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Preliminary study of the variations on the spatio-temporal distribution of a potentially exploitable species (*Patagonotothen* spp.) in the southwest Atlantic, using GIS techniques

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ABSTRACT

The genus *Patagonotothen* is the most common Nototheniid on the Patagonian Shelf and slope and is part of the by-catch species in the bottom trawl fisheries. This paper presents preliminary results from the EC CRAFT project “Promoting higher added value to a finfish species rejected to sea”, aiming to develop the research and the technology necessary to promote higher added value to fishing activity by taking profit from a finfish species (Rockcod, *Patagonotothen* spp.) not known to consumers and currently discarded by the EU fishing fleet operating in the South West Atlantic in order to supply the EU seafood industry with a good quality raw material for human food manufacturing. Historical fishery data series (26 168 commercial hauls of which 12 745 were positive), including effort, catches and discards, as well as biological and environmental information, from 1988 onwards was used to describe and quantify patterns and spatio-temporal changes in the rockcod fishery. These data was collected by scientific observers on board commercial vessels.GIS analysis was carried out in order to study the seasonal geographical changes in the distribution of abundance, SST and densities calculated from CPUE. Fishery and environmental data as well as SST data derived from the NOAA Advanced Very High Resolution Radiometer (AVHRR), were analysed in order to find monthly variations in spatial and depth distribution of *Patagonotothen* spp. Preliminary results demonstrated that, within areas of occurrence, there are significant correlations between fish abundance (CPUE), the oceanographic conditions of the area (SST gradients) and depth in certain months.

Keywords: *Patagonotothen* spp, Rockcod, SW Atlantic, discards, GIS, environment, spatio-temporal pattern

INTRODUCTION

The genus *Patagonotothen* is the most common Nototheniid on the Patagonian Shelf and slope and is part of the by-catch species in the bottom trawl fisheries. It contains 14 species in the waters off southern South America of which *P. ramsayi* is the most abundant (Ekau, 1982; Norman, 1937; Hart, 1946). The rock cod *Patagonotothen ramsayi* Regan, 1913 (Nototheniidae) is the commonest notothenioid fish inhabiting the Argentine Patagonia south of 35º S and the largest fish as Nototheniidae, being its depth range about 50 ~ 500 m (Nakamura *et al.*1986) and is common on the outer shelf and slope (mainly 150 – 400 m) around the Falkland Islands, being its south-eastern geographical range on the Falkland shelf the main fishing ground for the squid, *Loligo gahi* (Laptikhovsky and Arkhipkin, 2003).

Throughout its range distribution off the Patagonian shelf, it occurs at depths from 50 to 960 m. *P. ramsayi* is a secondary catch target in the southwestern Atlantic area. Observations made from Polish fishing ships indicated that the greatest concentrations, and thus the best fishing results, were obtained in the southern area of the Boordwood Bank. Despite its low biomass in comparison with other fish and squid caught in this area, *Patagonotothen ramsayi* occur in concentrations on the Patagonian Shelf which can be of interest to fisheries and this species can be the target of catches (Sosinski and Janusz, 2003).

Marine environment at austral South America is rich in coastal fronts, having different forcing, and temporal and spatial scales. Marine front patterns may be seen as part of the structural complexity of the pelagic realm at the seascape scale. The open ocean circulation is dominated by the opposite flow of the Brazil (subtropical) and the Malvinas (subantarctic) currents. Both currents meet, in average, at 36º S. In this area, referred to as the Brazil/Malvinas Confluence, the two flows turn offshore in a series of large amplitude meanders. The shelf-break front is a permanent feature that characterizes the border of the shelf. The inner boundary lies between the 90 and 100 m isobath. The geographical location of the front may vary according to the dynamics of the Falkland (Malvinas) Current, for which cyclical variations—including semi-annual, annual and biannual periods—have been reported (Olson *et al*., 1988; Fedulov *et al*., 1990;.Acha *et al*., 2004).

Since early 1980s, an important fishery targeting hakes (*Merluccius hubbsi* and *M. australis*) and cephalopods (*Illex argentinus* and *Loligo gahi*) have been developed by Spanish bottom trawlers off the Patagonian Shelf, catching also important quantities of other bycatch species such as kingclip (*Genypterus blacodes*), hoki (*Macruronus magellanicus*), red cod (*Salilota australis*), etc, which have been gradually introduced into the market with a good acceptance by the consumers. Even rock cod has been exploited in the past by Polish vessels, this species is discarded almost 100% by Spanish fleet.

The fishing grounds in the Patagonian Shelf in which vessels flying Spanish flag are operating can be divided in two main fishing zones, one of them around the Falkland/Malvinas islands in what are known as Falkland Islands Interim and Outer Conservation Zones (FICZ and FOCZ respectively) and the second one in the High Seas, outside the Argentinean EEZ. The activity of the Spanish vessels in the High Seas is reduced to those portions of the continental shelf and slope sticking out of the Argentinean EEZ, i.e. a small patch around 42º S and a bigger area comprised between parallels 43º 30' and 48º S, namely "Area 42 and 46" respectively. The fishing grounds around the isles have been divided in three sub areas Malvinas North (MN), Malvinas West (MW) and Malvinas South (MS).

DATA AND METHODS

Data used into the GIS

Spatially referenced commercial fishery data, as well as bathymetric data were examined using Geographic Information System (GIS) techniques in order to map and represent information about the distribution and the abundance of catches of *Patagonotothen* spp. recorded by IEO scientific observers (Fig. 1) in the Falkland Islands and in the High Seas from 1988 to 2003.

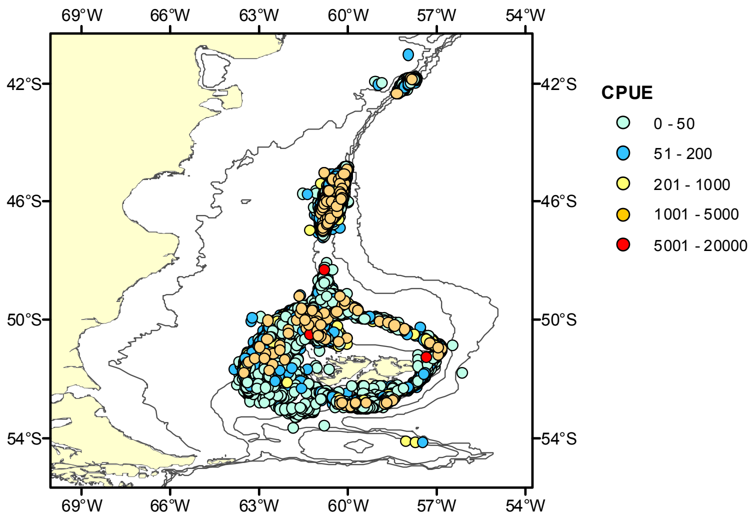


Figure 1. Haul locations positive for *Patagonotothen* spp. from 1988-2003.

