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PROGRESS REPORT ON THE DEVELOPMENT OF POSTSTRATIFIED ESTIMATORS OF TOTAL CATCH FOR THE PURSE-SEINE FISHERY PORT-SAMPLING DATA

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1. SUMMARY

This document summarizes progress in the evaluation of the areas used in stock assessments and in poststratification of the port-sampling data for estimating total catches by species. The focus of the work to date has been on purse-seine sets on tunas associated with dolphins. A multivariate regression tree approach was used to simultaneously analyze spatial-temporal pattern in length-frequency distributions and annual trends in catch per unit of effort (CPUE). The four-area stratification that was obtained from this analysis shows similarities to the stock assessment areas currently in use. The preliminary evaluation of poststratification methods for total catch estimation was based on the use of linear and generalized linear models to study spatial and temporal variability in average weight and species count data. The results of these analyses suggest that an estimator of total catch with somewhat fewer strata than that currently in use may be reasonable. Future work will include a sensitivity analysis of the spatial stratification for stock assessment, and additional analysis of poststratification definitions for catch estimation, as well as estimates of variance of total catch.

2. INTRODUCTION

Stratification is used in stock assessment to address differences in stock and fishery dynamics. In general, the fisheries data (catch, CPUE, and age/size-composition data) are stratified (after data collection) to support the assumption that fishery-related parameters (catchability and selectivity) are constant over time. Stratification also can be used during data collection to guard against skewed sample allocations (which might lead to bias) and to minimize variance of the estimators of population totals (*e.g.*, Holt and Smith 1979; Thompson 1992). Thus, the goals of stratification for stock assessment and data collection are often in agreement. However, they may differ if the characteristics of the fisheries have changed over time.

Presently, tuna stock assessment for all tuna species in the eastern Pacific Ocean (EPO) (*e.g*., Aires-da-Silva and Maunder 2010; Aires-da-Silva and Maunder 2012a; Aires-da-Silva and Maunder 2012b) uses large areas formed by aggregating the spatial strata used in the collection of port-sampling data (*e.g*., Figure 1a-b). However, as fisheries evolve over time, it is desirable to consider alternative spatial partitions of the EPO. For example, the purse-seine fishery on floating objects in the EPO has expanded considerably offshore since the early 1990s (Watters 1999). By contrast, the sampling strata used for surface fisheries in the EPO were primarily developed in the late 1960s (Suter 2010, and references therein) when the fishery was more coastal (Watters 1999). The fishery at that time was dominated by yellowfin and skipjack tuna catches by purse-seiners setting on tuna associated with dolphins and tuna in unassociated schools, and by pole-and-line vessels. Although these sampling strata were refined in the late 1990s (Suter 2010), it is worthwhile to reevaluate their utility with the current fisheries, particularly for use in stock assessment for fisheries with a strong offshore component, such as the purse-seine fisheries on floating objects and on dolphins.

Poststratification (*e.g*., Holt and Smith 1979; Valliant 1993) is a technique used in data analysis to group samples, after the data have been collected, when estimates of population totals are desired for groups whose definitions were not expressly part of the data-collection protocol. A general approach for selecting a poststratified estimator for total catch was presented in Lennert-Cody *et al*. (2011). This document describes the progress in the development of options for defining both areas for stock assessment and poststrata for total catch estimation within those areas. To date this work had focused on the analysis of port-sampling data collected during 2000-2011 for sets on dolphins by size-class 6 (greater than 363 metric tons carrying capacity) vessels for the external review of IATTC yellowfin tuna assessment methods and assumptions in October 2012. This document is organized as follows: Section 3: background information on data collection and poststratification; Section 4: preliminary evaluation of stock assessment areas; Section 5: preliminary evaluation of poststrata; Section 6: work to be undertaken in preparation for the external review.

3. BACKGROUND

3.1. Data collection

Data on the species and size composition of the catches of tuna by purse-seine vessels are collected when vessels arrive in port to unload (Tomlinson 2004; Suter 2010). To ensure that the samples collected are representative of the entire fishery, categories, or ‘strata’, have been established to guide sample collection. These sampling strata are defined by the location of fishing (13 areas, Figure 1a), the month of fishing and the mode of fishing (six modes, based on purse-seine set type and size of vessel), for a total of 936 possible strata. Not all strata have fishing activity in any given year. Samples are collected by stratum according to a ‘two-stage’ approach, where the wells of a vessel are the first stage, and the fish within a well are the second stage. Because the number of wells in a stratum is not known in advance and because some vessels may unload in ports where logistics make sampling prohibitively difficult, wells to be sampled are selected opportunistically. However, a well is sampled only if all the catch it contains is from the same sampling stratum (*i.e*., same area, month and fishing mode). Over the course of a year, unequal numbers of wells will be sampled per stratum, and not all strata with fishing activity can be sampled due to logistic complications and the level of sampling resources. Nonetheless, as regards yellowfin in dolphin sets, sampling has generally been proportional to the level of fishing effort and catch (Figure 2).

