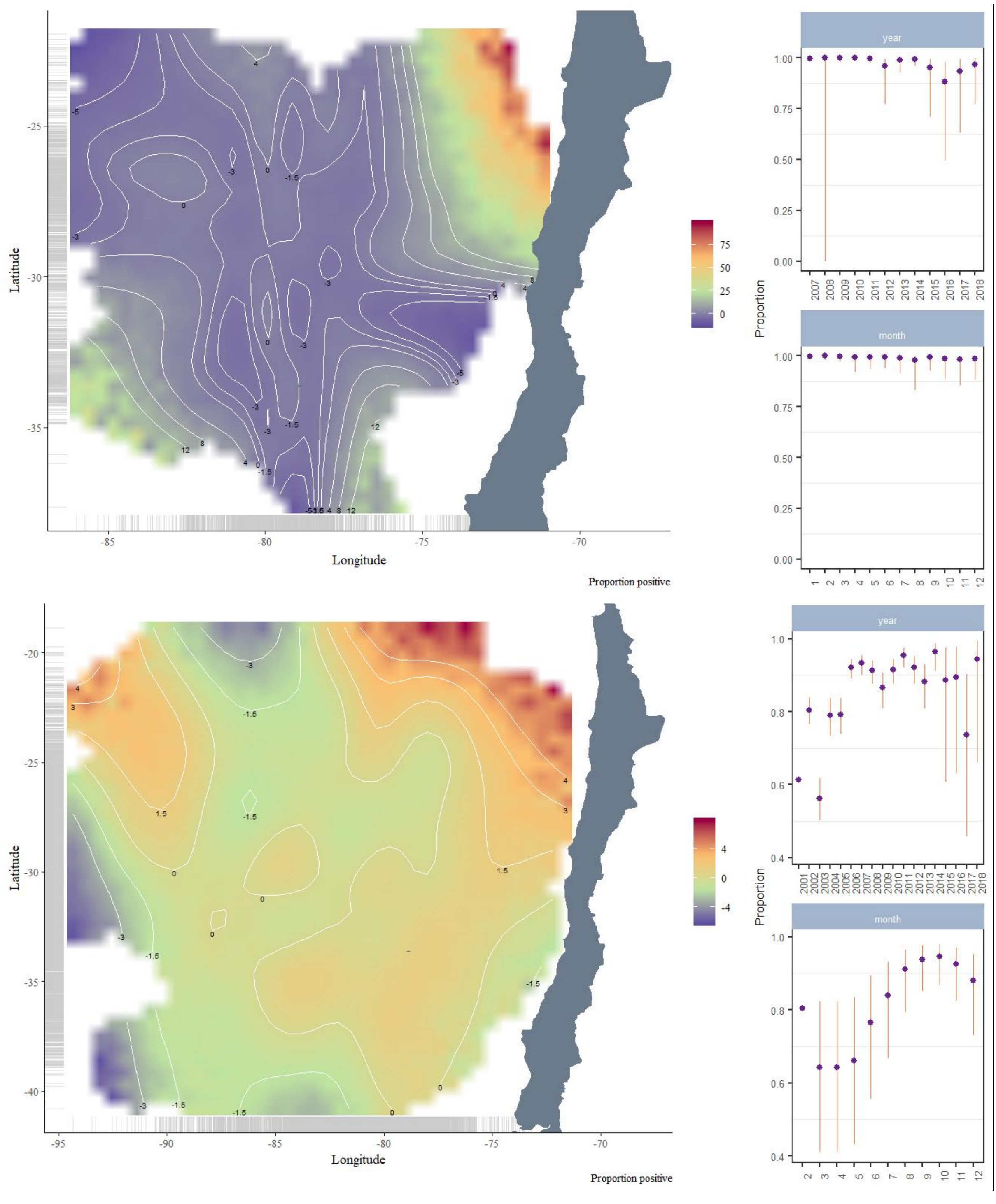

Figure 9: Blue shark spatial, annual and monthly distributions of the proportions of non-zero catches in large artisanal (above) and industrial (below) fisheries. Distributions are marginal distributions for each parameter estimated using generalized additive models. Higher catch rates are represented by warmer colours. The rug components of the plot show the distribution of the data.

