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EVALUATION OF ASPECTS OF THE IATTC PORT SAMPLING DESIGN AND ESTIMATION PROCEDURES FOR TUNA CATCHES

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CONTENTS

SUMMARY

The representativeness of IATTC port sampling data collected for purse seiners and the estimation procedures for surface fishery catches were explored using descriptive data analysis techniques and simulations. Analyses and simulations are based on port sampling data and fisheries observer data collected since 2000. The results of the descriptive analyses suggest that catches from purse-seine sets that were loaded into wells later sampled by the port sampling program tended to be greater than catches from sets that were loaded into unsampled wells. The percentage of bigeye tuna in the catch from floating-object sets loaded into sampled wells was sometimes greater than that of sets loaded into unsampled wells, but the results were not strongly consistent across years nor across test statistics. Significant differences were mostly positive, suggesting a greater percentage of bigeye tuna from floating-object sets loaded into sampled wells. However, the magnitude of the differences were small. Variability in average fish length within well samples from purse-seine vessels was generally found to be much less than the variability in average length among wells. Simlarly, the variability among wells in the percentage of bigeye tuna catch from purse-seine sets on floating objects exceeded that within well samples. With regard to the estimation procedures for surface fishery catches, simulations for bigeye tuna catch indicate that the average bias of the estimated catch is approximately an order of magnitude less than the average standard deviation. A conclusion of the analyses is that, with a fixed budget of sampling personnel time, emphasis should be given to sampling more wells rather than increasing the sampling within wells.

1. INTRODUCTION

Assessments of the status of tuna stocks are dependent on representative samples of the size distribution of the catch, as well as unbiased estimates of fishery totals. Sampling of tuna lengths and species composition of the catch at the time of vessel unloading is a commonly-used method of data collection (Fonteneau 2008; Lawson 2008). An advantage of this in-port sampling is its practicality. Disadvantages include difficulties associated with obtaining random samples due to logistical constraints, and requirements associated with stratification (only vessel wells that contain catches from the same strata are sampled). To estimate fishery totals, ratio-type estimators are often employed. However, these types of estimators are biased (*e.g*. Cochran 1977), the amount depending on the sample size.

A number of aspects of port-sampling programs and estimation procedures of the Inter-American Tropical Tuna Commission (IATTC) have been reviewed (*e.g*. Tomlinson *et al*. 1992 and references therein; 2002). In this document we present the preliminary results of further investigation of the properties of the in-port sampling design and estimation procedures used by the IATTC since 2000. Two types of analyses were undertaken: an analysis of the representativeness of the port sampling data ('Descriptive analysis'), and a simulation to evaluate the bias and variance of the estimation scheme for the fraction of bigeye tuna in the catch ('Simulation'). The representativeness of the port sampling data was studied in two ways. The first was an analysis of fishery observer data to compare catch amounts and species composition of sets that were loaded into vessel wells which were later sampled by the port-sampling program to those of sets that were loaded into wells which were not later sampled. The second was an analysis of the port-sampling data itself, to compare variability among sampled wells to variability within sampled wells for average length and species composition. Investigations of species composition were limited to the percentage of bigeye tuna in floating-object sets because of ongoing management concerns regarding the status of this stock (Aires-da-Silva and Maunder 2008).

2. DATA

2.1. Descriptive analysis

2.1.1. Observer data

The fisheries observer data used in this analysis were collected aboard purse-seine vessels of more than 363 mt of fish-carrying capacity between 2000 and 2007. Observers from the IATTC and national observer programs were placed aboard these vessels to collect data on fishing operations, catches, and bycatches. A description of this observer program can be found in Bayliff (2001). Data were limited to sets made within the eastern Pacific Ocean (EPO).

A comparison of the characteristics of catches of tunas from sets that were loaded into vessel wells that were later sampled as part of the port sampling program ('sampled' sets) and catches from sets that were loaded into vessel wells not later sampled by the port sampling program ('non-sampled' sets) was based on those sets with a retained catch of at least one of the three main tuna species (yellowfin, bigeye, skipjack). (For clarification, the port sampling program samples wells, not sets; wells may contain fish from more than one set.) The numbers of sampled sets in this data set was 5-12%, annually, of the number of non-sampled sets (Table 1). In what follows, we refer to the sum of yellowfin, skipjack and bigeye tunas loaded aboard the vessel as 'tuna catch.' The percentage of bigeye tuna in the catch was computed as the amount of bigeye tuna retained by the vessel divided by the tuna catch, multiplied by 100. The descriptive analysis of the percentage of bigeye tuna in the catch was further limited to floating-object sets.

2.1.2. Port sampling data

The port sampling data used in this analysis were the result of a stratified two-stage sampling design (Tomlinson, 2002; Suter, 2008). Within a purse-seine set type and vessel size class, sampling strata are defined by date and area of fishing (13 areas and 12 months). Although generally opportunistic, sampling at both stages is assumed to approximate simple random sampling. Vessel wells are the primary sampling unit within a stratum, with unequal numbers of wells sampled per stratum. Fish within a vessel's well are the secondary sampling unit. Wells are only sampled if all the catch within the well came from the same stratum. Data used in the descriptive analysis were limited to samples from 2000-2007 for purse-seine vessels with greater than 363 mt fish-carrying capacity.

Details of the sampling instructions given to port samplers can be found in the Appendix of Suter (2008). Briefly, the sampler is to count, independently from measuring, the number of each species in a random sample of several hundred fish. The number of fish counted depends on the number of species believed to be in the well (determined in advance from observer data or the vessel's logbook). Additionally, the sampler randomly removes a number of fish of each species (ideally 50) and measures the fork length to the nearest millimeter. Depending on the port of unloading, fish may be sorted by size and/or species as they are unloaded. These sorted samples are not considered in the descriptive analysis.

Port sampling data used in the descriptive analysis of length-frequency samples were limited to yellowfin tuna from dolphin and unassociated sets, and to bigeye tuna from floating-object sets. Following the recommendations of Hennemuth (1957) for 50-fish samples, only well samples with at least 40 fish measured were included in the analysis. In addition, the analysis was limited to strata (area–month combinations) represented by at least four sampled wells. The average length of the fish in each sample was the average of measured lengths in the sample. In this analysis, samples were not raised to the total well catch.

Because the methods used to estimate total catch (Tomlinson 2002) use the average weight of the fish in the sample, not the average length, the average weight for each sample was also computed and analyzed in the descriptive analysis. Individual lengths were converted to weights, using the formula weight = $a \cdot \text{length}^b$ (Tomlinson 2002). The species-specific coefficients (a, b) are provided in Suter (2008). The average weight for a sample was then the average of these individual weight estimates. As with length, weights were not raised to the total well catch.

Port sampling data used in the descriptive analysis of species composition were limited to samples with a non-zero count for bigeye tuna, and a non-zero count of at least one of the other two main tuna species (samples with estimated counts were excluded). In other words, this was a conditional analysis, conditional on the presence of bigeye tuna and presence of either skipjack or yellowfin tuna encountered during the species composition phase of the port sampling of the well. As with the descriptive analysis of the average lengths, the analysis was limited to strata (area–month combinations) represented by at least four sampled wells. The percentage of bigeye tuna in the sample was computed as the number of bigeye tuna counted divided by the total number of yellowfin, skipjack and bigeye tuna counted, multiplied by 100.

