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DEVELOPING FISHERY DEFINITIONS FOR THE SKIPJACK TUNA STOCK ASSESSMENT IN THE EPO

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SUMMARY

Skipjack tuna length-composition data from Class-6 purse-seine vessel sets on tunas associated with floating objects (OBJ) and on unassociated schools (NOA) were analyzed using regression tree methods for frequency distributions to determine the fishery structure for use in the interim stock assessment. Latitude, longitude, quarter, and cyclic quarter were used as candidate predictors to define the fisheries. Although year was also considered as a candidate predictor, standardizing the length-composition data, by dividing by the mean year-quarter proportions at length to remove recruitment variation, caused year to have little explanatory power. Quarter and cyclic quarter also had little explanatory power. Candidate fishery definitions were based on a subjective evaluation of the tradeoff between a practical number of fisheries (maximum of 6) and the percentage of variation explained by the number of splits (i.e., partitions of the length-frequency data based on the predictor variables and their values). The first split, at 120°W longitude, was common to both the OBJ and NOA set data, but the subsequent splits differed by set type. Using the OBJ splits for the NOA data degraded the percentage of variation explained for that set type. Consequently, and because of spatial differences in the area of operations of the two fisheries, different fishery definitions for each set type were chosen. A total of three splits (four fisheries) were used to define the fisheries for each set type in the stock assessment.

1. INTRODUCTION

Accounting for spatial structure in stock assessment and fisheries management is important to ensure sustainability of fish stocks and their fisheries. Unfortunately, direct information on stock structure (e.g., tagging or genetics) is usually unavailable, as is information needed to conduct spatial stock assessments (e.g., movement rates). Therefore, other sources of information and approximations to spatial stock assessments must be used. One approach is to use the fisheries-as-areas method, which approximates spatial population structure by applying different selectivity curves in each area (Waterhouse *et al*. 2014). This approach recognizes that there are spatial differences in the size (age) of fish and that fishing in different areas will remove different size (age) fish from the population. However, it generally assumes that fish will instantaneously redistribute so that all individuals are vulnerable to a fishery except as modified by its selectivity curve. This approach requires defining fisheries on a spatial basis. The spatial size-specific availability may also differ by quarter due to seasonal movement.

We identify fisheries for the interim skipjack assessment (SAC-13-07) defined by area and/or season based on analyzing length-frequency data. A regression tree approach for frequency distributions is used to identify areas and/or seasons that have similar length composition of the catch (Lennert-Cody *et al*. 2010; 2013). The analysis is conducted for the two main purse-seine fisheries that catch skipjack tuna in the EPO: 1) sets on tunas associated with floating objects (OBJ); and, 2) sets on free swimming schools (NOA). Fishery definitions for each set type are determined from the regression tree structure. Given that the output of the regression tree analysis is an input to the assessment model, the number of fisheries selected for each set type is determined subjectively, as a balance between the percentage of variation explained by the tree and the number of fisheries that would result, striving to explain as much variation in the length-frequency data as possible with a manageable number of fisheries. This is in contrast to the typical regression tree analysis where a 'best' tree is selected using pruning with cross-validation (Breiman *et al*. 1984).

2. METHODS

A regression tree approach for frequency distributions based on the methods presented in Lennert-Cody *et al*. (2010; 2013) is used to categorize fisheries length-frequency data into homogeneous groups based on the 5° latitude, 5° longitude, quarter, and cyclical-quarter associated with the catch. We also investigate using year as a numerical predictor. The data are first separated by set type, OBJ and NOA. We only use data from Class-6 vessels, and we do not use data from wells for which the catch was first sorted into weight categories before it was accessible to samplers. The length-frequency data are collected by port samplers (see Suter 2010 and references therein), and only wells with catch from the same set type, sampling area, and year-month are sampled. Fish are measured in millimeters. We focus on the data starting in 2000 since the sampling protocol used by the IATTC port-sampling program changed in 2000 and the OBJ fishery expanded westward within the eastern Pacific Ocean (EPO) during the 1990s. However, we also conducted analyses on the data from 1990-1999 for comparative purposes (see Appendix B). We do not use data from 2020 and 2021 due to the effect of the COVID-19 pandemic on the port-sampling data collection (e.g. SAC-13 INF-L; SAC-13-05). The raw length-frequency data were aggregated into 10 cm length bins, except for the first and last bins, which are "plus" bins: [1,39] [40,49] [50,59] [60,69] [70,∞]. However, as a sensitivity to investigate any bias that might have been introduced by excessive binning, the regression tree analysis was also run on the length-frequency data binned at a 5 cm resolution.

We analyze the binned length-frequency data in three ways:

1) Individual wells ("Wells");
2) Aggregated by 5° latitude, 5° longitude, and year-quarter ("Aggregated");
3) Individual wells divided by the average proportions for the year-quarter ("Standardized").

The Wells method gives each well sample equal weight, while the Aggregated method implicitly weights each well sample by the catch in the well. The discrepancy measure used by the tree methodology is designed for distributions, so it may not be theoretically appropriate for the Standardized approach, but in as much as the regression tree technique we are using is an exploratory data analysis tool, we consider that it still provides useful insights when applied to the standardized data. The Standardized approach is an attempt to remove the effects of temporal factors, such as strong cohorts moving through the population, on length composition; these factors, which may distort the length-frequencies, are unrelated to effects of selectivity or spatial distribution by size. We also investigate standardizing the aggregated data, and using a finer length bin size (5 cm) with the plus bins modified to 30 cm and 80 cm. The finer length bin resolution was used to investigate whether the 10 cm bin scale may have hidden any bimodality in the length compositions. Bimodality is an indicator that two fisheries that should have separate selectivities are combined. We allowed a maximum of 5 splits in the regression tree analysis to restrict the number of fisheries to make the stock assessment practical.

The analysis is implemented using the R package FishFreqTree (developed by Haikun Xu and based on code originally written by Cleridy Lennert-Cody), which is available using the installation command devtools::install_github('HaikunXu/FishFreqTree',ref='main').

3. RESULTS

To simplify presentation of the results, we have used a labeling system to identify the scenarios. We use the format WWW.XXX.YYY.ZZZ, where WWW is the set type (OBJ, NOA), XXX is the year (1990 = years 1990-1999; 2000 = years 2000-2019), YYY indicates the type of pre-analysis of data processing (Well = each well sample is a data point; Agg = the data are aggregated to quarter and 5° area; Std = standardized the data by dividing the proportions at length by the average proportions at length for all data points in that year-quarter where each well sample is a data point; Both = standardized by the mean length-frequency proportions for that year and then the data are aggregated to quarter and 5° area), ZZZ is whether year is used as a predictor (noYear = year is not used as a predictor; Year = year is used as a predictor). For example, the analysis for OBJ sets with individual well samples as data points, using the data for 2000 and later, not including year as a predictor, and not standardizing the data by year would be notated OBJ.2000.Well.noYear. When the label refers to all the categories within a group, we replace the category with the three letters corresponding to that group (e.g. OBJ.1990.YYY.noYear indicates all results for OBJ sets using the data from 1990-1999 and not using year as a predictor, independent of the type of data "points": Well, Agg, Std, and Both).

In the subjective framework within which we have conducted the regression tree analyses, there are many results to consider for each scenario analyzed. In particular, each split of the regression tree for a particular scenario has many alternative splits. In our case, several of these alternatives often have similar amounts of variation explained, likely due to a high degree of variability inherent in the raw length-frequency data. Depending on what split is taken, the subsequent splits can differ. A comprehensive analysis could involve analyzing alternative splits with similar variation explained, but this would lead to many analyses and results to interpret. For example, take the first split for the analysis for OBJ.2000.Well.noYear. Longitude explains by far the most variance, but the exact split is uncertain (arguably it could be anywhere between 125°W to 110°W) (Figure 1). In the first few splits, the type of split (latitude, longitude, quarter, year) was well determined. However, some later splits were uncertain. For example, in the third split for OBJ.2000.Agg.noYear, it is uncertain if the split should be latitude or longitude.

The best splits for each analysis of the 2000 - 2019 data are provided in Table 1 (results for the 1990 - 1999 data are provided in Appendix B). The splits chosen among the different methods (Well, Agg, Std) are sometimes the same or similar (e.g. OBJ.2000.YYY.noYear), but they can also be quite different (e.g., OBJ.1990.YYY.noYear). Year is often chosen when it is included as a predictor, but not always (e.g., NOA.1990.Well.Year). In all cases, when the data are standardized by dividing by the year-quarter average, year is either first chosen in the same step as when the data are not standardized or at a later split (See appendix C).

Given the inconsistencies between the late and early period, we focus on the late period which is consistent with the period considered for the interim stock assessment (ultimately quarter 1 2005 to 2021 was used in the stock assessment) and avoids the period when the fishery expanded. Also, given the propensity for the year predictor to be chosen when allowed, which could be due to annual variability in recruitment strength, we focus on the results from the approaches which standardize the data by dividing by the mean proportions for each year-quarter and do not include a year predictor (see Appendix C for the results including the year predictor). The first split for OBJ and NOA is the same at 120°W longitude. However, the second split for each set type is quite different, with OBJ splitting at 10°S latitude and NOA splitting at 85°W longitude. It is useful to investigate how these different splits for each set type perform for the other set type. A longitude of 85°W provides the third best split for the OBJ.2000.Std.noYear with a 15 unit or 20% reduction in the measure of heterogeneity. A latitude of 10°S provides the second best split for the NOA.2000.Std.noYear with a 10 unit or 17% reduction in the measure of heterogeneity.

We ran the two set types forcing these alternative splits from the other set type to determine how well the models perform. We identify these model runs by adding "xisy" at the end of the notation, where split x is fixed at the y^{th} candidate from the original model that was based on the best choice for every split. For the OBJ.2000.Std.noYear.2is3 model, the five-split model explained essentially the same amount of variation while the NOA.2000.Std.noYear.2is2 five-split model explained about half a percent less of the variation (Table 2). The 3rd and 4th splits for OBJ.2000.Std.noYear.2is3 were the same, with the original 2nd split coming in as the 5th split (Table 2), producing different fishery definitions (Figure 4). The 3rd split for NOA.2000.Std.noYear.2is2 was the same and the 4th split moved to be the 5th split.

We also investigated alternatives for the third split. The 3rd split of the NOA.2000.Std.noYear is at latitude 20°N and this is the 46th best candidate for both OBJ.2000.Std.noYear and OBJ.2000.Std.noYear.2is3 models and therefore not considered further.

The 3rd split of the OBJ.2000.Std.noYear is at longitude 100°W and this is the 8th best candidate for the NOA.2000.Std.noYear and the 9th for NOA.2000.Std.noYear.2is2 models. We ran the NOA.2000.Std.noYear.2is2 model using 100°W longitude as the third split. This produced a five-split model that explained 1.8% less variation than the best model.

Finally, we also ran all combinations of models with three splits allowing for the first three alternatives at each split and this found the second best choice for the second split for both set types to produce essentially the same variation explained. For OBJ, this only swapped the order of the second and third splits, but changes the grouping of the southern central area (Figure 5). The areas are not changed for NOA.

