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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

Inside Front Cover

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Title page

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INTRODUCTION

The Southwest Region (SWR) of the National Marine Fisheries Service (NMFS) is required to provide an annual report concerning sea turtle takes in the Hawai'i-based longline fishery to the Assistant Administrator for Fisheries. The Honolulu Laboratory provided the SWR with estimates of turtle takes and mortalities and nontechnical descriptions of the estimation procedures for inclusion in the 1994, 1995, and 1996 annual reports. This paper will document the estimates provided and describe in some detail the different methodologies used on the three occasions. Background events leading up to the requirement for these estimates are described below.

The Hawai'i-based longline fishery expanded rapidly in the late 1980s, and interactions with Hawaiian monk seals (*Monachus schauinslandi*) were documented and interactions with sea turtles became the subject of dockside talk. Consequently, the NMFS conducted a review of the fishery; i.e., a Section 7 Consultation under the Endangered Species Act (Consultation) resulting in the issuance of the May 15, 1991 Biological Opinion and Incidental Take Statement (Opinion) (hereafter referred to as Consultation and Opinion, respectively). An allowable take of up to 25 sea turtles per year was set, using hearsay information on the take and opinions on the status of turtle stocks because neither take estimates nor published stock assessments were available. Moreover, no more than one leatherback (*Dermochelys coriacea*), olive ridley (*Lepidochelys olivacea*), or green (*Chelonia mydas*) turtle could be killed. Starting in November 1990, regulations adopted under the Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region (FMP) required fishermen to maintain and submit to the NMFS daily longline logbooks. In June 1992, the NMFS found that the incidental take of sea turtles reported in the 1991 logbooks exceeded the level set in the Opinion. Therefore, the NMFS conducted a second Consultation to review the reported takes and the status of the turtle stocks using recent assessments. In the resulting June 10, 1993 Opinion, the NMFS 1) determined that the Hawai'i-based longline fishery did adversely impact the turtle species taken in the fishery but was not likely to jeopardize their continued existence, 2) required the establishment of an observer program and an annual review of turtle take using the observer data, 3) revised the allowable take (752) and mortality (299), with no more than150 leatherback turtles taken in a manner resulting in mortality or serious injury, and 4) required a Consultation to be reinitiated no later than 12 months from the issuance date of the1993 Opinion. A pilot survey design for the observer program was completed in November 1993 (DiNardo, 1993), and the first observer trip departed on February 24, 1994. The reinitiated Consultation (the third) resulted in issuance of the June 25, 1994 Opinion in which the allowable take and mortality limits were revised (Table 1) including for the first time levels for hawksbill turtle (*Eretmochelys imbricata*). Several requirements issued in the 1993 Opinion were reiterated and strengthened.

EXECUTIVE SUMMARY

Estimates of the takes and mortalities of turtles were provided the SWR for the preparation of three annual reports on turtle interactions in the Hawai'i-based longline fishery. The statistical estimation procedure was improved for the second and third annual reports to better deal with variability in the survey data. For the 1994 annual report, the estimates were computed for the 12-month period February 24, 1994-February 23,1995. The estimated takes are given in Table 2 (Annual Report column, 1994 row), and the estimated mortalities in Table 3 (Annual Report column, 1994 row). None of the estimates of take or mortality exceeded the allowable limits (Table 1). The estimation procedure is based on survey sampling theory and involves four steps. First, the take rate for all turtle species (total turtle take per 1,000 hooks) was computed on a per-stratum basis using survey data collected by observers. Second, the take in each stratum was computed by multiplying the estimated take rate times the population of hooks fished taken from logbook data. Third, the total take estimates were obtained by summing the estimated takes across strata. Lastly, species-specific takes were estimated by multiplying the total take estimate by the observed species proportions. While the observer data were collected using a stratified random design with strata based on historical fish species targeting practices of the fleet (the pilot stratification or design), the estimates were computed from a post-stratification based on boat length, which resulted in a smaller estimated variance. Mortality estimates were computed by multiplying the take estimates by the mortality (15.1%) taken from the 1993 Opinion. These and other aspects of the computations are summarized in Table 4 for comparison with procedures used for the 1995 and 1996 annual reports.

For the 1995 annual report, the SWR requested that the take and mortality estimates be provided for calendar year 1995 rather than for the next 12-month period. To facilitate comparisons, extrapolated estimates for calendar year 1994 were provided. Take rates were computed by calendar year using available observer data (12 months in 1995 and approximately 10 months in 1994). The estimation procedure differed from that used for the 1994 annual report in the following ways (Table 4): the pilot stratification was used rather than any of six post-stratifications examined because none of them resulted in a substantive reduction in estimated variance; variation of the estimates was computed using a nonparametric bootstrap procedure; and species-specific takes were estimated directly by stratum using ratio estimates. The estimated takes (413) and mortalities (62) of loggerhead turtles in 1995 (Annual Report column, 1995 row in Tables 2 and 3) exceeded the allowable levels (Table 1). No other species exceeded these levels in either year.

For the 1996 annual report, the estimation procedure was changed completely (Table 4). Regression tree analysis replaced the survey sampling methodology, sets became the basis of the analysis rather than trips, and mortalities were estimated from observer data. The regression tree procedure was used to evaluate the predictive capability of a suite of factors and select only those with statistically significant effects. The suite of factors included those for the pilot stratification and the post-stratifications used during analyses for the1994 and 1995 annual reports. Significant predictive factors were found only for loggerhead turtles (latitude and swordfish catches) and olive ridley turtles (yellowfin tuna catches). The estimated takes of loggerhead turtles in 1995 and 1996 (Annual Report column, 1996 row in Table 2) exceeded the allowable takes (Table 1). In addition, the mortality estimates of loggerhead and olive ridley turtles (Annual Report column, 1996 row in Table 3) exceeded the allowable limits in 1994, 1995, and 1996.

DATA SOURCES

The SWR Hawai'i Longline Observer Program was established to collect data on interactions between the longline fishery and protected turtle species and became operational on February 24, 1994. The observer data were then used to estimate turtle take rates and, for the 1996 annual report, mortality rates as well. Information such as the condition (dead, live, injured), method of capture (hooked, entangled), and hooked location (e.g., flipper, ingested) are recorded for every turtle. Also recorded are interactions with other protected species (birds and mammals), the fish species (singular) to be targeted on the trip, fish catches, size measurements of captured organisms, and operational characteristics of each set and haul (e.g., date, time of day, number of floats, hooks, and light sticks, location, bait species). For the period of this study, these data were collected using the pilot design (DiNardo, 1993), that is a stratified random sampling of boat-trips within four boat strata based on historical fishing practices: swordfish, tuna, mixed (a total catch or value strategy), or switcher (target either swordfish or tuna on different trips or sets within a trip). In practice, an observer trip ends when the boat returns to port and the trip length is judged to be typical for a boat in its stratum. The strata were sampled in proportion to the historical number of fishing trips within the strata. The variances were too poorly estimated from the few available voluntary and mandatory observer trips to allow sampling in proportion to stratum variance, as is preferable. DiNardo (1993) computed the sample size (number of trips) required to estimate the aggregate take of turtles. He noted that greater sample sizes would be required to estimate the take of each species, and sample size would vary considerably depending on the rarity of the takes.

The NMFS Western Pacific Longline Logbook Program became operational in November 1990 for monitoring the Hawai'i-based longline fishery and assessing the fish stocks harvested. Fishermen recorded fish catches and discards, encounters with protected species, and operational characteristics of each set (e.g., date, time of day, number of hooks/float, hooks, and light sticks, location, and bait species) on daily logbook forms. Thus, fishing boat operators and NMFS observers independently record much of the same information. In addition, NMFS staff add a code for the species group targeted on the trip (tuna, swordfish, or mixed). Either the vessel operator provides this information, or the NMFS staff determines it based on where the boat fished, the species composition of the reported catches, and knowledge of the past fishing practices of the boat and its operator. Logs are to be submitted to the NMFS at the completion of each trip. In practice, a trip ends when a boat that has fished returns to port in Hawai'i for any reason, and a logbook is collected from its operator. For this report, the logbook data represent the "population" from which the observer trips were drawn for sampling. This dataset provided population levels of fishing effort, trips, sets, and hooks for use in expanding the take rate estimates to takes for the entire fleet.

Amounts of fishing effort (boats, trips, sets, and hooks) as observed (Observer Program) and as logged (Logbook Program) are presented in Table 5). The SWR Observer Program surveyed about 5% of the longline trips in the first year of the program (24 February 1994-23 February 1995), somewhat less when computed for calendar year 1994, a little above 4% in 1995, and nearly 5% in 1996. In 1994, the coverage rate in terms of trips (and hooks) by pilot survey stratum was swordfish 3.6% (4.8%), tuna 3.8% (3.7%), switcher 6.9% (7.8%), and mixed 4.5% (4.1%). The unexpectedly low coverage of the swordfish stratum was caused by a high percentage of swordfish boats returning to the U.S. east coast in 1994.

The nominal observed (Observer Program) and logged (Logbook Program) takes of turtles are presented in Table 6. Given the 4-5% coverage rate, the logged take was much smaller than expected. With respect to reported species composition, green, leatherback, and olive ridley were overrepresented in the logbook data, while loggerhead were underrepresented, relative to the observer data. No hawksbill turtle takes have ever been observed, but three turtles were logged as hawksbill turtles in 1995. No green turtle takes were observed in 1995. The distribution of longline sets and turtle takes from the observer data for 1994-96 is presented in Figure 1.

METHODS

Estimates for the 1994 and 1995 annual reports were computed using similar statistical procedures based on survey sampling theory. For the 1996 annual report, the estimates were computed using a regression tool originally developed for classification (systematics) problems. Technical aspects of the statistical procedures are documented below.

1994 and 1995 Annual Reports

Survey sampling

The estimation procedure for the 1994 and 1995 annual reports was based on well known survey sampling theory (Cochran, 1963; Mendenhall et al., 1971; Sampford, 1962). A ratio estimator (turtle take rate or takes/1,000 hooks) was employed because it is known to provide better estimates than using (in our case) takes alone when takes and hooks are correlated (Mendenhall et al., 1971; Sampford, 1962). Within each stratum j of the sample survey data, the take rate of turtles, R, was estimated using the population ratio estimator (note that a subscript j has been left off every term in Equation 1 and Equation 2 below).

$$\hat{R} = r = \frac{\sum_{i=1}^{n} T_i}{\sum_{i=1}^{n} H_i}, \tag{1}$$

where T_i = turtle takes on sampled trip i of n sampled trips, and
H_i = hooks fished on sampled trip i.

For the 1994 annual report, we chose to estimate the take of turtles in the aggregate (paralleling DiNardo's (1993) estimation of sample size) and then to allocate takes among species using species proportions computed from the observer data. For the 1995 annual report, the take rate of each species was estimated individually.

The variance of the ratio estimator r, within each stratum j, is

$$\hat{V}(r) = s^2 = \left(\frac{N-n}{nN}\right)\left(\frac{1}{\mu_H^2}\right)\frac{\sum_{i=1}^{n}(T_i - rH_i)^2}{n-1}, \tag{2}$$

where (within each stratum j)

N = the population of trips,
n = the sample of trips, and
μ_H = the population mean of hooks per trip, i.e., H/N.

A pooled or overall estimate of the take rate and its variance were obtained by summing the within-strata take rate estimates weighted by the proportion of hooks observed relative to the population of hooks reported by the fishermen. The estimator of the population take rate for a stratified random sample is a weighted average of the within-stratum ratio estimators:

$$\bar{r} = \frac{1}{N}\sum_{j=1}^{L} N_j r_j \ , \tag{3}$$

where N = the population of all trips,
N_j = the population of trips in stratum j of L strata, and
r_j = the ratio estimate for stratum j.

The parametric variance of the population mean take rate ($\bar{r}$) is

$$\hat{V}(\bar{r}) = \frac{1}{N^2}\sum_{j=1}^{L} N_j^2 s_j^2 \ , \tag{4}$$

where $N = \sum_{j=1}^{L} N_j$, and
s_j^2 = the sample variance of the ratio estimator r for stratum j, given by Equation 2.

While $\bar{r}$ is commonly reported in the literature and used to project future total take, it is generally not used to estimate total take for the survey period. Since the proportions of hooks actually fished by stratum (logbook data) differed from the proportions sampled by stratum (observer data), $\bar{r}$ would result in biased estimates of take .

Thus, total take was estimated by computing take within each stratum (sample take rate from the Observer Program times population hook data from the Logbook Program) and summing across the strata. The estimator for population turtle take is:

$$\hat{T} = \sum_{j=1}^{L} H_j r_j \, , \qquad (5)$$

where H_j = population of hooks in stratum j, and
$r_{j.}$ = equation 1.

For the 1994 annual report, variation of the estimated takes was computed using a parametric procedure and reported as the coefficient of variation (CV) and the 90% or 95% confidence limits (CL). The parametric variance of the population take is

$$\hat{V}(T) = \sum_{j=1}^{L} H_j^2 \hat{V}(r_j) = \sum_{j=1}^{L} [\frac{N_j(N_j - n_j)}{n_j} * \frac{\sum_{i=1}^{n} (T_{ij} - r_j H_{ij})^2}{n_j - 1}] \, , \qquad (6)$$

where n_j = the sample of trips in stratum j.

For the 1995 annual report, a non-parametric bootstrap procedure (Efron, 1982; Efron and Tibshirani, 1993) was used to estimate variation of the take estimates rather than the traditional parametric formula (the bootstrap analysis was conducted by Jerry Wetherall, NMFS Honolulu Laboratory). Bootstrap distributions of species-specific take estimates were generated by resampling the longline observer data 10,000 times with replacement, using observed sample sizes. A two-tiered Monte Carlo procedure was employed to randomly resample the observer data. Specifically, within each stratum the observed fishing trips were resampled (selected) at random, with replacement. Then, longline sets were resampled with replacement from within each selected trip where each set's nominal effort (number of hooks) and turtle take (number of turtles) became the bivariate data of the bootstrap sample. The ratio estimator (Equation 1) was then computed by stratum and applied to the reported levels of longline fishing effort for the fleet to generate a bootstrap estimate of the total fleet turtle take (Equation 5). The results produced an empirical bootstrap distribution of 10,000 take estimates for each species. A variety of sample statistics was computed for each of these empirical bootstrap distributions by species: 1) bootstrap mean estimate of total take (mean of the bootstrap distribution); 2) variance of the take estimate (variance of the bootstrap distribution); 3) CV of the take estimate (CV of the bootstrap distribution); 4) 90% confidence interval estimate of total take (the interval defined by the 5th and 95th percentiles of the bootstrap distribution); and 5) relative error of the total take estimate at the 90% confidence level (one-half of the 90% confidence interval divided by the bootstrap mean).