Fishery, bathymetric and SST data were integrated within the GIS (ArcGIS version 8.2). This process allows a visual analysis and also the extraction of more information about the parameters that are having an influence in the catches distribution.

1- Environmental data- SST

Sea surface temperature (SST) data collected by scientific observers on board commercial vessels were geo-referenced to a base map of the Southwest Atlantic and was used to analyse its relationship with *Patagonotothen* spp. abundance .

2- Bathymetry data

Bathymetric contours of the Patagonian shelf were extracted from GEBCO (General Bathymetric Chart of the Oceans) Digital Atlas. This bathymetry data were entered into the GIS. Bathymetric contours represented here are 0 m, 200 m, 500 m and 1000 m.

3- Fishery data- FIFD and Spanish data

Daily fishery data for the present study were collected by observers working for the IEO (Instituto Español de Oceanografía, Vigo, Spain) and FIGFD (Falkland Islands Government Fisheries Department, Stanley) on board commercial vessels for the 17-year period 1988-2003. All data were integrated into a MS Access database and used in analysis and modelling.

Fishery data were imported and integrated into the GIS as monthly time-series grids at spatial resolution of 0.5 degrees. CPUE (catches per unit effort, kg/hr) was used as an index of abundance in the fishery. This index reflects fish abundance and accounts for changes in fleet activity over the 17-year period. Maps were visually analysed in order to find relations between bathymetry, SST and fisheries data for the same month.

Geographical Information System methods

GIS maps

Patagonotothen spp. raster data sets were created with the GIS in a monthly basis. Each cell in the map, is a square that represents a specific portion of an area with a spatial resolution of 0.5 degree longitude and 0.5 degree latitude square. The size of the cell was selected in order to accomplish a detailed analysis of the temporal evolution of the features represented in the maps (CPUE , ratio of catches to the total catches and modal length).

Density surface maps

Patagonotothen spp. density surfaces were created in the GIS as monthly raster layers. Each cell in every layer gets a density value based on the number of features (hauls with CPUE > 0 kg/h) within a radius cell of 1.5 degrees. To create a density surface we have used the Kernel method that uses a mathematical function to give more importance to features closer to the center of the cell. With this method, maps with patterns that are easier to interpret were obtained. The GIS defines a neighbourhood (based on the search radius specified, in this case 1.5 degrees) around each cell centre. It then totals the number of features that fall within that neighbourhood and divides that number by the area of the neighbourhood. That value is assigned to the cell. The GIS moves on to the next cell and repeats the same procedure, resulting in the creation of a smoothed surface. Mapping density shows where the highest concentration of *Patagonotothen* spp. is found on a monthly basis.

Besides the visual analysis of the maps, the rank correlation was carried out between *Patagonotothen* spp. abundance and other variables (month, latitude, longitude, average depth, SST, lunar cycle and sky pattern) in order to quantify the correlations between them.

Statistical analysis and modelling

Generalized additive models (GAMs)

Generalized Additive Models (GAMs) are able to deal with non-linear relationships between an independent variable and multiple predictors and are particularly appropriate to our study.

In order to model the variations of *Patagonotothen* spp. abundance we have used GAMs. GAMs were first proposed by Hastie & Tibshirani (1990) and some of the first applications to fishery data were by Swartzman *et al*. (1992, 1994, 1995). A GAM is a non-parametric regression method with less strict assumptions of normality and linearity than linear regression. This method is an extension of the generalized linear models (GLMs; McCullagh & Nelder, 1989). The principal strength of additive models is their ability to fit complex smooth functions (smooths) in the predictor rather than being constrained by the linearity implicit in GLMs. A GAM, the generalized version of an additive model, is expressed as:

$$g(E[y]) = \beta_0 + \sum_k S_k(x_k)$$

The right-hand side of the equation is the additive predictor. β_0 is an intercept term and S_k is a one-dimensional smoothing function for the k^{th} spatial covariate, x_k. The degree of smoothing is determined by the degrees of freedom (d.f.) associated with the smoothing function. The larger the degrees of freedom, the less the smoothing performed and more flexible the function obtained.

GAMs were fitted using the "gam" command in S-Plus and using cubic smoothing splines to smooth covariates. Spline smoothers are popular smoothers because they have a theoretical justification that can be used to determine the appropriate smoothness for the fit. Smoothing splines are locally cubic splines that minimize a penalized residual sum of squares, drawing a smoothed curve through the data points.

In our model, the expected value of *Patagonotothen* spp. abundance is expressed as a sum of smooth functions of the covariates (month, latitude, longitude, SST and average depth). All data were imported into S-Plus from excel files and configured as data objects. Data were screened to reveal characteristics of data sets and scatter plots were made for each pair of variables. The error distribution used was the Gaussian distribution, which is normally appropriate for describing spatial heterogeneity and abundance data (Maravelias, 1997; Swatzman *et al*., 1994).

To measure the goodness of fit of the model, a pseudo-coefficient of residual determination, PCf, is estimated (Swartzman *et al*., 1992):

$$PCf = 1 - \frac{RD}{ND}$$

where RD is the residual deviance, i.e. the deviance of the full model, similar to the residual sum of squares in a linear model, and ND the null deviance, i.e. the deviance of the model with only the intercept term. PCf values obtained are listed in Table 1.

Table 1. Summary of GAM results for weighted and unweighted models

Unweighted model		
ND	**RD**	**PCf**
1651276711 (12831 d.f)	1611545572 (12811 d.f)	0,024060861
Weighted model		
ND	**RD**	**PCf**
6281336497 (12831 d.f)	6137622872 (12811 d.f)	0,022879466

Unweighted model		Weighted model	
Variable	Pr(F)	Variable	Pr(F)
Month	0	Month	0
Latitude	0	Latitude	0
Longitude	0.17	Longitude	0.16
AvgDepth	0	AvgDepth	0
SST	0	SST	0

In this work, the fishing effort variable was used as a weighting factor. The amount of fishing effort can be considered as an index of the quality of the sampling, and more effort probably implies more reliability in the data. Therefore, in the weighted model, less importance is assigned to data with low fishing effort and more importance to data with high fishing effort. An unweighted model was also fitted for comparison. Scatter plots and GAM plots are shown in figures 8 and 9 respectively.