Once a well of a vessel has been selected to be sampled, individual fish are sampled from the well as the catch is unloaded. A number of fish of each species (typically 50) are measured for length. From the same well, and independently of the measured fish, several hundred fish are counted for species composition. The fish sampled from the well are selected one at a time, from an opportunistically established starting point, as circumstances permit. Depending on the port of unloading, some well catches may be sorted by species and weight category before the catches are accessible to IATTC staff for sampling. Catches from these types of unloadings are therefore sampled slightly differently; details of the port-sampling data collection procedures can be found in the appendix of Suter (2010).

3.2. Spatial resolution of the port-sampling data

The feasibility of modifying the stock assessment areas and/or implementing a poststratified estimator for total catch depends in part on the spatial resolution of both the total landed catch (for all species combined) and of the port-sampling data. The total landed catch is allocated to the sampling strata using information from observer data and vessel logbooks. Observer and logbook spatial information is recorded in terms of latitude and longitude, with a coarsest resolution of 5° area (unless completely unavailable). Therefore, the total landed catch generally will be known equally well with respect to the spatial sampling strata as for any spatial poststratification that is similarly derived from combinations of 5° areas.

If the spatial poststrata are large, it is anticipated that most, if not all, port-sample spatial information will be known to the spatial poststratum level. Since 2000 both the sampling area and the 5° area were recorded for most samples. A comparison of the 5° areas of port samples to the actual positions of the sets whose catches went into the sampled wells indicates that about 81% of all samples from 2000-2011 were in agreement with actual set positions at the 5°-area level, and about 97% of all samples were within one 5° area of the 5° area of the corresponding set. Thus, poststratification appears feasible for the 2000-2011 data as long as stock assessment areas and poststrata for estimation of total catch are constructed from combinations of 5° areas.

3.3. Estimators of total catch by species

The current estimator of total catch by species (Tomlinson 2004) has the general form of a ratio-type estimator of the stratum total (*e.g.*, Thompson 1992) based on the amount of the catch in sampled wells. The total estimated annual catch (in weight) of species i (i = 1,…, 3 for yellowfin, skipjack and bigeye tunas) in sampling stratum h is given by:

$$\widehat{W}_{hi} = W_h \hat{p}_{hi}$$

$$= W_h \left[\frac{\sum_{j=1}^{q} W_{hj} \left(\dfrac{\dfrac{w_{hij}}{m_{hij}} \dfrac{n_{hij}}{n_{h.j}}}{\sum_{i=1}^{3} \dfrac{w_{hij}}{m_{hij}} \dfrac{n_{hij}}{n_{h.j}}} \right)}{\sum_{j=1}^{q} W_{hj}} \right]$$

$$= W_h \left[\frac{\sum_{j=1}^{q} W_{hj} \left(\dfrac{\overline{w}_{hij} f_{hij}}{\sum_{i=1}^{3} \overline{w}_{hij} f_{hij}} \right)}{\sum_{j=1}^{q} W_{hj}} \right]$$

$$= W_h \frac{\left[\sum_{j=1}^{q} W_{hj} \cdot g(\overline{w}_{hij}, f_{hij}, i = 1, \dots, 3) \right]}{\left[\sum_{j=1}^{q} W_{hj} \right]} \qquad (1)$$

where W_h is the total weight of all species combined in sampling stratum h (assumed known), $\hat{p}$ is the estimate of the species fraction (derived from weight) in the stratum, W_{hj} is the total weight of all species combined in the j^{th} well sampled from sampling stratum h (also assumed known), j=1, …, q wells sampled, w is the sum of the weights of fish measured (converted from lengths), m is the number of fish measured, n is the number of fish counted for species composition, and g represents the function of the sample means ($\overline{w}$) and sample species fractions (f) shown in curved brackets (*i.e.*, a function of only the

w's, m's and n's).

Two candidate poststratified estimators of catch by species in poststratum c have been proposed which preserve the specific function g of equation (1) (Lennert-Cody *et al*. 2011). The first candidate estimator of total species catch, $\widehat{W}_{ps-I;\,ci}$, was developed based on the assumption that both the sampling strata and the poststrata contain important information with respect to the estimation of catch (following the general approach of Valliant (1993)). In other words, within a poststratum c, the distinction between sampling strata, or fractions thereof, needs to be preserved such that effectively poststratum c is further subdivided by the sampling strata $\{h\}$. This estimator of total catch of species i in poststratum c is the sum of catch estimates of species i from entire sampling strata h, or parts thereof, that belong to poststratum c:

$$\widehat{W}_{ps-I;\,ci} = \sum\nolimits_{h:\, h\cap c} W_{h\cap c} \frac{\left[\sum_{j\in h\cap c} W_{hj} \cdot g(\dots)\right]}{\left[\sum_{j\in h\cap c} W_{hj}\right]} \qquad (2)$$

where the outer summand is over sampling strata h that intersect poststratum c, $h \cap c$ refers to the region of sample stratum h that is also in poststratum c, and $W_{h\cap c}$ is the total fishery catch in that region. For example, in Figure 1d is an example of four spatial poststrata (A-D). It can be seen that sampling areas 6, 11, and 12 would be bisected to create the inshore poststratum D, whereas sampling areas 7 and 13 are totally contained within poststratum D. $\widehat{W}_{ps-I;\,ci}$ will prove problematic if there are many h for which each $h \cap c$ is small and contains few or no sample data.