2.2. Simulation

2.2.1. Port sampling data

The port sampling scheme attempts to obtain a species composition estimate from the surface fishery (*i.e.*, excluding catches from the longline fishery) for each stratum with catch, where catch is defined as the sum of yellowfin plus skipjack plus bigeye tuna. For the surface fishery, the strata are defined as follows. The EPO is divided into 13 areas and the year into 12 months. Within each area-month, there are seven possible surface fishing methods: pole and line, small purse seine fishing floating objects, small purse seine fishing non-associated schools, small purse seine fishing dolphin, large purse seine fishing floating objects, large purse seine fishing non-associated schools, large purse seine fishing dolphin. A small purse seiner has a fish-carrying capacity of 363 mt or less; a large purse seiner has a fish-carrying capacity of greater than 363 mt.

There are two types of unloading procedures that influence the port sampling and the estimation scheme used for fishery catch. The most common procedure is to unload the fish at random, and the other is to sort the fish during unloading by both weight and species. The sorted unloadings are therefore sampled for length, but not for species composition. These sorted samples are pre-processed to provide an estimate for the well that was sampled so that it has the same format as a non-sorted unloading. In order to evaluate the variance and possible bias, it was necessary to treat all sampled wells as if they came from unsorted unloadings. Therefore, for each sampled well, the data were pre-processed to obtain an estimate of the fraction, in numbers, that belong to each of the three tuna species, estimates of the average weights of each species, and of the standard deviations of the estimated average weights. Some strata were found to have catches, but no samples. In these cases, the samples from a nearby stratum with samples were selected to represent the unsampled strata. Port sampling data from 2000-2008 were used in the simulation.

3. METHODS OF ANALYSIS

3.1. Descriptive analysis

3.1.1. Comparison of tuna catch in sampled and non-sampled sets

The purpose of this analysis was to compare the amount of tuna catch from sets loaded into sampled wells (‘sampled’) to that from sets that were not loaded into sampled wells (‘non-sampled’). The sum of tuna catch was grouped by stratum (combinations of sampling area and month) within each year and by each of the three purse-seine set types.

The difference in tuna catch between sampled sets and non-sampled sets was tested using a randomization test (Manly, 2007), applied separately to the data for each purse-seine set type and year, for a total of 24 tests (three set types by eight years). The null hypothesis of the randomization test is that the label of the set (‘sampled’ *versus* ‘non-sampled’) makes no difference to the amount of tuna catch. To perform the randomization test, the label (‘sampled’, ‘non-sampled’) was randomized among sets within each stratum. Only strata with at least 10 sets for each of ‘sampled’ and ‘non-sampled’ were included in this analysis (*i.e.*, tests were based on fewer sets than are shown in Table 1). Two test statistics were computed: 1) the sum over strata of the within-stratum difference in mean tuna catch, and 2) the sum over strata of the within-stratum difference in mean *log*(tuna catch). A total of 9,999 randomizations was done for each year and set type. The randomization test ‘*p*-value’ for a two-tailed test is the proportion of test statistics (including that of the real data) that were as large or larger in absolute value as the real-data value.

The *p*-values from these tests were combined for a 'global' test across years within a set type, using the truncated product method (TPM) of Zaykin *et al.* (2002; $\tau = 0.05$). The TPM procedure is intermediate between no correction for multiple comparisons and the Bonferroni method of correction for multiple comparisons (Rice 1988). In this case, the global hypothesis is that there is no difference in the tuna catch between sampled and non-sampled sets.

3.1.2. Comparison of the occurrence of bigeye tuna in sampled and non-sampled floating-object sets

The purpose of this analysis was to compare the occurrence of bigeye tuna in the catch between sampled and non-sampled floating-object sets. For the analysis, catches were grouped by stratum (combinations of sampling area and month) within each year. Two characteristics of the catch of bigeye tuna were considered: the percentage of bigeye tuna in the catch, and the presence/absence of bigeye tuna in the catch (presence was defined as any set catching a non-zero amount of bigeye tuna). In both cases, the tuna species identification used was that recorded by the observer.

Differences in the occurrence of bigeye tuna in the catch between sampled sets and non-sampled sets were tested using randomization tests, applied separately to the data for each year. Only strata with at least 10 sets for each of 'sampled' and 'non-sampled' were included in this analysis. Three test statistics were computed: 1) the sum over strata of the within-stratum differences in the mean percent bigeye tuna catch, 2) the sum over strata of the within-stratum differences in the median percent bigeye tuna catch, and 3) the sum over strata of the within-stratum differences in the proportions of sets that caught bigeye tuna. A total of 9,999 randomizations was done for each test. *p*-values for these individual tests were combined in order to estimate a *p*-value for the overall hypothesis of no difference between sampled and non-sampled sets, using the TPM.

3.1.3. Comparison of within-well versus among-well variability in average length and average weight

The purpose of this analysis was to evaluate the magnitudes of within-well and among-well variability in average length and average weight. However, because there are no replicate samples taken from a well, 'replicates' were created separately for each well sample by resampling of lengths from that sample. Resampling of lengths was done with replacement, to the number of fish measured in each sample, based on the empirical probability distribution function of the data. Three 'replicates' were generated in this manner for each well sample. For these resamples to be considered representative, it must be assumed that the original sample of lengths adequately characterized the true but unknown length distribution of the fish in the well.

To provide a description of the differences in variability among resamples *versus* among wells, a mixed-effects linear model (Pinheiro and Bates 2004) was fitted separately to the data for each year and purse-seine set type. The model had the following form:

$$y_{ijk} = \alpha_i + b_j + \varepsilon_{ijk},$$

where y is the average length from replicate *k* of stratum *i* and well *j*, α is the stratum effect (fixed effect), b is the well effect (random effect), ε is the error, and i=1,..,number of strata, j=1,…, number of wells, and k=1,..,4 (original well sample, plus three 'replicates'). It was assumed that $b_j \sim N(0, \sigma_b^2)$ and $\varepsilon_{ijk} \sim N(0, \sigma^2)$. Thus, b_j is a random variable that represents the deviation of the j^{th} well from the stratum mean, and ε_{ijk} represents variability among the four replicates of well *j* and stratum *i*. Estimates of the approximate 95% confidence intervals for σ_b and σ, which are based on a log-normal distribution, were obtained from fitting the above model to the data. A comparison of these confidence interval bounds provides a measure of the differences in variability among resamples compared to that among wells.

3.1.4. Comparison of within-well versus among-well variability in the percentage of bigeye tuna in floating-object sets

The purpose of this analysis was to evaluate the magnitudes of within-well and among-well variability in percentage of bigeye tuna in the species composition counts for floating-object sets. Because there are no replicate samples from a well, 'replicates' were created separately for each well sample by resampling individual fish (*i.e.*, the species identification), with replacement, to the number of fish counted in each well sample, based on the empirical probability distribution function of the data. Three 'replicates' were generated in this manner per well sample.

To provide a description of differences in variability among resamples *versus* among wells, a two-step process was used. The first step was to fit a fixed-effects logistic regression model (McCullagh and Nelder 1989) to the fish count data (success = fish was a bigeye tuna; total counts assumed known) to model the stratum effect. Deviance residuals were then computed from this fitted model, and a linear mixed-effects model of the following form fitted to the deviance residuals:

$$d_{jk} = \mu + b_j + \varepsilon_{jk},$$

where d is the deviance residual for the well sample j and replicate k, μ is the overall mean (fixed effect), b is the well effect (random effect), ε is the error, and $j=1,\ldots,$ number of wells, and $k=1,..,4$ (original well sample, plus three 'replicates'). For this preliminary analysis, it was assumed that $b_j \sim N(0, \sigma_b^2)$ and $\varepsilon_{ijk} \sim N(0, \sigma^2)$ (but see Results and Discussion below). A comparison of the approximate 95% confidence interval bounds for σ_b and σ provides a measure of the differences in variability among resamples compared to that among wells.