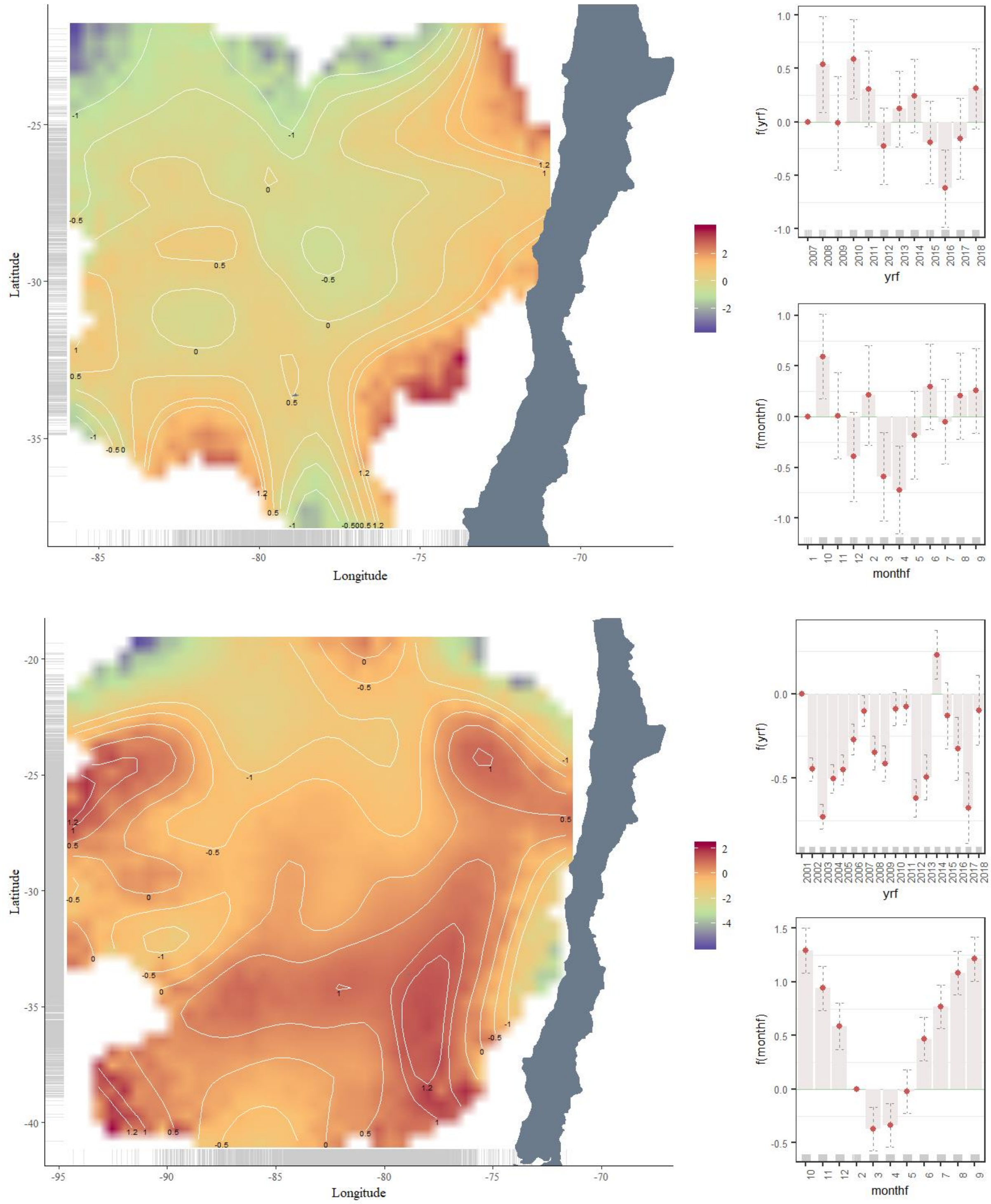

Figure 10: Blue shark spatial distributions of catch rates in non-zero catches in large artisanal (above) and industrial (below) fisheries. Distributions are marginal distributions for each parameter estimated using generalized additive models. Higher catch rates are represented by warmer colours. The rug components of the plot show the distribution of the data.

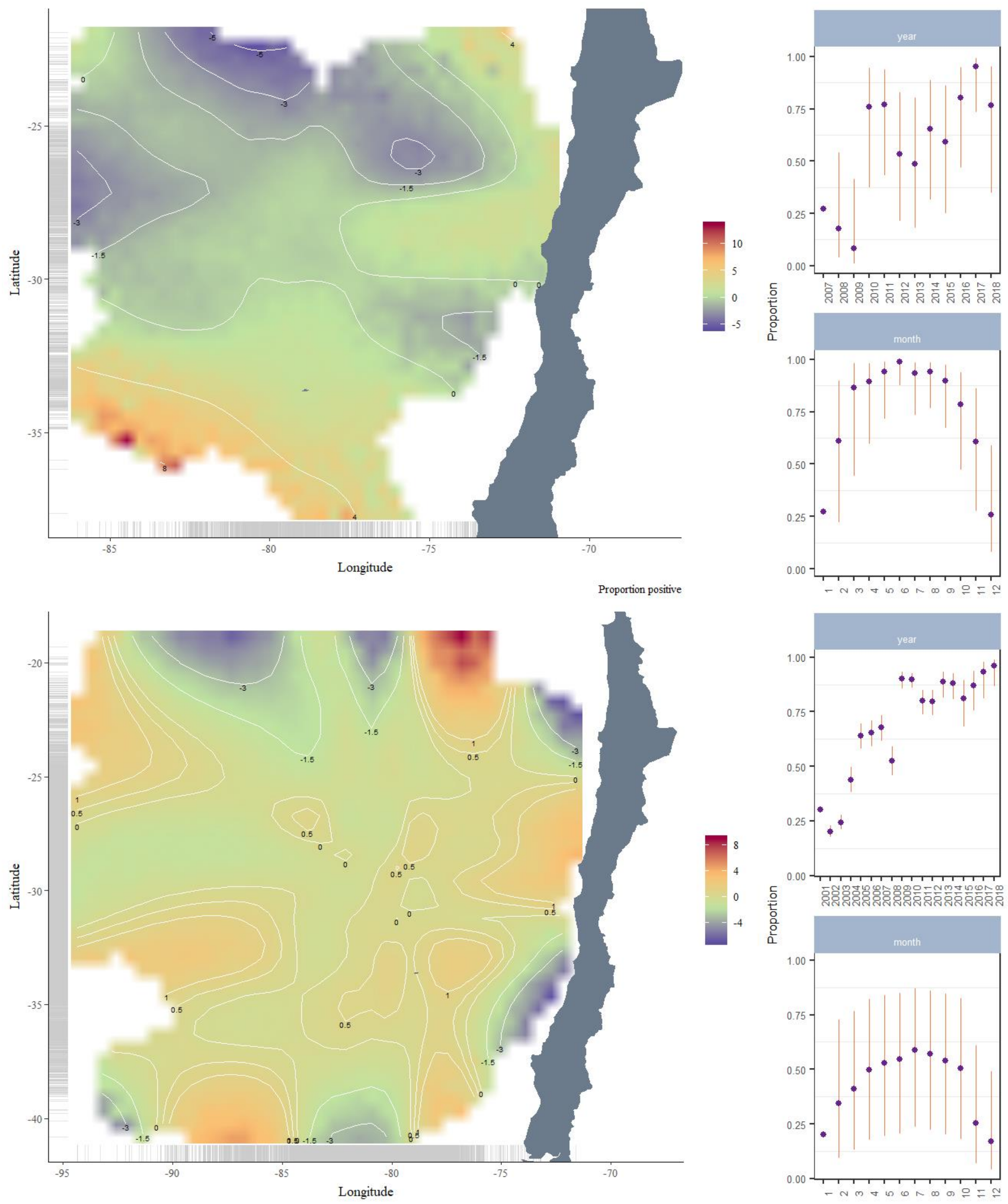

Figure 11: Shortfin mako spatial, annual and monthly distributions of the proportions of non-zero catches in large artisanal (above) and industrial (below) fisheries. Distributions are marginal distributions for each parameter estimated using generalized additive models. Higher catch rates are represented by warmer colours. The rug components of the plot show the distribution of the data.

