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REPORT ON PINNIPED AND CETACEAN MORTALITY IN CALIFORNIA GILLNET FISHERIES: 1990-1991

By

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Report on Pinniped and Cetacean Mortality in California Gillnet Fisheries: 1990-1991

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Abstract

The number of marine mammals that were killed in California gillnet fisheries is estimated for the time period July 1990 to June 1991, based on observations made by technicians placed aboard commercial fishing vessels. A log-linear model was used to identify stratifying variables and factors related to marine mammal mortality. For the halibut and angel shark set-net fishery, geographic area, soak time, season, and selected fish catches were significantly associated with mortality of California sea lions and harbor seals. Water depth was also significant for harbor seals only. For the shark and swordfish drift-net fishery, only depth was significantly associated with marine mammal mortality. Analyses are conducted to identify better or alternative methods for quantifying fishing effort. Currently, the number of fishing days is the only available measure of effort for these fisheries; therefore, effort-days are used to extrapolate from observed to total estimated mortality. The estimated mortality (and standard errors in parentheses) for the set-net fishery was 2487 (346) California sea lions, 819 (134) harbor seals, 146 (51.2) northern elephant seals, and 62 (27.3) harbor porpoise. The estimated mortality (and standard errors in parentheses) for the drift-net fishery is 92 (63.7) California sea lions, 23 (22.1) harbor seals, 92 (44.9) northern elephant seals, 393 (155) common dolphins, 69 (51.1) northern right whale dolphins, 69 (38.9) Pacific white-sided dolphins, 46 (31.4) Risso's dolphins, 46 (30.2) Dall's porpoise, 23 (22.5) mesoplodont beaked whales, and 23 (22.1) short-finned pilot whales. Standard errors for the above mortality estimates are estimated based on the assumption that fishing effort is known without error.

1. Introduction

During the late 1970's and early 1980's, there was a rapid expansion in the use of entangling nets (drift gillnet, set gillnet, multi-panel and trammel nets) in coastal California waters (Herrick and Hanan, 1988). The incidental kill of many non-target species, including marine mammals, with these nets has become a focus of concern for state and national environmental and legislative bodies.

In this report, we examine pinniped and cetacean entanglement and mortality from July 1990 through June 1991 for two fisheries: a set-net fishery for California halibut and Pacific angel shark, and a shark/swordfish drift-net fishery. Specifically, we use log-linear regression models to explore factors that may be correlated with entanglement and attempt to identify any potentially useful predictors of mortality. Finally, we estimate the total pinniped and cetacean mortality due to these set-net and drift-net fisheries for the period July 1990 to June 1991, using data collected by observers aboard gillnet fishing boats during that period. For a detailed description of the two fisheries and a discussion of their relation to the Marine Mammal Protection Act (MMPA), see Barlow et al. (1990) and Lennert, Kruse, and Beeson (1991).

This report is divided into 10 sections. In the second section, we give a brief description of the observer data used throughout the entire report. The third section describes the general model and methods that we used for the analyses in sections 4 through 7. The fourth and fifth sections present an exploratory analysis of potential predictors of entanglement rates for both the set-net and drift-net fisheries. In the sixth section, we analyze the effect on entanglement rates of the fishers' prior knowledge of their obligation to carry an observer. The seventh section is a comparison of different measures of effort in predicting total numbers of entanglements. In the eighth and ninth sections, we estimate the total fishing effort and total marine mammal mortality in both the set-net and drift-net fisheries. Finally, the last section discusses biases, uncertainties, and other problems with the statistical models used in this paper.

2. Observed Entanglements

The data analysed in this report were collected primarily by National Marine Fisheries Service (NMFS) personnel (observers) aboard commercial gillnet fishing boats and cover the period from July 1990 to June 1991. The observers recorded data on position, environment, gear, catch, and bycatch (including marine mammal entanglements) for each observed net pull.

Arrangements for putting NMFS observers aboard the fishing boats were made primarily in one of three ways. The bulk of the trips observed were selected on a systematic basis, specifically, each known, active boat would have an observer placed on it approximately every fifth trip. Notification to the fishers of their obligation to carry an observer could be either before or after the nets were set. Some trips were also selected at random. In this case, notification was made after the nets were set. Thus, the three observation types were pre-set systematic (type 1), post-set systematic (type 2), and post-set random (type 3). Some observations were also made under other, unspecified types of arrangements (type 4). For a detailed description of the sampling methods used, see Lennert et al. (1991).