RESULTS AND DISCUSSION

Spatial distribution of catches of *Patagonotothen* spp.

Figures 2 represents the annual location of hauls and CPUE values (Kg/hr) for *Patagonotothen* spp. over the period 1988-2002 meanwhile figure 3 illustrates the annual CPUE values (Kg/hr) by 0.5º x 0.5º rectangles during the same period. Rockcod catches in 14 years does not describe a clear spatio-temporal pattern. In general terms we conclude that higher CPUE values were recorded between 1996 and 1999. Over the rest of the period, the CPUE values were very fluctuant.

Figures 4 and 5 show monthly CPUE values by haul and by 0.5º x 0.5º rectangles. Fish abundance was higher in the austral summer than in the winter. February, March and April were the months in which higher CPUE values were recorded. From February to May there is an expansion in the distribution of the catches from the western area towards the eastern area.

The distribution of *Patagonotothen* spp. per depth strata (Fig. 6) give us an idea about the habitat of the species. Peak CPUEs were recorded in 100-200 m and 200-300 strata as shown in figure 6. Poor catches were recorded in 0-100, 300-400, 400-500 and at depths bigger than 500 m. Catches in the 0-100 m strata were mainly located in divisions 46, 49 and MS. In the 300-400 m strata catches were located mainly in divisions 42, 46 and MS. Strata 400-500 m and higher than 500 m show few catches at division 42 and MS. Catches located between 100-200 m were found all around the islands and also in the High Seas.

Density maps

Density surface maps represented in figure 7 show the abundance distribution of this species through the year. Density maps show a similar temporal pattern than figures 4 and 5. Maximum density values were recorded within March, July and August. These values are located in all cases in division 46. April was characterized by the presence of high density values in division 46 and 49. From August to December there is a clear fall in density values, reaching the minimum in December.

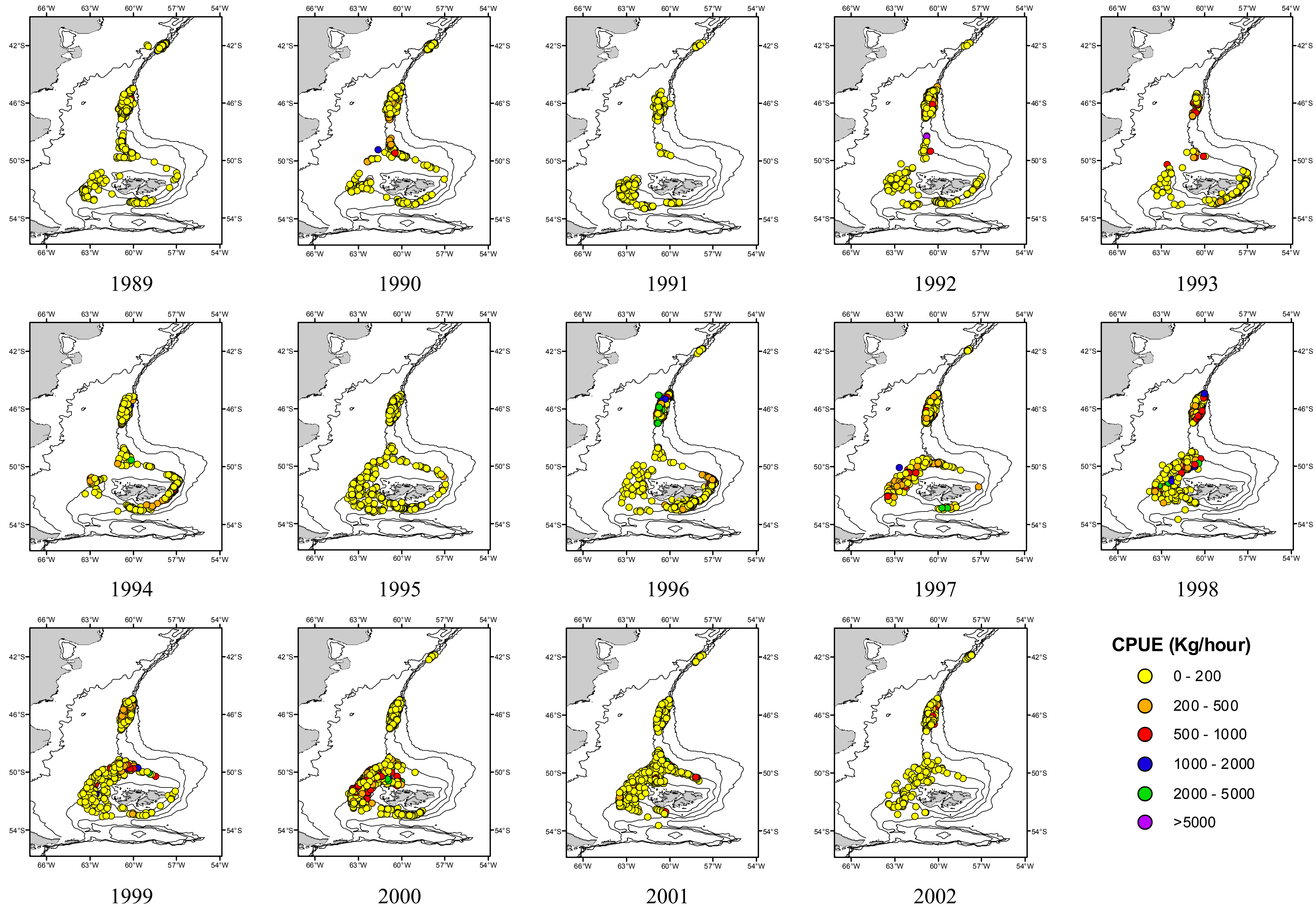


Figure 2. Annual location of hauls and CPUE values (Kg/hr) for *Patagonotothen* spp. over the period 1989-2002