The splits were the same when using the 5 cm bins, but the variance explained differed (Table 3). The 5 cm resolution allows a better illustration of the length composition for each area (Figures 6 and 7). For each analysis, a multimodal distribution is seen in the central northern area for OBJ and the offshore area for the NOA fishery. However, these were still maintained in the best 5-split analyses and in the NOA analyses bimodality occurred in another area (Figures 8 and 9, the area definitions are given in Figures 10 and 11).

4. FISHERY DEFINITIONS FOR THE STOCK ASSESSMENT

There are several tradeoffs that need to be considered when defining the fishery definitions. More fisheries should be modelled to adequately represent the removals from the stock, but there should not be so many as to be representing random sampling error rather than actual differences in the size of individuals among areas. The number of fisheries should also be limited to ensure that the stock assessment model is practical to run in terms of computation time and convergence issues. It is also useful to have the same fishery definitions among the different fishing methods, particularly if spatial management is being considered. However, the stock assessment can use different definitions by fishing method when the areas as fisheries approach is used (i.e., spatial structure is not explicitly modelled). Finally, too many fisheries may produce small areas with low sample size causing issues in constructing the catch and length-composition estimates for the assessment.

The regression tree analysis results provide the amount of variation explained as each split is made. As more splits are made, less additional variation is explained. There is currently no quantitative criteria to determine the appropriate number of splits for defining fisheries for a stock assessment, which should likely involve feedback on performance from the assessment model. Thus, at this stage, the choice on number of splits is made arbitrarily, taking into consideration several factors, including those listed above.

For the skipjack stock in the EPO, a split around 120°W longitude is chosen as the first split for both the OBJ and NOA data, and thus it is an obvious split to include in the fishery definitions. However, common splits after that could not be identified, and using the OBJ splits for the NOA data degraded the amount of variation explained. Therefore, we decided to define fisheries differently for each set type, particularly since the areas fished differ somewhat (SAC-13 INF-K). Based on the reduction in the percentage of variation explained, for each set type we decided to use the first three splits from the regression tree analysis that used 2000-2019 standardized well-level data (i.e., standardized by dividing each well sample by the year-quarter mean proportions). This resulted in four fisheries for each set type (Figures 2 and 3). These fishery definitions do not perfectly represent the spatial variation in the length-composition data (see Appendix A), and future research should consider more flexible and possibly irregular spatial grouping. The small area in the north for NOA may result in small sample sizes, which can result in biased inputs to the stock assessment when the catch estimation methodology must rely on data from other areas and/or time points to generate catch used in the stock assessment. Therefore, the stock assessment may have to consider fixing or borrowing the selectivity for this fishery and not fitting to the length-composition data.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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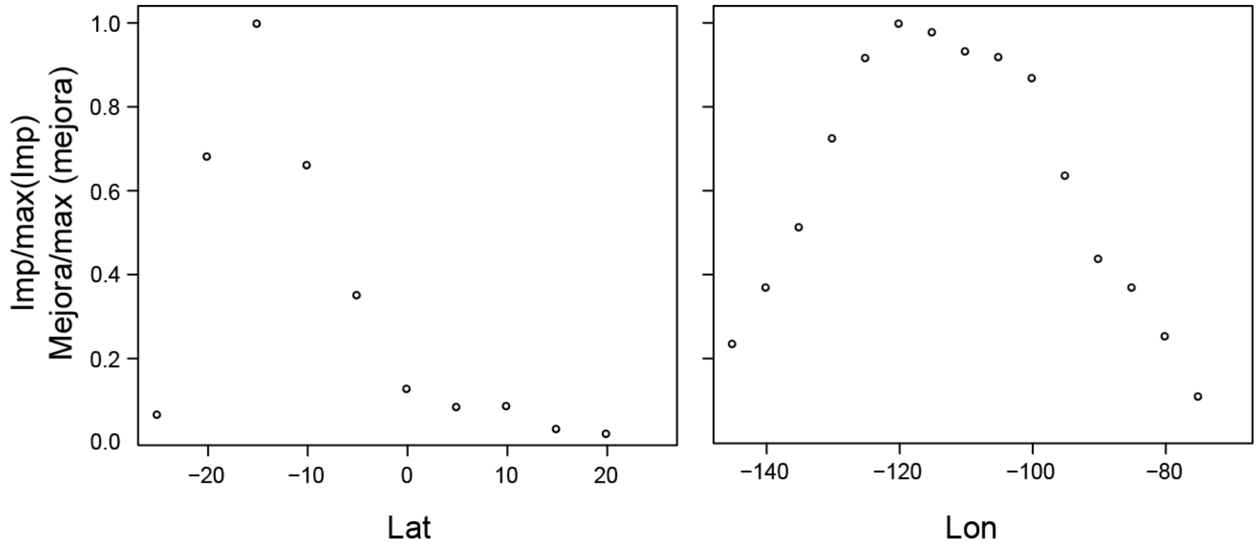

FIGURE 1. Scaled (maximum of one) improvement for latitude (left) and longitude (right) for the OBJ.2000.Well.noYear model.

FIGURA 1. Mejora escalada (con un valor máximo de uno) para la latitud (izquierda) y la longitud (derecha) para el modelo OBJ.2000.Well.noYear.

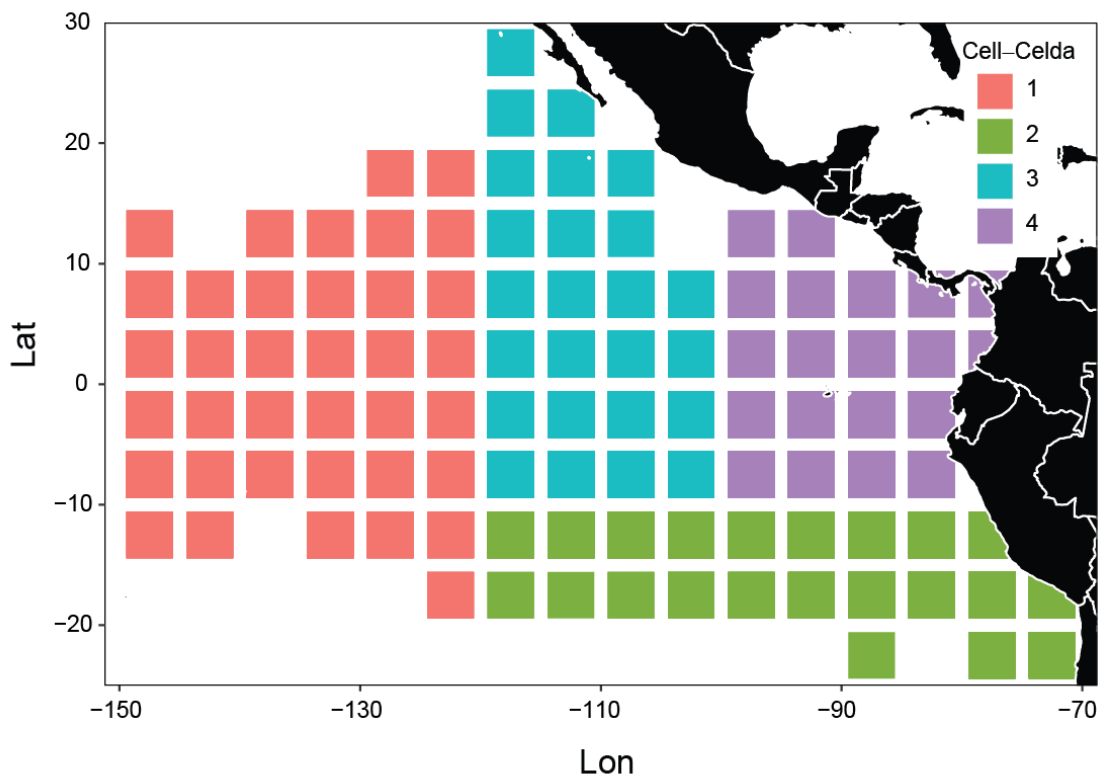

FIGURE 2. Fishery definitions chosen for the floating-object fishery for skipjack in the EPO from the best 3 splits in the OBJ.2000.Std.noYear analysis.

FIGURA 2. Definiciones de pesquerías elegidas para la pesquería sobre objetos flotantes de barrilete en el OPO a partir de las 3 mejores divisiones en el análisis de OBJ.2000.Std.noYear.

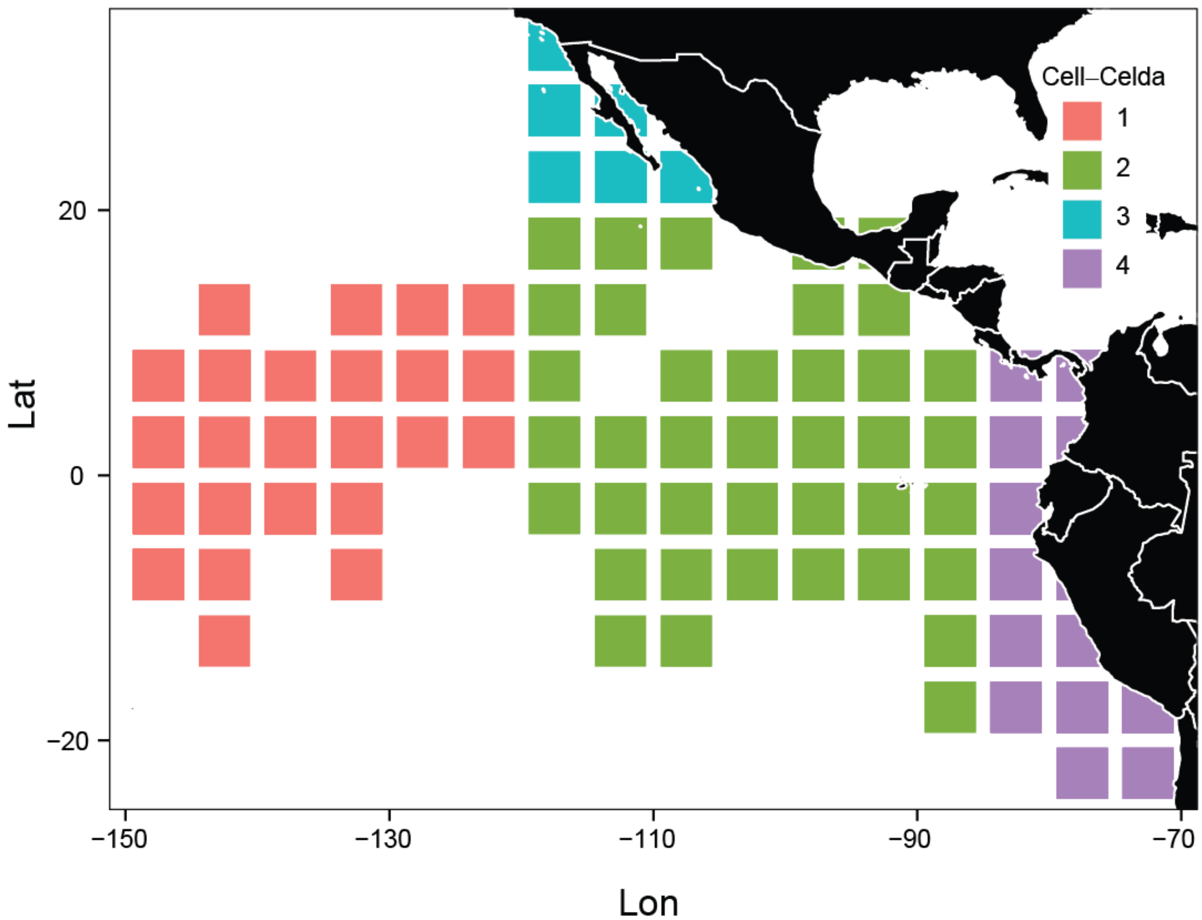

FIGURE 3. Fishery definitions chosen for the unassociated fishery for skipjack in the EPO from the best 3 splits in the NOA.2000.Std.noYear analysis.
FIGURA 3. Definiciones de pesquerías elegidas para la pesquería no asociada de barrilete en el OPO a partir de las 3 mejores divisiones en el análisis de NOA.2000.Std.noYear.