Post Stratification

During analysis of data from the first year of the observer program, the SWR asked the Honolulu Laboratory to investigate simpler and more efficient survey designs. The SWR had found that fielding of the 4-stratum pilot design was cumbersome, had experienced budgetary shortfalls and had observed that our preliminary estimates had sizable error bounds. This request led to the testing of two post-stratifications of the observer data (Sampford, 1962, p. 98). First, examination of data on the fish species (singular) to be targeted on each trip from the Observer Program suggested three strata (swordfish, tuna, and mixed). Second, turtle takes per 1,000 hooks by trip plotted against the U.S. Coast Guard registered length of the boats suggested three strata (Fig. 2). Boats ≤66 ft had few interactions with turtles-no more than one interaction on any trip. Boats between 66 and 78 ft had more frequent encounters and some had a take of two turtles on a trip. Boats ≥79 ft also had more frequent encounters with turtles and included trips with three or more turtle takes. The parametric CVs of the estimated turtle take resulting from these two post-stratifications were computed for comparison with that from the pilot design stratification.

Discussions with the SWR about redesigning the observer survey design continued into the period of computing the estimates for the1995 annual report. These discussions led to a reexamination of boat length and an examination of latitude using observer data from the start of the program through 1995. Plots of observed turtle takes versus boat length (U.S. Coast Guard registered length) suggested two alternative stratifications (Fig. 3). First, a three-boat size stratification with ≤48.0, 48.1-74.9, and >74.9 ft strata was characterized by zero turtle takes, one turtle take, and two or more turtle takes per trip, respectively. Second, a two-boat size stratification with strata ≤70.0 and >70.0 ft was characterized by mostly zero turtle takes and two or more takes per trip, respectively. Similarly, plots of observed turtle take against latitude suggested two alternative stratification schemes (Fig. 4). First, a 3-latitude stratification with strata ≤17.2°, 17.3-28.7°, and > 28.7°N was characterized by zero turtle takes, one turtle take, and two or more turtle takes per trip, respectively. Second, a 2-latitude stratification with strata ≤24.0° and >24.0°N was characterized by zero or one turtle takes and two or more turtle takes, respectively. Then, two cross designs using three-boat strata with 3-latitude strata and two-boat strata with 2-latitude strata were evaluated. Again, the parametric CVs of the estimated turtle take resulting from these two post-stratifications were computed for comparison with that from the pilot design stratification.

Mortality

Mortality estimates were computed by taking 15.1% of the take estimates. This percentage was computed directly from the table of allowable takes and mortalities in the 1994 Opinion. The allowable mortalities were computed during the Consultation based on the following information: 1) voluntary and mandatory observer data from the Hawai'i fishery indicated that 4% of the turtles taken were dead on retrieval; 2) mandatory observer data from the Hawai'i fishery indicated that 86.6% of the turtles were hooked (rather than entangled) and that 46.6% of those hooked had ingested the hook; and 3) the post-release mortality rate of hooked turtles was set at 29.9% based on work on loggerhead turtles in the Atlantic swordfish longline fishery (Aguilar et al., 1992).

Tree-based Regression

Tree-based modeling can be used as an exploratory statistical tool for revealing structure in data (Chambers and Hastie, 1992, Venables and Ripley, 1994). We had used this tool to investigate the relationships between operational and fishing gear factors and turtle takes for mitigation purposes and to assist in redesigning the observer survey program. As an outgrowth, regression tree models were built and used to estimate turtle take for comparative purposes. The tree analysis involved 20 predictor variables collected by the observers or computed from their observations. The variables included month, latitude and longitude, fishing leader material, use of longline shooter, number of light sticks, bait type, number of floats, float line length, hook size, hook type, soak time, percent of full moon, sun elevation at time of set, time of set, registered boat length, and percentage of albacore, blue shark, mahimahi, and swordfish in the catch. We followed the recommended practice of allowing the procedure to include as many variables as possible in the model and then "pruning" the model back to contain only the most important explanatory variables. This tool is explained in more detail in the following section for the 1996 annual report since it was the method used to estimate takes.

1996 Annual Report

Tree-based Regression

The estimation procedure followed for the 1996 report differs from the previous analyses in several ways (Table 4). First and foremost, a regression model was employed instead of a survey sampling theory. This change is not a substitution of a regression equation for a ratio estimator as commonly discussed in textbooks. This regression procedure evaluated the explanatory power of several variables that have been used for stratification as well as a number of other variables for inclusion in the regression model. Second, the basic unit of operation used in the analysis was a longline set, rather than a longline trip. Third, the regression model was fitted with linked observer and logbook set data, rather than with only observer data as was done with the survey sampling method. Fourth, the regression model was fitted to data for the entire study (February 24, 1994-December 31, 1996) thus yielding a pooled or overall take rate estimate. Fifth, mortality rates were computed from the observer data rather than the1994 Opinion.

The strategy for this phase of the analysis (Fig. 5) was to develop statistical models relating various factors (independent variables) to the expected number of turtle takes (the dependent variable) in a longline set, with one model for each of the four turtle species observed in interactions. The models could then be applied using the independent variables recorded for all the longline logbook sets to predict the annual take (and mortality) for the whole longline fishery.

Regression tree models (Clark and Pregibon, 1992) were chosen because they can be efficiently applied to a multitude of independent variables comprising a mixture of numeric and categorical types. In addition, complex interactive effects between variables are automatically accounted for, and situations of missing data can be accommodated. The independent variables from the logbooks, included in the analysis (Table 7), had to do with spatial and temporal location of the set, some with operational characteristics of the set, and one was an environmental variable (sea surface temperature). Also included were the catches of several species of fish as well as albatross, the registered boat length, and the species group targeted on the trip. Some variables were not included because they were not available for the entire period of the study or had too many missing values.

Regression tree models were fitted to data consisting of records for 1,700 observed longline sets. Each record consisted of the number of turtle takes by species and concomitant values of independent variables. Given the underreporting of turtle takes in the logbook data (Table 6), the regression tree models were developed using values for the dependent variable (turtle takes) taken from the observer data. However, for the independent variables, values were for the most part taken from logbook entries corresponding to sets in the observer data. This is because the values reported by the fishermen and recorded by the observers often differed, which means that a model developed from observer data only could result in biased take estimates and underestimation of variability. For a small number of observed sets (32 out of 1,700), values from the observer data were used because these sets were missing altogether in the logbook data. In addition, they included one observed turtle take. Being a rare event, one observed take can strongly influence the final estimates. Therefore, it was deemed important to include these missing sets.

Before using regression tree models to estimate total takes, the models were pruned by cross validation (Clark and Pregibon,1992). Retaining only the statistically significant independent variables minimizes bias due to overfitting. The cross validation procedure consisted of randomly assigning the 1,700 data points to 10 approximately equal groups. A regression tree, grown using only nine of the data groups, was pruned to various sizes and the deviance measured at each size when the pruned trees were applied to the reserved (not used) data group. This process was conducted 10 times with each of the 10 data groups serving in turn as the reserved group, and the deviances at each tree size were summed. The whole procedure, including random assignment to data groups, was repeated 10 times, and the minimum of the average deviance by tree size was chosen to indicate, to the nearest integer, the optimum tree size.

For loggerhead and olive ridley turtles, annual point estimates of take were obtained by applying the pruned models to the significant independent variables recorded for all longline sets in the logbook data (whether observed or not) during 1994–96. The resulting predicted takes by set were aggregated by year. For leatherback and green turtles, cross-validation indicated that none of the independent variables were significant. In these cases, annual point estimates of take were obtained by applying the overall hooking rate (take per hook) in observed sets (1994–96) to the total numbers of hooks deployed by the fishery in each year. Except for leatherbacks, point estimates of take were adjusted upward by a factor of 1.10 to account for distributing eight unidentified hardshell turtles in the observer records (Table 8) among 77 observed takes of hardshell turtles of known species ($1.10 \approx 1+8/77$).

A bootstrap procedure (Press et al., 1992) was used to deal with uncertainty in estimates based on regression trees. Bootstrap selections of data from observed sets were used to develop 1,000 regression trees, which were then pruned to the same size as the original tree and used to make 1,000 synthetic take estimates for each year. In the fitting process, the bootstrap regression trees were limited to the independent variables determined to be significant in cross-validation of the original regression trees. The 95% confidence bounds were estimated using the 2.5% and 97.5% quantiles of the synthetic estimates. For estimates based on hooking rate, the distribution of Ty, the take estimate in year y, was computed using the binomial likelihood function $\mathcal{L}(Ty) = B(To, Ho, Ty/Hy)$, where the number of observed successes is To (takes recorded by observers, 1994–96), the number of observed trials is Ho (total hooks in observed sets, 1994–96), and the unknown probability of success is Ty/Hy, where Hy is the number of hooks deployed in all sets in year y. The 95% confidence bounds are the 2.5% tails of $\mathcal{L}(Ty)$. Except for leatherback, before confidence bounds were chosen, bootstrap and binomial likelihood distributions were adjusted by the same factor as point estimates to account for unidentified hardshell turtles.

Mortality

The expected number of deaths per take by turtle species was first estimated from information recorded by observers on the condition of turtles on release (Table 9). The only information available on the death of turtles released from longline gear interaction suggests that loggerhead turtles have a 29%

probability of dying as a result of ingesting a longline hook and those being hooked internally (Aguilar et al., 1992). Therefore, for turtles observed with an ingested hook, the death rate was set to 0.29, and this rate was assumed to apply to all the turtle species. Turtles recorded as dead were assigned a death rate of 1.0, and turtles recorded as "OK" were assigned a zero death rate, as were turtles hooked externally to the throat (i.e., had not ingested the hook but had become hooked externally) or entangled. Turtles hooked in an unknown location of their body were assigned the average death rate of the turtles of their species with a known hook location, and turtles with unknown condition (code "NR") were assigned the average death rate of turtles of the same species with condition code "OK," "internal," or "external." In the case of turtles reported as hardshell and with unknown hook location or condition, data were averaged over all turtles but leatherbacks. To compute the deaths per take by species (last column of Table 9), the recorded numbers of unidentified hardshell turtles taken (total) and dead were allocated to specific hardshell species (Table 9) in proportion to the recorded takes and deaths of identified hardshell turtles (last column of Table 9). Finally, to get point estimates of mortality, the deaths-per-take figures were multiplied by the take estimates. For measures of uncertainty, deaths-per-take figures were multiplied by either the synthetic, bootstrap estimates (loggerheads and olive ridleys) or the binomial likelihood function (leatherbacks and greens) estimates of confidence limits.

RESULTS AND DISCUSSION

1994 Annual Report

Stratification Evaluation

Measures of dispersion about the models using three alternative stratifications are summarized in Table 10. The poorer fit of the post-stratification based on the vessel operator's declared species targeting (CV of 68.36%) compared to that using historical fishery targeting (CV of 39.56%) is surprising. Apparently the post-classification of logged trips into a fishery targeting category either by the vessel operator or Honolulu Laboratory staff is more closely correlated with turtle interactions than for target species declared at the start of trips. Based on a lower coefficient of variation, we chose to use the boat-length stratification for estimating turtle take rate. However, improvement over the pilot design stratification was slight (35.70% compared to 39.56%). During the analysis for the 1995 annual report when we examined a number of post-stratifications, we concluded that none showed a clear advantage for estimating turtle takes over the pilot design.

Survey Design Take Estimates

None of the estimated takes or mortalities by individual or all species in the aggregate using the boat-size post-stratification (Table 11) exceeded allowable levels (Table 1). However, using the pilot stratification as was done for the 1995 annual report, the estimated take of 364 and mortality of 55 for loggerhead turtles exceeded the allowable levels.

Regression Tree Estimates

Of the 20 predictor variables tested, only four were found to be statistically significant: 1) latitude, 2) percentage of full moon, 3) percentage of albacore in the catch, and 4) percentage of swordfish in the catch (Fig. 6). These findings support the belief that most sea turtle takes resulted from swordfish fishing operations. Significance of the percentage of albacore in the catch variable was consistent with reports of longline fishermen who said that albacore are often found in association with swordfish or at least in fishing grounds similar to those selected for targeting on swordfish. The regression tree estimated take of loggerhead turtle (309) also exceeded the allowable level (Table 1). The regression tree estimate of turtle take for all species and the 95% confidence limits (right column of Table 11) fell between estimates using the pilot design stratification and the boat-size post-stratification. The use of measures of variability (e.g., CV) to determine which stratification alternative of the survey model better fitted the collected observer data addresses the issue of precision of the estimates. Two completely different statistical procedures, with different underlying assumptions yielding comparable estimates, provided some indication that the estimates were accurate. Of course, biased estimates could have resulted if the survey design did not monitor the true occurrence of turtle-fishery interactions. We chose not to use the regression estimates for reporting to the SWR until we had further examined the tool.

Preliminary estimates

The SWR released preliminary estimates of sea turtle take and mortality (Table 12) in a draft annual report for the first year (February 24, 1994-February 23, 1995) of the Observer Program. The estimated take (442) and mortality (52) of loggerhead turtles exceeded the allowable limits (Table 1). None of the other estimates by species or overall estimates across all species exceeded the allowable limits. However, all of the SWRs estimates were higher than those computed using the sample survey procedure. This preliminary estimate was computed using a simple ratio estimator (total takes/total hooks) from the observer data multiplied by the total number of hooks fished from the logbook data. The species breakdowns and mortality estimates were computed in the same manner as our estimates, except that the percentage of mortality used was 11.8%. Their approach did not take into account the reduction in total statistical variability that would be gained by dividing the data into strata having similar variation and response and was prone to bias because it did not take into account the differential sampling of the strata.

1995 Annual Report

Stratification Evaluation

Based on the CV of the sea turtle take rate estimates, none of the post-stratification schemes resulted in estimates markedly less variable compared to the pilot design (Table 13). Thus, we concluded that the pilot stratification should be used in computing the estimated takes of turtles. However, Skillman et al. (1996) recommended that the SWR adopt the two-boat stratification design for conducting the Observer Program rather than continue to use the pilot survey. This recommendation was made because the two-boat size stratification would be simpler to administer, performed about as well as any other stratification, and would involve more effective allocation of observer resources.