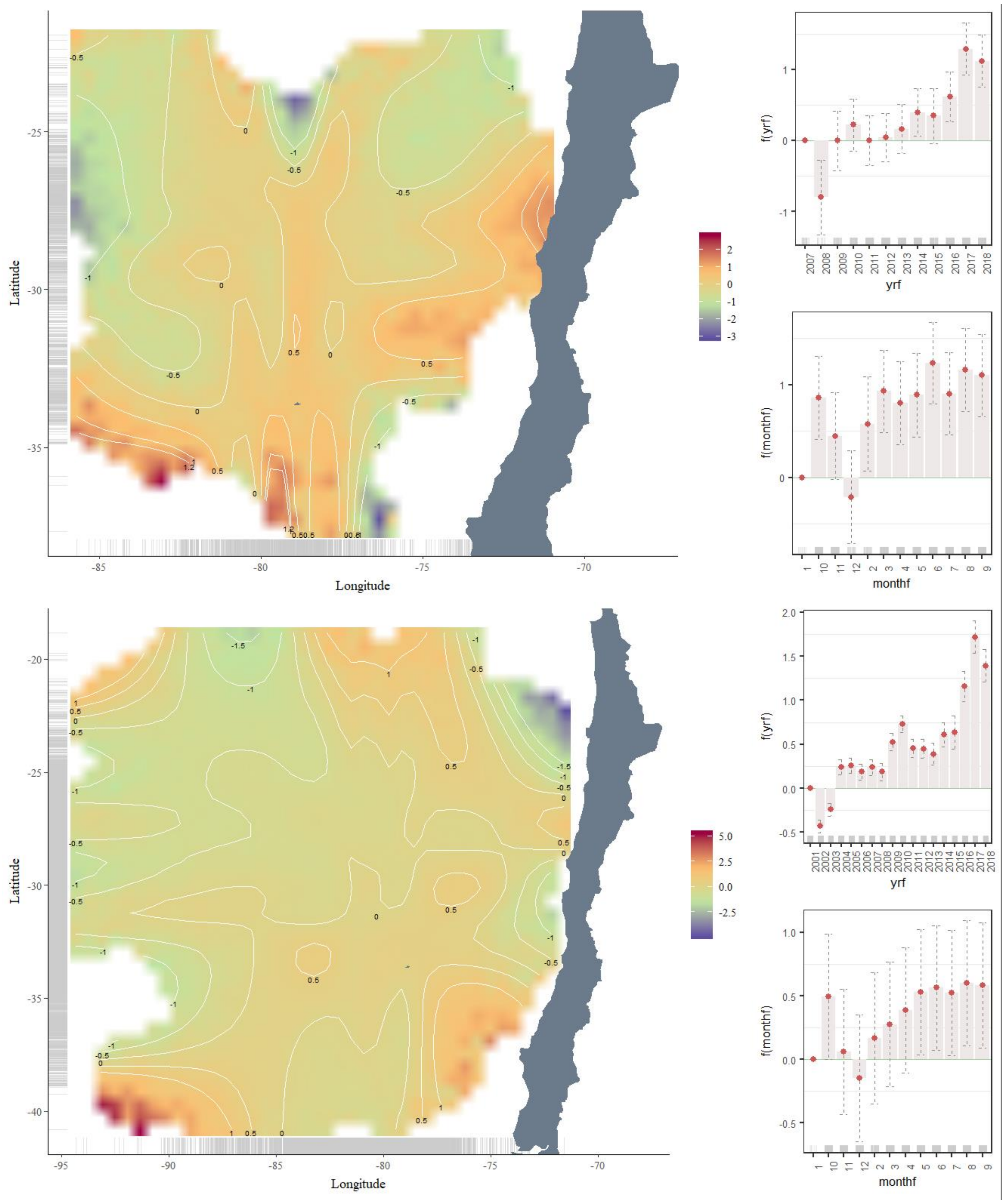

Figure 12: Shortfin mako shark spatial distributions of catch rates in non-zero catches in large artisanal (above) and industrial (below) fisheries. Distributions are marginal distributions for each parameter estimated using generalized additive models. Higher catch rates are represented by warmer colours. The rug components of the plot show the distribution of the data.

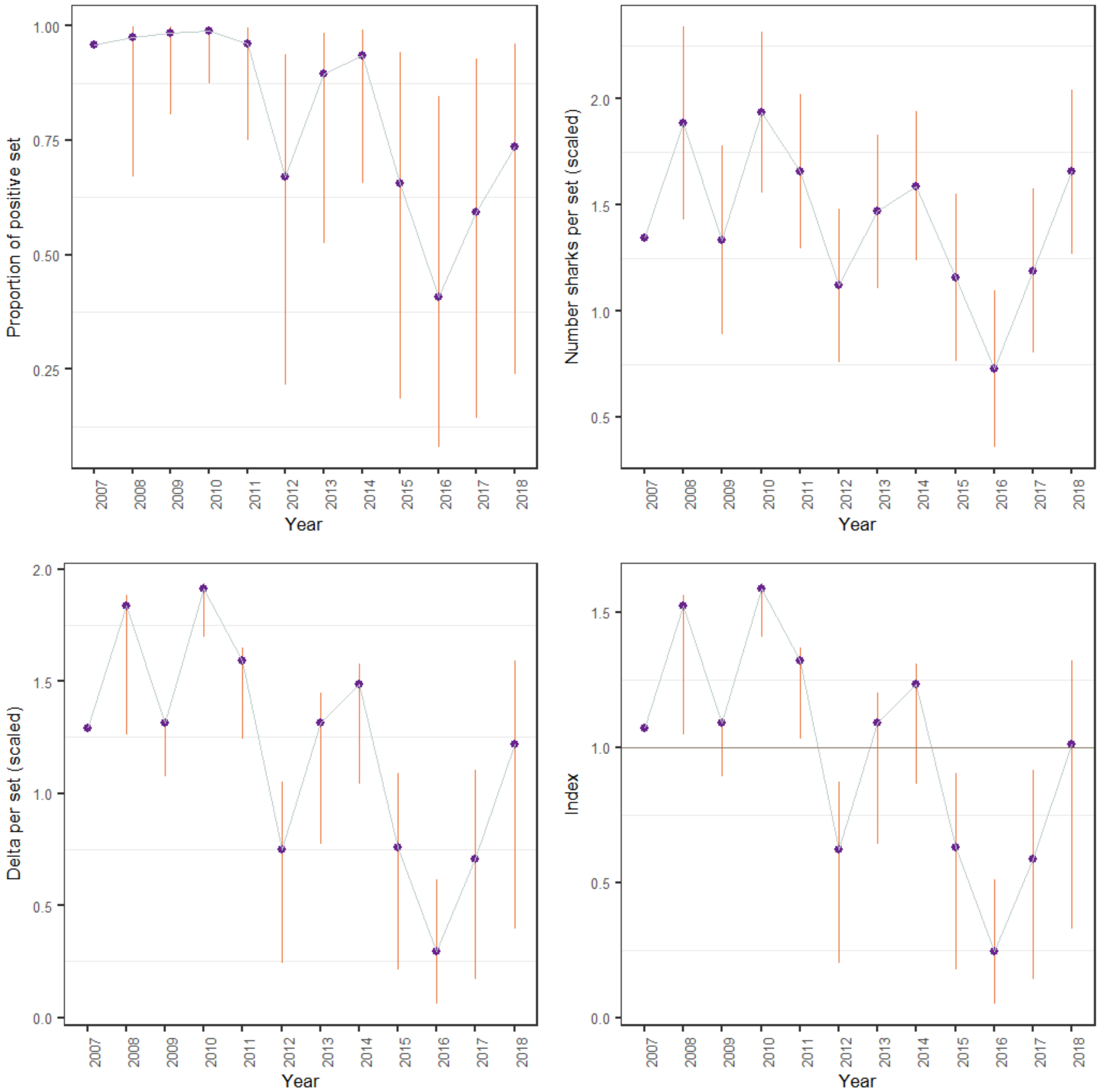

Figure 13: Blue shark large artisanal fleet standardized CPUE indices, including a) proportions of non-zero sets (top left), b) catch rates in non-zero sets (top right), c) the abundance index as a product of a and b (bottom left), and d) the abundance index normalized to a mean of 1 (bottom right).