The second candidate estimator was developed by disregarding the sampling strata. This results in a poststratified estimator identical in form to equation (1), but with W_h and W_{hj} replaced by W_c and W_{cj}, respectively. In other words, this second poststratified estimator of the total catch of species i in poststratum c, $\widehat{W}_{ps-II;\,ci}$, is given by:

$$\widehat{W}_{ps-II;\,ci} = W_c \frac{\left[\sum_{j=1}^{q^*} W_{cj} \cdot g(\dots)\right]}{\left[\sum_{j=1}^{q^*} W_{cj}\right]} \qquad (3)$$

where q^* is the number of samples in poststratum c.

The analysis presented in Section 5 provides a preliminary comparison of the utility of equation (2) *versus* equation (3) for hypothetical yellowfin tuna stock assessment areas (for dolphin sets) obtained from a multivariate regression tree method for simultaneous analysis of spatial patterns in length-frequency distributions and annual trends in CPUE (Section 4).

4. PRELIMINARY ANALYSIS OF THE STOCK ASSESSMENT AREAS

A multivariate regression tree analysis, developed for simultaneous analysis of spatial-temporal patterns in length-frequency distributions and in trends in nominal catch-per-unit-effort (CPUE) (Lennert-Cody *et al*., submitted), was applied to the data for yellowfin tuna in dolphin sets.

4.1. Data

The method was applied to the port-sampling length data (2000-2011), and to catch and effort data obtained from observers and logbooks (1975-2011). The port-sampling length data were pre-processed in the following manner (see also Lennert-Cody *et al*. 2010). First, all sample data were raised to the well catch. In this way samples from both non-sorted and species/weight-category sorted unloadings could be used in the analysis. Second, to be consistent with the yellowfin tuna stock assessment model, which has a quarterly time step, the 1-cm length intervals were 'grown' or 'shrunk' to the middle month of each quarter (January-March, April-June, July-September, October-December) by adding or subtracting a monthly length increment, where applicable (the middle month of each quarter requires no adjustment). It was assumed that, from year to year for the same quarter, the length composition remained stable, however, within quarters the length adjustment was necessary because length-frequency samples taken from the same population but in different months of the same quarter could appear to represent different populations due solely to growth. The monthly length increments used to grow or shrink fish were obtained from the Gompertz growth model of Wild (1986). Finally, counts of fish in 1-cm length intervals were grouped into the following 11 larger intervals: ≤ 58 cm, 59-69 cm, …, 136-146 cm, 147-159 cm, and ≥ 160 cm. The proportions of yellowfin for each sample in these larger intervals was used as one of the multivariate response variables for the simultaneous tree analysis.

CPUE trends were estimated from observer and logbook data on catch and effort following the method outlined in Lennert-Cody *et al*. (submitted). First, nominal yellowfin CPUE (catch per day fishing) for each month in each 5° area was computed, following the same method as is used in the stock assessment (Maunder *et al*. 2010) . Then, for each quarter-5° area, the temporal trend (over years) in nominal CPUE was summarized using penalized cubic regression splines (Wood 2006). The vector of estimated spline coefficients for each quarter-5° area (excluding the coefficient of the constant term) was used as the other multivariate response variable for the simultaneous tree analysis.

4.2. Description of the simultaneous tree method

The simultaneous regression tree was built by recursively partitioning the length-frequency distribution data and CPUE trend coefficients data into smaller and smaller subgroups that were more homogeneous, following the general idea of classical regression tree analysis (Breiman *et al*. 1984). This multivariate tree method uses the 5° latitude, the 5° longitude and the quarter of fishing as predictor variables. For each binary partition ('split') of the two data sets into subgroups, the predictor variable that defines the split (and its specific value) was chosen so as to maximize a combined measure of reduction in "impurity". The measures of impurity used were different for the two data types. Impurity for the length-frequency vectors of proportions was measured using the Kullback-Leibler divergence. Impurity for the vectors of CPUE trend coefficients was measured with a modified version of the classic squared-error loss function.

The simultaneous regression tree that is built by this method reflects agreement among competitor splits that are common to both data types. In general, when building a regression tree, there are split-variable values not selected at each step that may be nearly as useful ('competitor' splits). At each step the simultaneous tree procedure identifies similar competitor splits within each data set that are common to both data sets.

4.3. Results

The spatial stratification that resulted from applying the simultaneous regression tree approach to the yellowfin data is shown in Figure 1c. The main branches of the simultaneous tree were spatial partitions of the data, suggesting that, overall, spatial structure may be more important in these data than temporal (quarterly) structure. The simultaneous tree divides the EPO into two areas, north and south of 5°N; the former is further partitioned latitudinally at 20°N, and the latter into an inshore and an offshore area longitudinally at 95°W. The simultaneous tree areas (Figure 1c) show similarities to the current stock assessment areas (Figure 1b), which include a north-south partition of the EPO between 0° and 5°N and an inshore-offshore partition of the southern region at 80°-85°W. Also, the spatial stratification that would have been obtained if only the length-frequency data had been used in a multivariate tree analysis (Figure 1e) has very similar structure to the current three stock assessment areas (Figure 1b).