Estimates of Variation

The bootstrap distribution statistics (Table 14) indicate that the estimates of take have a lower precision than is evident from applying the standard parametric approach. The bootstrap method produces higher CVs, higher estimates of relative error, and wider confidence intervals than the parametric approach. Bootstrap CVs for the estimated annual total take of all turtle species combined are 30-38%. The bootstrap measures of relative error indicate that at the level of observer sampling implemented in 1994 and 1995, annual estimates of total take for all species combined would be within 50-60% of true take levels with 90% confidence. Precision is even lower, of course, for estimates of take by species. The bootstrap distributions are clearly non-normal and skewed, as illustrated by the results for olive ridleys and all species combined in 1994 (Fig. 7). Further, the low frequency of turtle takes for some species (e.g., olive ridley), coupled with the small Observer Program sample size, results in a high degree of discreteness in the bootstrap distributions.

The accuracy of the standard parametric formula used to estimate the variation of the total take estimate for the 1994 annual report depends on certain conditions. This formula is a function of the variance of the ratio estimate of the take within strata. The latter is an approximation that assumes that the distributions of effort (hooks per trip) and turtle take (turtles taken per trip) are normal. In addition, the standard confidence interval estimates of the turtle take assume that the take rates are normally distributed. In practice, the effort distribution may be normal, but the distribution of takes per trip is not. Because of the patchy distribution of turtles at sea and a low encounter rate, the distribution of takes per trip is strongly skewed with a high probability of zero takes. Further, the combination of a low frequency of turtle takes and a low sampling coverage in the Observer Program may result in a high degree of discreteness in the take rate distributions. The pitfalls of the standard approach can be avoided by using the bootstrap method (Efron, 1982; Efron and Tibshirani, 1995) to estimate the sampling distribution of take estimates. The bootstrap method does not require the restrictive assumptions of the standard approach, yet it provides empirical estimates of the statistical dispersion of take estimates (e.g., variances and CVs) and confidence intervals for total take that have desirable asymptotic properties.

Take Estimates

The annual estimates (Table 2, Annual Report column, 1995 rows) of 441 for all turtles taken in 1994 and 575 in 1995 do not exceed the take of 849 allowed in the 1994 Biological Opinion. The allowable take determination in the Opinion was based on a maximum potential level of fishing effort estimated under Amendment 7 to the pelagics FMP (15.4 million hooks being set if all 167 permitted fishing boats actively fished) and a take rate of 0.055 turtles/1,000 hooks. In 1994 and 1995, 125 and 109 active boats set 12 and 14 million hooks respectively (Table 5), and the computed take rates were 0.037 and 0.041.

The species-specific, parametric estimates of takes and the bootstrap estimates of confidence limits are also provided in Table 2 (Annual Report column, 1995 rows). The estimated take of loggerhead (413) in 1995 exceeded the allowable limit (305). Also, the upper confidence limit for loggerhead (403) in 1994 exceeded the allowable limit. For the remainder of the species, neither the estimated take nor the upper confidence limit exceeded the allowable levels. No takes of green turtles in 1995 nor of hawksbill in either year were observed.

The estimates of mortality, computed as 15.1% of the take estimates, are shown in Table 3 (Annual Report column, 1995 rows). The estimated mortality of loggerhead (62) in 1995 exceeded the allowable limit (46). None of the estimated mortalities for any other species or for all turtles exceeded the allowable levels.

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Regression Tree Estimates

An unrestricted regression tree for loggerhead takes against the independent variates listed in Table 7 showed latitude as the most important variable followed by swordfish catches and then a jumble of other variables (Fig. 8). The average of repeated cross-validations suggested an optimal tree size of three (Fig. 9), and pruning the tree to that size yielded the final regression tree containing only latitude and swordfish catch as independent variables (Fig. 10).

After cross-validation, the pruned regression tree for olive ridleys contained yellowfin tuna catch as the only significant variable (Fig. 11). Cross-validation for the leatherback regression tree suggested pruning the size to one (Fig. 12), which in effect eliminates the regression tree altogether. A similar result was obtained for green turtles. Therefore, simple expansion of overall hooking rates was used instead of regression trees to obtain take estimates for leatherback and green turtles (see Methods section).

Annual take estimates are given in Table 2 (Annual Report column, 1996 rows) and the allowable takes in Table 1. The point estimates of takes for loggerheads exceed the allowable level in 1995 and 1996. None of the point estimates exceed the allowed levels for the other species. The 95% confidence ranges span the allowed take levels for all three years for both loggerhead and olive ridley turtles, but the range is below the allowed take levels in all years for leatherback and green turtles. A rough indication of the probability that the actual number of takes (as opposed to the estimated number) was in fact greater than the allowable take level is given by the proportion of bootstrap estimates that exceeded the allowable level (Table 15). In the case of leatherback and green turtles, the proportion is based on the binomial likelihood distribution). This probability is greatest for loggerheads and vanishingly small for both leatherback and green turtles.

Annual mortality estimates are presented in Table 3 (Annual Report column, 1996 rows), with the allowable mortalities in Table 1. The point estimates of loggerhead and olive ridley kill exceeds the allowable level in all 3 years. The confidence ranges for kill estimates are merely a reflection of the confidence ranges of the take estimates and do not account for uncertainties in estimating kill per take from the condition information recorded by observers. The confidence ranges on Table 3 are therefore minimal indications of the uncertainties in the kill estimates, and the estimated probabilities that allowable levels were exceeded (Table 16) likewise carry an extra degree of uncertainty.

Annual take and kill results are displayed graphically in Figures 13-16. In all cases, time trends are overwhelmed by the large regions of uncertainty, and indeed, though year was offered as a possible independent variable (Table 7), it was never found to be significant by the regression tree analysis. The take and kill distributions for leatherback and green turtles are smooth because they are based on a theoretical mathematical function, whereas the distributions of loggerhead and olive ridley turtles are jagged, being based on empirical bootstrap results.

DISCUSSION

Loggerhead turtles appeared in the largest number (56) of observed takes over the 3 years (Table 6). Latitude was the most important explanatory variable followed by swordfish catches for the take of loggerhead. Juvenile loggerheads occupy a large part of the transition zone and the distribution of loggerhead takes is concentrated in this area (Fig. 1). Thus, it is not surprising that location of longline gear in waters where turtles are present would be the foremost explanatory variable for turtle interactions. Within these northern waters, swordfish catches (in the context of the regression tree analysis) provide a secondary explanation of the interactions and may be a proxy for finer scale information on the co-location of the turtles and the fishing gear. It is likely that loggerheads and swordfish are attracted to specific, though not necessarily the same fine scale features of the transition zone. However, because such oceanographic features shift in strength geographically and temporally, it is unlikely that latitude (or longitude) would indicate proximity to such features very well. Since swordfish catches presumably are an indicator of where swordfish are concentrated, the occurrence of swordfish catches as the second most important explanatory variable suggests that loggerheads and swordfish may be attracted to similar oceanographic features in the northern areas of the fishery. Obviously, loggerhead turtles are vulnerable to capture with longline operations conducted and gear configured to take swordfish. However, since swordfish longline gear is most often deployed in the northern fishing waters and the U.S. domestic longline fleet seldom configures longline gear for any other species when fishing in northern waters, statistically significant explanatory gear factors have not yet emerged from the analysis.

Olive ridley turtles appeared in 16 observed takes over the 3 years, considerably fewer than loggerheads. Nevertheless, one variable (yellowfin catch) emerged as significant. The implication is either that olive ridleys are vulnerable to configurations of gear targeting yellowfin or that olive ridleys and yellowfin tuna tend to co-locate. This is a very tentative conclusion, based on only four turtle takes in nine sets that caught 18 or more yellowfin each, as opposed to 12 turtle takes among 1,691 sets in which less than 18 yellowfin were caught (Fig. 11). The high estimates of olive ridley mortality (Fig. 14 and Table 16) are likewise tentative, being largely influenced by only two animals that observers recorded as dead (Table 8). If uncertainties in the determination of mortality per take had been considered, the range of uncertainty would have been proportionately greater for the mortality estimates than for the take estimates. For loggerhead and olive ridley turtles, the probabilities that allowable mortalities were exceeded (Table 16) would have been closer to 50%.

Leatherback turtles were involved in 21 observed takes, more than olive ridleys, yet no significant variables emerged. Leatherbacks apparently have a wide geographic distribution throughout the region of the longline fishery (Fig. 1), which could explain why neither latitude nor longitude emerged as significant in this case. It is possible that no other variables were significant because there are no true functional effects among the variables tested. It is possible that there are no functionally significant variables to be found. This would be the case if leatherbacks were not attracted to the bait but simply bumped into the gear. The reported condition of leatherbacks is consistent with this interpretation. In the majority of observed leatherback takes where the condition was known, the turtle was either listed as hooked externally or listed as "OK" (probably meaning that the animal was just tangled with the longline).

Green turtles, with five observed takes, also showed no significant variables. This result was expected since there were so few takes.

A desirable outcome of the Observer Program would be to identify significant variables that affect the chances of turtle takes by the longline fleet and that suggest possible mitigative measures. The fact that few significant independent variables were found in the analysis does not mean that few variables exist (or no variables, as in the case of leatherback and green turtles) that truly influence the chances of taking turtles on longline gear. In addition to the possibility that we have not yet tested the right variables, there are additional factors that make for difficulty in discerning real effects from among the variables that we did test. With so few turtle takes observed, the effect of a variable must be very strong to overcome the statistical noise. An additional problem is that the independent variables are not all precisely determined, which adds another component of statistical noise. Also, colinearity among the independent variables means that the true effect of a variable can be masked by a correlated variable.

The statistical situation, i.e., low coverage rate of the fishery by observers and the fact that turtle takes are rare events, dictates that take and kill estimates are embedded in wide confidence regions and that inferences about the presence (or lack) of causative relationships must be considered preliminary. This situation can be improved in the short term only by markedly increasing the coverage rate. In the long-term, if the present coverage rate is maintained, the situation will slowly improve as data accumulate, as long as the functional relationships between turtles and gear remain stable. If, however, fishing gear and fishing practices change markedly, the statistical situation will not improve. Of course some changes might be desirable, such as truly effective preventive measures against turtle takes. Unfortunately, unless such measures are highly effective, it is quite possible that the effect would not be statistically detectable given the current noisy background data.

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Table 1.--Allowable take and mortality of sea turtles listed in the in the 1994 Biological Opinion and Incidental Take Statement.

Species	Take	Mortality
All	849	129
Loggerhead	305	46
Leatherback	271	41
Olive ridley	152	23
Green	119	18
Hawksbill	2	1

Table 2.--Estimates of turtle take and 95% (90% for the 1994 annual report) confidence limits by species and in the aggregate for the three annual reports. The periods are for calendar years except for the first year which is from February 24, 1994-February 23, 1995. Statistics in bold exceed the allowable limits (Table 1). Confidence limits were not computed for the total takes in annual report 1996.

Annual report	Period	Estimation procedure	Logger-head	Leather-back	Olive ridley	Green	Hawks-bill	Total
1994	1st year	Survey	291	119	66	26	-	502
		sampling	-	-	-	-	-	189-815
1995	1994	Survey	207	122	78	34	-	441
		sampling	70-403	41-233	0-180	0-95		238-688
	1995	Survey	**413**	81	81	-	-	575
		sampling	153-764	0-187	0-191			272-970
1996	1994	Regression	301	132	120	34	-	587
		tree	212-447	87-202	60-179	15-81		-
	1995	Regression	**339**	156	123	41	-	659
		tree	225-476	103-239	66-194	18-96		-
	1996	Regression	**358**	159	129	42	-	688
		tree	237-481	104-243	68-193	18-97		-

Table 3.--Estimates of turtle mortality and 95% confidence limits by species and in the aggregate for three annual reports. For the 1994 and 1995 annual reports, mortality was computed as 15.1% of the estimated takes. For the 1996 annual report, mortality was estimated from the observer data. The periods are for calendar years except for the first year which is from February 24, 1994-February 23, 1995. Statistics in bold exceed the allowable limits (Table 1).

Annual report	Period	Estimation procedure	Logger-head	Leather-back	Olive ridley	Green	Hawks-bill	Total
1994	First year	Survey sampling	34	14	8	3	-	59
			-	-	-	-	-	-
1995	1994	Survey sampling	31	18	12	5	-	67
			-	-	-	-	-	-
	1995	Survey sampling	**62**	12	12	-	-	87
			-	-	-	-	-	-
1996	1994	Regression tree	**51**	9	**32**	1	-	93
			36-75	0-14	0-47	0-2	-	-
	1995	Regression tree	**57**	11	**33**	1	-	102
			38-80	7-16	18-49	0-2	-	-
	1996	Regression tree	**60**	11	**34**	1	-	106
			40-81	7-16	18-51	0-2	-	-

Table 4.--Characteristics of estimation procedures for the 1994, 1995, and 1996 annual reports.

Report	Characteristics	Description
1994	Statistical method	Survey sampling theory
	Ratio estimator	Trip-wise takes per 1,000 hooks
	Estimator period	12 months
	Stratification	Post stratification based on boat length
	Variation of estimate	Parametric
	Species estimates	Allocated using observed proportions
	Mortality estimates	Based on % in Biological Opinion
	Period definition	Trip-wise month/year of landing + haul date
1995	Statistical method	Survey sampling theory
	Ratio estimator	Trip-wise takes per 1,000 hooks
	Estimator period	Each calendar year
	Stratification	Pilot stratification based on historical targeting
	Variation of estimate	Nonparametric bootstrap
	Species estimates	Computed directly
	Mortality estimates	Based on % in Biological Opinion
	Period definition	Trip-wise month/year of landing + haul date
1996	Statistical method	Regression tree
	Ratio estimator	Not applicable (dependent variable in takes by set)
	Estimator period	1994-96 inclusive
	Stratification	Not applicable (independent variable evaluation)
	Variation of estimate	Nonparametric bootstrap
	Species estimates	Computed directly
	Mortality estimates	Observed data + reference post-release death rate
	Period definition	Date of set, within calendar year

Table 5.--Measures of fishing effort as observed (Observer Program) and as logged (Logbook Program). The first year of the Observer Program was February 24,1994-February 23, 1995. In calendar year 1994, the observer data covered about 10 months while the logbook data spanned 12 months; coverage rate during the 10 months was 5%.