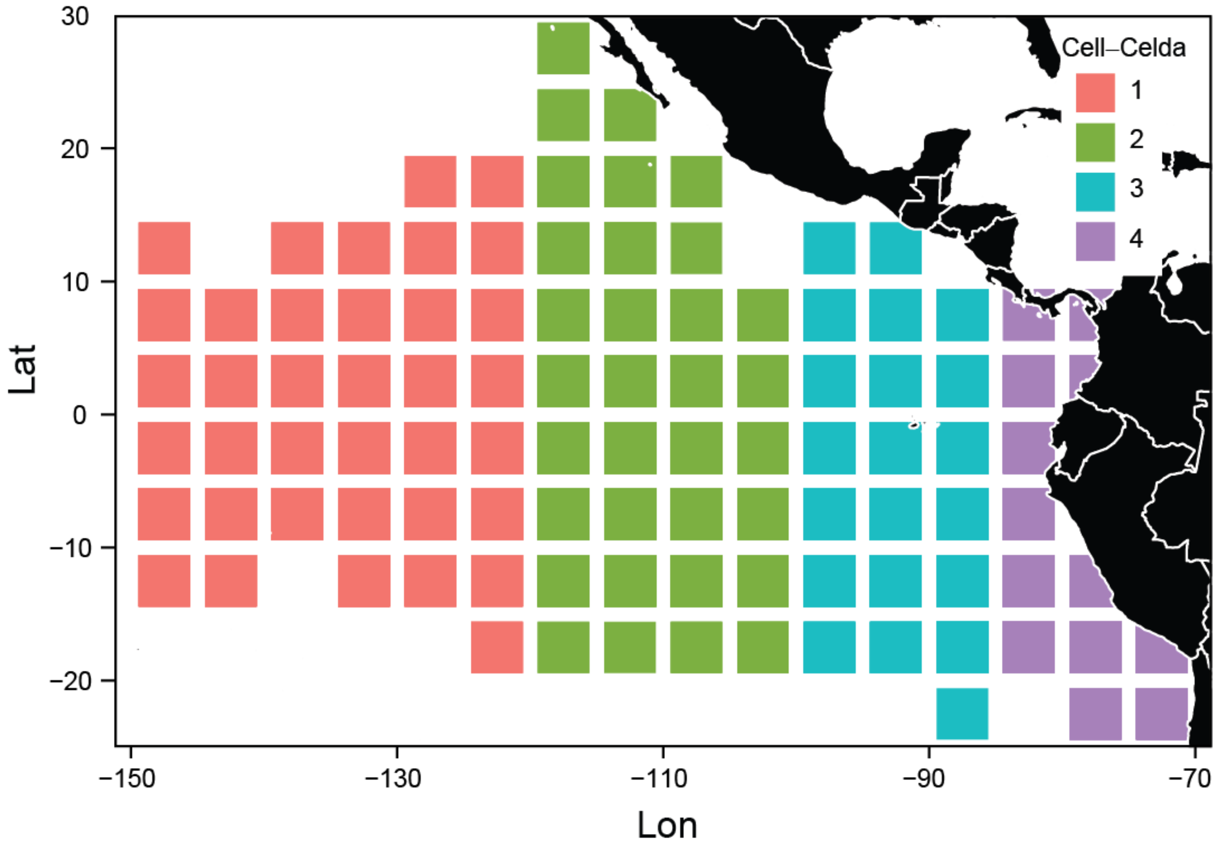

FIGURE 4. Fishery definitions chosen for the floating-object fishery for skipjack in the EPO when the 2nd split from the NOA.2000.Std.noYear is used as the 2nd split in the OBJ.2000.Std.noYear analysis.

FIGURA 4. Definiciones de pesquerías elegidas para la pesquería sobre objetos flotantes de barrilete en el OPO cuando la 2ª división de NOA.2000.Std.noYear se utiliza como la 2ª división en el análisis de OBJ.2000.Std.noYear.

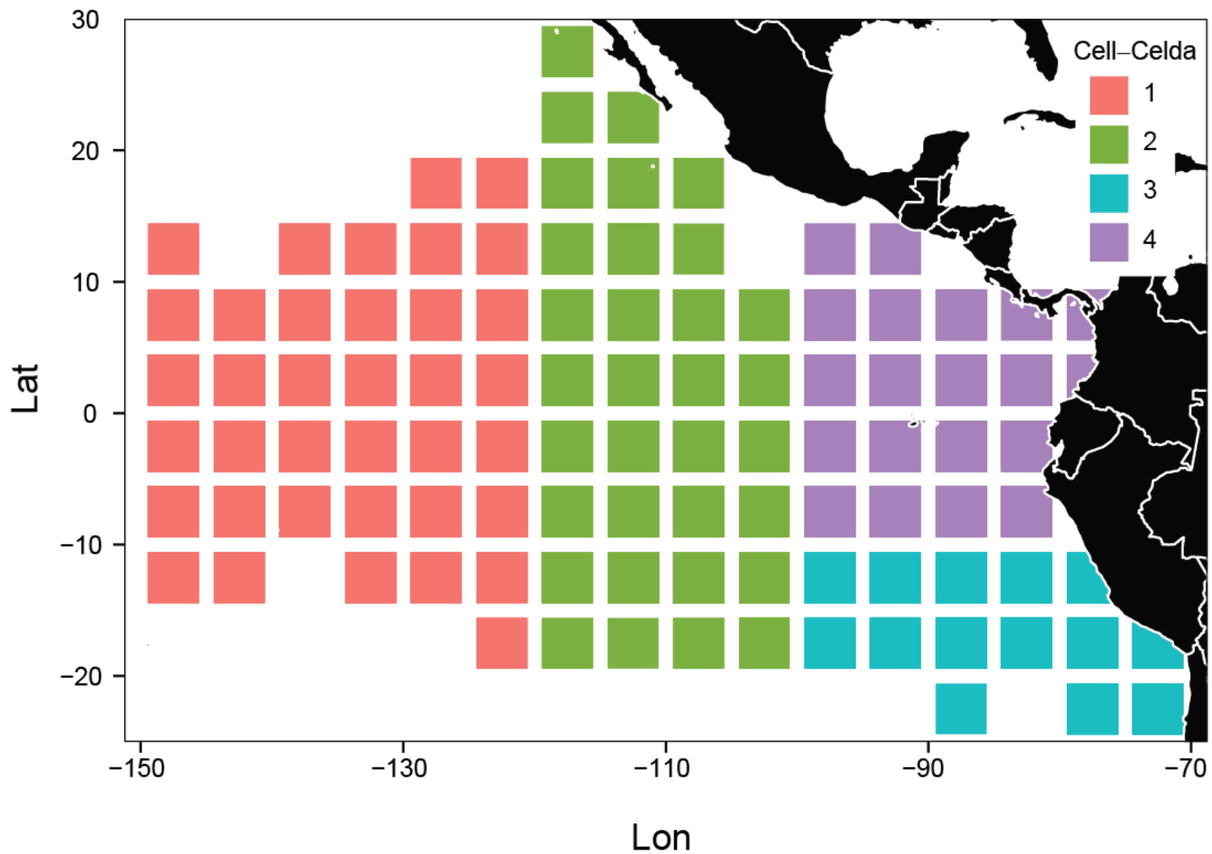

FIGURE 5. Fishery definitions chosen for the floating-object fishery for skipjack in the EPO when the second and third splits are reversed in the OBJ.2000.Std.noYear analysis.

FIGURA 5. Definiciones de pesquerías elegidas para la pesquería sobre objetos flotantes de barrilete en el OPO cuando se invierten la segunda y tercera divisiones en el análisis de OBJ.2000.Std.noYear.

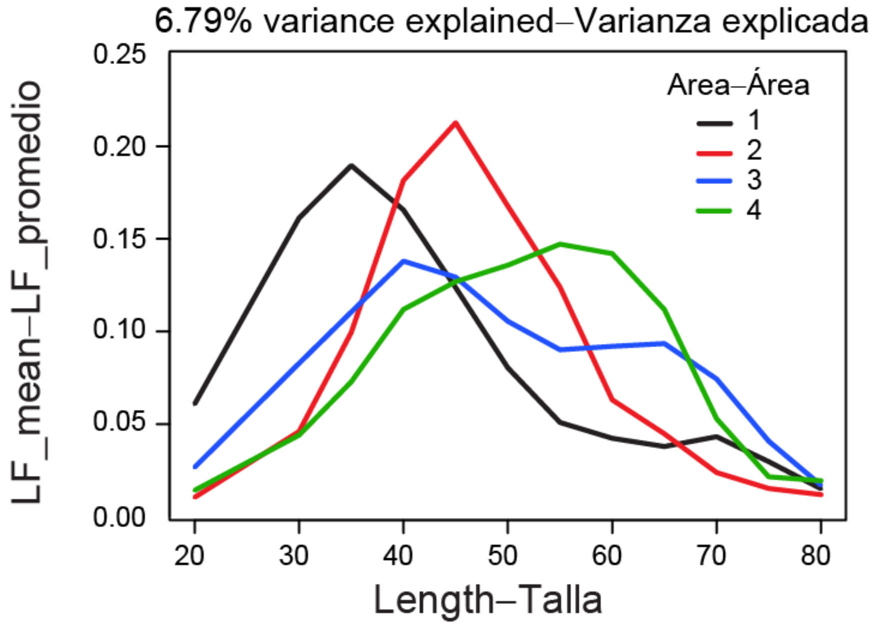

FIGURE 6. Length-frequency distributions for the 4 areas chosen by the best 3 splits for the OBJ.2000.Std.noYear.5cm analysis. The points are indicated by the bin lower bounds.
FIGURA 6. Distribuciones de frecuencias de talla para las 4 áreas elegidas por las 3 mejores divisiones para el análisis de OBJ.2000.Std.noYear.5cm. Los puntos se indican en el límite inferior de los intervalos.