5. PRELIMINARY ANALYSIS OF POSTSTRATIFICATION

5.1. Spatial and temporal stratifications considered

Four spatial stratifications and two temporal stratifications were considered in this preliminary analysis. The first spatial stratification was the three-area stratification presently used for stock assessment (Aires-da-Silva and Maunder 2012a) ("stock assessment areas"; Figure 1b); the second was the four-area simultaneous-tree stratification described in Section 4 above ("tree areas"; Figure 1c); the third was the

13-area stratification used for the port-sampling data collection (“sample areas”; Figure 1a); and the fourth was a combination of the simultaneous-tree analysis areas and the port-sampling areas (“sample-tree areas”; Figure 1d). The two temporal stratifications were month and quarter.

5.2. Methods of analysis

Two types of models were fitted to the port-sampling data to evaluate the explanatory ability of combinations of spatial and temporal strata. The sample data from 2000-2011 for average weights and species counts that were used in these analyses are components used to evaluate g (*i.e.*, are the basis for $\overline{w}$ and f of equation 1).

For average weight, several levels of spatial and temporal complexity were evaluated with the following linear models:

i) $sqrt(\overline{w}_j)$ = overall constant + stock assessment area effect + error
ii) $sqrt(\overline{w}_j)$ = overall constant + tree area effect + error
iii) $sqrt(\overline{w}_j)$ = overall constant + sample area effect + error
iv) $sqrt(\overline{w}_j)$ = overall constant + sample-tree area effect + error
v) $sqrt(\overline{w}_j)$ = overall constant + month effect + error
vi) $sqrt(\overline{w}_j)$ = overall constant + month effect + stock assessment area effect + error
vii) $sqrt(\overline{w}_j)$ = overall constant + month effect * stock assessment area effect + error
viii) $sqrt(\overline{w}_j)$ = overall constant + quarter effect * stock assessment area effect + error

The square root transformation (“*sqrt*”) was used to improve assumption of normality of the data for the j^{th} sample (per inspection of quantile-quantile plots). ‘*’ denotes a model with main effect and first-order interactions; “stock assessment area effect” refers to the areas shown in Figure 1b; “tree area effect” refers to the areas shown in Figure 1c; “sample area effect” refers to the areas shown in Figure 1a; “sample-tree area effect” refers to the areas shown in Figure 1d. Each model was fitted separately to the data for each year, with weights equal to the individual-well total catch amounts, to be consistent with the ratio estimator weighting (equation 1). Time-area interactions were only evaluated for the stock assessment spatial stratification because of the sparseness of the data at the time step of a month (even with only three areas, some month-area combinations had no sample data). The Akaike Information Criterion (AIC; Burnham and Anderson 2002) was computed for each model, and the difference in AIC between each model and the model with the lowest AIC ($\Delta AIC = AIC - AIC_{min}$, Burnham and Anderson 2002) was used to compare models. Models that performed similarly to model with the lowest AIC will have a low ΔAIC value (~2 or less), whereas those that performed poorly by comparison will have a high ΔAIC value (~ > 10). In addition, for models (i)-(iv), the adjusted R^2 was also computed.

The same type of evaluation was done for species composition by fitting a logistic regression model to the sample counts of yellowfin and skipjack. In this analysis the data were limited to samples from wells for which the catch had not been sorted by species and/or weight categories during unloading (although future analyses may attempt to include the data of these types of samples). A binomial response was used instead of a multinomial response, because no bigeye tuna occurred in these sample data. Only about 15% of the samples contained skipjack. As a result, the sample species fractions (f) were mostly close to 1 (yellowfin) or 0 (skipjack), which complicates modeling these data with standard techniques. For this reason, in this preliminary analysis, only the following spatial models were fitted to the species count data:

i) $\log(r_j/[1\text{-}r_j])$ = overall constant + stock assessment area effect
ii) $\log(r_j/[1\text{-}r_j])$ = overall constant + tree area effect
iii) $\log(r_j/[1\text{-}r_j])$ = overall constant + sample area effect
iv) $\log(r_j/[1\text{-}r_j])$ = overall constant + sample-tree area effect

where r_j is the probability that a fish drawn from the j^{th} well was a skipjack. As with the models for average weight, these generalized linear models were fitted with weights equal to the individual-well catch amounts.