3.2. Simulation

The purpose of the simulation was to evaluate the estimation scheme used in the EPO for the total retained catch of bigeye tuna. For each stratum with catch *n* wells were sampled. These wells were resampled *n* times, at random with replacement, and new estimates for the fractions by species and the average weights by species were generated. The resampling was implemented based on the following assumptions: 1) the species fractions for each sample can be treated as resulting from a trinomial distribution with parameters as estimated from the original data, and 2) the average weights for each sample can be treated as resulting from independent normal distributions with means and standard deviations as estimated from the original data. For the wells that were sorted before sampling, the number of fish counted during the unloading of the well was assumed to be 300, and the above resampling procedure was followed.

After applying this procedure to all strata with catch, a new estimate of the total catch is made for the year and the whole procedure was repeated 1000 times. These 1000 estimates can then be used to estimate the average resampled estimates and their standard deviations.

4. RESULTS AND DISCUSSION

4.1. Descriptive analysis

4.1.1. Comparison of tuna catch in sampled and non-sampled sets

The tuna catch in sampled sets tended to be greater, on average, than that of non-sampled sets in many areas in most years (Figure 1). With the exception of dolphin sets and unassociated sets in 2004, all randomization test *p*-values based on test statistic (1) were less than or equal to 0.01. The same was true of test statistic (2), with exception of the test for dolphin sets in 2007, which had a *p*-value of 0.02. Annually, the number of strata (sampling area and month combinations) used in these tests ranged from 10 to 27 for dolphin sets, four to 17 for unassociated sets, and seven to 33 for floating-object sets, depending on the year. TPM estimates of the *p*-value associated with a global hypothesis of no difference between sampled and non-sampled sets (across years within a set type) were all less than 0.01. These results are consistent with results of analyses of port-sampling data from other oceans (Lawson, 2008).

Future work could consider comparisons within particular areas, and should explore any differences among vessels.

4.1.2. Comparison of the occurrence of bigeye tuna in sampled and non-sampled floating-object sets

The occurrence of bigeye tuna in the catch from sampled floating-object sets was greater than that in non-sampled floating-object sets in some areas in some years (Figure 2), but the results were not strongly consistent across years nor across test statistics (Table 2). Significant differences were mostly positive, indicating a greater percentage of bigeye tuna (greater occurrence of bigeye tuna) in sampled sets than in non-sampled sets. However, on average, the magnitude differences in the percentage of bigeye (and proportion of sets with bigeye) between sampled and non-sampled sets were small (Figure 2, Table 2). Although more analysis is needed, the differences in results between the first and second test statistics is presently attributed to the skewness of the data; a large percentage of sets catch no bigeye tuna, but in some sets the catch can be quite large. The results were similar to analyses limited to the main areas where bigeye tuna catch occurs (sampling areas 7, 9, 11 and 12, or equivalently, stock assessment areas 2 and 3). The results from additional analyses of sets with non-zero catches of bigeye tuna only also yielded conflicting results, with positive significant differences in two of three years and a negative significant difference in the other year. The TPM *p*-value for the overall hypothesis of no difference between sampled and non-sampled sets was less than 0.05 for the test statistic based on median differences and that of the proportion of sets with bigeye tuna (Table 2).

Other analyses of bigeye tuna catches (Harley *et al*. 2004, 2007; Lennert-Cody *et al*. 2008) have found that individual-vessel fishing behavior may be an important consideration with regard to bigeye tuna catches. Therefore, future work will update the above analyses, taking into account individual vessels, and will explore the use of other test statistics that may be more powerful, given the variability in the data. In addition, to address concerns about identification of bigeye tuna (Suter, J.M., pers. comm.), future work will include a comparison of observer estimates of tuna species composition of the catch to estimates based on the port sampling data of single-set wells during 2000-2007.

4.1.3. Comparison of within-well versus among-well variability in average length and average weight

Variability in average length among resamples was generally found to be much less than variability among wells (Figure 3). This result was consistent across years and across the tuna species and purse-seine set types considered (Table 3). Similar results were obtained when using average weights, and are therefore not shown. These results are consistent with previous work (Hennemuth 1957; Tomlinson 2002).

Diagnostic plots of model fit suggested that among-well variability may differ in some cases by stratum. Future work will fit a model that allows σ_b^2 to differ among strata. An analysis of well samples with smaller sample sizes (*i.e*., fewer than 40 measured fish) may be considered.

4.1.4. Comparison of within-well versus among-well variability in the percentage of bigeye tuna in floating-object sets

As with average length and average weight, the variability among wells in the percent bigeye tuna exceeded that among resamples within a well (Figure 4). Estimates of the among-well standard deviation were consistently larger across years than that of the among-well replicates (Table 4). Thus, given that bigeye tuna was detected in the counts, the variability within resamples was found to be much less than the variability among wells.

Diagnostic plots suggested that the deviance residuals were short-tailed compared to a normal distribution, and their non-Gaussian behavior is not surprising (McCullagh and Nelder 1989). Future work will improve the model fitted to the data by implementing a logistic mixed-effects model that allows

σ_b^2 to differ among strata. In addition, future work will attempt to go beyond this type of conditional study, using a simulation to estimate the minimum amount of bigeye tuna that is likely to be detectable under the current sampling design when detection probabilities are less than one (c.f. MacKenzie *et al*. 2002).

4.1.5. Simulation

Nine years (2000-2008) of estimates were treated as described, and the results indicate that the estimation procedure has a slight bias, since eight of the nine years show an average difference in the same direction (Table 5). An example of the simulation results for the 1000 resamples is shown in Figure 5. As shown in Table 5, the average bias across years is 237 as compared to the average standard deviation of 3,397. Thus, the bias is very small compared to the deviation.

Acknowledgements

We thank Nickolas Vogel for data base assistance.