Because the set-net portion of this report deals only with the California halibut/Pacific angel shark fishery, we restricted analysis of set-net observer data to those sets with a mesh size of 8 inches or larger (stretched-mesh measurement). Thus, 67 from a total of 1608 observed set-net pulls were eliminated because the mesh size was too small. These net pulls included a single observed harbor porpoise entanglement. We did not attempt to classify set-net data by declared target species, because the reliability of that specification is questionable.

Observer data from 14 of the set-net trips (totalling 43 net pulls) from the Los Angeles port did not have positions. In the absence of any other information, these trips were assigned to the southern California mainland area for the purposes of area stratification (see Exploratory Data Analysis, below, for a description of the area stratification). All but 2 of the 509 observed set-net trips were single-day trips.

For the set-net fishery, there were a total of 1541 net pulls (totalling 516 boat-days or 509 trips) observed. Of these, 1325 net pulls (427 days, including 2 partial days) were observed in the southern California mainland area, 24 net pulls (10 days, including 2 partial days) were observed in the Channel Islands, and 192 net pulls (79 days) were observed in the central California area. There is no coastal set-net fishing allowed north of Bodega Bay in California. For the drift-net fishery, there were a total of 205 net pulls observed (totalling 205 days or 60 trips - there is exactly one net pull per day for this fishery). Of these, 129 were observed in the southern California mainland area, none were observed in the Channel Islands, and 76 were observed in the central/northern California area (17 of these were north of Pt. Arena). Fishery observation data (in number of net pulls and days) for both set-net and drift-net fisheries is shown by month in Tables 1 and 2.

3. Methods for Exploratory Data Analyses

We fit a model to the observer data in order to determine which factors are correlated with marine mammal entanglement. In the future, such factors could be used to stratify kill rates and so improve total mortality estimates, or to predict total mortality. To fit the data, we used a log-linear model with "Poisson-like" sampling and overdispersion, i.e., variance proportional to the mean (rather than equal to it - this attempts to account for the "clustered" nature of marine mammal entanglements). We fit this basic model at several different levels of detail (i.e., individual net pulls as the sampling unit vs. pooling the raw observations) to address different questions. The model is discussed at length in the context of generalized linear models (GLMs) by McCullagh and Nelder (1983). Specifically, the model assumes mean and variance for the number of entanglements as

$$\mu_i = E[Y_i] = \exp\{\mathbf{X}_i^T \mathbf{\beta}\} \text{ (or equivalently, } \ln(E[Y_i]) = \mathbf{X}_i^T \mathbf{\beta})$$

$$\mathrm{var}[Y_i] = \sigma^2 E[Y_i]$$

and a Poisson log-likelihood function

$$L(\mathbf{\beta}; Y_i, \mathbf{X}_i) = Y_i(\mathbf{X}_i^T \mathbf{\beta}) - \exp\{\mathbf{X}_i^T \mathbf{\beta}\}$$

where Y_i is the number of entanglements for observation i,
$\mathbf{X}_i$ are the predictor variable values for observation i, including terms for a constant term, main effects, and any interactions,
$\mathbf{\beta}$ are the model coefficients (to be estimated), and
σ^2 is the dispersion parameter (to be estimated).

For a given set of predictors, the GLM algorithm numerically computes the ML estimate for β using an iterative algorithm and estimates σ^2 from the resulting residuals. In a nested sequence of models, the reduction in model deviance as more predictors are added is distributed approximately chi-squared. In such a nested sequence, we selected the largest significant subset of the predictors using an approximate F-test to measure the change in deviance (normalized by the estimated dispersion parameter) for each added predictor.

The estimated coefficients in a GLM are approximately normal, and so we used an approximate t-test to measure the difference of a coefficient (normalized by the estimated coefficient variance) from zero. For categorical predictor variables, we constrained the coefficient for the first class to be identically zero for identifiability.