Year	Description	Observed	Logged	Coverage
First	Number of boats	52	124	41.9%
year	Number of trips	55	1,107	5.0%
	Number of sets	572	10,500	5.4%
	Number of hooks	599,700	11,884,081	5.0%
1994	Number of boats	47	125	37.6%
	Number of trips	49	1,105	4.4%
	Number of sets	509	10,799	4.7%
	Number of hooks	525,372	11,996,072	4.4%
1995	Number of boats	29	109	26.6%
	Number of trips	48	1,122	4.3%
	Number of sets	549	11,502	4.8%
	Number of hooks	617,576	13,964,322	4.4%
1996	Number of boats	48	104	46.2%
	Number of trips	53	1,100	4.8%
	Number of sets	641	11,641	5.5%
	Number of hooks	748,025	14,402,331	5.2%

Table 6.--Observed (Observer Program) and logged (Logbook Program) turtle takes during the first year of the Observer Program (February 24, 1994-February 23, 1995) and by calendar year in the Hawai'i longline fishery.

	First Year		1994		1995		1996	
Species	Observed	Logged	Observed	Logged	Observed	Logged	Observed	Logged
All	38	89	27	84	29	63	50	79
Loggerhead	20	23	11	27	19	14	26	24
Leatherback	9	1	8	41	4	15	9	18
Olive ridley	4	27	3	1	4	5	9	21
Green	2	0	2	15	0	19	3	9
Hawksbill	0	0	0	0	0	3	0	4
Unidentified hardshell	3	0	3	0	2	7	3	3

Table 7.–Independent variables tested in the regression tree analysis for statistical significance in affecting probability of turtle interaction. Used for the 1996 annual report.

Variable Groupings	Variable	Mnemonic	Type	Notes
Location in time and space:	latitude	lat	numeric	degrees
	longitude	lon	numeric	degrees
	year	year	categorical	94; 95; 96
	month	mon	categorical	Jan -- Dec
	time	time	numeric	0001 - 2400
Condition of gear:	hooks	hooks	numeric	count
	hooks/float	hkpfl	categorical	<17; >17; unknown
	bait	bait	categorical	6 categories
	light sticks	stiks	numeric	count
Environment:	temperature	btemp	categorical	<22C; >22C; unknown
Catch of other species:	bigeye	bet	numeric	catch in #
	yellowfin	yft	numeric	"
	skipjack	skj	numeric	"
	albacore	alb	numeric	"
	swordfish	swo	numeric	"
	blue shark	blshk	numeric	"
	mahimahi	mahi	numeric	"
	striped marlin	stmrl	numeric	"
	blue marlin	blmrl	numeric	"
	wahoo	wahoo	numeric	"
	spearfish	spear	numeric	"
	opah	opah	numeric	"
	albatross	albts	numeric	"
Other:	vessel length	veslen	numeric	registered length
	target	targ	categorical	7 categories

Table 8.--Turtle condition factors from observer data, 1994-96. "Take" is the number of turtles recorded by observers in various conditions at time of release. "Death rate" is the expected rate imputed from the given condition (see text). The "Total" column gives the total observed take (upper of each pair of numbers) and the deaths (lower of each pair) estimated as the sum of the products of take times death rate for each condition factor.

		Conditions						
Species	Factor	Internal	External	Hook	NR	OK	Dead	Total
Loggerhead	Take	30	21	2	1	2	--	56
	Death rate	0.290	0.000	0.171	0.164	0.000	--	9.2
Olive ridley	Take	8	6	--	--	--	2	16
	Death rate	0.290	0.000	--	--	--	1.000	4.3
Leatherback	Take	1	10	1	5	3	1	21
	Death rate	0.290	0.000	0.026	0.021	0.000	1.000	1.4
Green	Take	--	5	--	--	--	--	5
	Death rate	--	0.000	--	--	--	--	0.0
Hardshell	Take	3	--	3	2	--	--	8
	Death rate	0.290	--	0.163	0.159	--	--	1.7

Condition factors:

Internal -- hook was ingested
External -- hooked, but hook not ingested
Hook -- hooked in unknown location
NR -- condition not recorded
OK -- unharmed and able to swim normally
Dead -- dead upon gear retrieval

Table 9.--Calculation of death rate (deaths per take). Take and Deaths are observed total takes and estimated deaths from Table 8, with the takes and deaths of unidentified hardshell turtles distributed over loggerhead, olive ridley and green turtles in proportion to the known takes of those species.

Species	Take	Deaths	Death Rate
Loggerhead	61.8	10	0.16
Olive Ridley	17.7	4.7	0.264
Leatherback	21	1.4	0.068
Green	5.5	0.1	0.02

Table 10.--Coefficients of variation and 95% confidence limits of sea turtle take estimates for February 24, 1994-February 23, 1995 by alternative stratifications.

Stratification	Coefficient of variation	95% Confidence limits
Pilot design (historical fishery targeting)	39.56	628 ± 422
Post stratification-1 (captain's declared target)	68.36	732 ± 868
Post stratification-2 (boat lengths)	35.70	502 ± 313

Table 11.--Estimated turtle takes and mortality for the first year for February 24, 1994-February 23, 1995 using post-stratification based on boat size classes (<67, 67-78, >78 ft, USCG documented length). CV = coefficient of variation; CL = confidence limits (±). Estimates from the pilot stratification and regression tree provided for comparative purposes. Values in bold face exceeded the allowable levels (Table 1).

		Boat-Size stratification		Pilot stratification		Regression tree	
Species	Adjusted observed take	Estimated take	Estimated mortality	Estimated take	Estimated mortality	Estimated take	Estimated mortality
All	38	502	59	628	95	533	89
- CV		35.7		39.56			
- 95% CL		189-815		206-1050		397-726	
Loggerhead	22	291	34	**364**	**55**	**309**	37
Leatherback	9	119	14	149	22	126	15
Olive ridley	5	66	8	83	12	70	8
Green	2	26	3	32	5	28	3
Hawksbill	0	0	0	0	0	0	0

Table 12.--Preliminary estimate of sea turtle takes and mortality for February 24, 1994-February 23, 1995 based on non-stratified estimates of marine turtle take for the fishery. Values in bold exceeded limits in the Incidental Take Statement.

Species	Adjusted observed take	Estimated take	Estimated mortality
All	38	753	89
Loggerhead	22.3077	**442**	**52**
Leatherback	9	178	21
Olive ridley	4.46154	88	11
Green	2.23077	44	5
Hawksbill	0	0	0
Unidentified hardshell	--	--	--

Table 13.–Parametric coefficient of variation (CV) and the estimate of the turtle take rate by stratification alternative. Observer data from February 24, 1994 through December 31, 1995 (97 trips) were used.

Stratification alternative	Description	CV of the take rate	Take rate (#/1,000 hooks)
None		21%	0.049
Pilot design	Mixed, switcher, swordfish, tuna	21%	0.039
3-Boat strata	≤48.0, 48.1-74.9, >74.9 ft	19%	0.037
2-Boat strata	≤70.0, >70.0 ft	21%	0.037
3-Latitude strata	≤17.2, 17.3-28.7, >28.7°N	19%	0.052
2-Latitude strata	≤24.0, >24.0°N	20%	0.049
2 x 2 crosses	2-Boat bins x 2-Latitude bins	20%	0.037
3 x 3 crosses	3-Boat bins x 3-Latitude bins	18%	0.044

Table 14.--Bootstrap and parametric estimates of variation are compared. Estimates of coefficient of variation, 90% confidence limits and relative error (one-half of the 90% confidence interval divided by the bootstrap mean) for 1994 and 1995 for the Hawai'i longline fishery based on the pilot survey design employed in the NMFS Observer Program. -- indicates no interactions recorded in the Observer Program.

		Coefficient of variation		90% Confidence limits		Relative error	
Year	Species	Bootstrap	Parametric	Bootstrap	Parametric	Bootstrap	Parametric
1994	Loggerhead	48%	38%	70-403	78-336	80%	62%
	Leatherback	47%	34%	41-233	54-190	79%	56%
	Olive ridley	72%	53%	0-180	10-146	115%	87%
	Green	92%	67%	0-95	0-71	140%	104%
	Hawksbill	--	--	--	--	--	--
	Total	30%	24%	238-688	267-615	51%	39%
1995	Loggerhead	45%	39%	153-764	148-678	74%	64%
	Leatherback	71%	49%	0-187	16-146	115%	80%
	Olive ridley	71%	51%	0-191	13-149	118%	84%
	Green	--	--	--	--	--	--
	Hawksbill	--	--	--	--	--	--
	Total	38%	33%	272-970	263-887	61%	54%

Table 15.--The proportion of the bootstrap estimates of the binomial likelihood (P(>allowed)) that is greater than the allowable take levels.

Species	1994	1995	1996
Loggerhead	0.53	0.71	0.74
Olive Ridley	0.13	0.19	0.23
Leatherback	~0	~0	~0
Green	~0	~0	~0

Table 16.--The proportion of the bootstrap estimates of the binomial likelihood (P(>allowed)) that is greater than the allowable mortality levels. The bootstrap and binomial likelihood distributions do not include a component of error for uncertainties in determination of deaths per take.

Species	1994	1995	1996
Loggerhead	0.74	0.85	0.88
Olive ridley	0.82	0.88	0.88
Leatherback	~0	~0	~0
Green	~0	~0	~0

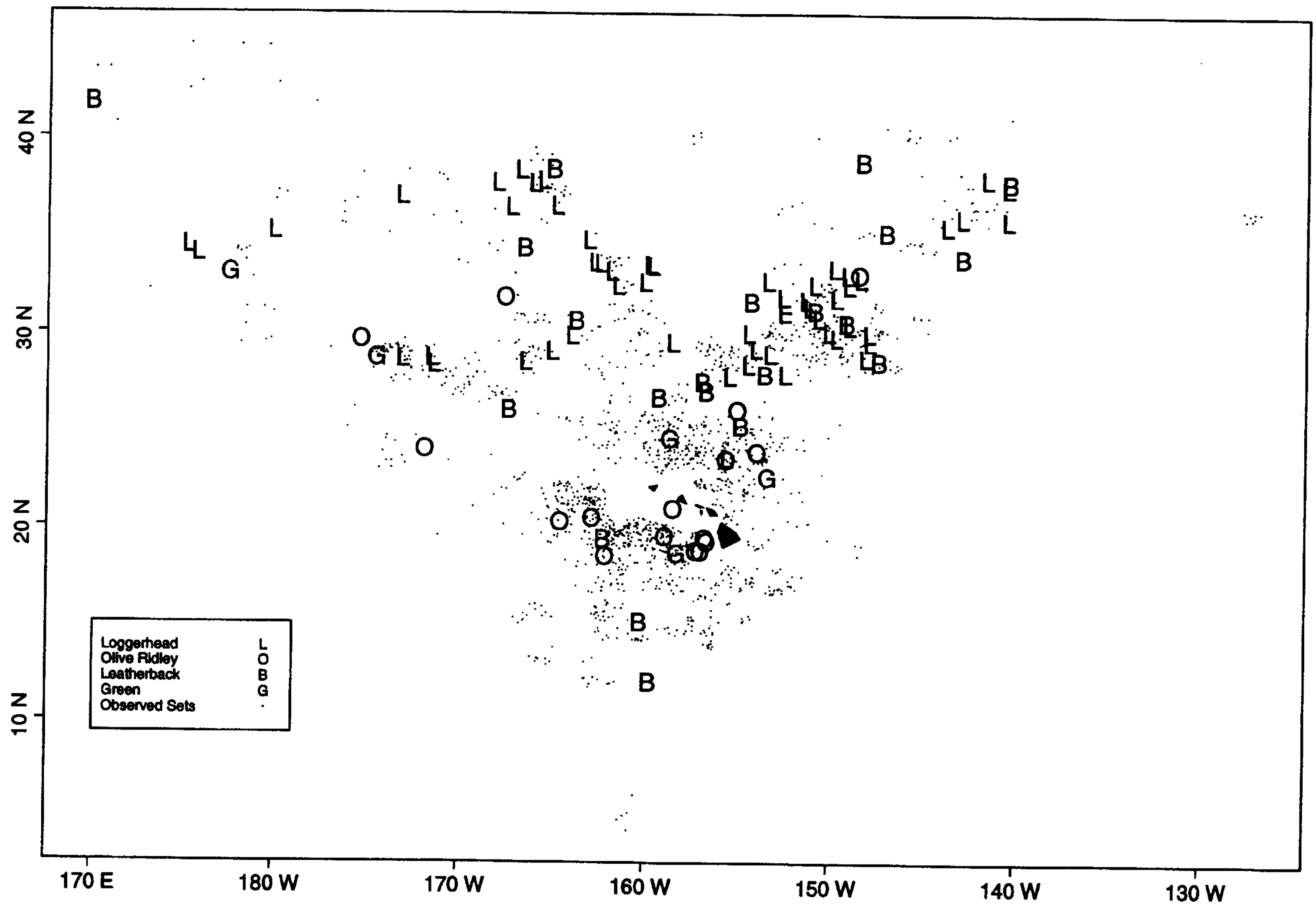

Figure 1.--Approximate positions of observed sets and observed turtle takes, 1994–96.