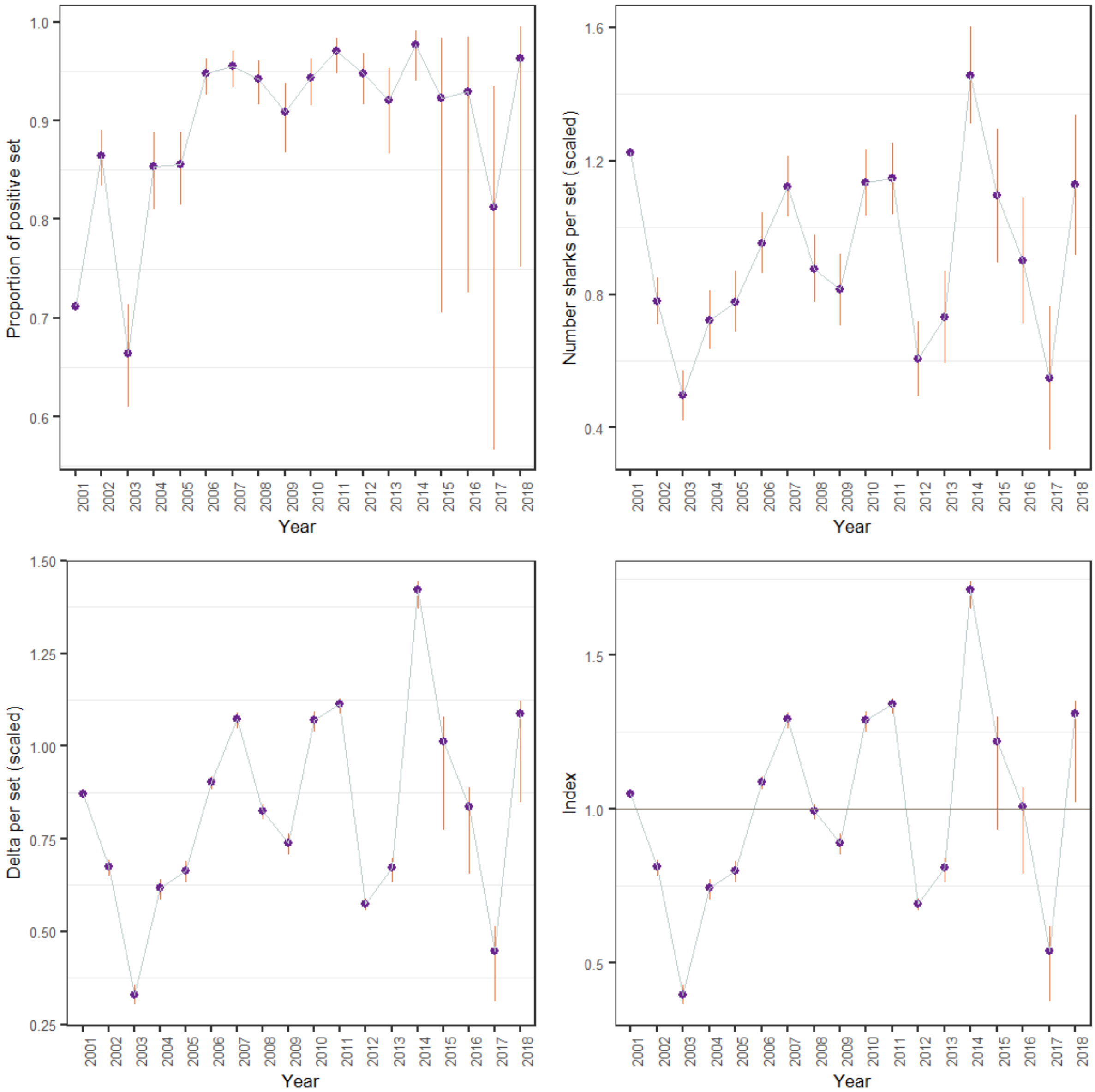

Figure 14: Blue shark industrial fleet standardized CPUE indices, including a) proportions of non-zero sets (top left), b) catch rates in non-zero sets (top right), c) the abundance index as a product of a and b (bottom left), and d) the abundance index normalized to a mean of 1 (bottom right).