For both the set-net and the drift-net data, we used net pulls as the observations, because these were the most detailed available data. This analysis attempted to model the expected number of entanglements for a given net pull. Of the data collected by the observer program, the following variables were tested as potential predictors:

1) location
2) date
3) observation type
4) water depth
5) net length

6) soak time
7) associated catch and non-mammal bycatch

The model includes only main effects for these variables. Some 2-way interactions involving date were also considered but not modelled (see below). Location, date, observation type, and depth were treated as categorical. Net length, soak time, and associated catch/bycatch were treated as continuous variables.

A priori, based on marine mammal distributions, we used three area strata: southern California mainland, Channel Islands, and central California (or central/northern California in the drift-net fishery). Central California includes all effort off the California coast, north of Point Conception (this includes California Department of Fish and Game area blocks numbered 100-650). The Channel Islands include all effort within CDFG blocks containing any part of the Channel Islands (CDFG blocks 684-690, 707-713, 760-762, 765, 806-807, 813-814, 829, 849-850, and 867). Southern California includes all effort south of Point Conception (CDFG blocks 651 and higher), excluding the Channel Islands.

We attempted to stratify date by quarters, although because of the unbalanced nature of the observations, this was not always possible (see below). The four quarters correspond to Jul-Sep 90, Oct-Dec 90, Jan-Mar 91, and Apr-Jun 91. In treating date as categorical, we attempted to account for seasonal effects but not for any linear trend, because this report covers only a single year.

Observation type (as described in Observed Entanglements, above) was stratified into two categories: pre-set notification (type 1) and post-set notification. Post-set notification includes those observations made under a systematic sampling plan (type 2) as well as those selected randomly (type 3).

We stratified depth into two categories, "deep" and "shallow", where the break point was defined based on the specific data used.

In using catch and non-mammal bycatch as predictors, we attempted to account for scavenging of nets by pinnipeds. Because of the large mesh sizes in the nets used, competition between pinnipeds and fishers for the same fish was not considered likely. One possible problem with using the catch data was that it was impossible to distinguish between zero catch and missing data. For variables such as soak time, net length, or depth, a missing value can only be interpreted as no value recorded, and numerous missing values did in fact occur for those variables. For catch however, it is not clear whether all sets with no number recorded actually had zero catch or simply were incomplete observations. We did not investigate this problem.

Net mesh size was not considered as a possible predictor because the range of sizes for both fisheries was very limited. One additional variable, distance offshore, may be a useful predictor in the future, however, few of the net pulls in the current dataset had a value recorded for this variable.

Each of the three continuous variables (net length, soak time, and catch) is in some sense a measure of effort for the net pulls. Rather than using these predictor variables directly in the linear predictor ($X^T\beta$), we used their natural logarithm. The expected number of entanglements is then proportional to some powers (the estimated coefficients) of these variables:

$$\mu \propto (\text{net len})^{\alpha}(\text{soak time})^{\beta}(\text{catch}+1)^{\gamma}$$

where (catch+1) is used to prevent taking the log of zero. The above proportionality depends on the remaining (categorical) effects, and is given by

$$\exp\{(\text{grand mean}) + (\text{area effect}) + (\text{season effect}) + (\text{obs. type effect}) + (\text{depth effect})\}$$

4. Exploratory Data Analysis - Set-Net Fishery

Data

Figure 1 shows the frequency distributions for the number of net pulls by month, observation type, depth, net length, and soak time. Of the 1541 observed net pulls, there were 1365 with no marine mammal entanglements. Of the 247 observed entanglements, 162 were sea lions (including 157 known to be California sea lions), 59 were harbor seals, 15 were northern elephant seals, 4 were unidentified pinnipeds, and 7 were harbor porpoise. There were 98 observed net pulls with 1 sea lion entanglement, 19 with 2 entanglements, 4 with 3 entanglements, 1 with 4 entanglements, and 2 with 5 entanglements. There were 48 observed net pulls with 1 harbor seal entanglement, 4 with 2 entanglements, and 1 with 3 entanglements. There were 9 observed net pulls with 1 northern elephant seal entanglement and 2 with 3 entanglements. There were 5 observed net pulls with 1 harbor porpoise entanglement, and 1 with 2 entanglements. Table 1 summarizes the total and mean (per net pull) number of entanglements by month and area for each of the four species observed. There were 5 unidentified sea lions and 4 unidentified pinnipeds observed entangled. We included these individuals with California sea lions for the model fits because no northern sea lion entanglements were observed, and because the bulk of the observed pinniped entanglements were California sea lions.