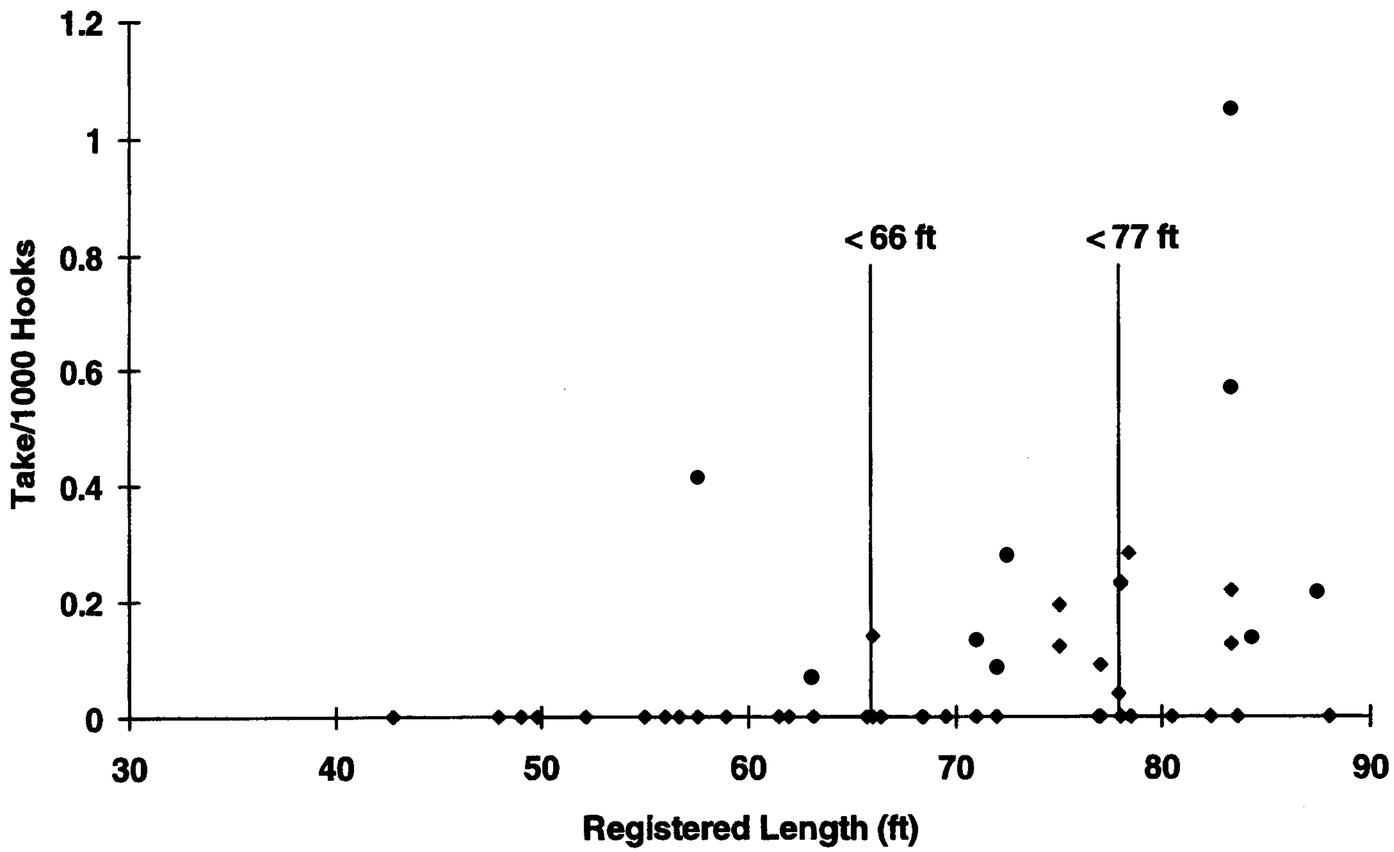

Figure 2.--Observed turtle take rate versus U.S. Coast Guard registered boat length, 55 observer trips. Vertical lines separate the small, medium, and large strata.

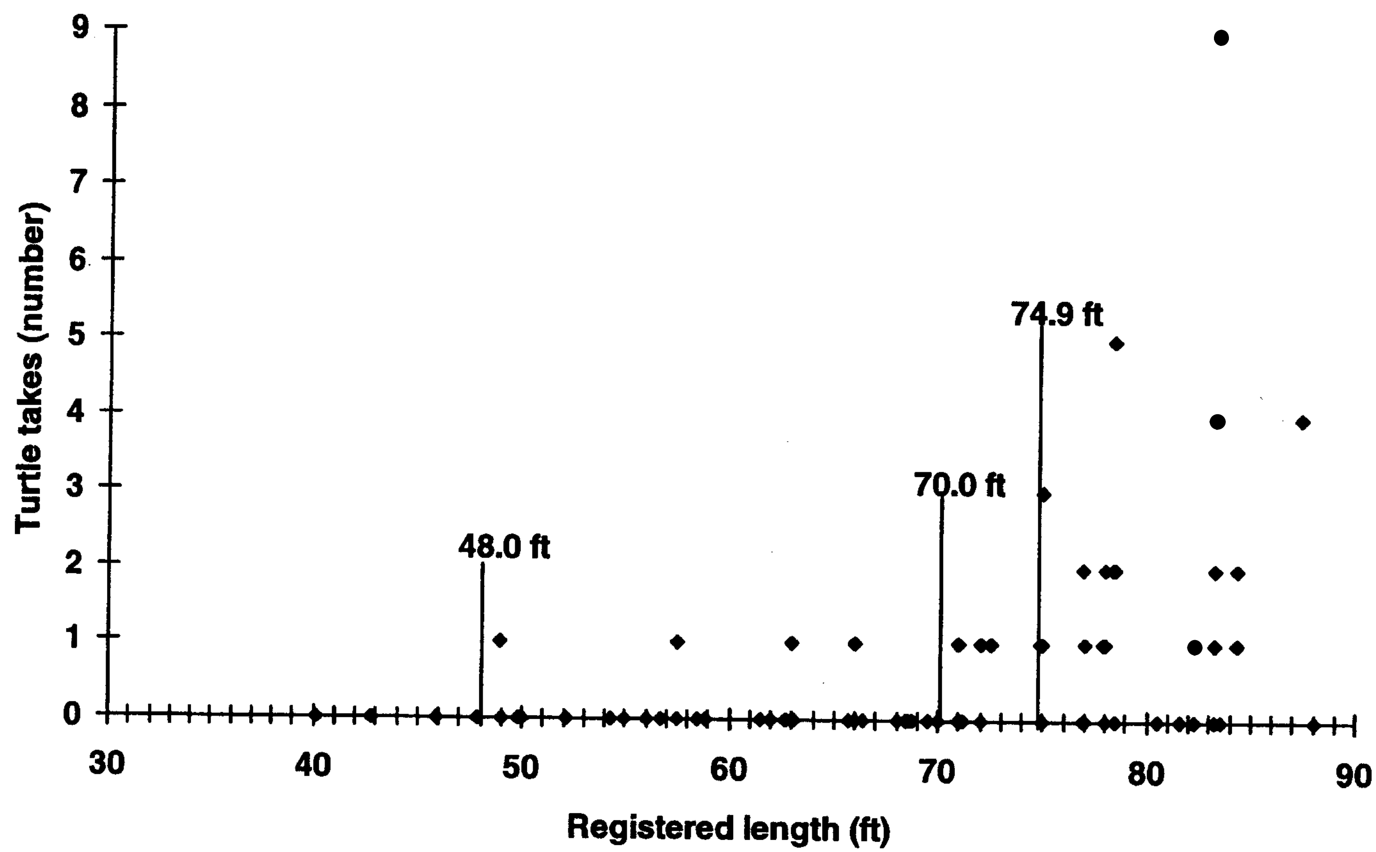

Figure 3.--Observed turtle takes versus U.S. Coast Guard registered boat length, 97 observer trips. Vertical lines separate the two strata (≤ or > 70 ft.) or three strata (≤48.0, 48.1-74.9 and >74.9 ft).

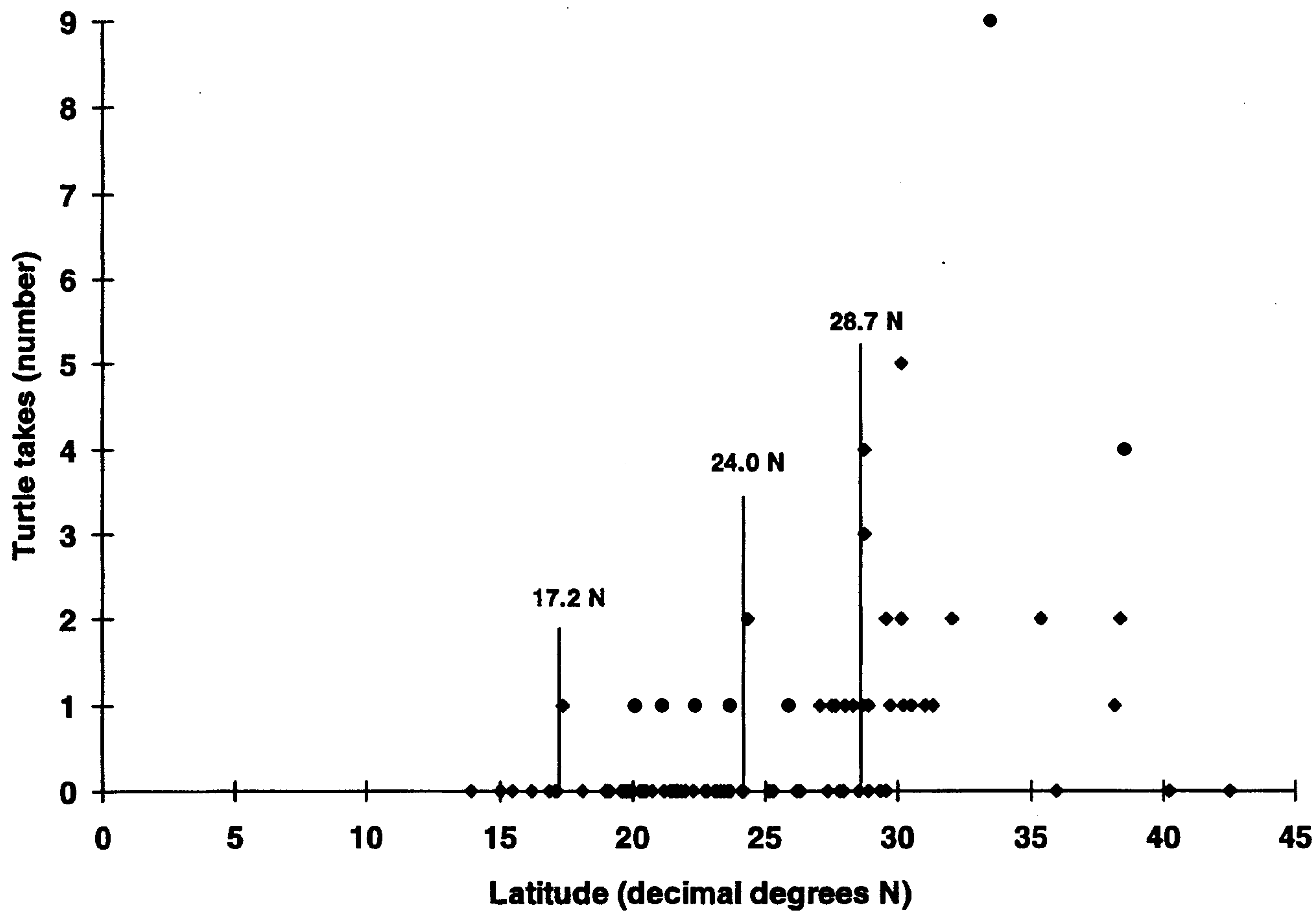

Figure 4.--Observed turtle takes versus latitude of first trip-set, 97 observer trips. Vertical lines separate the two strata (≤ or > 24.0 N) and for three strata (≤17.2, 17.3-28.7, and >28.7 N).

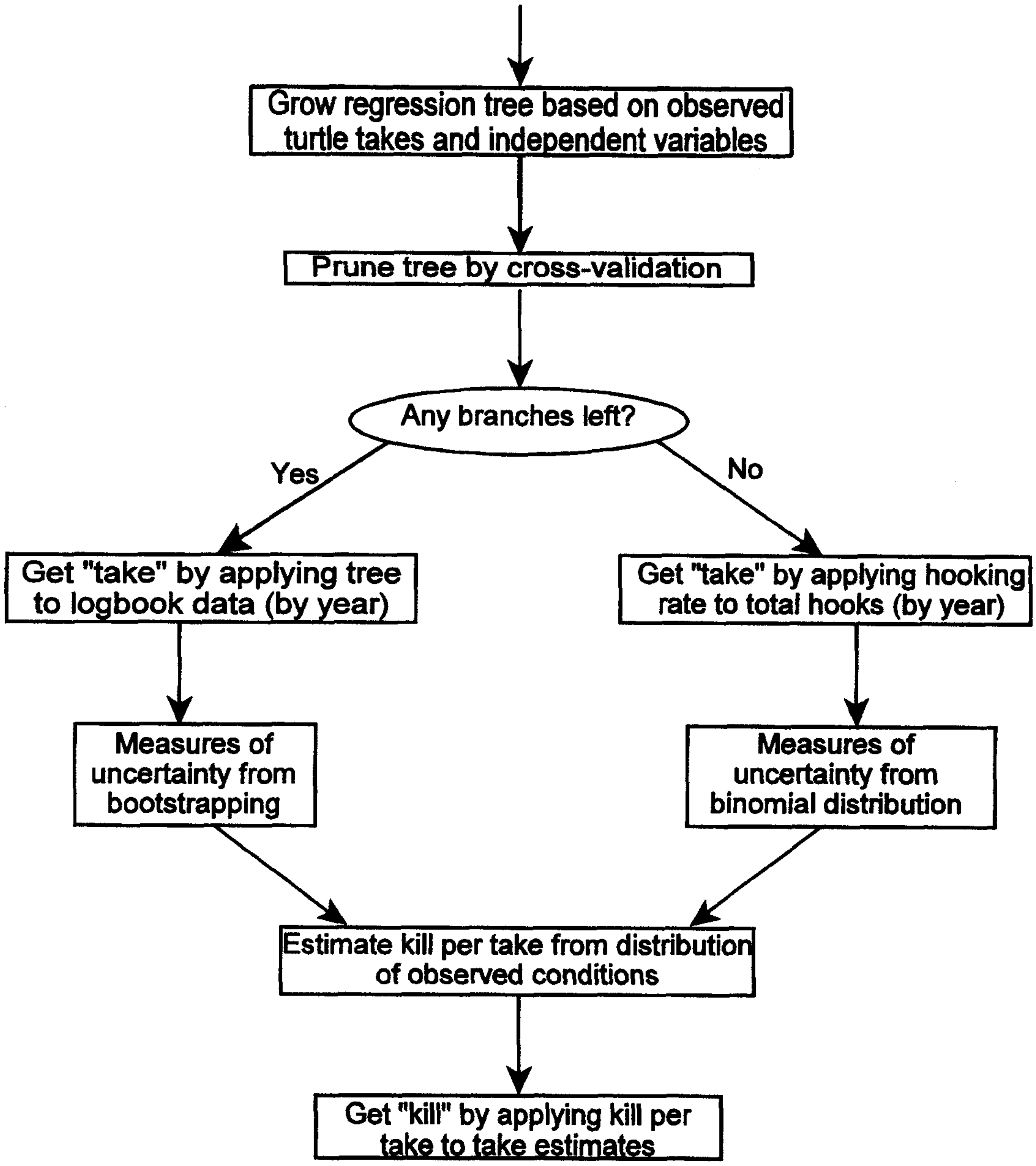

Figure 5.--Outline of procedure for estimating annual takes and kills from observer and logbook data.