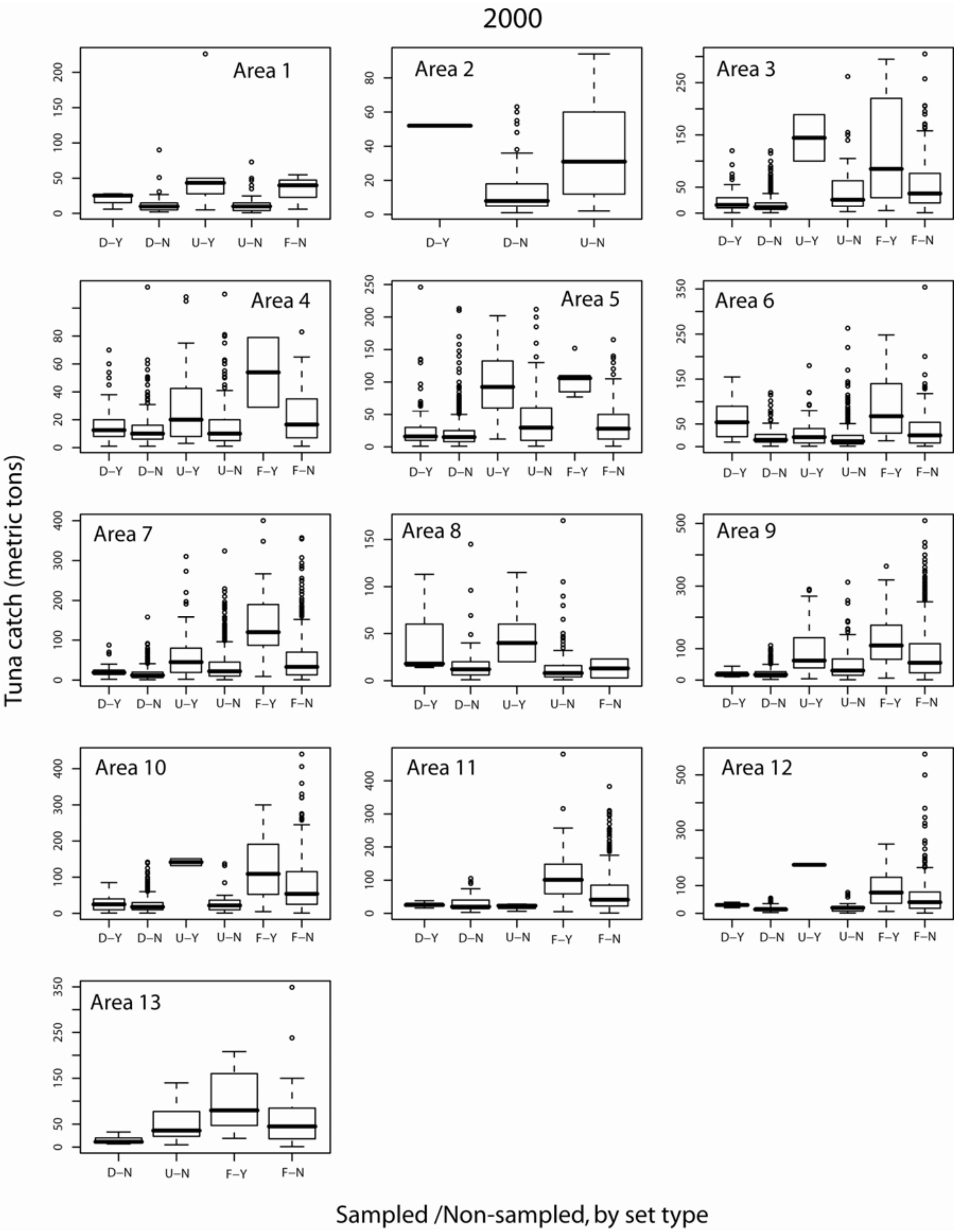

FIGURE 1. Box-and-whisker plots of tuna catch in 'sampled' and 'non-sampled' sets, by set type, for each area of years 2000 and 2005. The sum of retained catches of yellowfin, skipjack and bigeye tuna is shown on the y-axis (note that y-axis ranges differ by panel). Box labels on the x-axis are as follows: D-Y: dolphin set, sampled; D-N: dolphin set, non-sampled; U-Y: unassociated set, sampled; U-N: unassociated set, non-sampled; F-Y: floating object set, sampled; F-N: floating object set, non-sampled. Data within each area have been pooled over months for the year; each panel corresponds to a different sampling area.

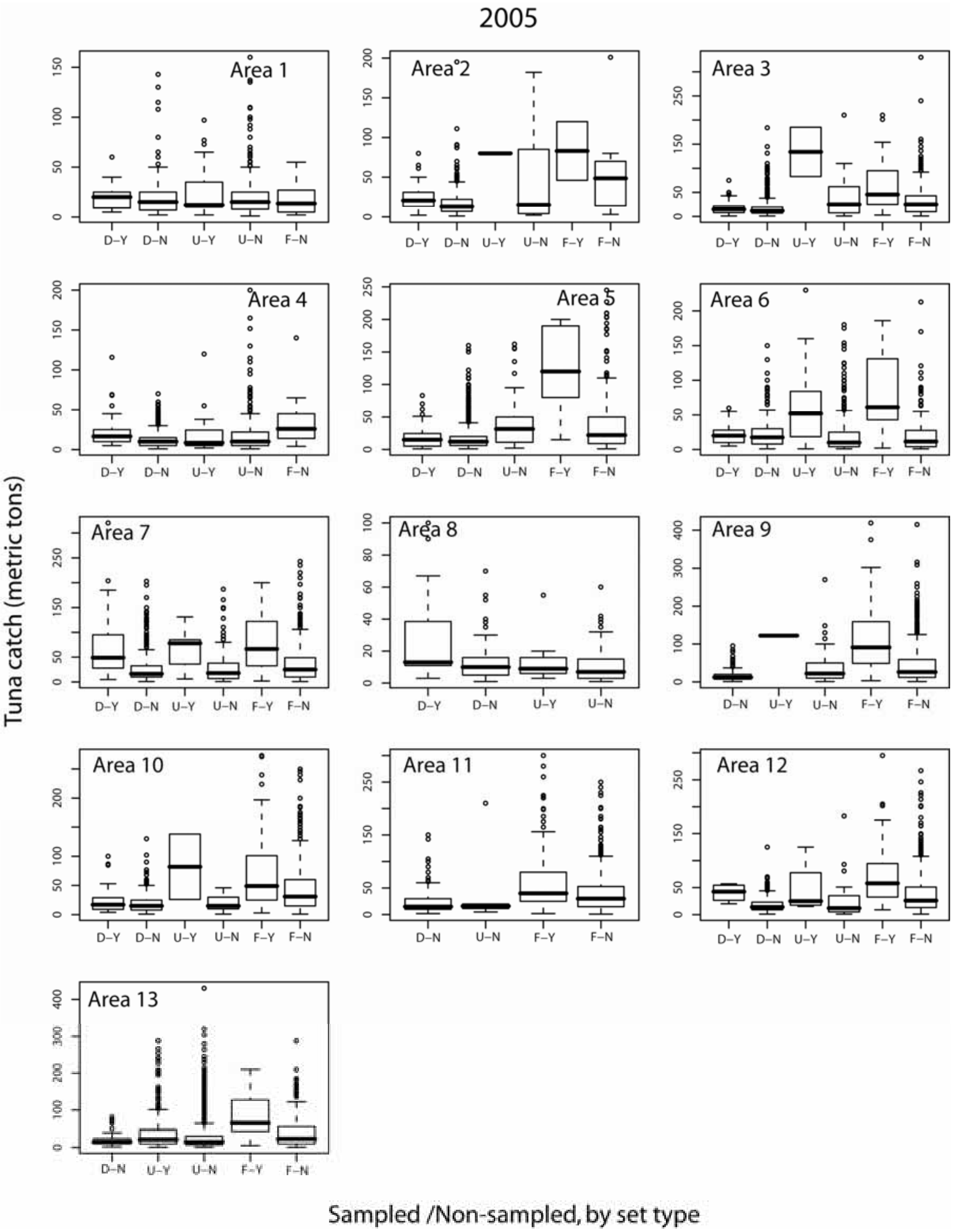

FIGURE 1. (continued).