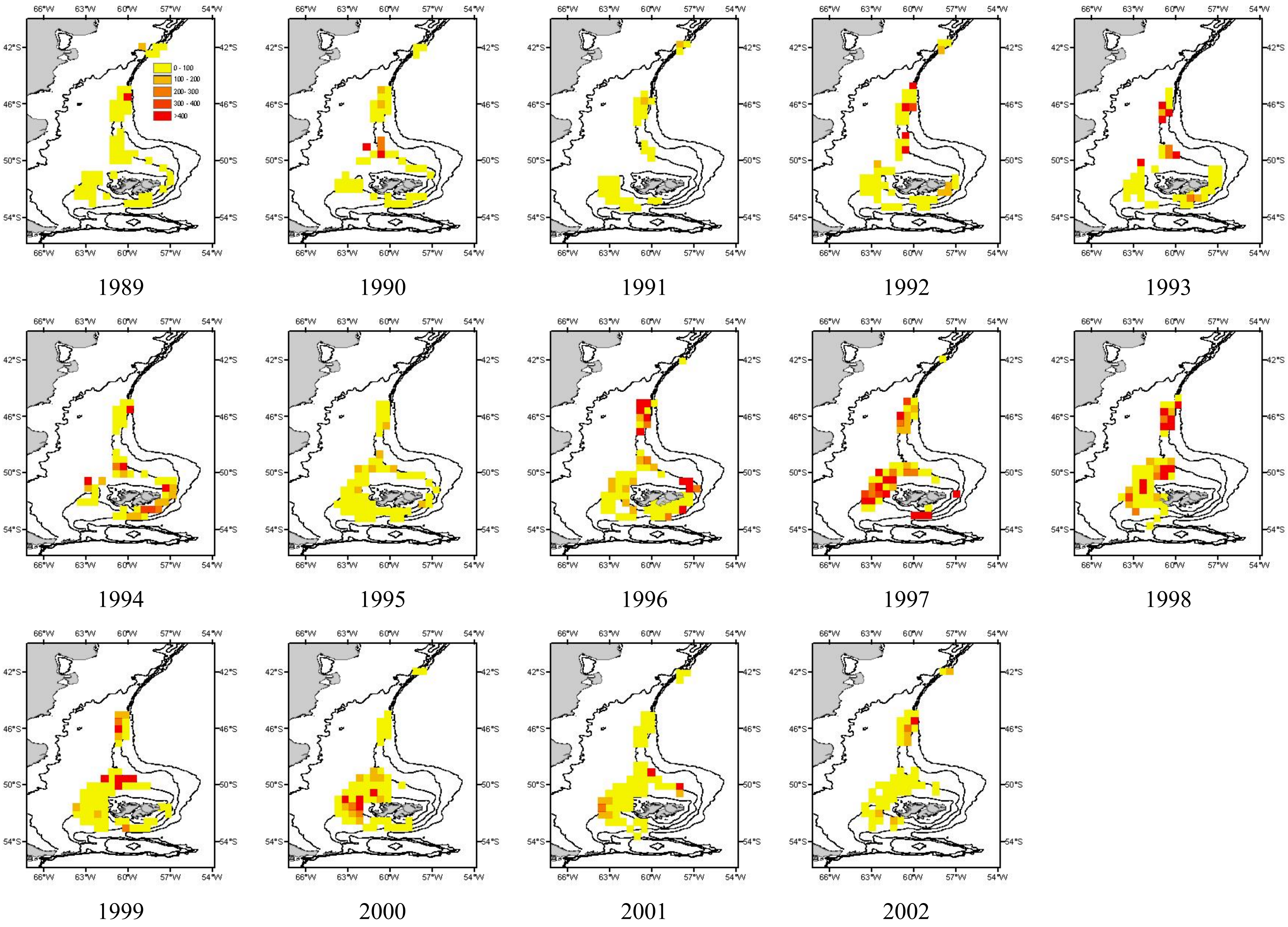


Figure 3. Annual CPUE values (Kg/hr) for *Patagonotothe*n spp. by 0.5º x 0.5º rectangles