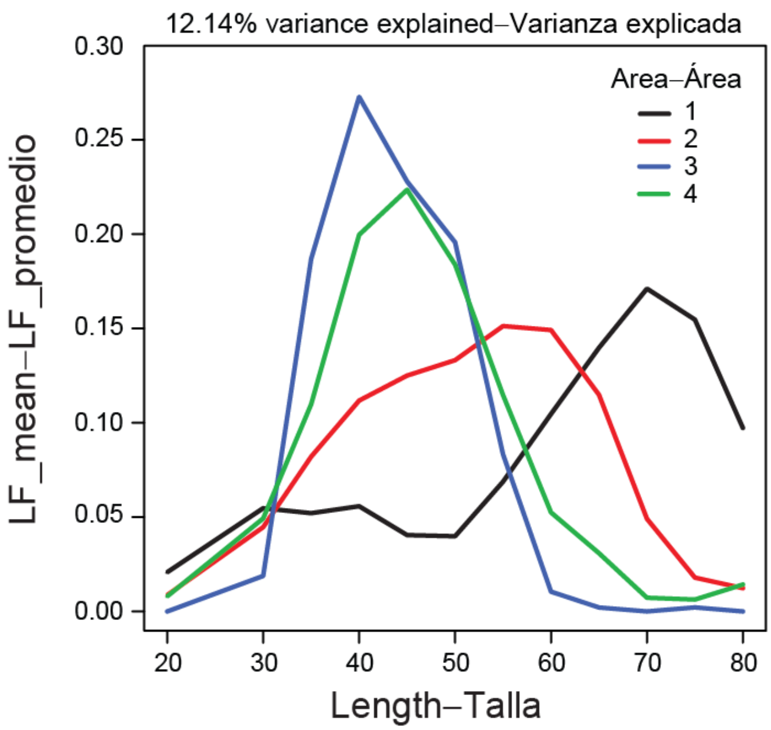

FIGURE 7. Length-frequency distributions for the 4 areas chosen by the best 3 splits for the NOA.2000.Std.noYear.5cm analysis. The points are indicated by the bin lower bounds.
FIGURA 7. Distribuciones de frecuencias de talla para las 4 áreas elegidas por las 3 mejores divisiones para el análisis de NOA.2000.Std.noYear.5cm. Los puntos se indican en el límite inferior de los intervalos.

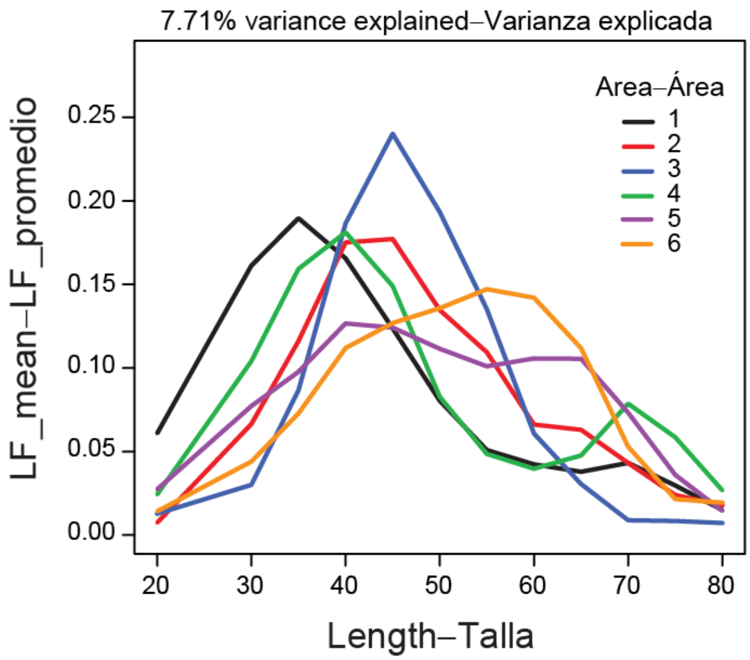

FIGURE 8. Length-frequency distributions for the 4 areas chosen by the best 5 splits for the OBJ.2000.Std.noYear.5cm analysis. The points are indicated by the bin lower bounds.

FIGURA 8. Distribuciones de frecuencias de talla para las 4 áreas elegidas por las 5 mejores divisiones para el análisis de OBJ.2000.Std.noYear.5cm. Los puntos se indican en el límite inferior de los intervalos.

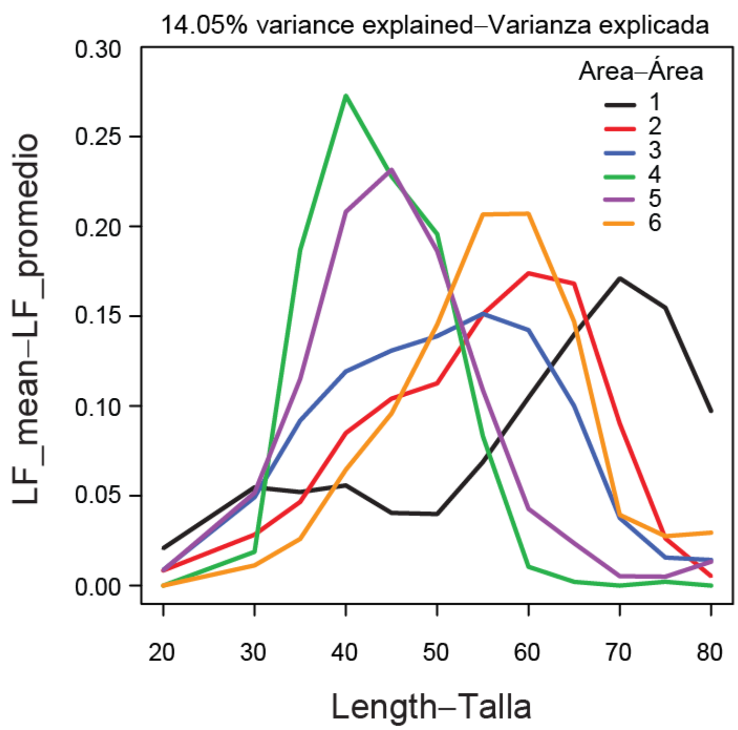

FIGURE 9. Length-frequency distributions for the 4 areas chosen by the best 5 splits for the NOA.2000.Std.noYear.5cm analysis. The points are indicated by the bin lower bounds.

FIGURA 9. Distribuciones de frecuencias de talla para las 4 áreas elegidas por las 5 mejores divisiones para el análisis de NOA.2000.Std.noYear.5cm. Los puntos se indican en el límite inferior de los intervalos.

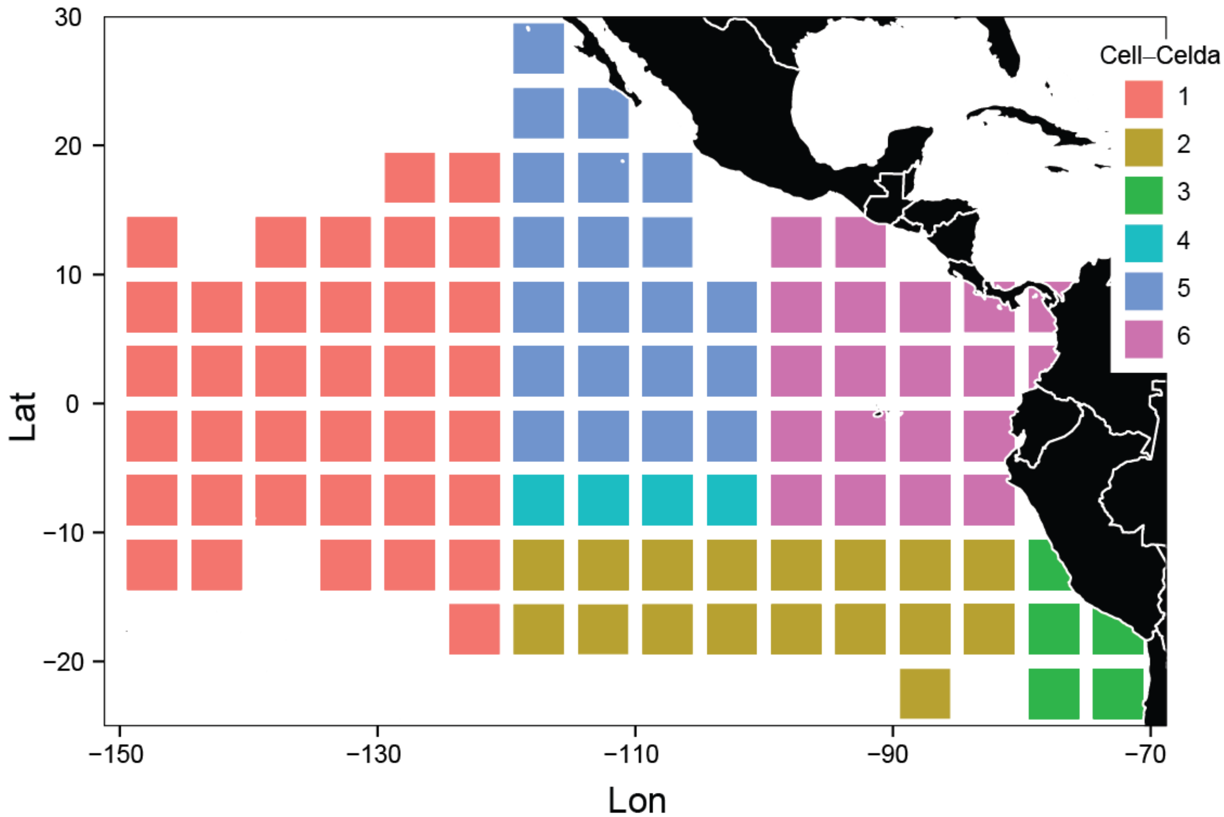

FIGURE 10. Fishery definitions chosen for the floating object fishery for skipjack in the EPO from the best 5 splits in the OBJ.2000.Std.noYear analysis.

FIGURA 10. Definiciones de pesquerías elegidas para la pesquería sobre objetos flotantes de barrilete en el OPO a partir de las 5 mejores divisiones en el análisis de OBJ.2000.Std.noYear.