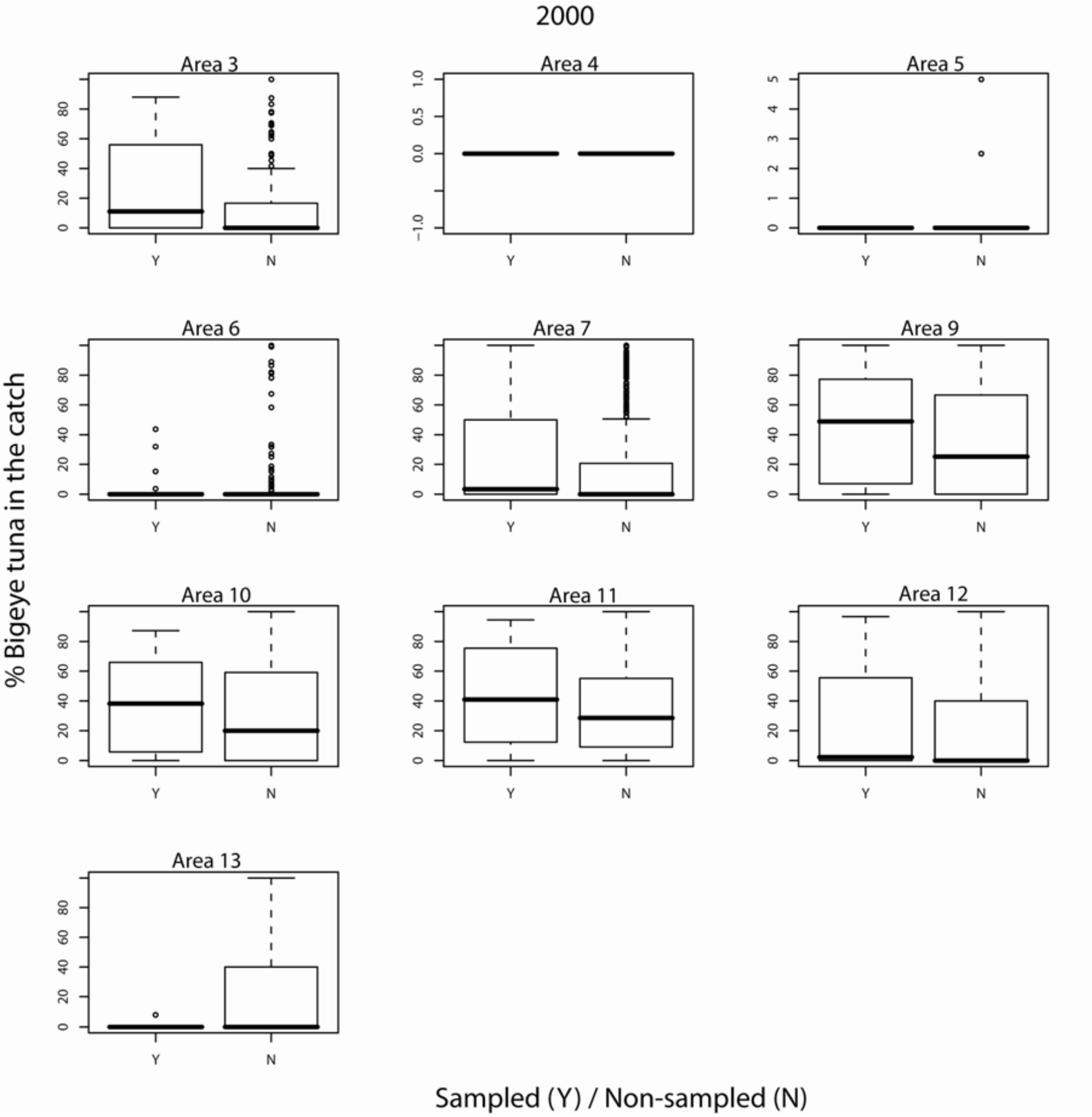

FIGURE 2. Box-and-whisker plots of the percentage of bigeye tuna in the catch of ‘sampled’ and ‘non-sampled’ sets, for each area of years 2000 and 2005. The amount of bigeye tuna divided by the sum of yellowfin, skipjack and bigeye tuna is shown on the y-axis (note that y-axis ranges differ by panel). Box labels on the x-axis are as follows: Y - sampled; N - non-sampled. Data within each area have been pooled over months for the year; each panel corresponds to a different sampling area.

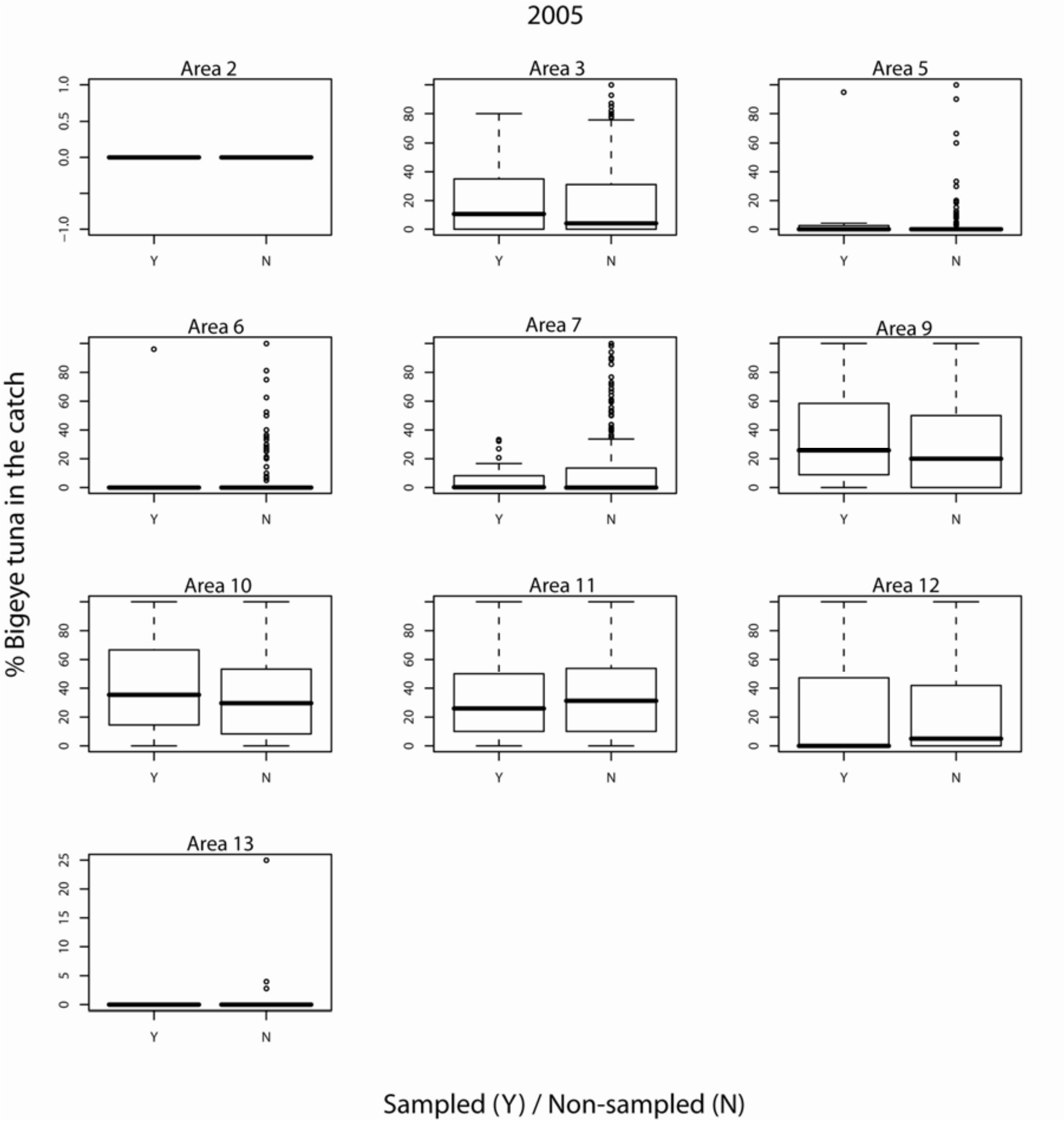

FIGURE 2. (continued).