The number of entanglements for northern elephant seal and harbor porpoise were so low (totalling 15 and 7, respectively) that we did not attempt to model them at all.

The data in Table 1 clearly show main effects for both area and month. Although we did not attempt to model area/month interactions, there are biological reasons to expect them. Specifically, we would expect higher entanglement rates during times of pinniped migration to and from breeding grounds. The data presented in Table 1 do suggest this, however, there was no observed effort in central California during the months April-June, and little observed effort for the Channel Islands at any time. Because the observed effort was so unbalanced in area and time, estimating these interactions was not possible.

The data in Figure 1 show no clear strata for depth values. We chose 20 fathoms as the break point between "deep" and "shallow" values.

Comparing the catch and bycatch species for net pulls with pinniped entanglements to the species for other net pulls revealed no apparent differences. Thus, rather than a simple presence or absence of particular "indicator" species, we used a measure of total catch size as a predictor. As a measure of catch size, we used the number of individuals of each species per net pull. The only fish species considered as predictors for the GLM fit were California halibut and Pacific mackerel. Pinnipeds may actually be attracted to the gillnets to forage on entangled fish from these species. Other species were either not prevalent enough to be useful or were not considered likely as targets for scavenging by pinnipeds. Figure 1 shows the frequency distribution for both fish species.

Of the 1541 observed net pulls, 105 had either no value for depth, soak time, or net length, or had unknown observation type. There were 19 marine mammal entanglements observed for these net pulls, including 15 sea lions, 1 unknown pinniped, and 3 harbor porpoises. These observations were not included in the GLM fits.

<u>Results</u>

There were a total of 8 predictor variables considered for this model. First, using an exhaustive search, we determined the "best subset" (based on model deviance) for each possible number of predictors. For both species considered (California sea lion and harbor seal), these "best subsets" comprised a nested set of models, and so the significance of using extra predictors could easily be tested by the change in deviance. Table 3 shows the nested sequences of "best subsets" and their approximate significance levels (p-values). As pointed out above, we did not model the entanglement data for northern elephant seal or harbor porpoise.

For both California sea lion and harbor seal, area was clearly the most important factor in explaining the variability in the entanglement rates. The quarterly effect was also significant for both species' entanglement rates, though it should be noted that because the data were so unbalanced, this effect was due mostly to data from southern California and may not be representative for the other areas.

Of the three measures of effort tested, soak time was an important effect for California sea lion entanglement, but less so for harbor seal entanglement (and see below for a further discussion of soak time). As Figure 1 suggests, although the soak times ranged from 2 hours to 168 hours, more than 90% had values very near 24 or 48 hours, and so the range of soak times may not have been large enough to accurately estimate the effect. In addition, more than half of the soak times were concentrated exactly at 24, 48, 72 or 96 hours, so it appears that many of the soak times were rounded to the nearest day, and this may also have affected the accuracy of the estimates. A priori, net length would seem to be a useful predictor of entanglement rates, however it was not significant for either fit. As shown in Figure 1, although the net lengths ranged from 10 to 1500 fathoms, 90% were between 150 and 400 fathoms, and over half were at exactly 200, 250, or 300 fathoms. As with soak time, the accuracy of the estimate may have been affected by the relatively limited range and the apparently rounded data. Of the two catch and bycatch fish species considered, mackerel was significant only for California sea lion entanglement, and halibut was significant only for harbor seal entanglement. This result agrees with known behaviors of the two species[1].

Depth was a significant predictor for harbor seal entanglement rates (with an estimated rate 3.4 times higher for deep water than for shallow water), but not for California sea lion rates. Observation type was not significant for either fit (but see Exploratory Data Analysis - Observation Type below for a further analysis of this variable).