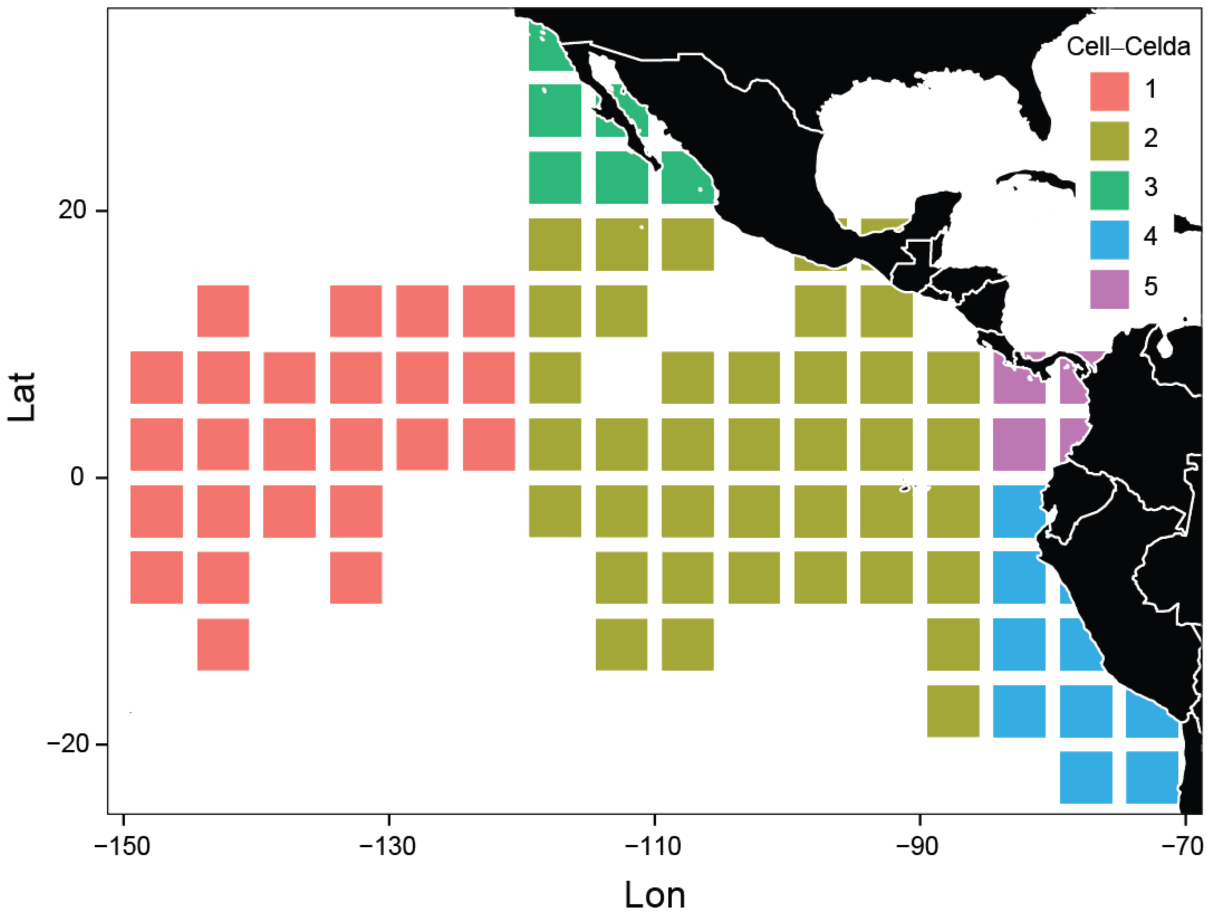

FIGURE 11. Fishery definitions chosen for the unassociated fishery for skipjack in the EPO from the best 5 splits in the NOA.2000.Std.noYear analysis. Note that the 5th split is cyclic quarter.

FIGURA 11. Definiciones de pesquerías elegidas para la pesquería no asociada de barrilete en el OPO a partir de las 5 mejores divisiones en el análisis de NOA.2000.Std.noYear. Cabe notar que la 5ª división corresponde al trimestre cíclico.

TABLE 1. Splits and variation explained using data from 2000-2019 for the three methods applied for the two set types. Interpretation of the splits is complicated because it depend on the previous splits and which area the split occurs in (this is indicated by Cell, but Cell refers to the previous areas not the final areas). Interpretation is easy when referring to the final fishery maps (see figures 9 and 10). Key is the type of predictor used in the split; Lon = Longitude, Lat = latitude, Qrt = quarter, CQrt = cyclic quarter, Year = year. Value is the value of the predictor where the split occurred. Values less than or equal to this are included in one group and values larger than this are included in the other group. Var_explained is the cumulative variance explained by that split and the previous splits.

TABLA 1. Las divisiones y la variación explicada con los datos de 2000 a 2019, para los tres métodos aplicados para los dos tipos de lance. Resulta complicado interpretar las divisiones debido a que la interpretación depende de las divisiones anteriores y del área en la que se produce la división (esto se indica en la columna "Celda", pero el valor de "Celda" corresponde a las áreas anteriores y no a las áreas finales). La interpretación es fácil en referencia a los mapas de pesquerías finales (ver Figuras 9 y 10). "Clave" corresponde al tipo de predictor utilizado en la división: Lon = Longitud, Lat = Latitud, Qrt = trimestre, CQrt = trimestre cíclico, Year = año. "Valor" corresponde al valor del predictor donde se produjo la división. Los valores menores o iguales a este valor se incluyen en un grupo y los valores mayores se incluyen en el otro grupo. "Var_explained" corresponde al porcentaje acumulado de varianza explicada por esa división y las divisiones anteriores.

OBJ.2000.Well.noYear						NOA.2000.Well.noYear				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	115°W	NA	7.12%		Split1	Lon	120°W	NA	11.38%
Split2	Lat	10°S	2	9.65%		Split2	Lon	85°W	2	16.81%
Split3	Lon	100°W	3	10.49%		Split3	Lat	20°N	2	21.78%
Split4	Lon	125°W	1	11.27%		Split4	Lat	0°	4	25.07%
Split5	Lat	5°S	4	11.84%		Split5	CQrt	134;2	4	25.86%
OBJ.2000.Agg.noYear						NOA.2000.Agg.noYear				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	115°W	NA	8.11%		Split1	Lon	125°W	NA	6.60%
Split2	Lat	10°S	2	10.04%		Split2	Lat	10°S	2	11.63%
Split3	Lat	5°S	1	11.09%		Split3	Lat	15°N	3	15.03%
Split4	Lon	125°W	2	12.23%		Split4	Lon	100°W	3	17.18%
Split5	Lon	100°W	5	13.11%		Split5	Lat	0°	4	18.85%
OBJ.2000.Std.noYear						NOA.2000.Std.noYear				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	5.82%		Split1	Lon	120°W	NA	6.45%
Split2	Lat	10°S	2	7.63%		Split2	Lon	85°W	2	9.63%
Split3	Lon	100°W	3	8.84%		Split3	Lat	20°N	2	14.14%
Split4	Lat	5°S	3	9.56%		Split4	Lat	0°	4	15.79%
Split5	Lon	80°W	2	9.99%		Split5	CQrt	134;2	2	16.36%

TABLE 2. Additional analyses to investigate alternative splits. See Table 1 for definitions.

TABLA 2. Análisis adicionales para investigar divisiones alternativas. Ver la Tabla 1 para consultar las definiciones.

OBJ.2000.Std.noYear.2is3				
	Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	5.82%
Split2	Lon	85°W	2	7.26%
Split3	Lon	100°W	2	8.34%
Split4	Lat	5°S	2	9.32%
Split5	Lat	10°S	5	10.01%
NOA.2000.Std.noYear.2is2				
	Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	6.45%
Split2	Lat	10°S	2	9.09%
Split3	Lat	20°N	3	12.64%
Split4	Lon	85°W	3	14.63%
Split5	Lat	0°	4	15.89%
NOA.2000.Std.noYear.2is2.3is9				
	Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	0.064479
Split2	Lat	10°S	2	0.090859
Split3	Lon	100°W	3	0.100643
Split4	Lat	20°N	3	0.130859
Split5	Lon	85°W	5	0.148292

TABLE 3. Evaluation with 5cm length bins and extending the accumulators to be 10 cm less and 10 cm more than in the other analyses. See Table 1 for definitions.

TABLA 3. Evaluación con intervalos de talla de 5 cm y con expansión de los intervalos adicionales para que queden en 10 cm menos y 10 cm más que en los otros análisis. Ver la Tabla 1 para consultar las definiciones.

OBJ.2000.Std.noYear.5cm				
	Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	4.42%
Split2	Lat	10°S	2	5.81%
Split3	Lon	100°W	3	6.79%
Split4	Lat	5°S	3	7.34%
Split5	Lon	85°W	2	7.71%
NOA.2000.Std.noYear.5cm				
	Key	Value	Cell	Var_explained
Split1	Lon	120°W	NA	5.55%
Split2	Lon	85°W	2	8.21%
Split3	Lat	20°N	2	12.12%
Split4	Lat	0°	4	13.49%
Split5	CQrt	134;2	2	14.03%

APPENDIX A: SPATIAL DISTRIBUTION OF LENGTH COMPOSITION AND MEAN LENGTH.

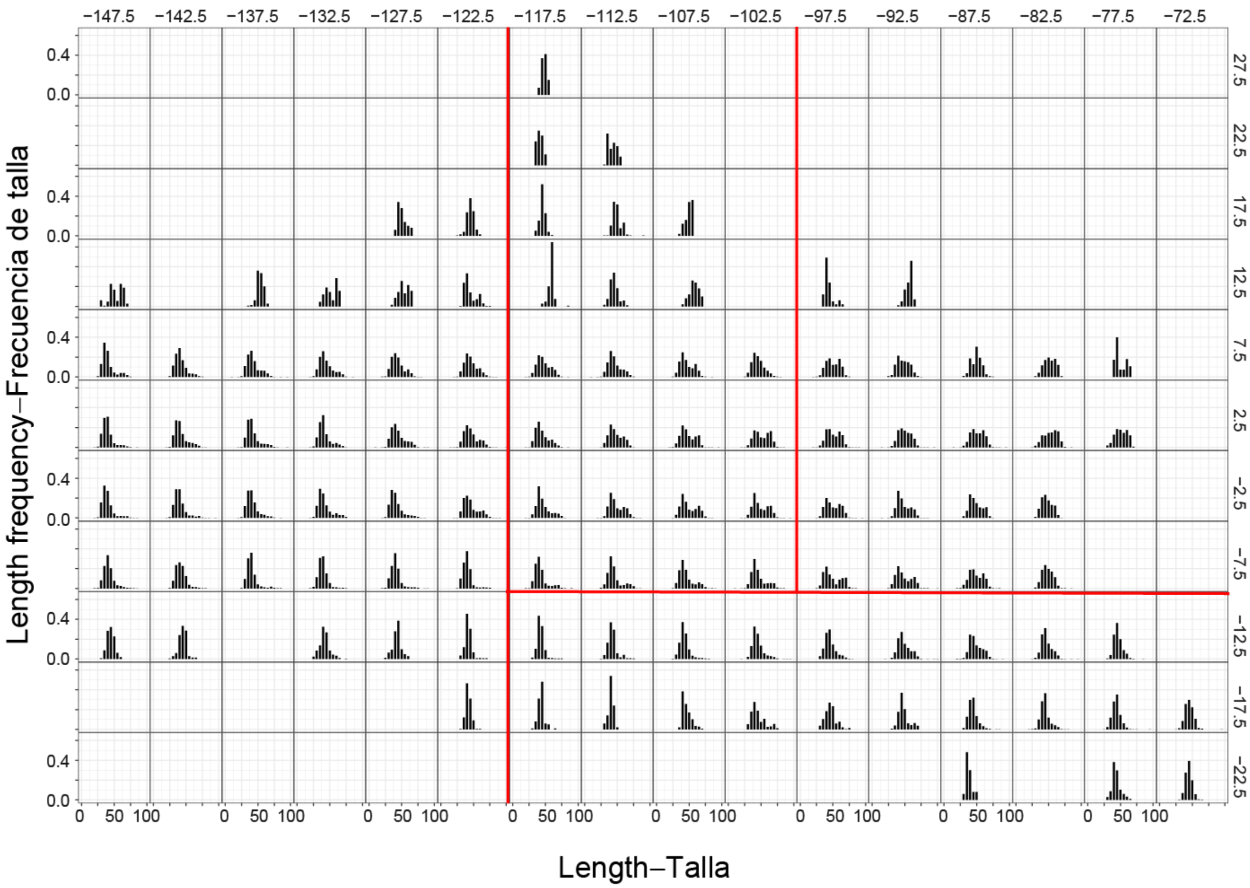

FIGURE A1. Spatial distribution of length-frequency data from 2000-2019 for sets on floating objects with the four fisheries. The x and y-axes are labeled at the mid-point of the 5 degree square.