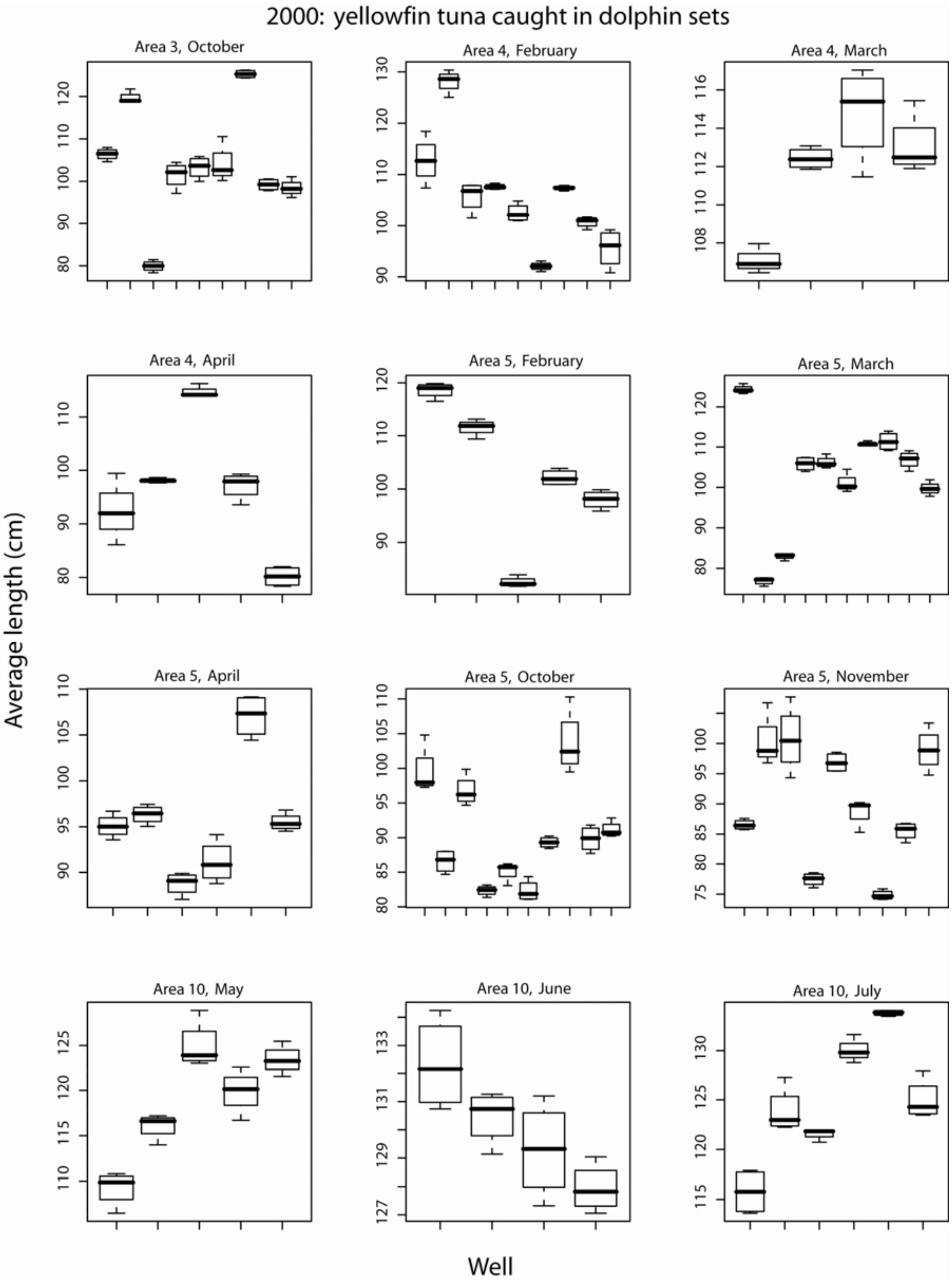

FIGURE 3. Box-and-whisker plots of average length (y-axis) by well (x-axis), for 12 strata (one stratum per panel), for yellowfin tuna in dolphin sets, yellowfin tuna in unassociated sets and bigeye tuna in floating object sets, for 2000. Variability within a well is shown by each individual box-whisker plot. Variability among wells is shown by comparing the spread of the individual box-whisker plots along the y-axis.

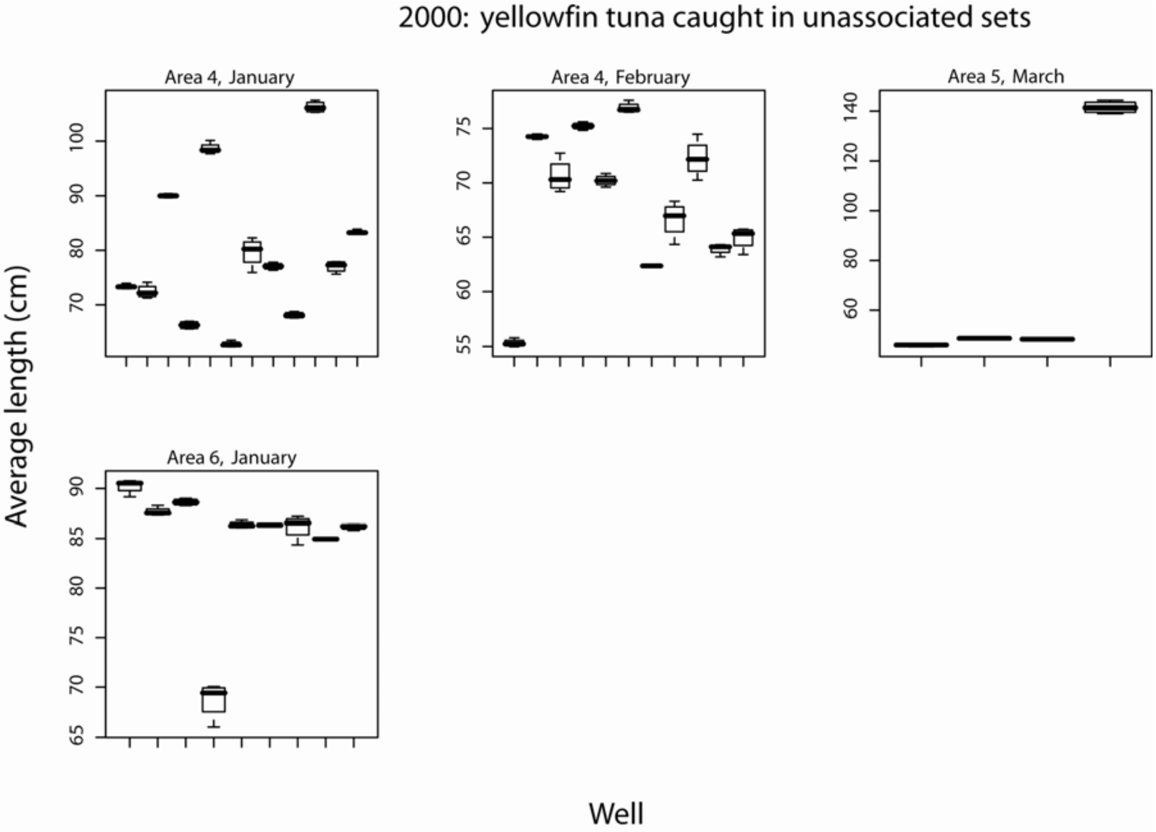

FIGURE 3. (continued).