Next, for each species we selected the largest subset that was incrementally significant at the .05 level. Table 4 shows the coefficients and their estimated standard errors, as well as estimates of the dispersion, for these models. Note that the coefficient for the first class of each categorical variable was constrained to be zero. For California sea lion, the estimated entanglement rates for the Channel Islands and central California, relative to southern California, were 12 times and 5 times higher. The estimated quarterly effects varied only by a factor of 2. California sea lion entanglement rates were

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[1] Lowry, M., Southwest Fisheries Science Center, P.O. Box 271, La Jolla CA 92038; personal communication.

estimated to be nearly directly proportional to soak time - the soak time coefficient was not significantly different from 1 at the 5% level. For harbor seal, the estimated entanglement rates for the Channel Islands and central California were 5 times and 7 times higher than for southern California. Excluding the period January-March, for which there was only a single harbor seal entanglement, the estimated quarterly effects varied by a factor of 3. For harbor seal entanglement rates, there were conflicting coefficient estimates between the two measures of effort found significant. The estimated coefficient for the number of halibut was positive, and that for soak time was negative. Probably only one of these variables should have been accepted as significant, although even without halibut in the model, the estimated coefficient for soak time remained significantly negative. This difference from the California sea lion estimates may be the result of low power due to the relatively low (about one third that of California sea lion) entanglement rates for harbor seal.

The fits did show evidence for overdispersion (larger variance than a Poisson model) - the estimated dispersion coefficient was larger than 1 in both cases. This reflects the fact that the entanglement data include longer tails (or equivalently, too many zeros) than would be expected for a Poisson model.

5. Exploratory Data Analysis - Drift-Net Fishery

Data

Figure 2 shows the frequency distribution for month, observation type, depth, net length, and soak time for the drift-net observer data. Of the 205 observed net pulls, there were 178 with no entanglements. Of the 39 observed entanglements, 17 were common dolphin, 12 were other cetacean species, and 10 were pinnipeds. The other cetaceans included 3 each of northern right whale dolphin and Pacific white-sided dolphin, 2 each of Risso's dolphin and Dall's porpoise, and 1 each of short-finned pilot whale and mesoplodont beaked whale. The pinnipeds included 5 sea lions (2 known to be California sea lions), 4 northern elephant seals, and 1 harbor seal. There were 10 observed net pulls with 1 common dolphin entanglement, and 1 each with 3 and 4 entanglements. For other cetacean species, there were 6 observed net pulls with 1 entanglement and 3 with 2 entanglements. For pinnipeds, there were 8 observed net pulls with 1 entanglement and 1 with 2 entanglements. Table 2 summarizes the total and mean (per net pull) number of entanglements for the species observed, stratified by month. The numbers of entanglements were low enough that we did not attempt to fit seperate models for each species. Rather, we fit a log-linear GLM (as in the previous model) for all species pooled.

The Channel Islands had no observed net pulls, so the corresponding area term was not included. Observations for central California were concentrated from July-November (the fishery is closed February-April), with only a single observation in December. Thus, the only seasonal main effect that seemed likely to be free from aliasing with area effects was "summer" vs. "winter", with the break at September. Table 2 shows that most entanglements occurred during fall, although this may be simply because the observed effort was highest during these months. Because of the small number of entanglements, we did not attempt to model area/season interactions.

All drift-net observations were pre-set notification, and all drift-net lengths were essentially the same, so those terms were left out of the drift-net model. Depth was treated as "deep-water" vs. "shelf/slope" with the break at 1200 fathoms.

Comparing the catch and bycatch species associated with pinniped entanglements to the species associated with other net pulls revealed no apparent differences. In addition, the only species prevalent enough to use as predictors were not considered likely candidates for scavenging by pinnipeds. Thus, catch and non-mammal bycatch were not included in the fit.

Of the 205 observed net pulls, 11 had no value for depth. 10 of these observations were assigned to the "deep-water" stratum, and 1 to "shelf/slope", using the specified positions and a depth chart. There was a single observed entanglement (Dall's porpoise) for these observations.

Results

There were a total of four predictor variables considered for this model. Considering all possible combinations of predictors, we determined the "best subset" (based on model deviance) for each possible number of predictors. As with the set-net fits, these "best subsets" comprised a nested set of models, and so the significance of using extra predictors could easily be tested by the change in deviance. Table 5 shows the nested sequences of "best subsets" and their approximate significance levels (p-values). As pointed out above, we fit a model to entanglement data pooled across all species.

As with the set-net fits, we selected the largest subset that was incrementally significant at the .05 level. Table 6 shows the coefficients and their estimated standard errors, as well as the estimate of the dispersion, for this model. Depth was the only variable found significant as a predictor of marine mammal entanglement. The estimated entanglement rate was 3 times higher for "shelf/slope" depths (<1200 fathoms) than for "deep water" (> 1200 fathoms). Note that the coefficient for the first depth class was constrained to be zero. As with the set-net fits, the drift-net fits did show evidence for overdispersion (larger variance than a Poisson model) - the estimated dispersion coefficient for the subset of predictors selected was 1.6.