FIGURA A1. Distribución espacial de los datos de frecuencia de talla de 2000 a 2019 para lances sobre objetos flotantes con las cuatro pesquerías. Los ejes ‘x’ y ‘y’ se encuentran marcados en el punto medio del cuadrángulo de 5 grados.

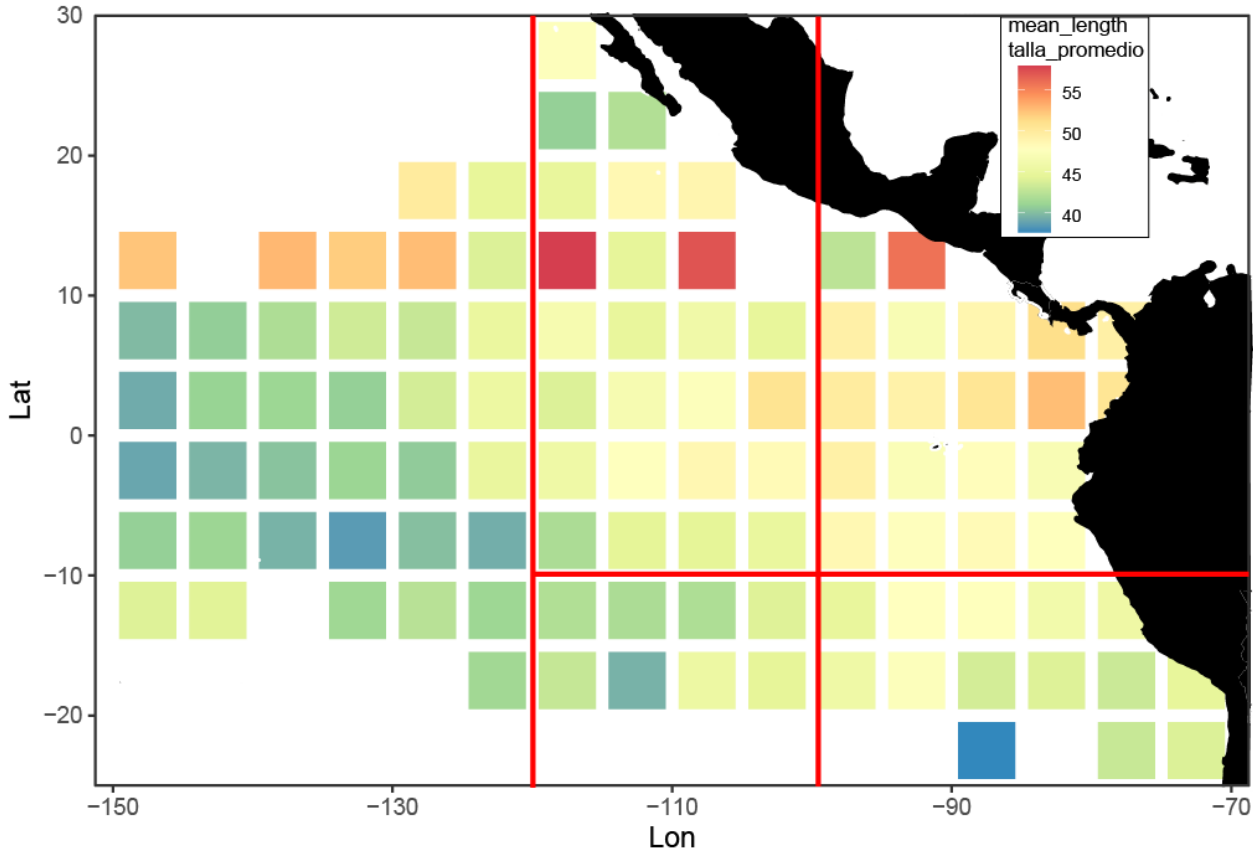

FIGURE A2. Spatial distribution of mean length from 2000-2019 for sets on floating objects with the four fisheries.

FIGURA A2. Distribución espacial de la talla media de 2000 a 2019 para lances sobre objetos flotantes con las cuatro pesquerías.

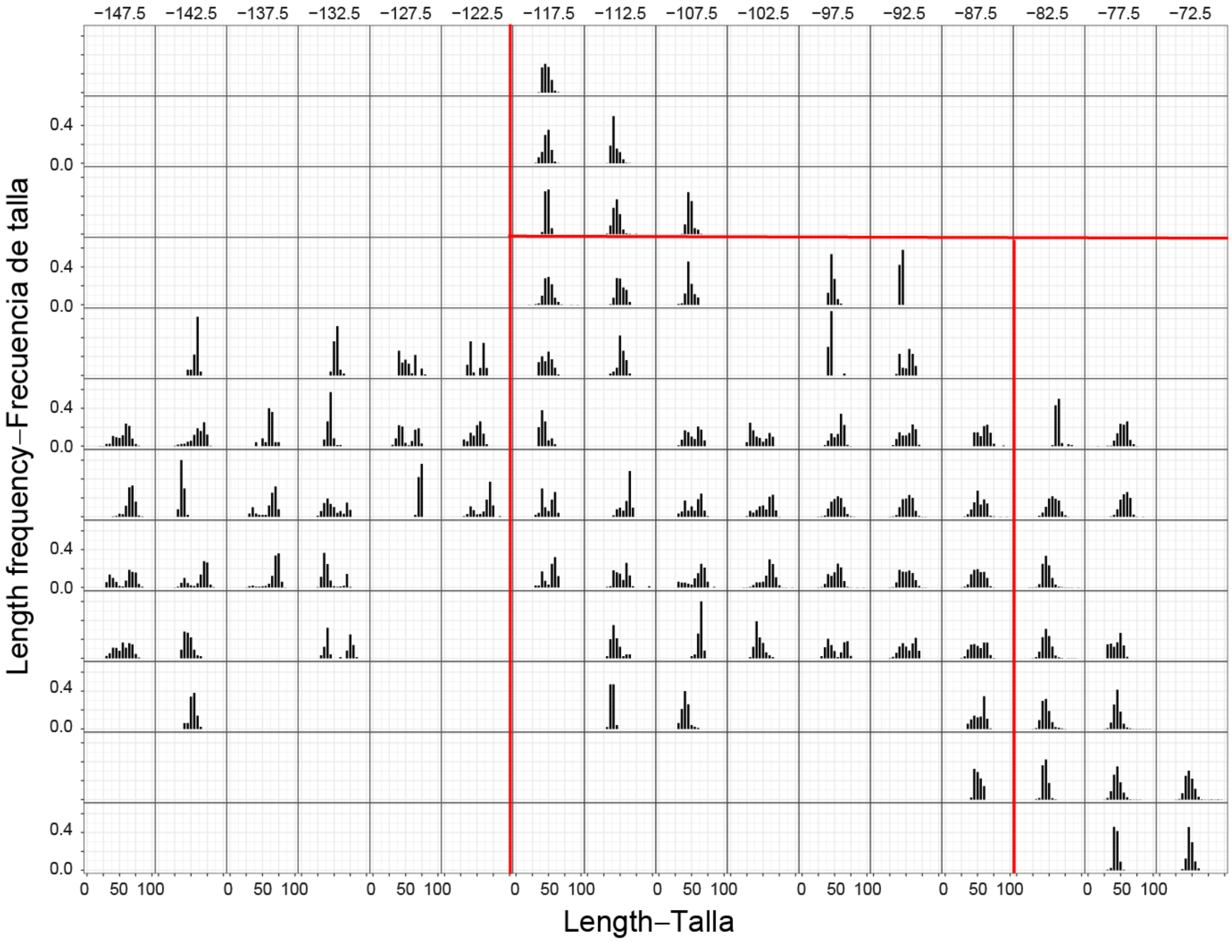

FIGURE A3. Spatial distribution of length-frequency data from 2000-2019 for sets on free swimming schools with the four fisheries. The x and y-axes are labeled at the mid-point of the 5 degree square.

FIGURA A3. Distribución espacial de los datos de frecuencia de talla de 2000 a 2019 para lances sobre cardúmenes libres con las cuatro pesquerías. Los ejes 'x' y 'y' se encuentran marcados en el punto medio del cuadrángulo de 5 grados.

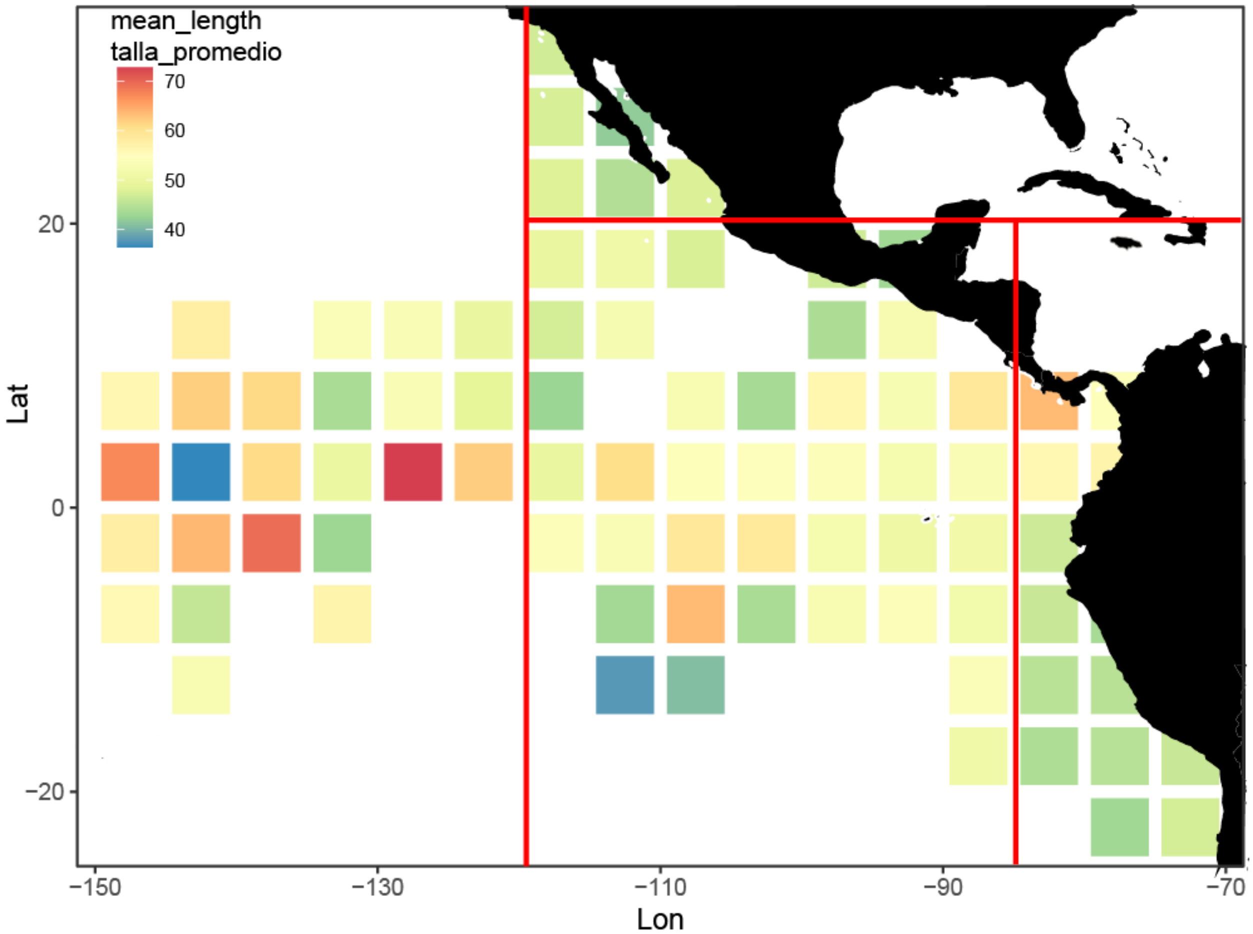

FIGURE A4. Spatial distribution of mean length from 2000-2019 for sets on free swimming schools with the four fisheries.