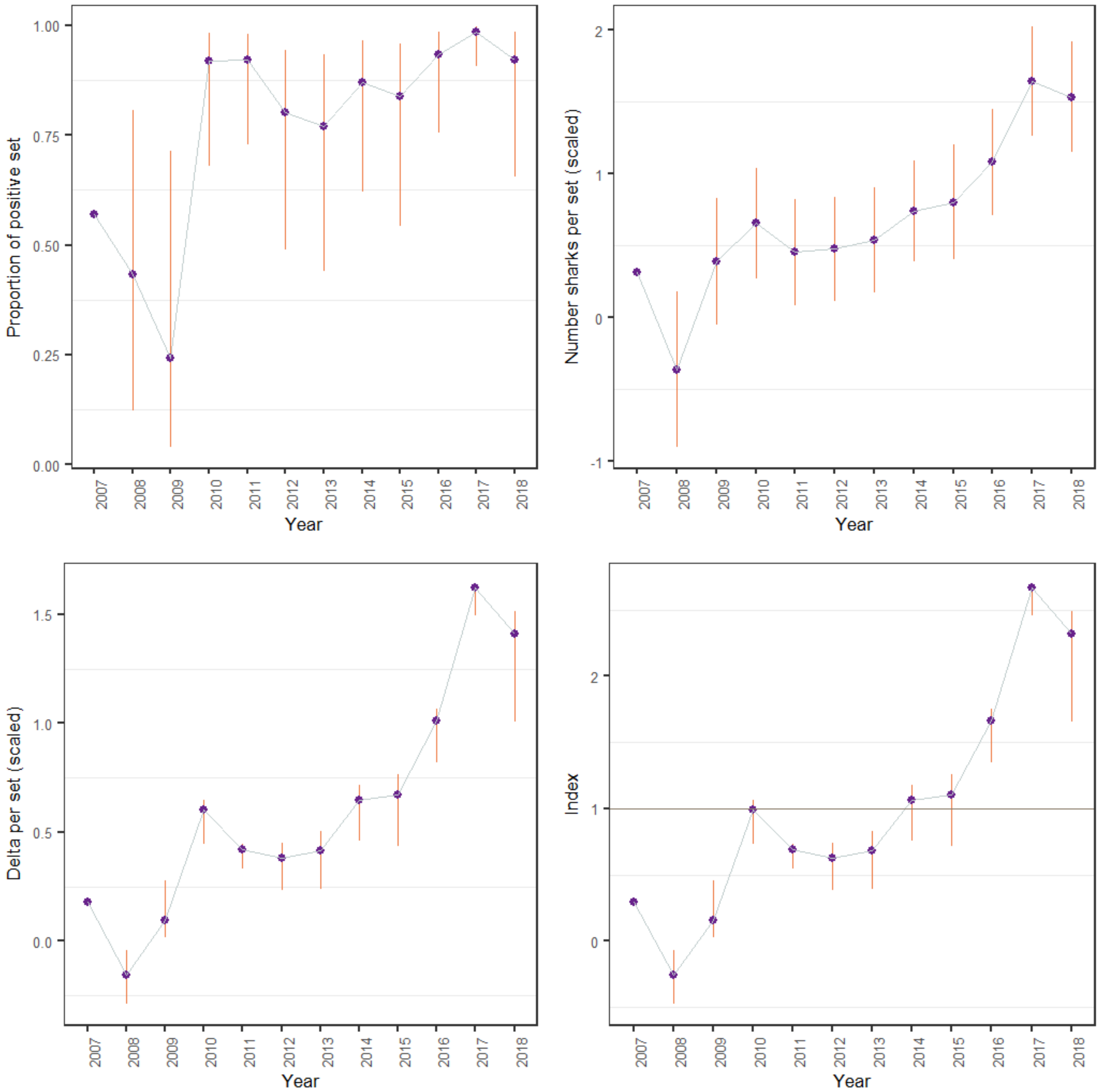

Figure 15: Shortfin mako large artisanal fleet standardized CPUE indices, including a) proportions of non-zero sets (top left), b) catch rates in non-zero sets (top right), c) the abundance index as a product of a and b (bottom left), and d) the abundance index normalized to a mean of 1 (bottom right).

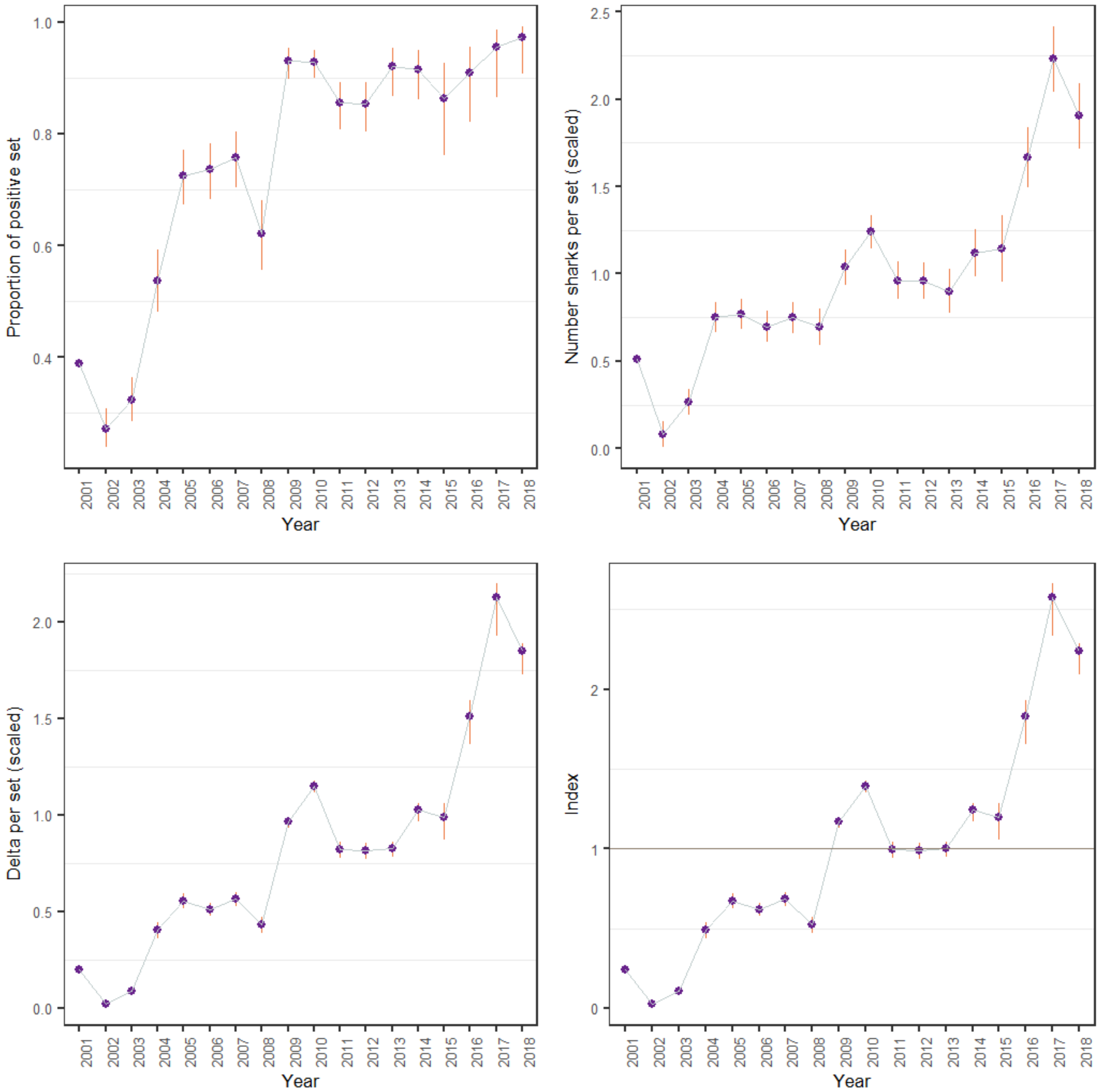

Figure 16: Shortfin mako shark industrial fleet standardized CPUE indices, including a) proportions of non-zero sets (top left), b) catch rates in non-zero sets (top right), c) the abundance index as a product of a and b (bottom left), and d) the abundance index normalized to a mean of 1 (bottom right).