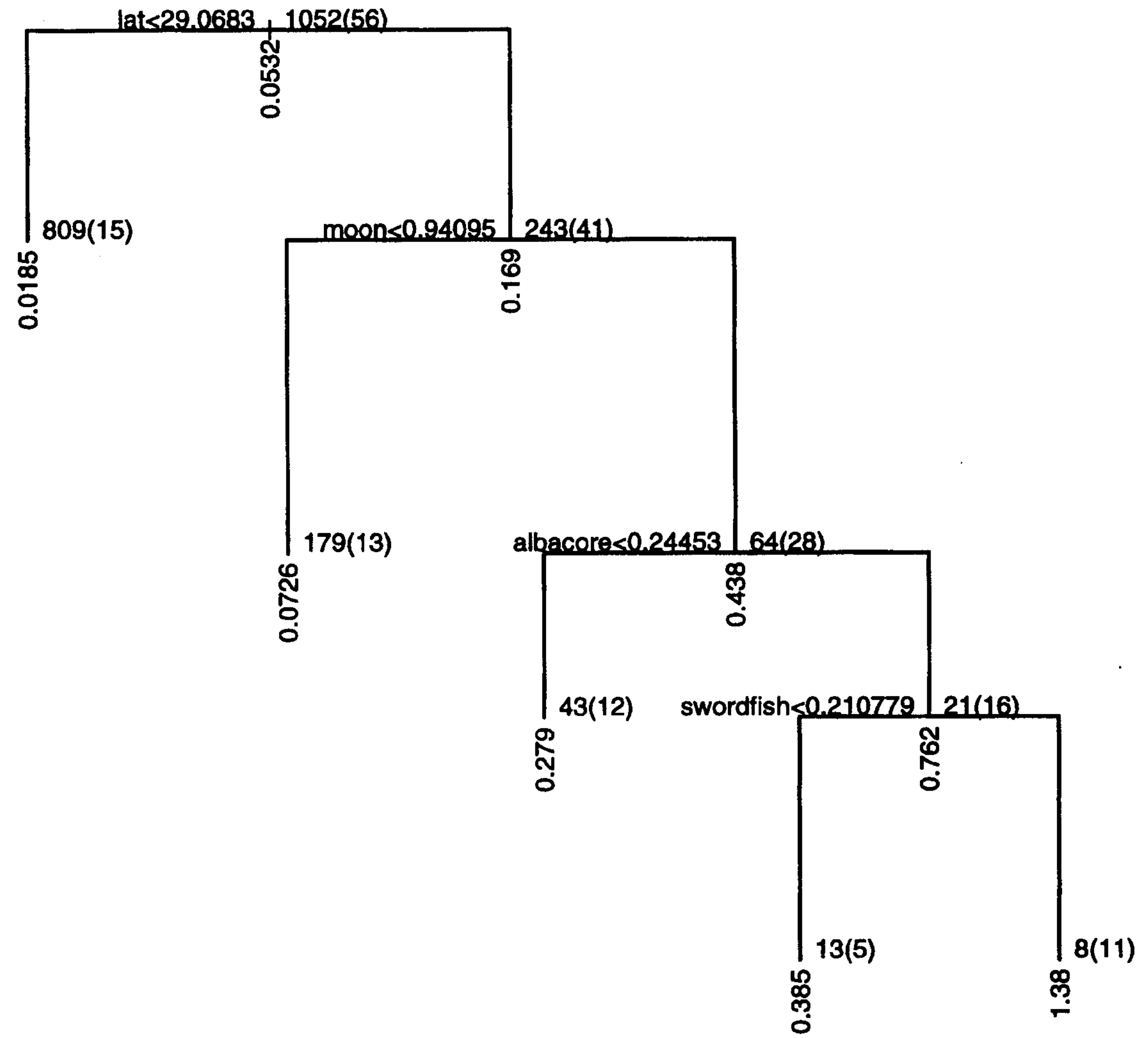

Figure 6.--Pruned regression tree model of the take of sea turtles in the Hawai'i longline fishery for first year of Observer Program (February 24, 1994-February 23, 1995). Each node is labeled with the variable mnemonic, the breakpoint of the left and right branches for that variable, the number of observed longline sets utilized at that node level, the observed turtle take in parentheses, and below the node the expected take per set at the breakpoint. The terminal values are the takes per set.

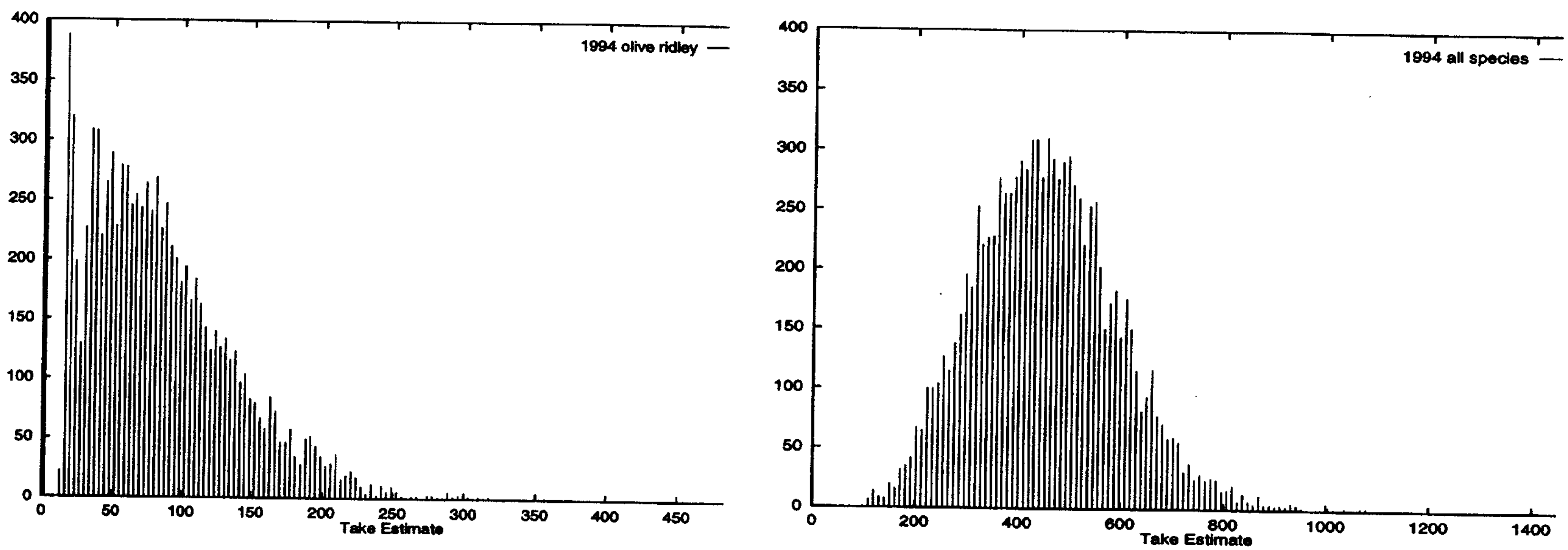

Figure 7.--Bootstrap distributions of 1994 take estimates for olive ridley (left) and for all species (right) based on 10,000 bootstrap replicates.

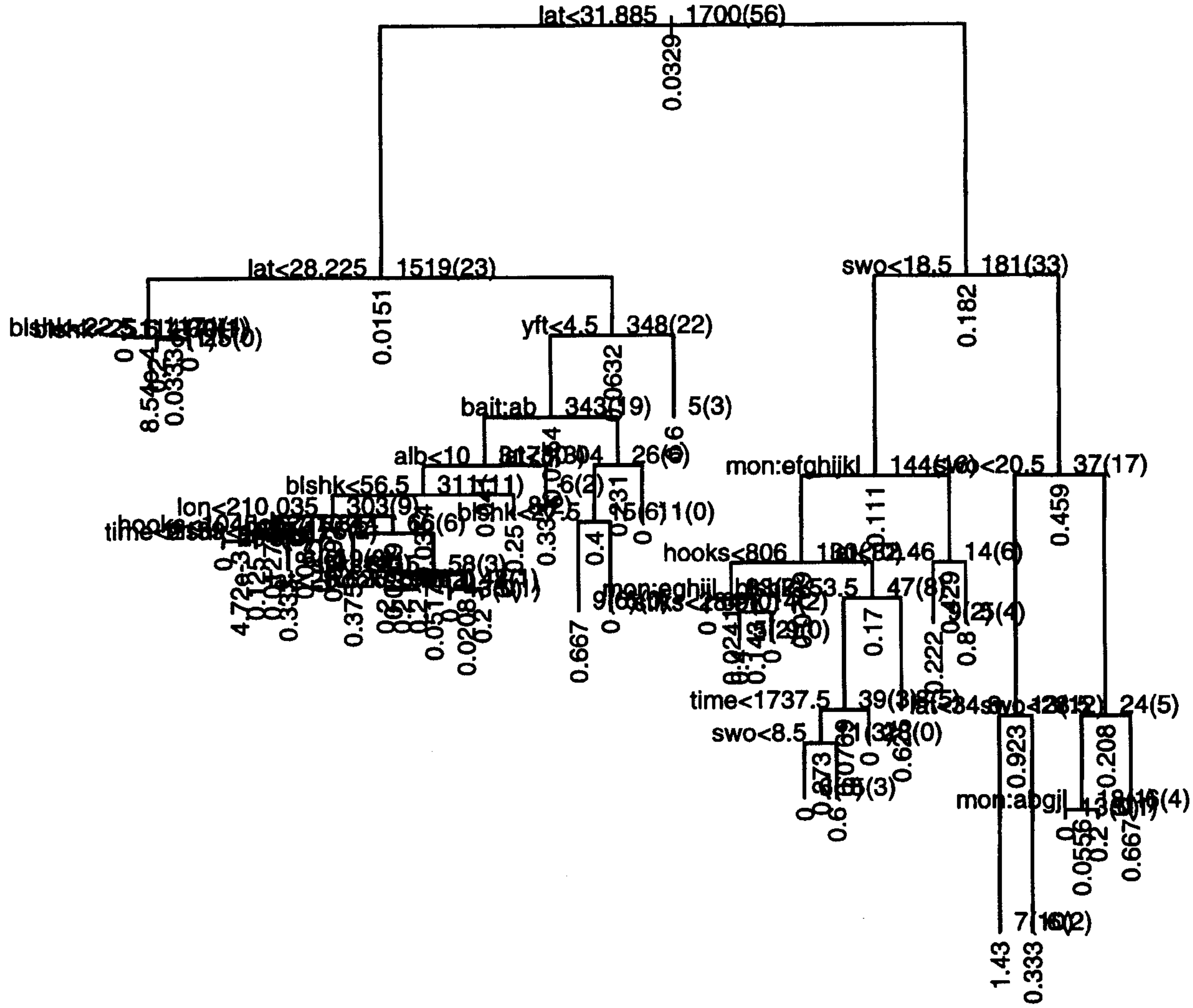

Figure 8.--Loggerhead regression tree, unpruned. Each node is labeled with the variable mnemonic, the breakpoint of the left and right branches for that variable, the number of observed longline sets utilized at that node level, the observed turtle take in parentheses, and below the node the expected take per set at the breakpoint. The terminal values are the takes per set.

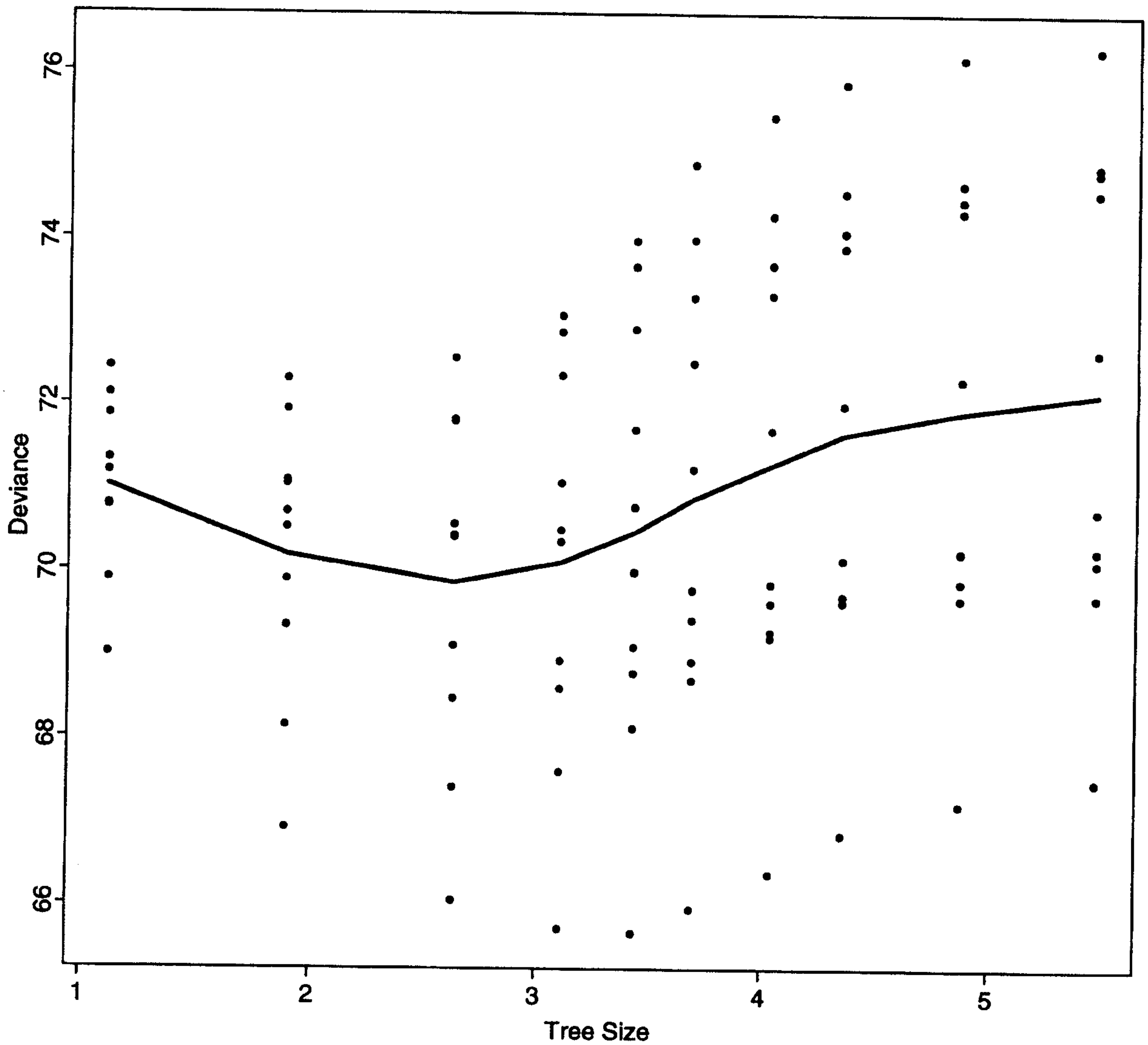

Figure 9.--Cross validation of loggerhead tree. The points in the figure are the results of 10 such cross validation runs, and the solid line is the average at each tree size. The final tree size was chosen at the minimum (to the nearest integer) of the solid line.