FIGURA A4. Distribución espacial de la talla media de 2000 a 2019 para lances sobre cardúmenes libres con las cuatro pesquerías.

APPENDIX B: ADDITIONAL ANALYSES

There are substantial differences in splits between the two set types and the time periods (compare Table 1 with table B.1). The early period selects latitude for the first OBJ split, but the later period splits on longitude. Similarly, the early period selects latitude for the first NOA split, but the later period splits on longitude. The secondary splits start to become more variable between the set types.

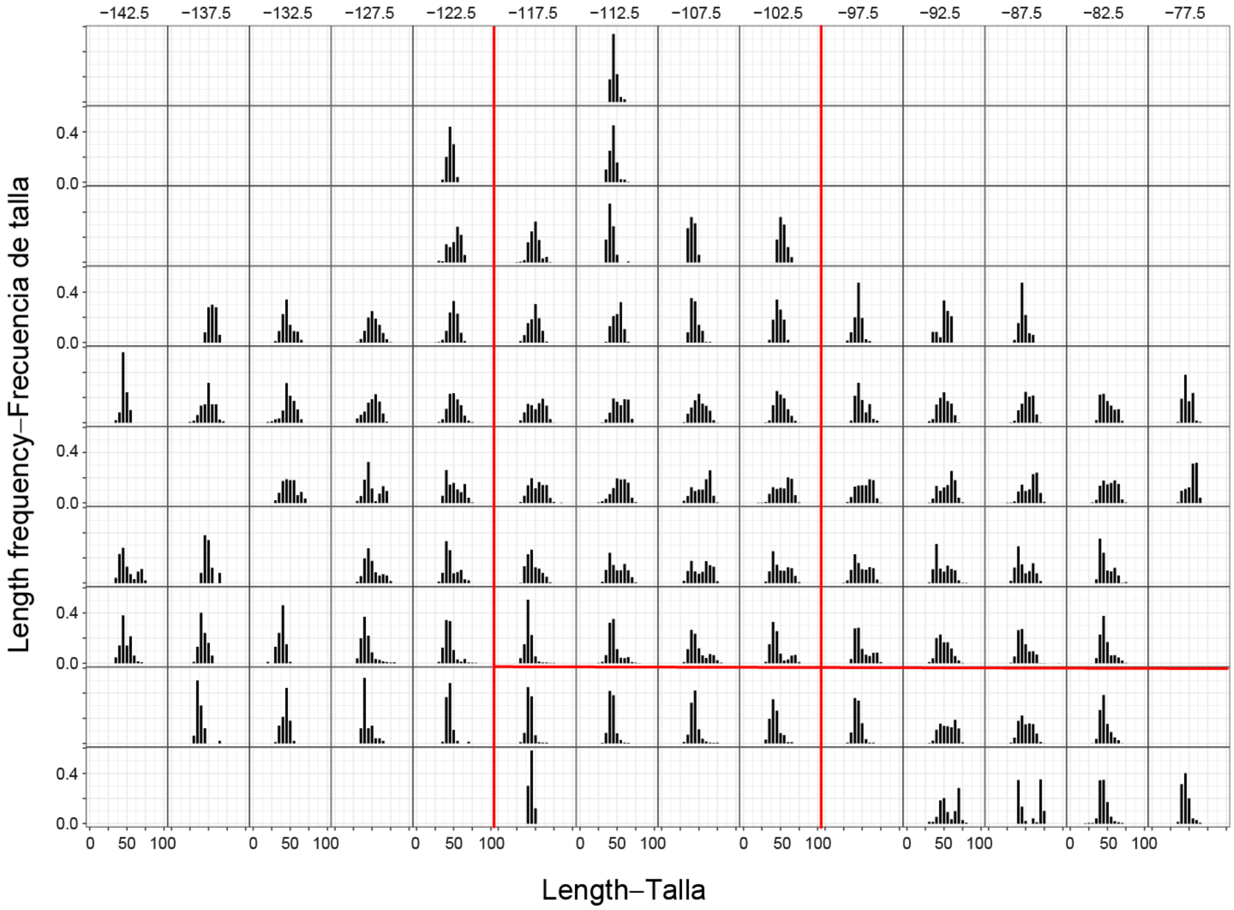

FIGURE B1. Spatial distribution of length-frequency data from 1990-1999 for sets on floating objects with the four fisheries. The x and y-axes are labeled at the mid-point of the 5 degree square.

FIGURA B1. Distribución espacial de los datos de frecuencia de talla de 1990 a 1999 para lances sobre objetos flotantes con las cuatro pesquerías. Los ejes ‘x’ y ‘y’ se encuentran marcados en el punto medio del cuadrángulo de 5 grados.

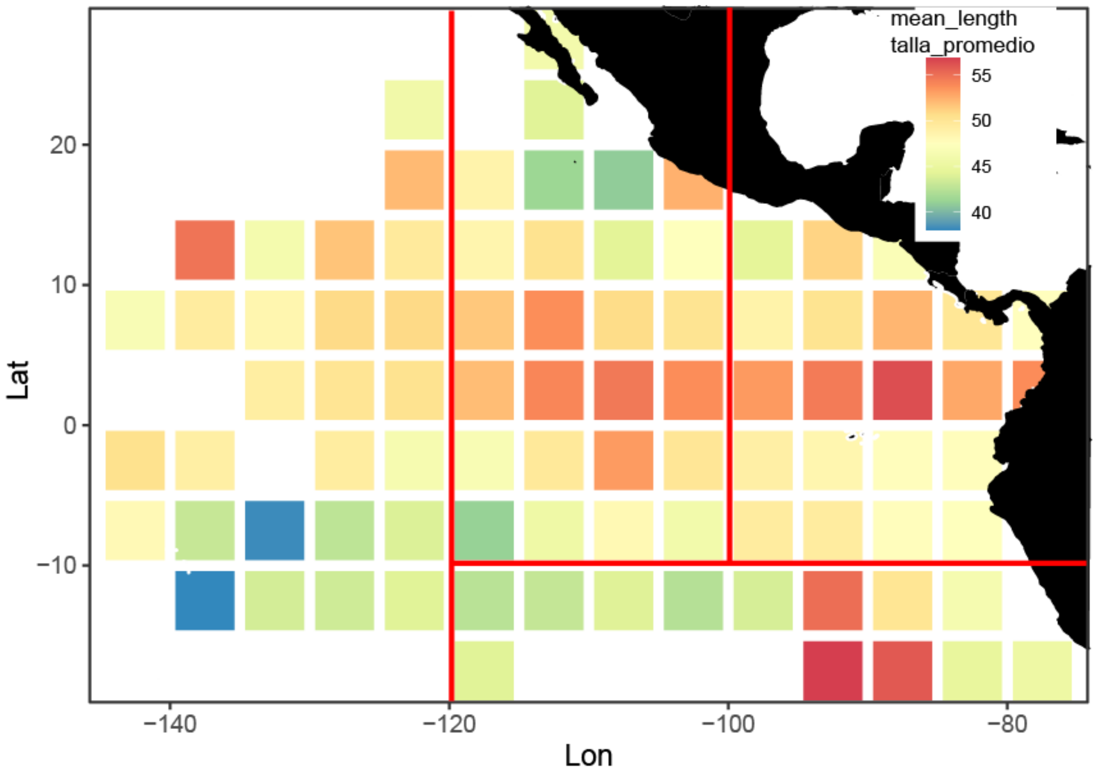

FIGURE B2. Spatial distribution of mean length from 1990-1999 for sets on floating objects with the four fisheries.
FIGURA B2. Distribución espacial de la talla media de 1990 a 1999 para lances sobre objetos flotantes con las cuatro pesquerías.