Annex 1

Table A2.1 - Total effort (in number of sets and hooks) deployed by year for the Industrial longline fleet. Also shown are the average, standard deviation, minimum and maximum numbers of hooks.

Year	N Set	sum Hooks	avg Hooks	std Hooks	min Hooks	max Hooks
2001	1985	2689914	1355	263	350	2000
2002	1850	2336048	1263	273	350	1990
2003	1773	2243495	1265	243	190	2180
2004	1319	1804780	1368	259	400	1980
2005	1506	2223242	1476	465	180	2700
2006	1161	1794169	1545	361	320	2500
2007	1164	1669080	1434	293	300	2200
2008	620	846302	1365	206	396	1881
2009	701	894009	1275	217	500	2500
2010	915	1151248	1258	153	428	1600
2011	546	695167	1273	121	700	1485
2012	629	772719	1228	152	440	1440
2013	426	531618	1248	124	735	1420
2014	239	279799	1171	149	245	1320
2015	108	123370	1142	95.1	825	1310
2016	129	147345	1142	73	825	1270
2017	114	124010	1088	94.6	825	1550
2018	105	108222	1031	118	320	1150

Table A2.2 - Total effort (sets y hooks) deployed by year for the Large artisanal longline fleet.

Year	N Set	sum Hooks	avg Hooks	std Hooks	min Hooks	max Hooks
2001	--	--	--	--	--	--
2002	298	336100	1128	80	500	1200
2003	457	511270	1119	132	535	1700
2004	583	666660	1143	111	600	1300
2005	567	647920	1143	99.5	800	1500
2006	568	663860	1169	75.1	1100	1320
2007	400	472689	1182	91.5	660	1350
2008	165	214438	1300	88.4	850	1350
2009	121	156387	1292	103	700	1430
2010	131	155361	1186	153	770	1340
2011	197	241879	1228	124	680	1350
2012	299	378165	1265	95.8	900	1500
2013	332	409335	1233	97	830	1370
2014	248	279960	1129	148	220	1408
2015	127	142485	1122	73	900	1320
2016	226	251695	1114	117	110	1320
2017	165	174175	1056	105	605	1250
2018	125	123070	985	113	600	1155

Table A2.3 - Total of fishing sets and percentage of positive sets with respect the total sets of the fleet.

	Industrial			Large artisanal			Small artisanal		
Year	N sets	% BSH	% MAK	N sets	% BSH	% MAK	N sets	% BSH	% MAK
2001	1985	79%	61%	-	-	-	-	-	-
2002	1850	88%	50%	298	-	19%	2672	13%	59%
2003	1773	78%	58%	457	11%	28%	3040	19%	57%
2004	1319	74%	60%	583	9%	31%	2664	14%	66%
2005	1506	69%	66%	567	18%	35%	2183	19%	49%
2006	1161	90%	81%	568	38%	50%	2881	23%	47%
2007	1164	89%	78%	400	33%	37%	2890	23%	37%
2008	620	92%	68%	165	34%	21%	2394	18%	32%
2009	701	84%	88%	121	77%	74%	1689	19%	29%
2010	915	85%	85%	131	58%	79%	1469	15%	23%
2011	546	96%	86%	197	89%	79%	1935	18%	23%
2012	629	85%	79%	299	74%	76%	578	71%	64%
2013	426	77%	77%	332	58%	55%	597	60%	60%
2014	239	94%	87%	248	94%	90%	730	60%	61%
2015	108	98%	82%	127	82%	69%	622	69%	80%
2016	129	98%	91%	226	72%	94%	397	79%	68%
2017	114	96%	96%	165	88%	98%	293	87%	65%
2018	105	99%	97%	125	92%	96%	300	90%	93%