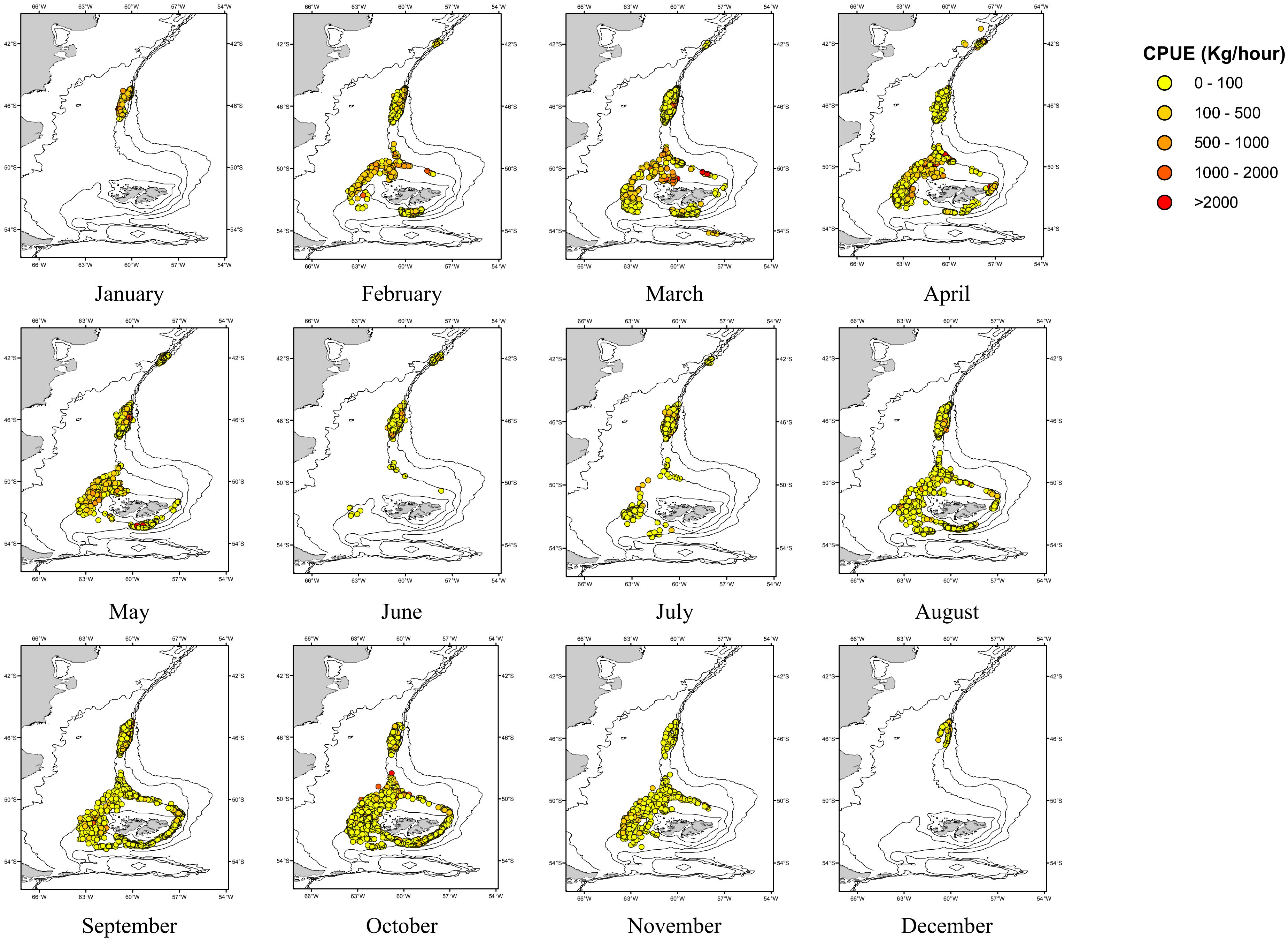


Figure 4. Monthly location of hauls and CPUE (Kg/h) values for *Patagonotothen* spp.