5.3. Results and discussion

Results of fitting the linear models to average weight for yellowfin are shown in Tables 1 and 2. These preliminary results can be summarized as follows:

1) For most years, spatial structure appears to dominate over temporal structure. ΔAIC for models with month only generally were larger than models with spatial strata only, and models with finer spatial stratification had often had lower ΔAIC than models with coarser spatial stratification and month (quarter) interactions. These models are, of course, not exhaustive in terms of the combinations of spatial and temporal effects.
2) For seven of the 12 years (2004-2010), there was little difference in the performance (ΔAIC < 3) of the sampling area stratification (model (iii)) and the sample-tree area stratification (model (iv)), and in only two years (2002-2003) did the sample-tree area stratification clearly outperform the sample area stratification (ΔAIC >> 10). (The adjusted R^2 values were very similar for the two types of models in all years). However, there appears to be a more statistically significant spatial structure in the average weight data than was captured by either the three stock assessment areas or the four tree areas (models (i) and (ii)), indicating that, with respect to estimating total catch, some further subdivision of those areas may prove useful.
3) In terms of adjusted R^2, in many years one or the other of the stock assessment (model (i)) and tree (model (ii)) stratifications performed fairly well compared to the sample area stratification (model (iii)). This suggests that, by adding a few sub-areas to the stock assessment or tree spatial stratifications, similar levels of variability may be explained without the complication of creating strata so small that they are unlikely to contain any sample data.

The overall results from the logistic regression models for species counts were similar to those of the linear models for average weight and are not shown. However, there was more interannual variability, and in one year, logistic models (iii)-(iv) failed to converge properly. This appears to be due to model instability caused by the predominance of yellowfin in dolphin-set samples. A classification algorithm for presence/absence of skipjack in the sample, fitted to the data for all years combined, but with year as an added predictor (in addition to 5° latitude, 5° longitude and month), showed only a 5% reduction in prediction error from the stock assessment areas compared to the tree or sampling areas, when the relative costs of the two types of misclassification errors were balanced. This suggests that the logistic regression results may be undesirably sensitive to skewed species fractions, and that other analysis techniques are needed.

In summary, these preliminary results suggest that an estimator with the level of spatial detail of equation (2) may not be necessary but that an estimator of the form of equation (3) may be not adequate because spatial variability remains to be explained in components of g beyond the level of the stock assessment or tree areas. Future work will decide upon a modification of equation (2) that is both practical (fewer sub-areas) yet captures more variability in the data than equation (3).

In the linear model analyses the effect of fish growth on the average weight was not considered when quarter was taken as a predictor (*cf.* simultaneous tree analysis of length-frequency distributions). Future analyses can take into consideration fish growth by repeating analyses on average weights of fish first grown/shrunk to a common time point of the year (quarter).

6. FUTURE WORK

The following analyses of dolphin sets during 2000-2011 will be undertaken in preparation for the IATTC External Review in October 2012:

1) A sensitivity analysis of the simultaneous regression tree results will be conducted in order to explore and prioritize other candidate stock assessment stratifications produced by that method. This

sensitivity analysis will include an evaluation of the effect of interannual variability in the length-frequency data on the stratification results.

2) An analysis of sub-stratifications (by area, time period) *within* each candidate stock assessment area (from (1) or elsewhere) will be conducted with the port-sampling data. Several types of analyses will be carried out in order to provide guidance on spatial-temporal sub-stratification. Regression tree analyses of the sample average weights, weighted by the total well catch, will be performed within each larger area. These types of analyses may not prove practical with respect to skipjack in all stock assessment areas because of the low level of occurrence of skipjack in dolphin sets. Therefore, the regression tree results will be compared to results of classification algorithms applied to data on the presence/absence of skipjack in the samples. The dependent variables used in these analyses will be 5° latitude and longitude, and month (quarter) of fishing. These analyses will be done with the data of all years, combined and separately by year.

3) The results of (2) are expected to produce candidate sub-strata within stock assessment areas that have irregular boundary definitions. Using multiple regression (or generalized linear models), the irregular sub-strata from (2) will be compared to similar but regularized sub-strata definitions, as well as to regularizations that are derived from collapsing sample areas and/or months within each stock assessment area. In addition, if sub-strata from (2) do not include a temporal aspect, these techniques can be used to evaluate sub-strata with a forced quarterly time step (*e.g.*, to be consistent with the stock assessment modeling). The various linear and generalized linear model sub-strata will be compared within each stock assessment area with AIC weights, statistics specifically designed for non-nested model comparisons (*e.g.*, Vuong 1989; Clarke 2007) and cross-validation. The results of (2) and (3) will be used to select a limited number of sub-strata within each stock assessment area.

4) Based on the results of steps (1)-(3), nearest neighbor substitution rules will be developed, to be used for estimating catch species composition for sub-strata that have catch but no sample data in a particular year.

5) Total catch by species will be estimated using the ‘best’ sub-stratification and several alternatives from (3) in order to investigate the magnitude of the effects of sub-stratification on the estimation of catch species composition. Estimates will be compared to the total catch estimates derived from the current stratification (13 sampling areas x 12 months).

6) Approximate variance estimates for the total catch will be computed using a bootstrap ‘half-sample’ procedure (Efron 1982) for the alternatives identified by (3), as well as for the current stratification. Resampling will be done from the empirical distributions of lengths and species composition, instead of implementing parametric bootstraps. This procedure does not include a finite population correction factor. However, given that the estimated annual level of sampling coverage of the catch during 2000-2010 was roughly 8% (computed as the sum of catch in sampled wells divided by the total fishery catch), this is probably not critical. If time permits, however, other variance estimation procedures will be explored (*e.g.*, resampling procedures for survey data that include a finite population correction; *e.g.*, Sitter 1992).