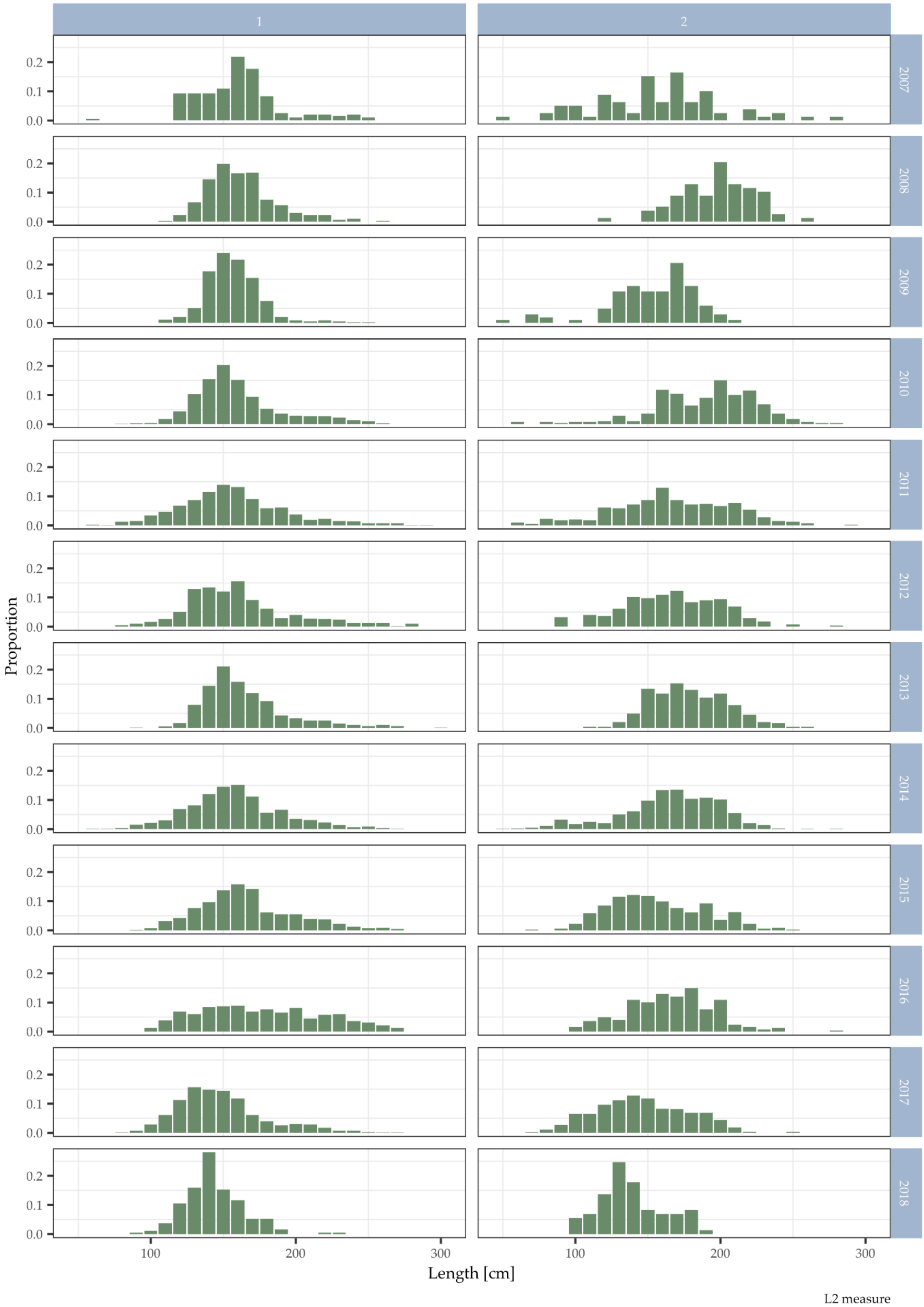

Figure A2.1: Blue shark proportions at length in artisanal longline fisheries for males (left) and females (right) by year.

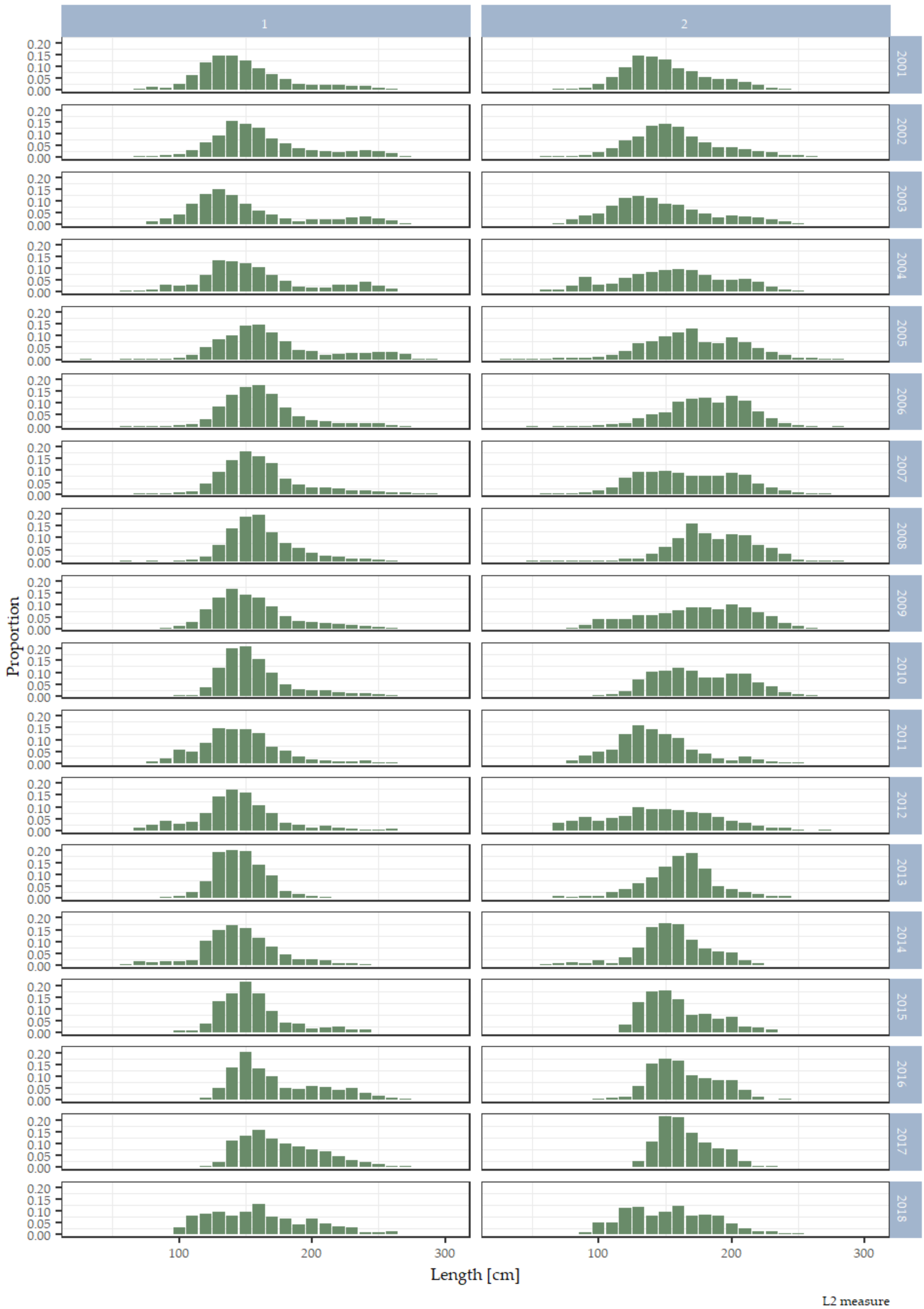

Figure A2.2: Blue shark proportions at length in industrial longline fisheries for males (left) and females (right) by year.