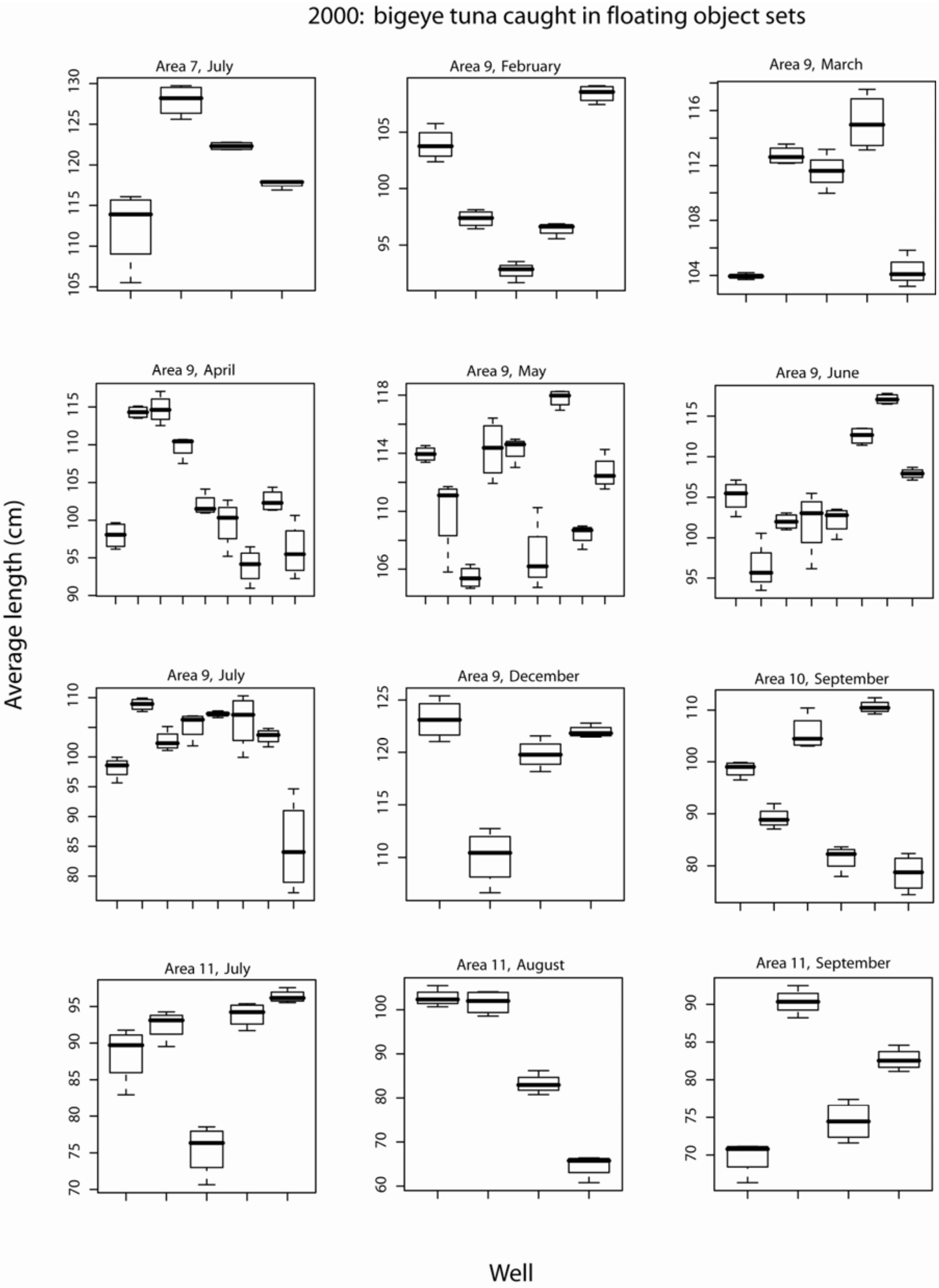

FIGURE 3. (continued).

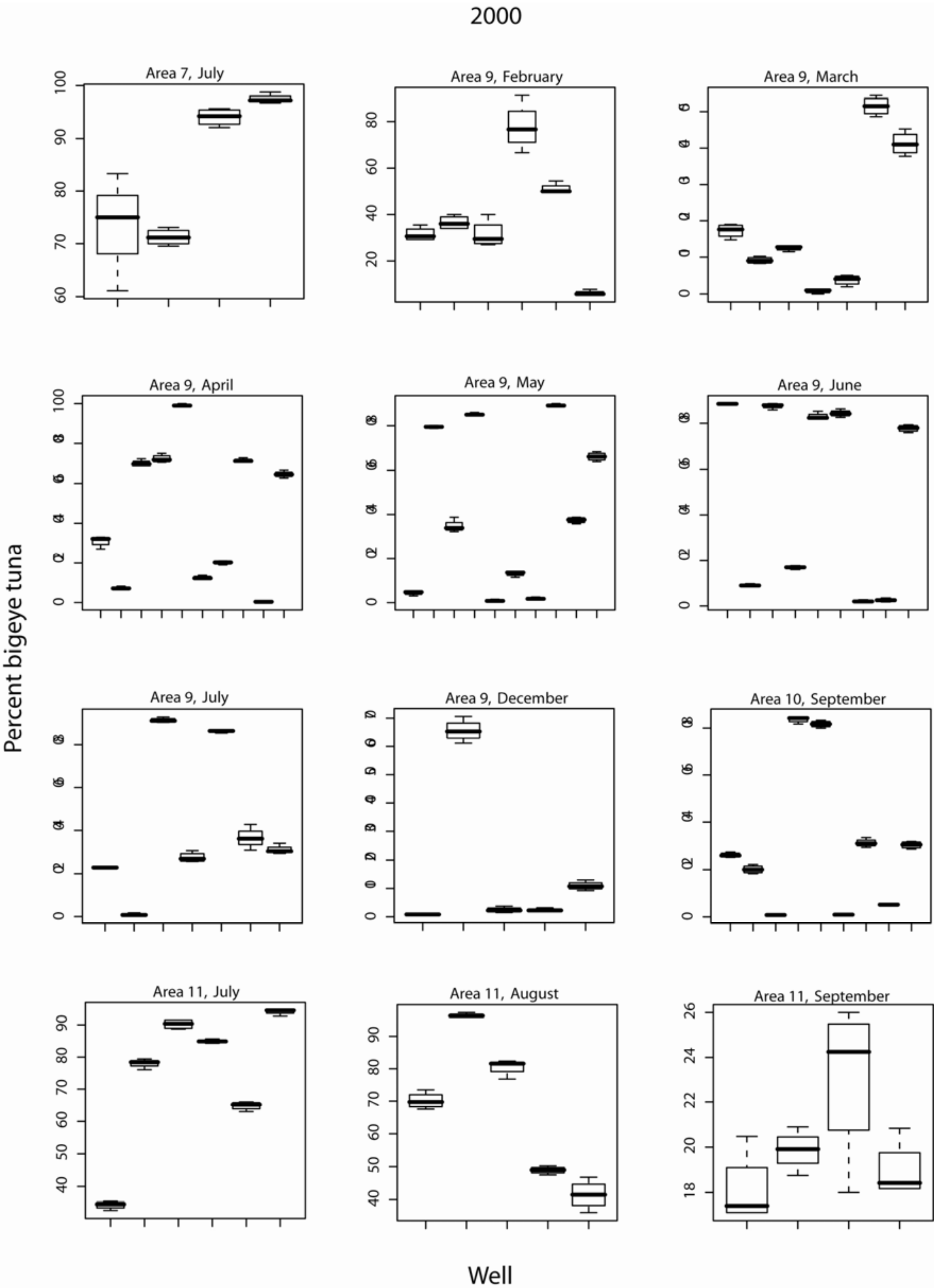

FIGURE 4. Box-and-whisker plots of the percentage of bigeye tuna in the sample (y-axis) by well (x-axis), for 12 strata (one stratum per panel), for floating object sets in 2000. Variability within a well is shown by each individual box-whisker plot. Variability among wells is shown by comparing the spread of the individual box-whisker plots along the y-axis.