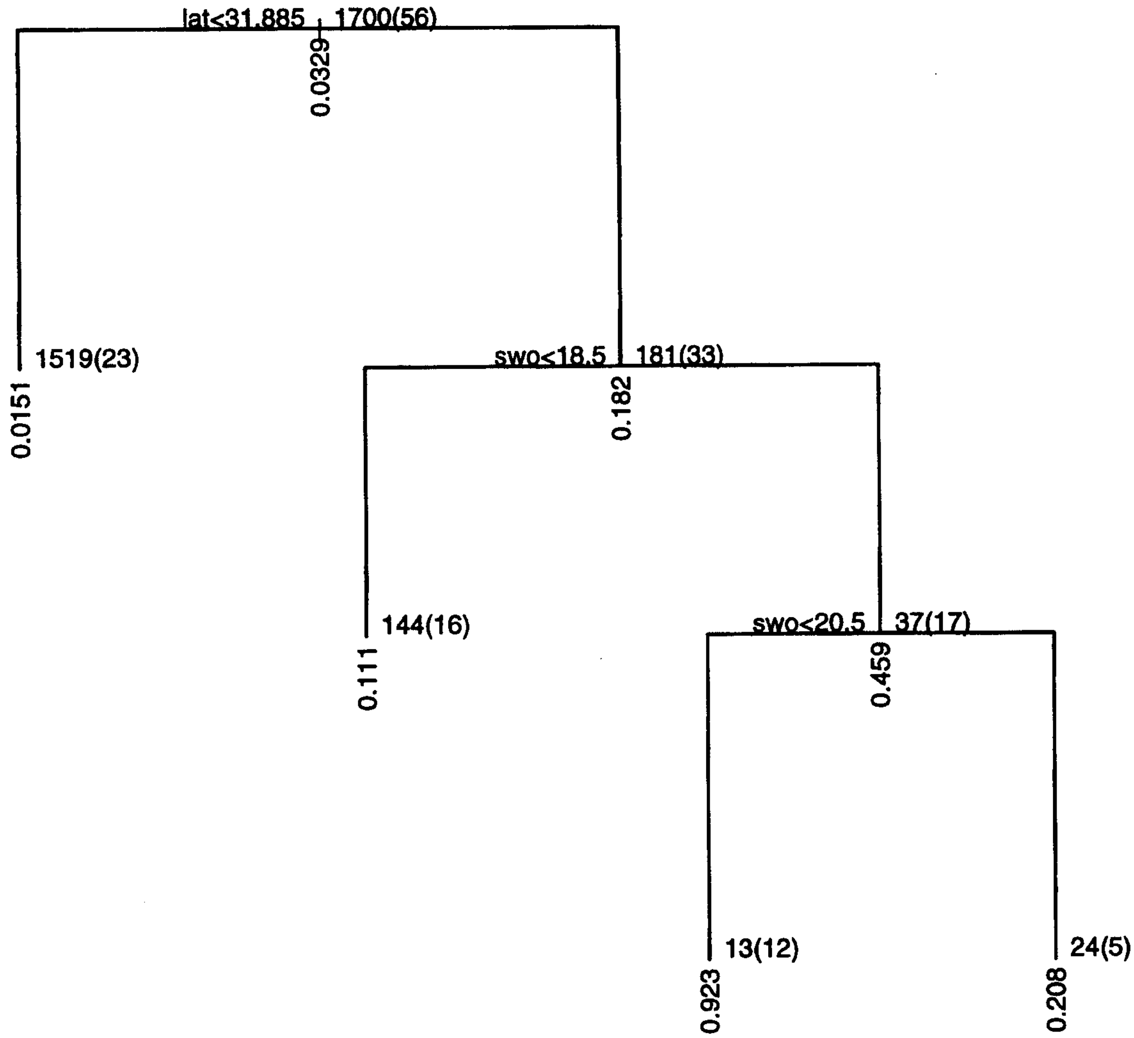

Figure 10.--Loggerhead tree after pruning to size = 3. Each node is labeled with the variable mnemonic, the breakpoint of the left and right branches for that variable, the number of observed longline sets utilized at that node level, the observed turtle take in parentheses, and below the node the expected take per set at the breakpoint. The terminal values are the takes per set.

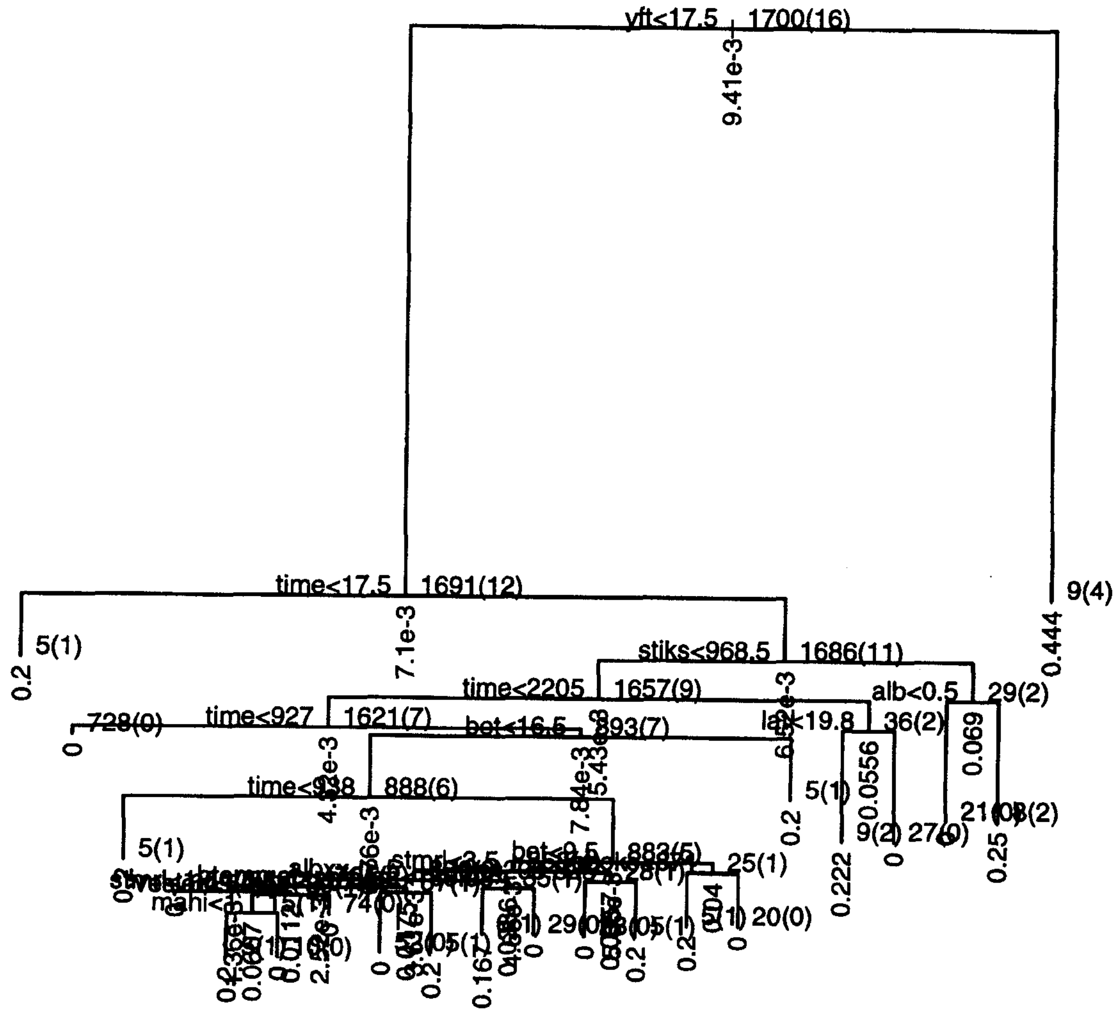

Figure 11.--Olive ridley tree, unpruned. Each node is labeled with the variable mnemonic, the breakpoint of the left and right branches for that variable, the number of observed longline sets utilized at that node level, the observed turtle take in parentheses, and below the node the expected take per set at the breakpoint. The final pruned version (size = 2) contained only the top (root) node and its two branches; i.e. yellowfin tuna catch was the only significant independent variable. The terminal values are the takes per set.

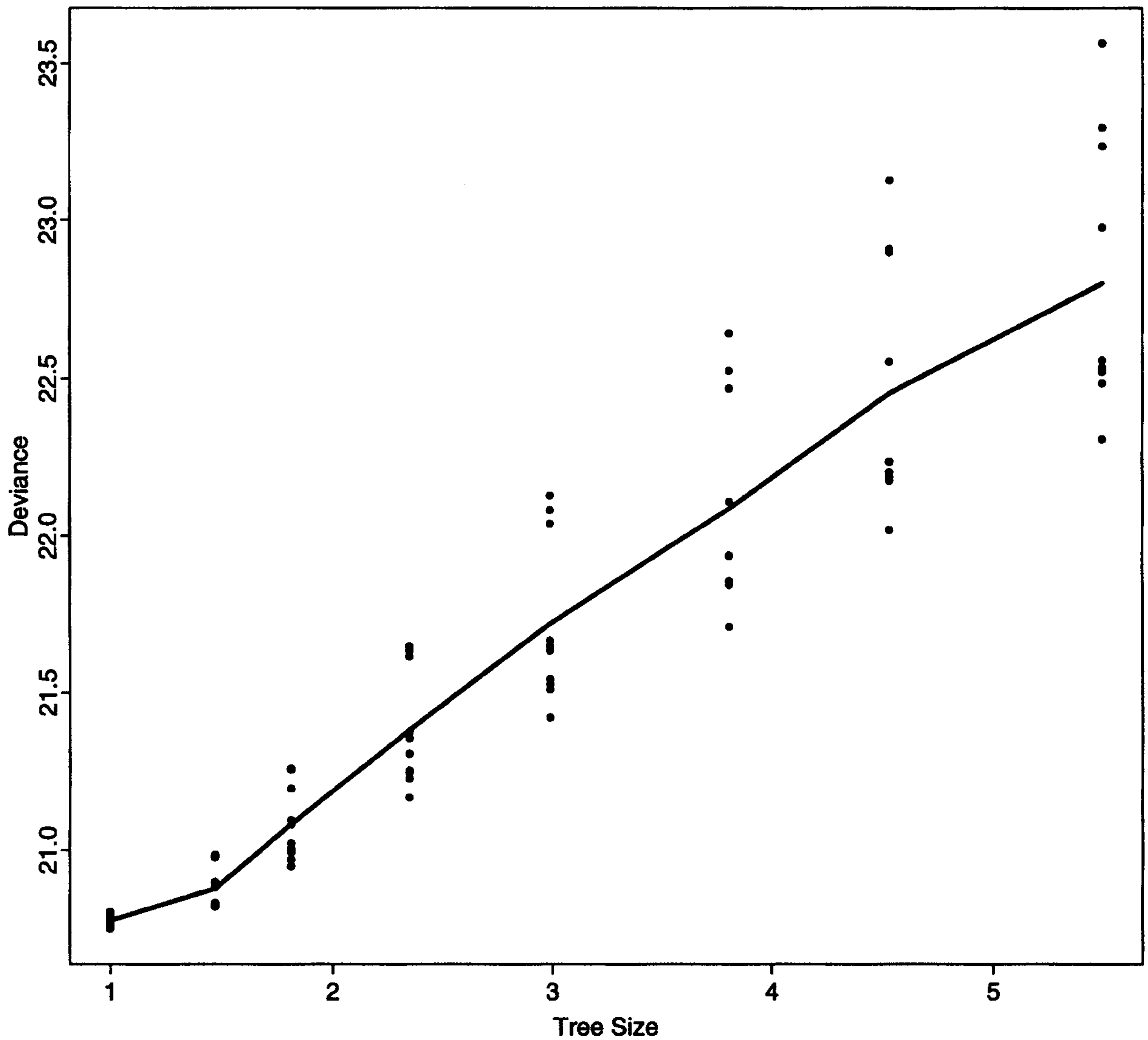

Figure 12.--Cross validation of leatherback tree. The minimum at size = 1 suggests pruning all the branches of the tree, which leaves the root node as a terminal node; i.e. there is no tree left. The results of cross validating the green turtle tree was essentially the same.