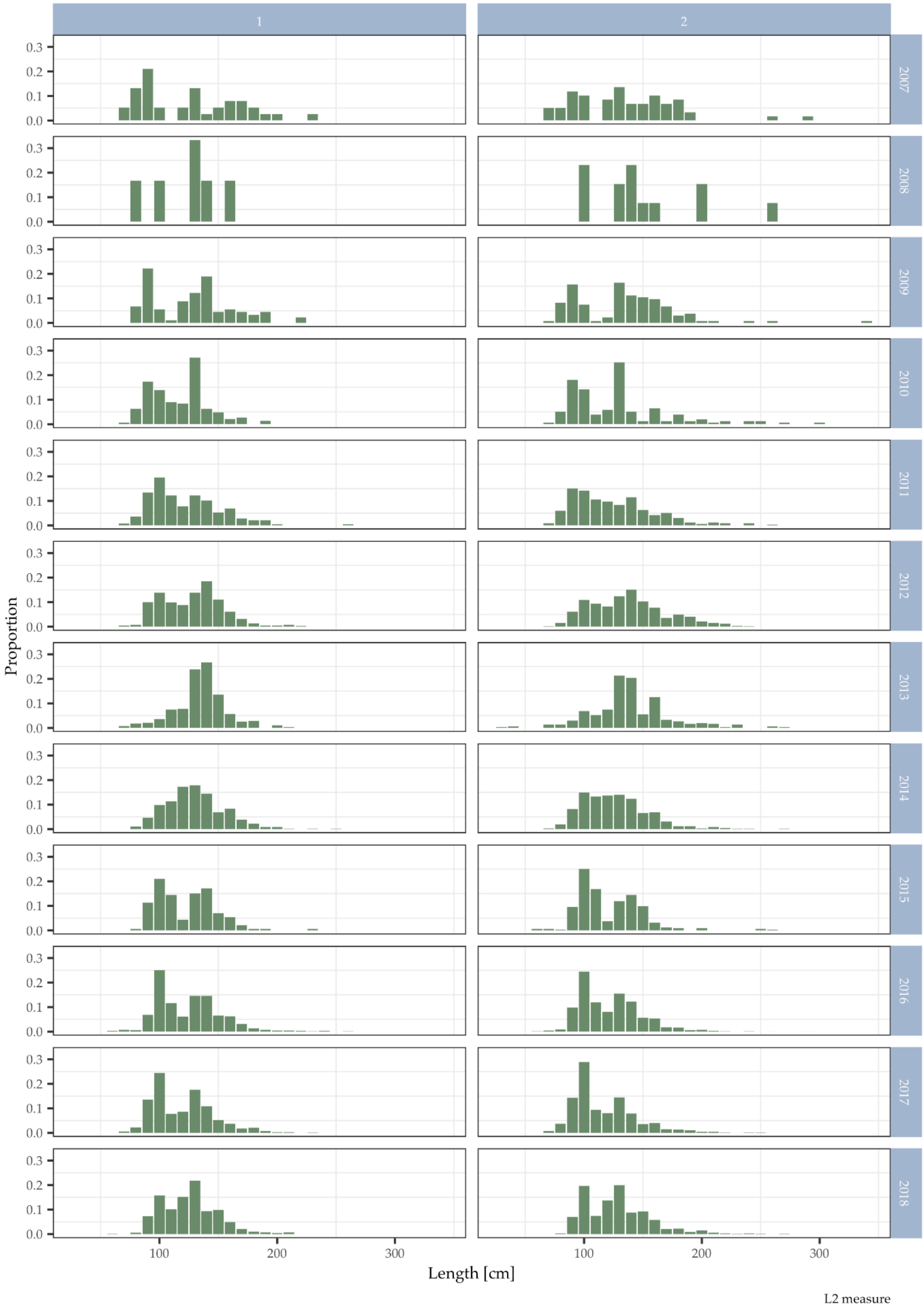

Figure A2.3: Shortfin mako shark proportions at length in artisanal longline fisheries for males (left) and females (right) by year.

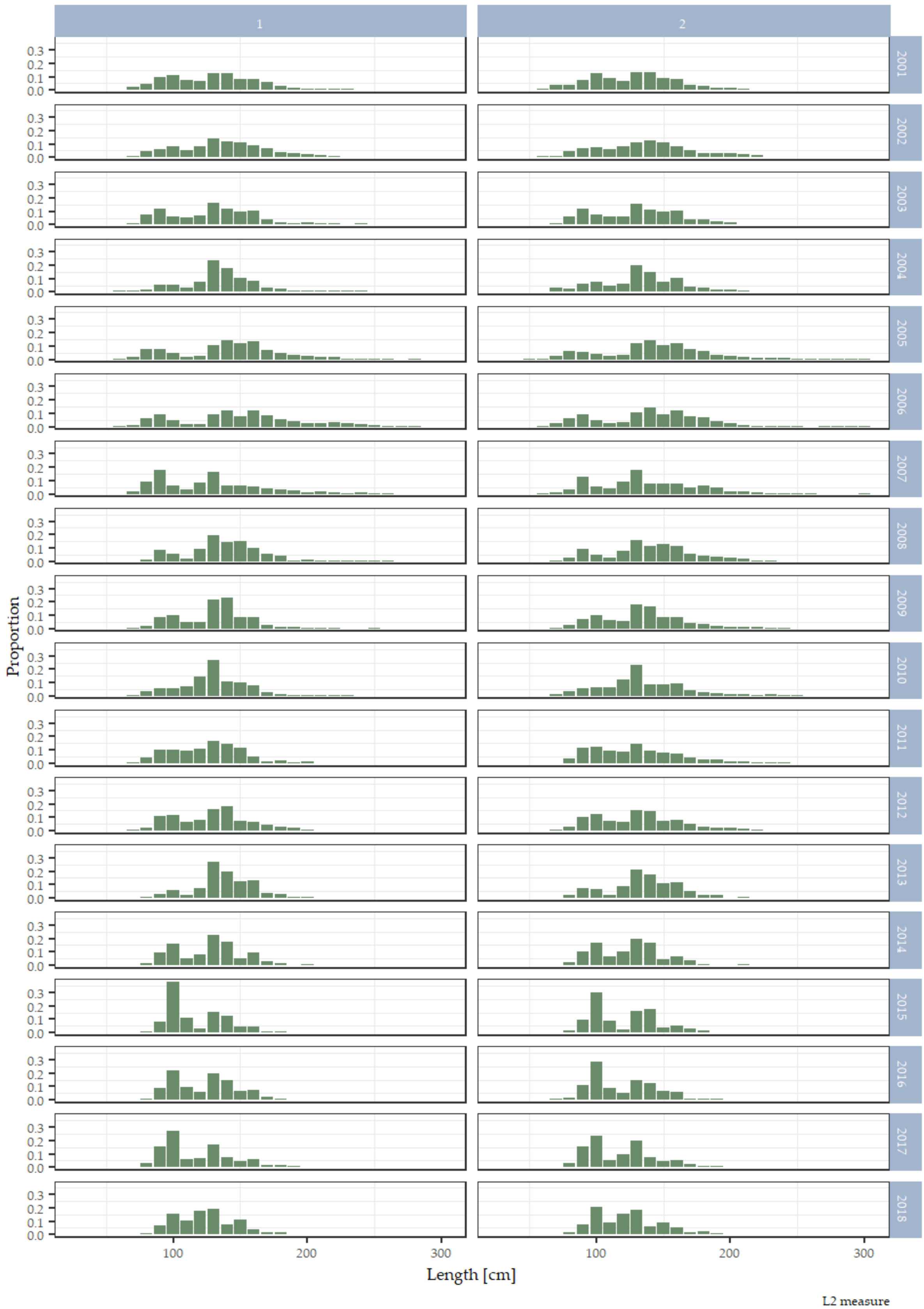

Figure A2.4: Shortfin mako shark proportions at length in industrial longline fisheries for males (left) and females (right) by year.