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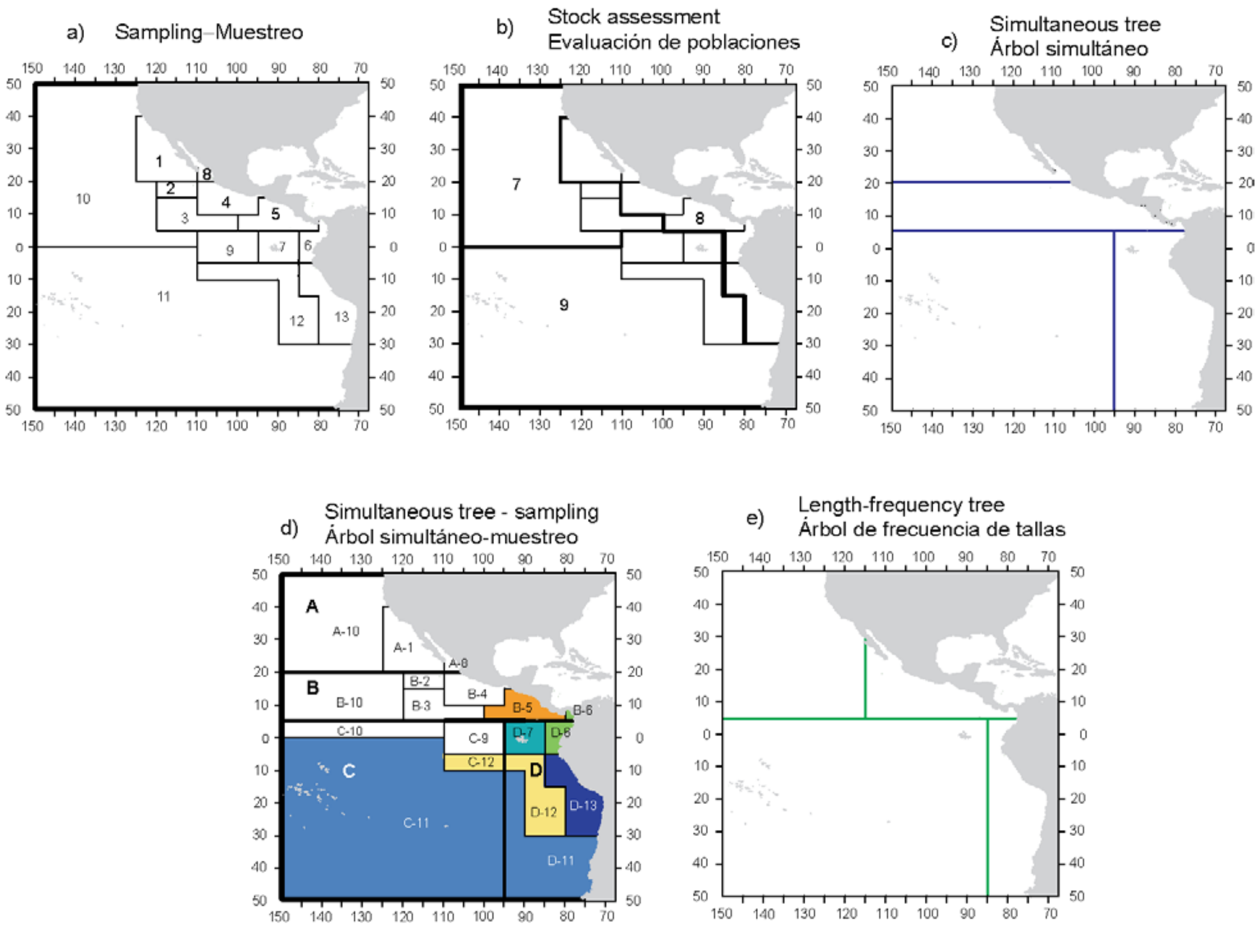

FIGURE 1. a) Sampling areas (Tomlinson 2004) (areas of spatial model (iii) of Section 5); b) stock assessment areas for yellowfin tuna in dolphin sets (thick black lines; Aires-da-Silva and Maunder 2012a) (areas of spatial model (i) of Section 5); c) stratification obtained from the simultaneous tree analysis (areas of spatial model (ii) of Section 5); d) the areas of (c) further divided by the sampling areas (a) (the sampling areas that are partially or totally contained in poststratum D are colored to illustrate sampling areas that cross poststratum boundaries) (areas of spatial model (iv) of Section 5); and e) the four-area spatial stratification obtained from a multivariate regression tree analysis of only the length-frequency data.