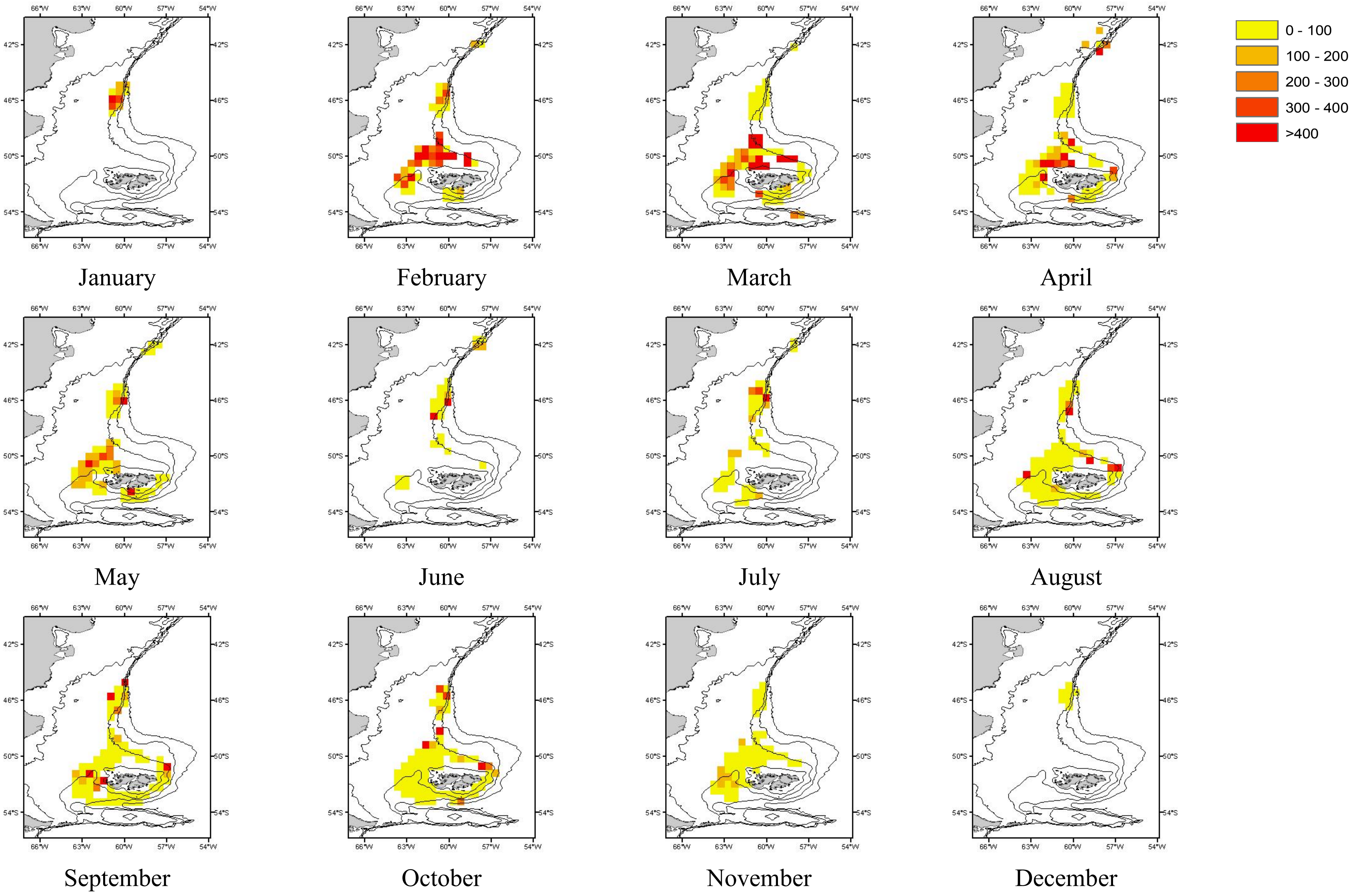


Figure 5. Monthly CPUE values (Kg/hr) by 0.5º x 0.5º rectangles

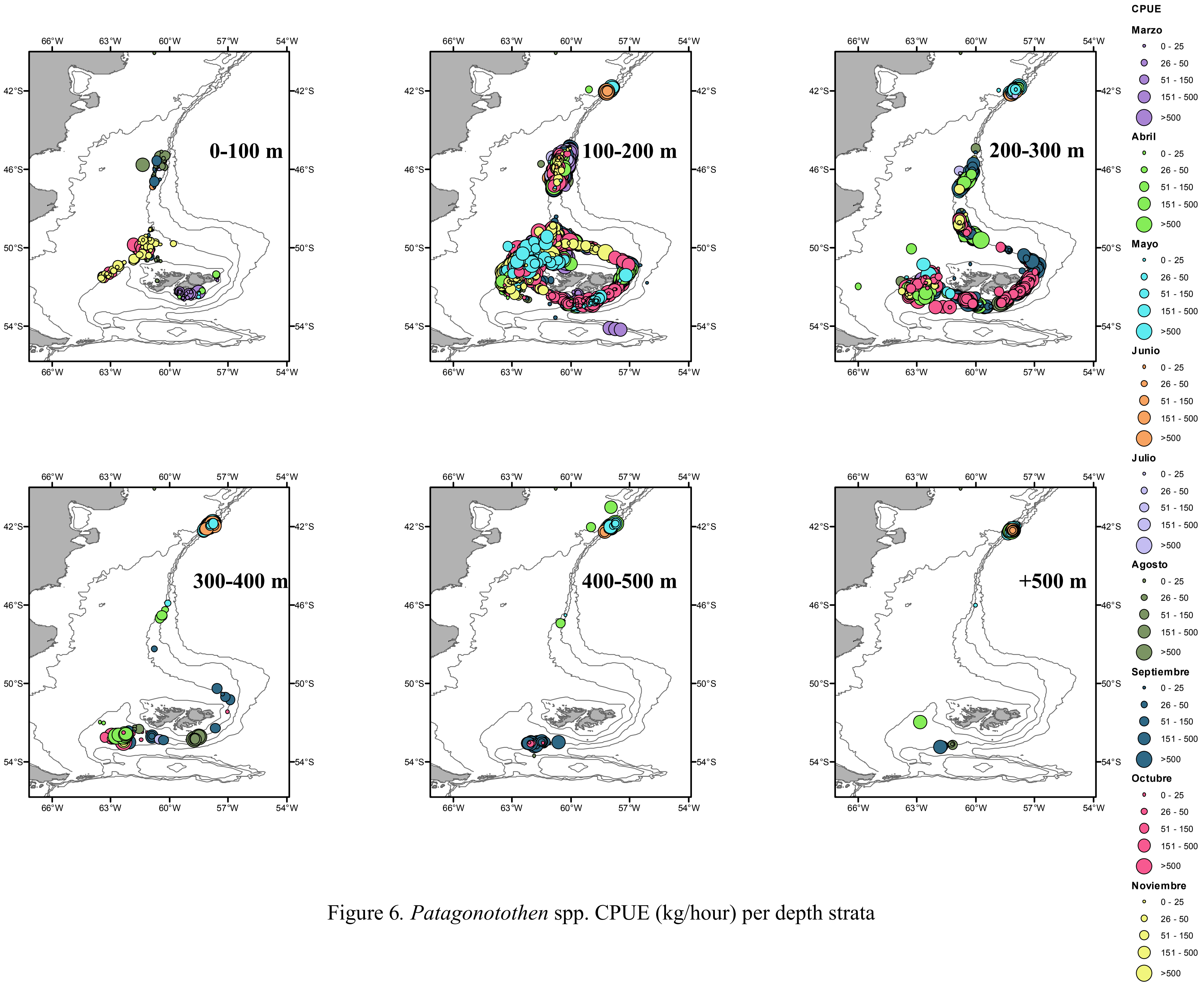


Figure 6. *Patagonotothen* spp. CPUE (kg/hour) per depth strata

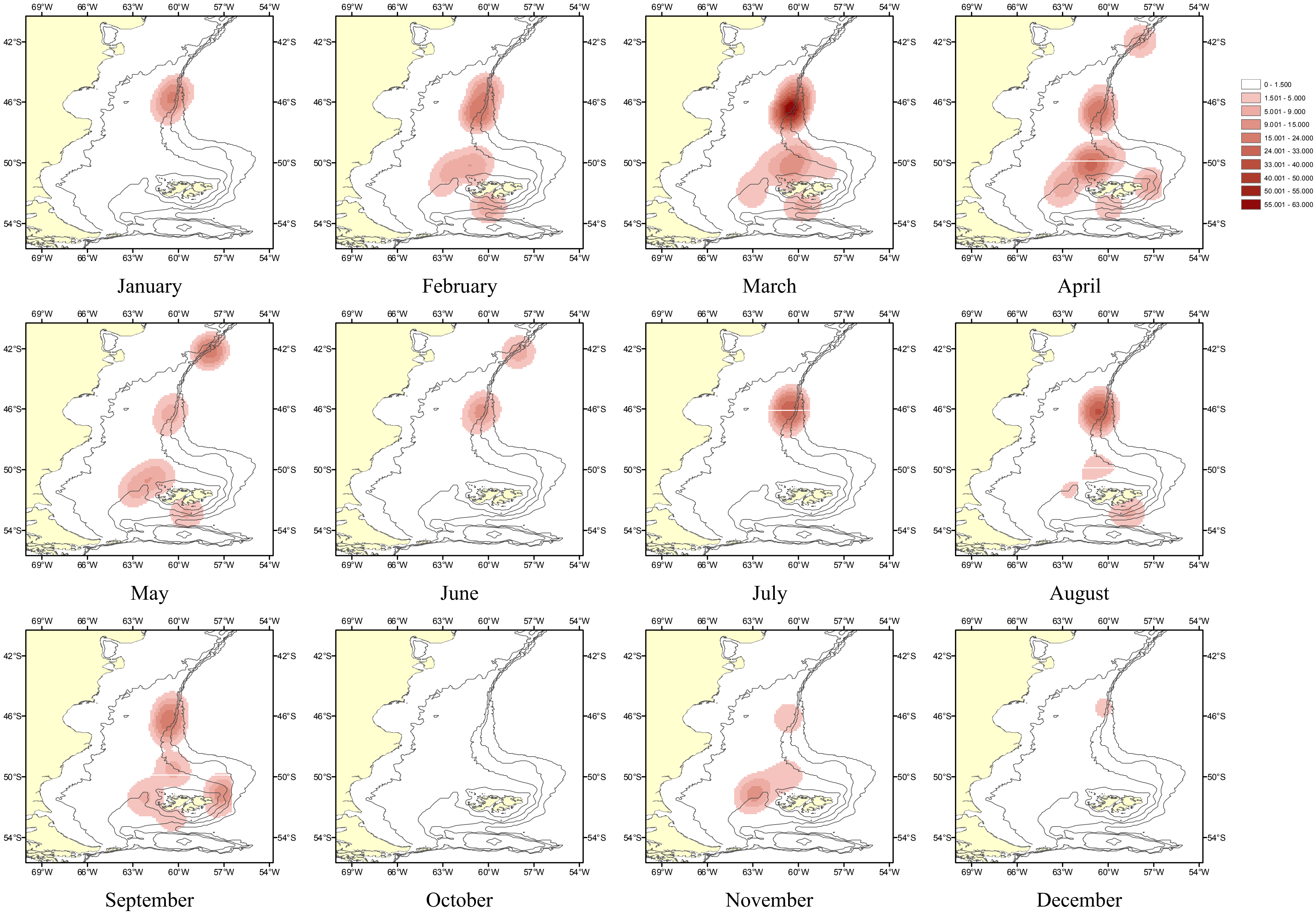
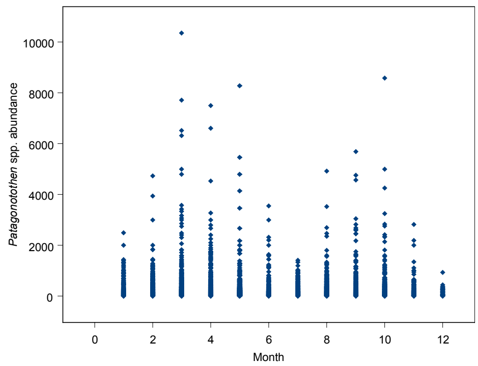