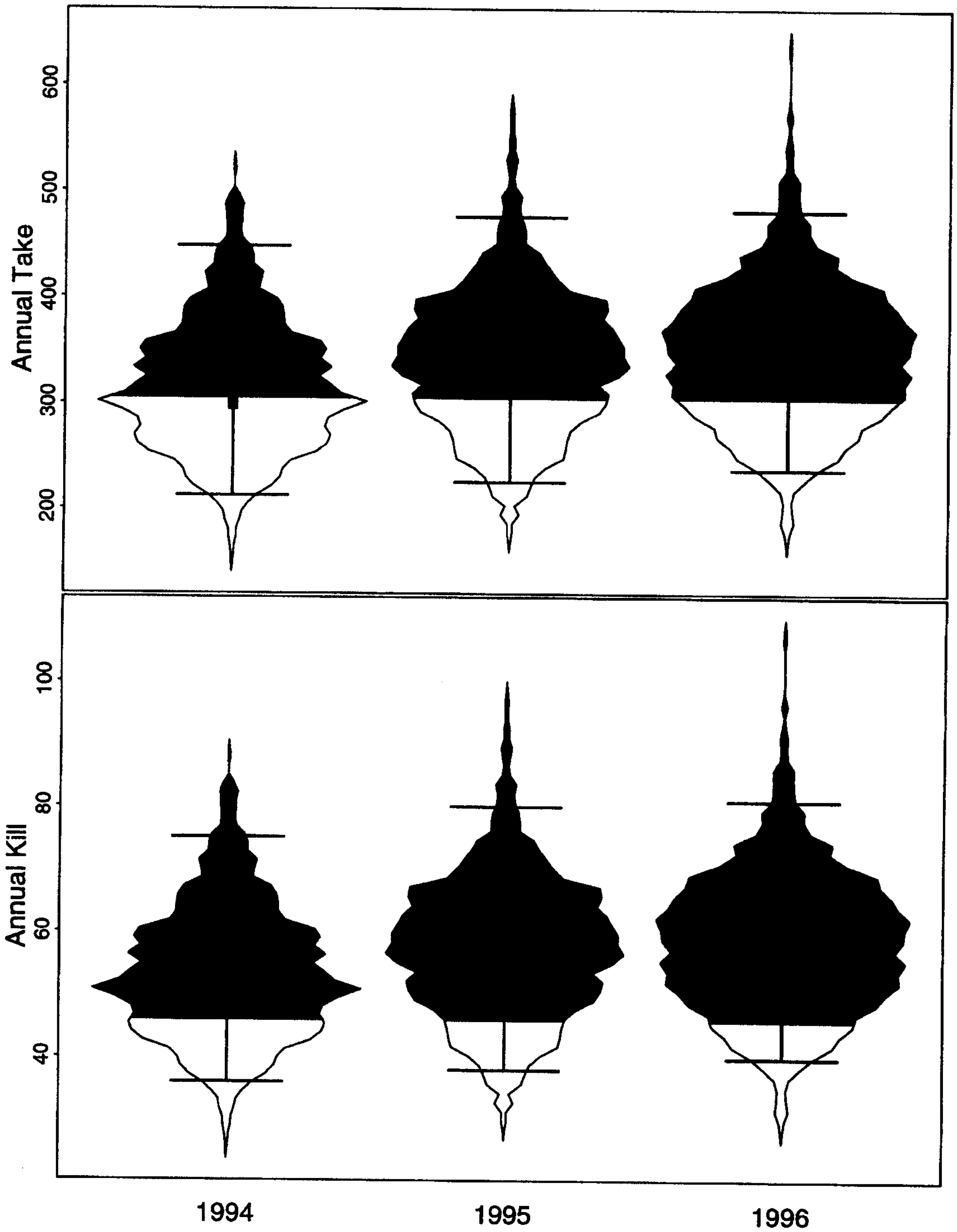

Figure 13.--Loggerhead turtles, distribution of bootstrap estimates of annual takes and mortalities by year, with point estimates (rectangles) and 95% confidence limits (horizontal bars). Shading indicates portion of distributions above the allowable take or mortality levels. The left and right distributions are mirror images for visual effect.

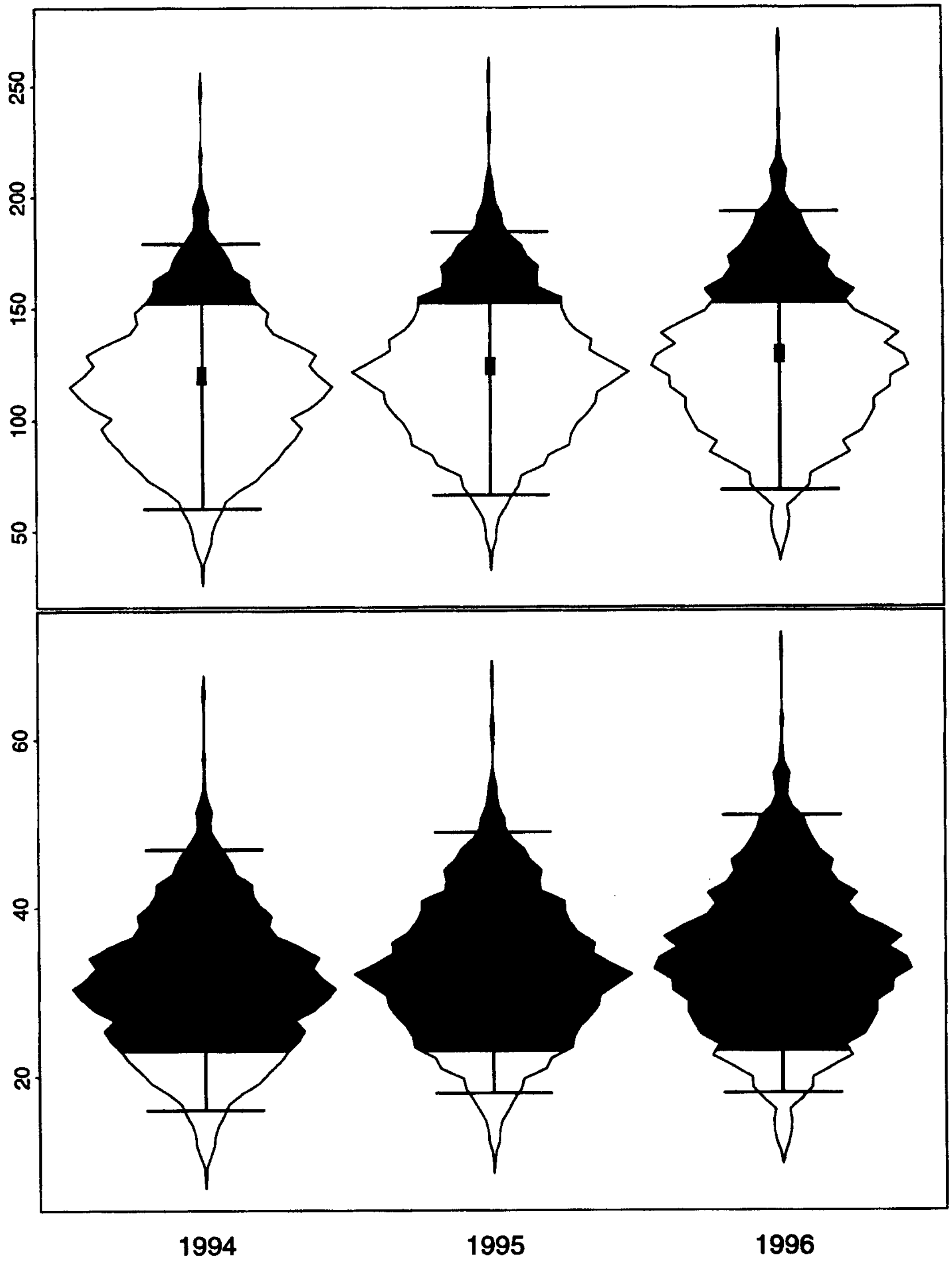

Figure 14.--Olive ridley turtles, distribution of bootstrap estimates of annual takes and mortalities by year, with point estimates (rectangles) and 95% confidence limits (horizontal bars). Shading indicates portion of distributions above the allowable take or mortality levels. The left and right distributions are mirror images for visual effect.

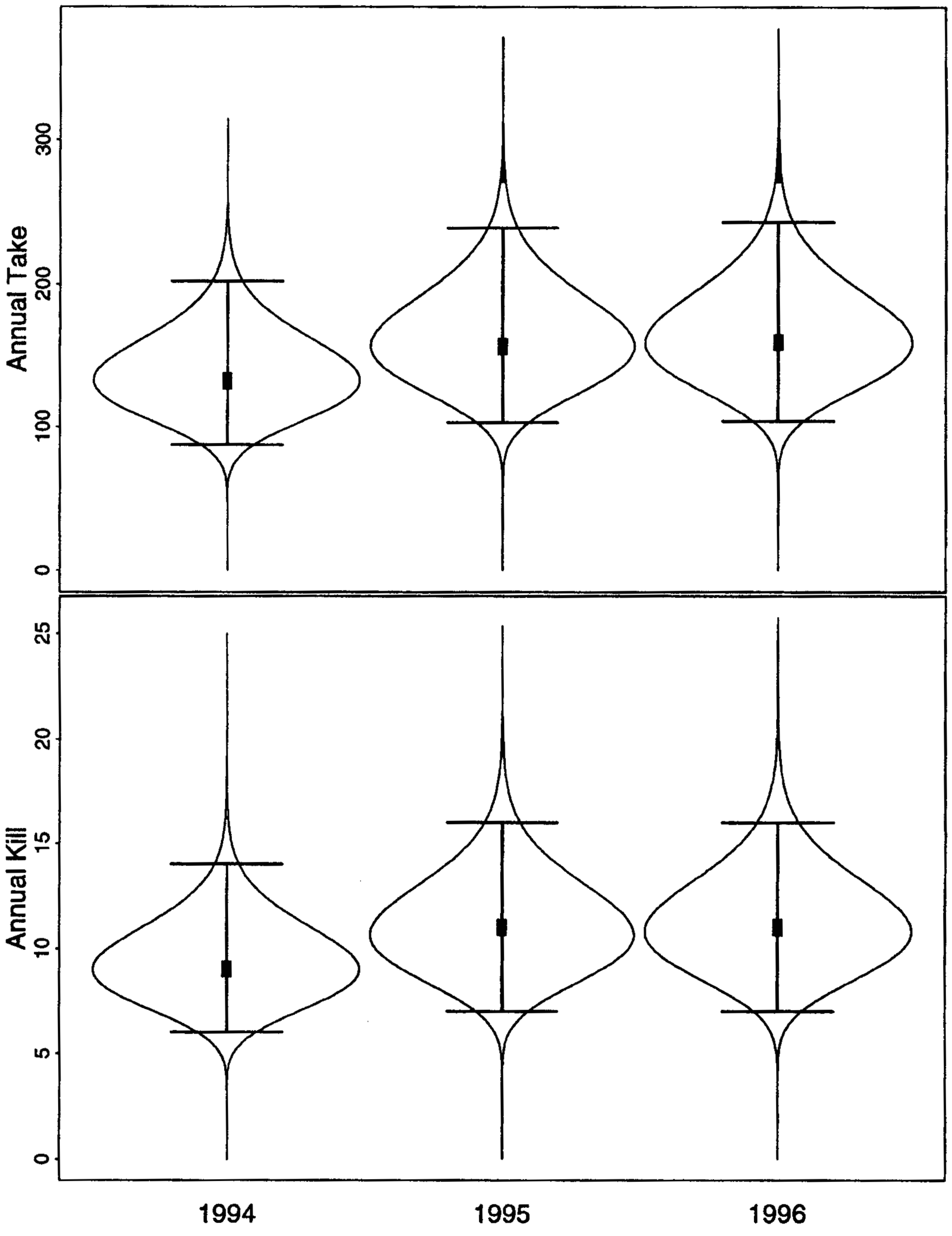

Figure 15.--Leatherback turtles, estimated binomial likelihood distribution of annual takes and mortalities by year, with point estimates (rectangles) and 95% confidence limits (horizontal bars). The proportion of the distributions above the allowable take and mortality levels are quite small, with shading visible only for takes in 1995 and 1996. The left and right distributions are mirror images for visual effect.

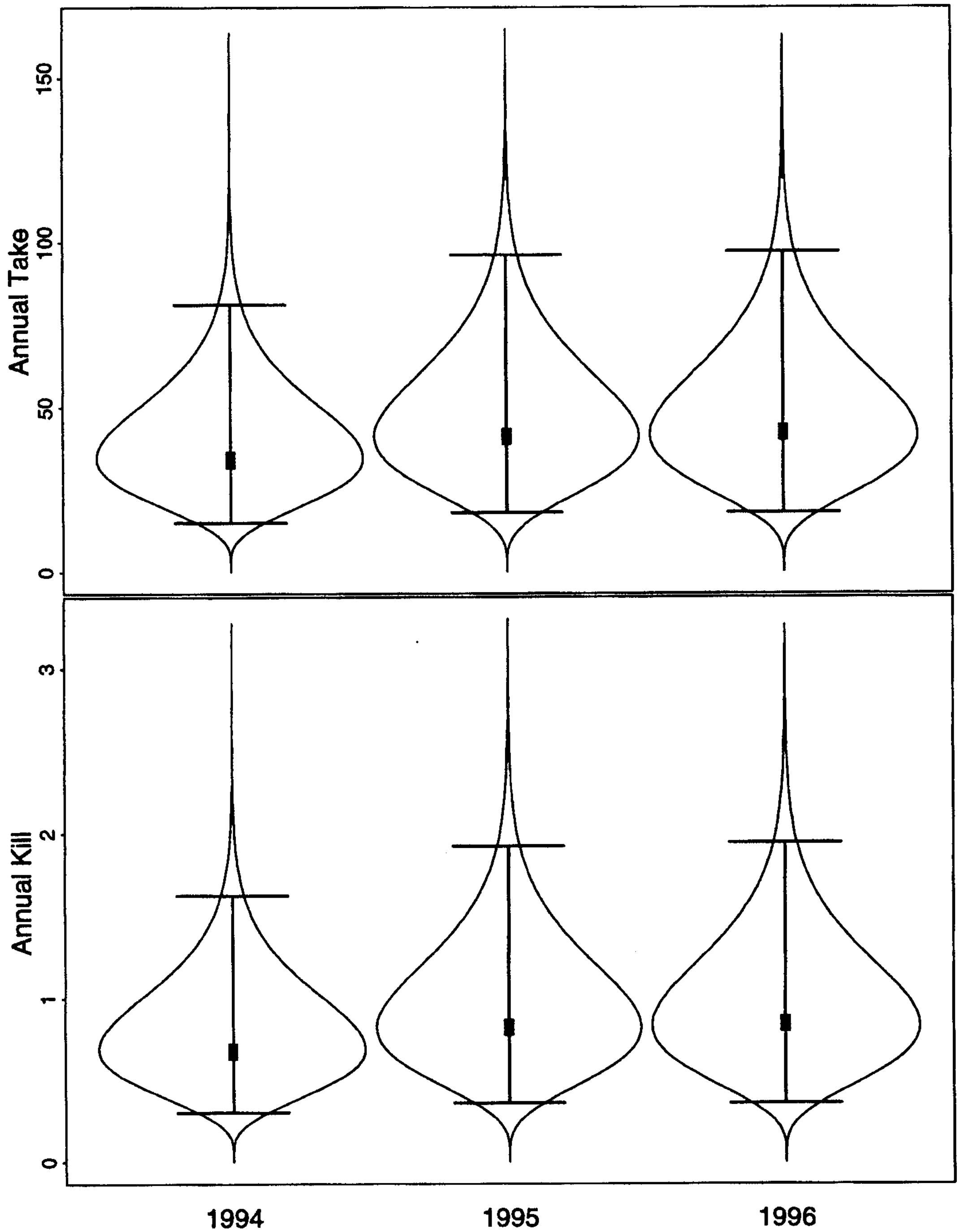

Figure 16.--Green turtles, estimated binomial likelihood distribution of annual takes and mortalities by year, with point estimates (rectangles) and 95% confidence limits (horizontal bars). The proportion of the distributions above the allowable take and mortality levels are quite small, with shading visible only for takes in 1995 and 1996. The left and right distributions are mirror images for visual effect.

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