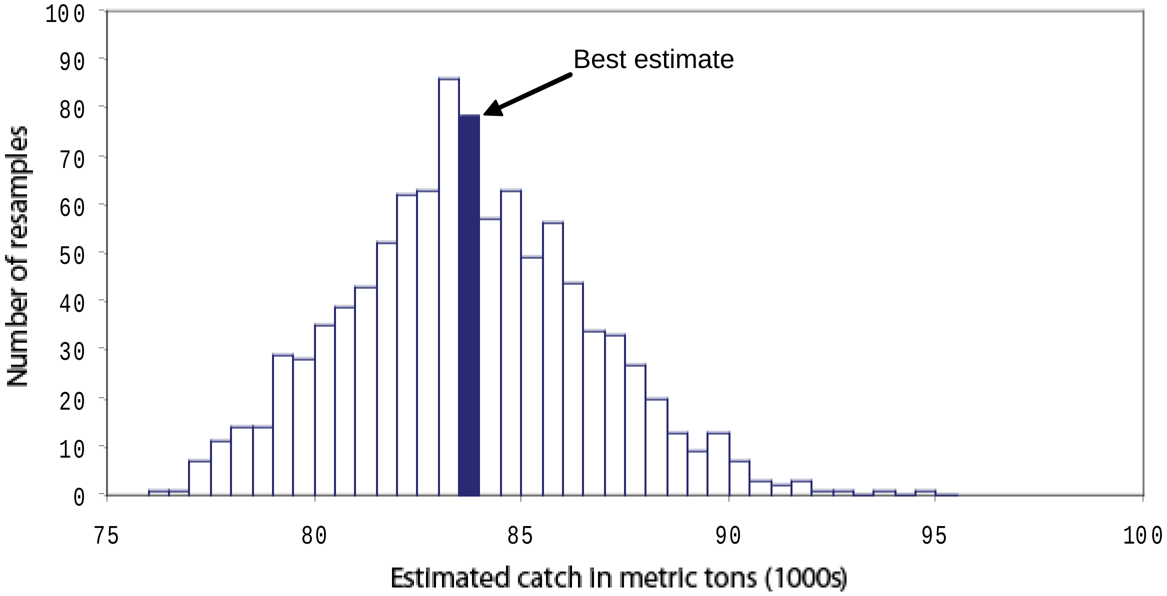

FIGURE 5. Histogram of simulation results (1000 resamples) for 2006.

TABLE 1. Number of sets associated with sampled wells ('Sampled') and sets not associated with sampled wells ('Non-sampled') that were available for comparison of tuna catch, 2000-2007. Data are pooled across set types, areas and months, within each year.

Year	Sampled	Non-sampled
2000	1,180	11,426
2001	1,422	11,980
2002	1,406	14,408
2003	1,294	16,071
2004	790	14,781
2005	1,342	16,099
2006	1,743	15,385
2007	1,310	13,219

TABLE 2. Test statistics, randomization test *p*-values, and average annual differences between sampled and non-sampled sets, for the occurrence of bigeye tuna in the catch. The average difference is the sum of stratum differences divided by the number of strata. TPM is the truncated product method estimate of the global *p*-value (see text for explanation).

	Number of strata	**Sum of differences in stratum means; *p*-value**	**Average difference (%)**	**Sum of differences in stratum medians; *p*-value**	**Average difference (%)**	**Sum of differences in stratum proportions; *p*-value**	**Average difference (proportion)**
2000	8	52; 0.04	6.5	88; 0.03	11.0	0.58; 0.07	0.07
2001	30	-15; 0.72	-0.5	26; 0.76	0.9	0.69; 0.23	0.02
2002	25	87; 0.01	3.5	179; <0.01	7.2	0.80; 0.10	0.03
2003	21	30; 0.22	1.4	35; 0.24	1.7	1.36; <0.01	0.06
2004	7	36; 0.03	5.1	31; 0.18	4.4	0.34; 0.09	0.05
2005	15	-0.2; 0.99	-0.01	-11; 0.76	0.7	0.48; 0.16	0.03
2006	33	23; 0.56	0.7	136; 0.02	4.1	1.44; <0.01	0.04
2007	25	-4; 0.92	-0.2	74; 0.28	3.0	1.04; 0.02	0.04
	TPM *p*-value	0.13		0.04		0.01	

TABLE 3. Approximate 95% confidence intervals for σ_b and σ from the mixed-effect models fitted to the average length per well sample of yellowfin tuna in dolphin sets and unassociated sets, and bigeye tuna in floating-object sets, by year.

	Yellowfin Dolphin	Yellowfin Unassociated	Bigeye Floating object
2000	σ_b: (8.5, 11.9) σ : (2.0, 2.3)	σ_b: (13.2, 21.6) σ : (0.9, 1.1)	σ_b: (7.5, 10.6) σ : (2.0, 2.4)
2001	σ_b: (6.6, 8.9) σ : (1.6, 1.9)	σ_b: (10.2, 15.7) σ : (0.8, 1.0)	σ_b: (14.4, 19.6) σ : (2.2, 2.6)
2002	σ_b: (9.7, 13.0) σ : (1.7, 2.0)	σ_b: (12.3, 30.9) σ : (0.7, 1.2)	σ_b: (15.0, 20.3) σ : (1.9, 2.2)
2003	σ_b: (10.8, 20.2) σ : (1.5, 2.1)	σ_b: (20.3, 36.6) σ : (0.7, 0.9)	σ_b: (8.3, 11.6) σ : (1.6, 1.9)
2004	σ_b: (3.0, 10.2) σ : (2.1, 3.8)	σ_b: (13.3, 24.0) σ : (1.3, 1.9)	σ_b: (8.2, 13.0) σ : (1.7, 2.2)
2005	σ_b: (7.9, 11.2) σ : (2.0, 2.4)	σ_b: (9.7, 15.2) σ : (0.7, 0.9)	σ_b: (12.4, 16.5) σ : (1.8, 2.1)
2006	σ_b: (13.1, 20.4) σ : (1.9, 2.4)	σ_b: (6.9, 10.9) σ : (1.2, 1.5)	σ_b: (8.8, 10.8) σ : (1.7, 1.9)
2007	σ_b: (7.6, 12.2) σ : (1.9, 2.4)	σ_b: (3.4, 6.2) σ : (0.8, 1.1)	σ_b: (9.8, 12.5) σ : (1.4, 1.6)

TABLE 4. Approximate 95% confidence intervals for σ_b and σ from the mixed-effect models fitted to the deviance residuals from the logistic regression model for the counts of bigeye tuna per well sample in floating object sets, by year.

	σ_b	σ
2000	(11.6, 15.2)	(0.71, 0.82)
2001	(9.9, 12.5)	(0.74, 0.84)
2002	(9.7, 12.5)	(0.70, 0.80)
2003	(9.1, 12.0)	(0.73, 0.86)
2004	(9.2, 13.3)	(0.68, 0.84)
2005	(9.4, 11.9)	(0.74, 0.84)
2006	(9.1, 10.8)	(0.78, 0.87)
2007	(12.1, 15.0)	(0.75, 0.85)

TABLE 5. Estimated metric tons of bigeye tuna retained by surface fleet, by year, and comparison to the average of 1000 resamples. Bias = Best estimate – Resampled average. CV = coefficient of variation.

Year	Best estimate	Resampled Average	Standard deviation	Bias	CV
2000	94642	94311	5148	330	0.054
2001	60856	60547	3465	309	0.057
2002	57438	57378	2814	60	0.049
2003	54174	53691	3300	484	0.061
2004	67545	68273	4368	-728	0.065
2005	69835	69615	2688	220	0.038
2006	83729	83212	2917	516	0.035
2007	63072	62648	2598	424	0.041
2008	75654	75135	3273	518	0.043

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