FIGURA 1. a) Áreas de muestreo (Tomlinson 2004) (áreas del modelo espacial (iii) de la sección 5); b) áreas de evaluación de la población de atún aleta amarilla en lances sobre delfines (líneas negras gruesas; Aires-da-Silva y Maunder 2012a) (áreas del modelo espacial (i) de la sección 5); c) estratificación obtenida del análisis de árbol simultáneo (áreas del modelo espacial (ii) de la sección 5); d) las áreas de (c) divididas por las áreas de muestreo (a) (se colorean las áreas de muestreo incluidas parcial o totalmente en el posestrato D para ilustrar áreas de muestreo que cruzan límites de posestratos) (áreas del modelo espacial (iv) de la sección 5); y e) la estratificación espacial de cuatro áreas obtenida de un análisis de árbol de regresión multivariable de los datos de frecuencia de talla solamente.

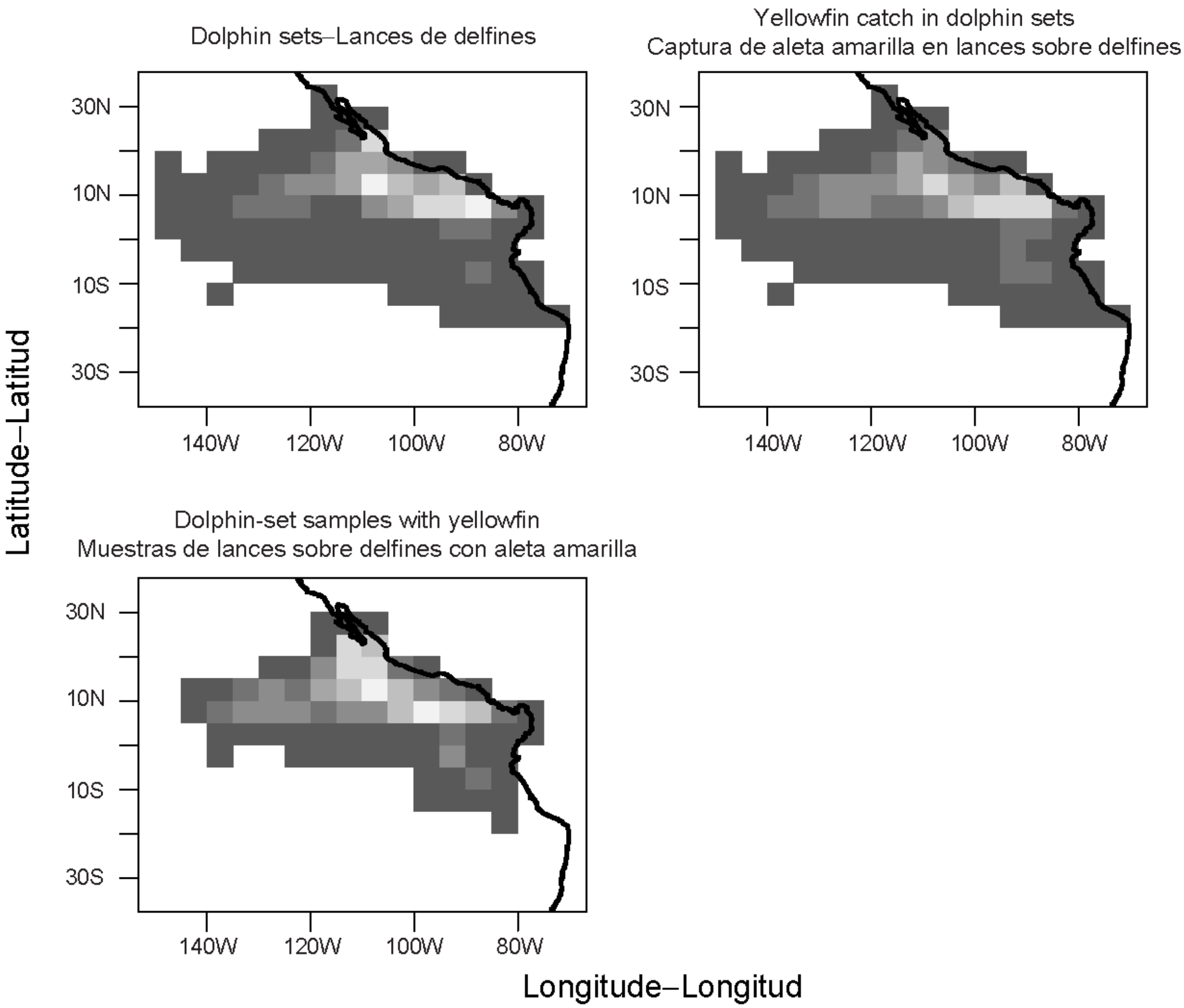

FIGURE 2. Proportions of numbers of dolphin sets, catch of yellowfin tuna in dolphin sets and number of dolphin-set samples with yellowfin, by 5° area (all data pooled over years and months). Grayscale values range from 1% or less (dark gray) to greater than 6% (lightest gray), in increments of 1%.
FIGURA 2. Proporciones del número de lances sobre delfines, captura de atún aleta amarilla en lances sobre delfines, y número de muestras de lances sobre delfines con aleta amarilla, por cuadrángulo de 5° (todos los datos agrupados por años y meses). Los valores en gris van de 1% o menos (gris oscuro) a más de 6% (gris más claro), en incrementos de 1%.