Figure 7. *Patagonotothen* spp. density maps (0.125 x 0.125 degrees resolution)

Scatter plots



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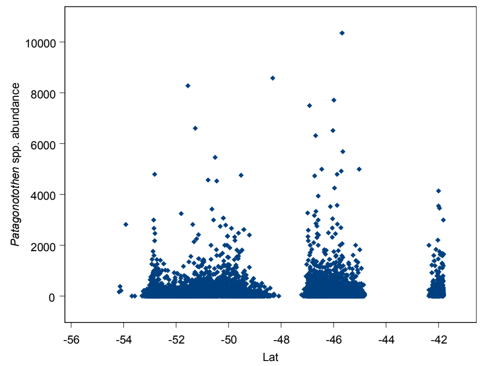

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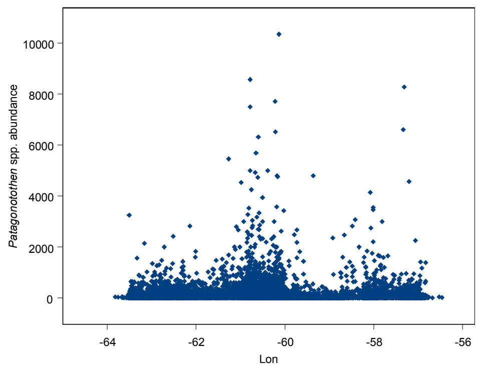

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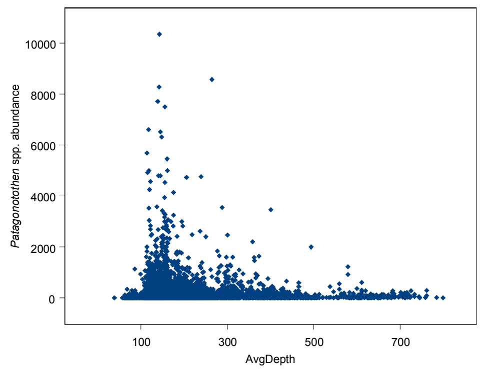

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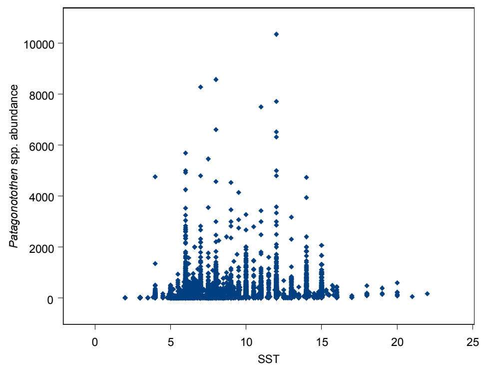


(e)

Figure 8. Scatter plots showing the relationship between *Patagonotothen* spp. abundance (CPUE as kg/h) and month (January to December), latitude (decimal degrees), longitude (decimal degrees), average depth (m) and SST (ºC)

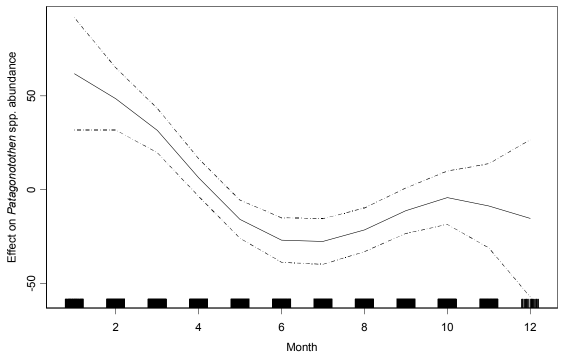
Scatter plots suggest the following relationships:

1. CPUE shows two peaks located in March and October. Minimum values were found during January, July and December.

2. The relationship of abundance (in terms of CPUE) with the geographic position (latitude and longitude) is basically indicating the location where the vessels are fishing. *Patagonotothen* spp. was fished all around the Falkland Islands and also in the High Seas, being the maximum abundance found at latitude 46º S and longitude 59º W
3. *Patagonotothen* spp. abundance seems to be positively related to 100-200 m depth range.
4. Highest *Patagonotothen* spp. CPUE values were associated with SST between 6.3º C and 12º C

Generalized additive models

Unweighted model *Weighted model*



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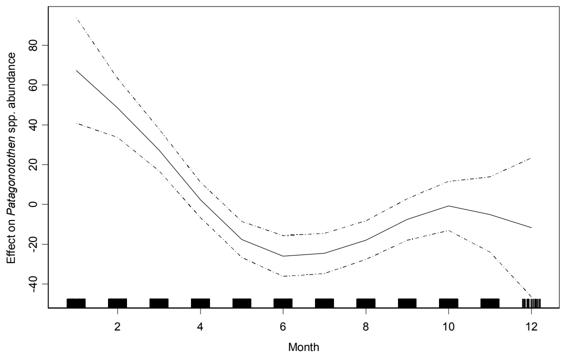

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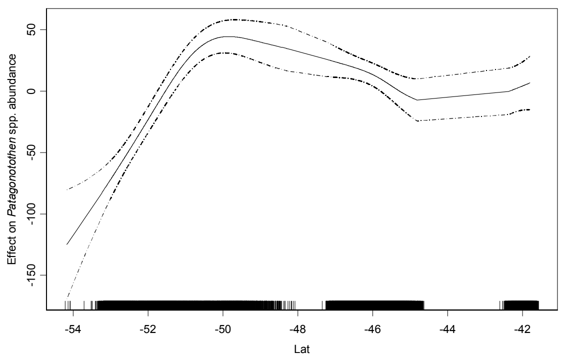