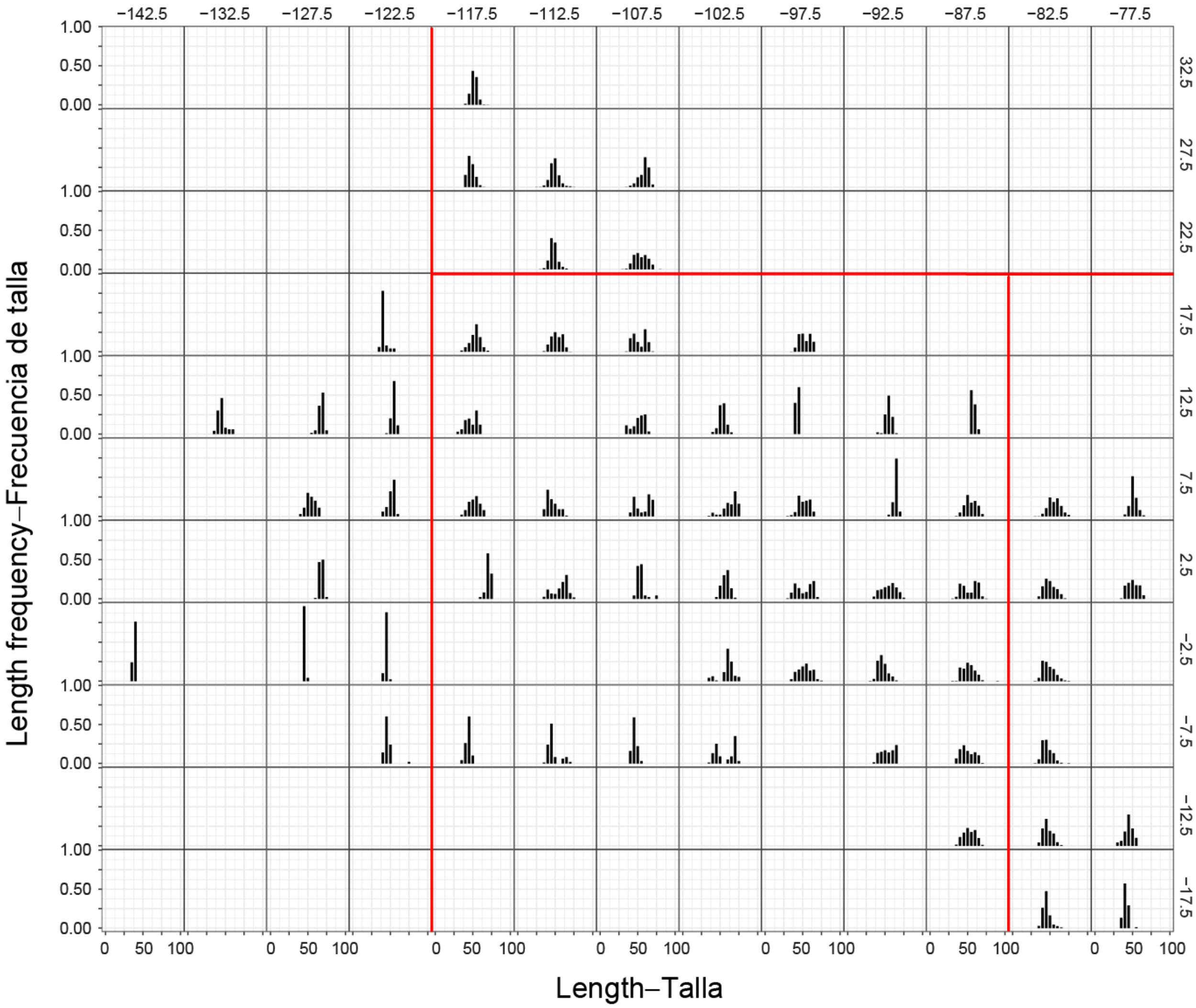

FIGURE B3. Spatial distribution of length-frequency data from 1990-1999 for sets on free swimming schools with the four fisheries. The x and y-axes are labeled at the mid-point of the 5 degree square.

FIGURA B3. Distribución espacial de los datos de frecuencia de talla de 1990 a 1999 para lances sobre cardúmenes libres con las cuatro pesquerías. Los ejes ‘x’ y ‘y’ se encuentran marcados en el punto medio del cuadrángulo de 5 grados.

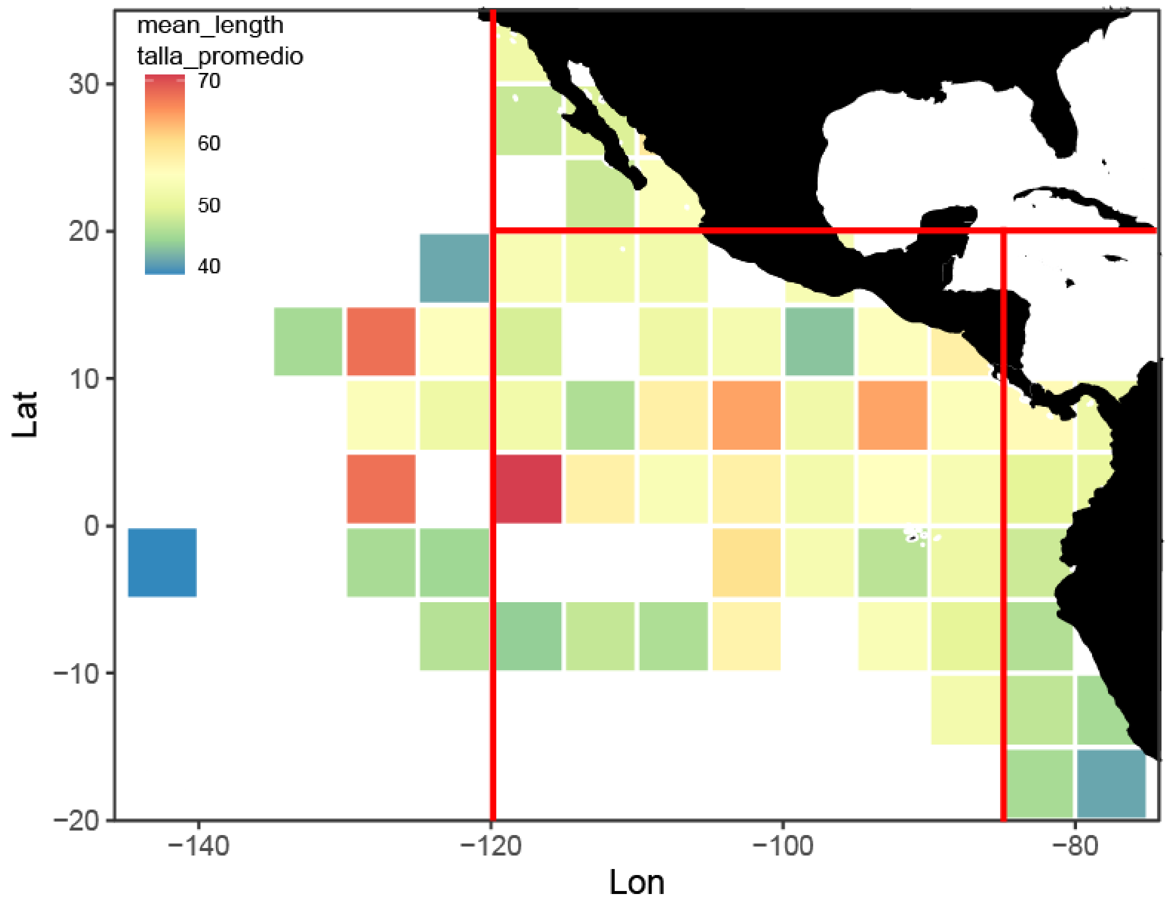

FIGURE B4. Spatial distribution of mean length from 1990-1999 for sets on free swimming schools with the four fisheries.

FIGURA B4. Distribución espacial de la talla media de 1990 a 1999 para lances sobre cardúmenes libres con las cuatro pesquerías.

TABLE B1. Splits and variation explained using data from 1990-1999 for the three methods applied for the two set types and two time periods. See Table 1 for definitions.

TABLA B1. Divisiones y variación explicada con datos de 1990 a 1999 para los tres métodos aplicados para los dos tipos de lance y los dos periodos de tiempo. Ver la Tabla 1 para consultar las definiciones.

OBJ.1990.Well.noYear						OBJ.1990.Well.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	-5	NA	7.79%		Split1	Lat	-5	NA	7.79%
Split2	Lat	5	2	11.18%		Split2	Year	1998	2	12.43%
Split3	Lon	-100	1	12.86%		Split3	Lat	5	2	15.84%
Split4	Lat	0	3	14.48%		Split4	Qrt	2	4	18.42%
Split5	Qrt	1	2	16.07%		Split5	Year	1996	2	20.80%
OBJ.1990.Agg.noYear						OBJ.1990.Agg.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	0	NA	6.68%		Split1	Lat	0	NA	6.68%
Split2	Lat	10	2	9.49%		Split2	Year	1998	2	10.41%
Split3	Qrt	2	2	11.33%		Split3	Year	1996	1	13.28%
Split4	Lon	-110	1	13.05%		Split4	Lat	5	3	15.70%
Split5	CQrt	14;23	2	14.71%		Split5	Qrt	2	5	17.84%
OBJ.1990.Std.noYear						OBJ.1990.Std.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	-5	NA	3.42%		Split1	Lat	-5	NA	3.42%
Split2	Lat	5	2	6.51%		Split2	Lat	5	2	6.51%
Split3	Lon	-95	1	8.36%		Split3	Lon	-95	1	8.36%
Split4	Lon	-85	2	9.66%		Split4	Year	1996	1	9.91%
Split5	Lat	10	5	10.40%		Split5	Lon	-85	3	11.21%

NOA.1990.Well.noYear						NOA.1990.Well.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	5	NA	3.81%		Split1	Lat	5	NA	3.81%
Split2	Lon	-110	2	8.39%		Split2	Lon	-110	2	8.39%
Split3	Lon	-85	1	11.41%		Split3	Lon	-85	1	11.41%
Split4	Lon	-80	4	14.31%		Split4	Lon	-80	4	14.31%
Split5	Lat	20	3	16.61%		Split5	Lat	20	3	16.61%
NOA.1990.Agg.noYear						NOA.1990.Agg.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	0	NA	2.82%		Split1	Lat	0	NA	2.82%
Split2	Lon	-110	2	5.05%		Split2	Year	1991	2	5.21%
Split3	Lat	5	2	9.30%		Split3	Lon	-110	3	7.61%
Split4	Lon	-85	1	11.12%		Split4	Lat	5	3	11.01%
Split5	Lon	-105	1	14.08%		Split5	Year	1990	1	13.11%
NOA.1990.Std.noYear						NOA.1990.Std.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lat	5	NA	4.34%		Split1	Lat	5	NA	4.34%
Split2	Lon	-110	2	7.05%		Split2	Lon	-110	2	7.05%
Split3	Lon	-85	1	9.36%		Split3	Lon	-85	1	9.36%
Split4	Lon	-80	4	11.55%		Split4	Lon	-80	4	11.55%
Split5	Lat	20	3	13.62%		Split5	Lat	20	3	13.62%

APPENDIX C. INCLUDING YEAR AS A PREDICTOR

In all cases, when the data are standardized by dividing by the year-quarter average, year is either first chosen in the same step as when the data are not standardized or at a later split (compare Table 1 with Table C1).

TABLE C1. Splits and variation explained using data from 2000-2019 for the three methods applied for the two set types when Year is included a as a predictor. See Table 1 for definitions.

TABLA C1. Divisiones y variación explicada con datos de 2000 a 2019 para los tres métodos aplicados para los dos tipos de lance cuando se incluye el año como predictor. Ver la Tabla 1 para consultar las definiciones.

OBJ.2000.Well.Year						NOA.2000.Well.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	-115	NA	7.12%		Split1	Lon	-120	NA	11.38%
Split2	Year	2001	2	11.36%		Split2	Lon	-85	2	16.81%
Split3	Lat	-10	3	13.25%		Split3	Lat	20	2	21.78%
Split4	Year	2003	1	14.74%		Split4	Lat	0	4	25.07%
Split5	Year	2006	5	15.75%		Split5	Year	2005	2	26.65%
OBJ.2000.Agg.Year						NOA.2000.Agg.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	-115	NA	8.11%		Split1	Lon	-125	NA	6.60%
Split2	Year	2001	2	12.53%		Split2	Lat	-10	2	11.63%
Split3	Year	2003	1	14.85%		Split3	Lat	15	3	15.03%
Split4	Lat	-10	4	16.36%		Split4	Year	2005	3	18.30%
Split5	Year	2013	2	17.40%		Split5	Year	2016	5	19.82%
OBJ.2000.Std.Year						NOA.2000.Std.Year				
	Key	Value	Cell	Var_explained			Key	Value	Cell	Var_explained
Split1	Lon	-120	NA	5.82%		Split1	Lon	-120	NA	6.45%
Split2	Lat	-10	2	7.63%		Split2	Lon	-85	2	9.63%
Split3	Lon	-100	3	8.84%		Split3	Lat	20	2	14.14%
Split4	Lat	-5	3	9.56%		Split4	Lat	0	4	15.79%
Split5	Year	2002	5	10.07%		Split5	Year	2015	3	16.65%