TABLE 1. Adjusted R^2 from the linear model analyses of average weight (Section 5).
TABLA 1. R^2 ajustado de los análisis de modelo lineal del peso promedio (Sección 5).

	Adjusted R^2—R^2 ajustado											
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Stratification (number of samples) Estratificación (número de muestras)	(215)	(300)	(321)	(225)	(145)	(174)	(122)	(131)	(179)	(248)	(266)	(285)
Stock assessment (model (i)) Modelo de evaluación de poblaciones (modelo (i))	0.37	0.37	0.45	0.61	0.45	0.20	0.23	0.51	0.20	0.24	0.25	0.12
Tree (model (ii)) Árbol (modelo (ii))	0.23	0.33	0.49	0.55	0.41	0.38	0.30	0.25	0.23	0.43	0.21	0.26
Sample (model (iii)) Muestra (modelo (iii))	0.50	0.42	0.50	0.70	0.56	0.52	0.34	0.60	0.34	0.58	0.38	0.35
Sample-tree (model (iv)) Muestra-árbol (modelo (iv))	0.50	0.43	0.54	0.74	0.57	0.53	0.36	0.60	0.35	0.58	0.38	0.37

TABLE 2. ΔAIC from the linear model analyses of average weight (Section 5).

	ΔAIC		ΔAIC
2000		2006	
Stock assessment (model (i))	46	Stock assessment (model (i))	12
Tree (model (ii))	90	Tree (model (ii))	1
Sample (model (iii))	6	Sample (model (iii))	1
Sample-tree (model (iv))	6	Sample-tree (model (iv))	0
Month (model (v))	125	Month (model (v))	36
Stock assessment + month (model (vi))	30	Stock assessment + month (model (vi))	7
Stock assessment * month (model (vii))	0	Stock assessment * month (model (vii))	4
Stock assessment * quarter (model (viii))	21	Stock assessment * quarter (model (viii))	7
2001		2007	
Stock assessment (model (i))	45	Stock assessment (model (i))	18
Tree (model (ii))	65	Tree (model (ii))	75
Sample (model (iii))	33	Sample (model (iii))	0
Sample-tree (model (iv))	27	Sample-tree (model (iv))	0
Month (model (v))	166	Month (model (v))	95
Stock assessment + month (model (vi))	10	Stock assessment + month (model (vi))	22
Stock assessment * month (model (vii))	0	Stock assessment * month (model (vii))	16
Stock assessment * quarter (model (viii))	9	Stock assessment * quarter (model (viii))	19
2002		2008	
Stock assessment (model (i))	49	Stock assessment (model (i))	27
Tree (model (ii))	28	Tree (model (ii))	23
Sample (model (iii))	27	Sample (model (iii))	2
Sample-tree (model (iv))	0	Sample-tree (model (iv))	0
Month (model (v))	211	Month (model (v))	69
Stock assessment + month (model (vi))	45	Stock assessment + month (model (vi))	32
Stock assessment * month (model (vii))	33	Stock assessment * month (model (vii))	1
Stock assessment * quarter (model (viii))	25	Stock assessment * quarter (model (viii))	19
2003		2009	
Stock assessment (model (i))	78	Stock assessment (model (i))	140
Tree (model (ii))	109	Tree (model (ii))	70
Sample (model (iii))	32	Sample (model (iii))	0
Sample-tree (model (iv))	0	Sample-tree (model (iv))	2
Month (model (v))	280	Month (model (v))	204
Stock assessment + month (model (vi))	79	Stock assessment + month (model (vi))	130
Stock assessment * month (model (vii))	51	Stock assessment * month (model (vii))	128
Stock assessment * quarter (model (viii))	72	Stock assessment * quarter (model (viii))	119
2004		2010	
Stock assessment (model (i))	26	Stock assessment (model (i))	42
Tree (model (ii))	38	Tree (model (ii))	59
Sample (model (iii))	1	Sample (model (iii))	0
Sample-tree (model (iv))	0	Sample-tree (model (iv))	0
Month (model (v))	123	Month (model (v))	117
Stock assessment + month (model (vi))	43	Stock assessment + month (model (vi))	31
Stock assessment * month (model (vii))	42	Stock assessment * month (model (vii))	17
Stock assessment * quarter (model (viii))	32	Stock assessment * quarter (model (viii))	36
2005		2011	
Stock assessment (model (i))	85	Stock assessment (model (i))	88
Tree (model (ii))	40	Tree (model (ii))	40
Sample (model (iii))	3	Sample (model (iii))	9
Sample-tree (model (iv))	0	Sample-tree (model (iv))	0
Month (model (v))	95	Month (model (v))	81
Stock assessment + month (model (vi))	68	Stock assessment + month (model (vi))	57
Stock assessment * month (model (vii))	80	Stock assessment * month (model (vii))	51
Stock assessment * quarter (model (viii))	63	Stock assessment * quarter (model (viii))	80