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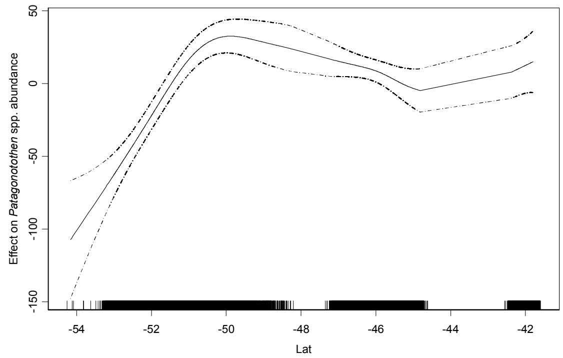

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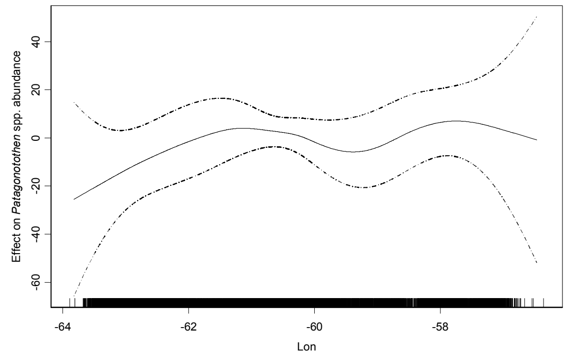

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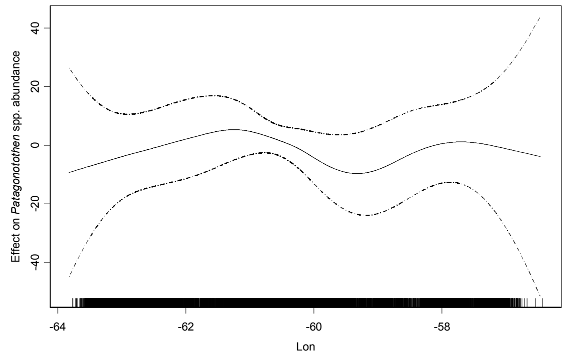

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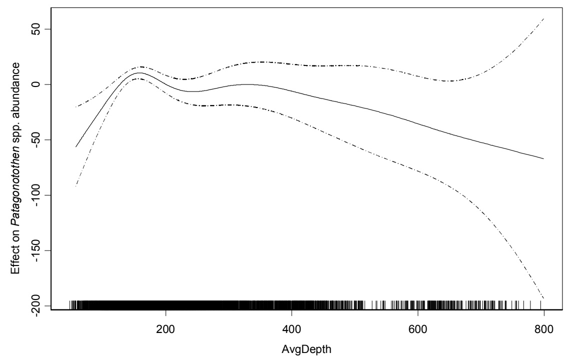

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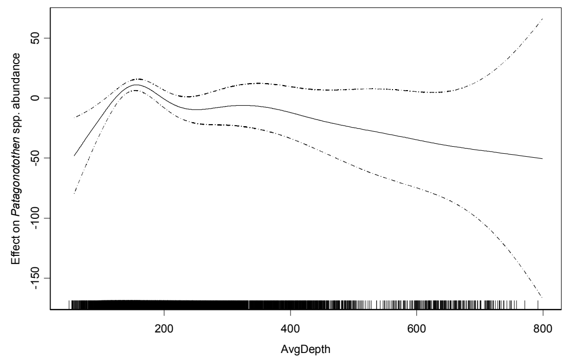

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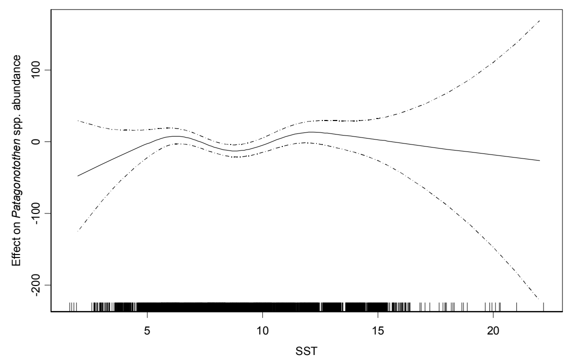
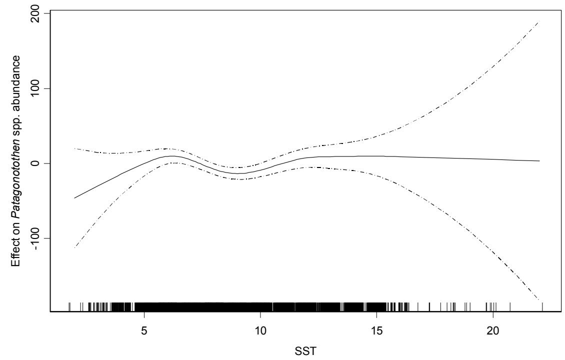


(i)



(j)

Figure 9. Results of GAM regression for unweighted and weighted model

Generalized additive models (GAMs) were used to model the spatio-temporal distribution of *Patagonotothen* spp.

The variables included in the GAM were Sea Surface Temperature (SST), month, latitude, longitude, month, average depth and cubic spline smoothers were used. GAM plots show the best fitting smoothers for the unweighted and weighted model. The partial components, as represented by the y-values on the GAM plots, express the relationship between the abundance and each of the variables included in the model (Fig. 9)

Results show that:

1. There is a general decrease in abundances that reaches the minimum value in July. From July, GAM plot depicts a slight increasing trend that reaches a peak in October, when the curve undergoes a decrease.

2. Results from the GAM plots related to latitude (Fig. 9 c & d) show an increasing trend from 54º S to 49º S, where the maximum abundance of *Patagonotothen* spp. was found. From latitude 49º S onwards there is a slight decreasing trend that reaches the minimum at latitudes around 46º S and 44º S. Figures 9 e & f show the effect of longitude on abundance. Longitude GAM plots (Fig. 9 e & f) show two peaks: one located around 61º W, the other placed at 58º W. These peaks are slightly well-defined in the weighted model.

3. In terms of depth, figures 9 g & h show that for both models there is a clearly defined maximum value located between 100 and 200 m.

4. The GAM demonstrates that the relationship between CPUE and SST is non linear for weighted and unweighted model. Highest CPUE were found, for both models, at temperatures around 6.3º C and 12º C.

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