6. Effect of Observation Type

Methods and Data

Because the effect of pre-net set vs. post-net set notification in the set-net fishery is an important issue for the observer program, we used a second model to specifically test whether observation type had an effect on the observed number of entanglements. We tested the observation type effect using a 1-tailed t-test of the hypothesis that the post-notification effect was greater than zero. Because the coefficient for pre-notification is constrained to be zero, this test is equivalent to a comparison of the two effects. Note that coefficients in a GLM model are only asymptotically normal, and any p-values calculated from them are approximate. Lennert et al. (1991) made a similar test using a log-normal linear model, where they estimated the probability of at least one entanglement, and found no significant difference between entanglement rates for pre-set and post-set notification.

We used observations only from the set-net fishery in central California, because that was the only case which had a reasonable balance between observation types. Based on the results of the previous fits, we used quarter and soak time, as well as observation type, as predictors. Note that we did not include an area effect or a 2nd quarter effect because there were no observations in central California during April-June. Because any observation type effect is not likely to be species specific, we pooled entanglements first across all pinniped species, and then across pinnipeds and cetaceans. The other details of this model were the same as for the first model.

Results

Table 7 shows the estimated coefficients, estimated standard errors, and p-values of the coefficients, using only pinniped data and using data for pinnipeds and cetaceans combined. In both fits, the grand mean, quarter, and soak time coefficients were all significantly different from zero using a 2-tailed t-test. Using the 1-tailed t-test for post-notification described above, the p-values for that coefficient in the two fits were .071 and .046, respectively. This is evidence that entanglement rates may have been higher when the fishers were notified of their obligation to carry an observer after the net was set. In both cases, the estimated entanglement rates are over 50% higher for post-set notification than for pre-set notification. Fitting the same model only with individual species entanglement data produced results where not only the observation type effect, but some or all of the other main effects were not significant, probably indicating that more data were needed, due to the large number of zero responses.

The fact that observation type was only marginally significant may simply indicate that fishers do not change their behavior appreciably in the presence of observers. However, as discussed by Lennert et al., it may also be due to the fact that all of the post-net set notifications for central California were in fact from a systematic sampling plan (an observer placed on a boat approximately every fifth trip), and the fishers may have anticipated their obligation to carry an observer.

7. Comparison of Fishing Effort Measures

Methods and Data

Here we compare different measures of fishing effort for the purpose of estimating total mortality. For this model, we summarized the set-net observer data in a 2-way table (area vs. quarter) and used the total number of entanglements for each cell as count data. The continuous variables net length, soak time, net length times soak time, and catch were also summed for each cell, and included as measures of total effort for that cell. Finally, we included the number of net pulls and number of days of fishing for each cell as the last two effort variables. Using the cell counts rather than the raw net pull data allowed us to compare net pulls and days with the other effort variables and, in addition, significantly reduced the number of zero counts in the analysis. Based on the results of the previous models, neither depth nor observation type were included in this analysis.

Using one of the effort measures at a time, we fit a log-linear GLM with Poisson likelihood and computed the total model deviance. Using the log of the effort, the expected number of entanglements for each cell, μ, is then proportional to some power (the estimated coefficient, α) of the effort measure being tested:

$$\mu = \exp\{(\text{grand mean}) + (\text{area effect}) + (\text{season effect})\}(\text{effort})^{\alpha}$$

To compare the different effort measures, we computed the model deviances, normalized by the estimated dispersion. Because these models do not make up a nested sequence, the chi-squared approximation for the difference in deviances does not hold, and we were not able to put significance levels on the differences between models. However, to check the adequacy of each model individually, we computed the difference in deviances between each model and the saturated model (i.e., one parameter per cell). Because the deviance of the saturated model is zero by definition, the differences simplify to the raw deviances of each individual model. Thus, using an approximate F-test for the normalized deviance amounts to testing whether the data are better explained by the saturated model than by the reduced model with a grand mean, area and quarter effects, and an effort term. Note that using the deviance is also equivalent to a likelihood ratio test. Because we could not estimate dispersion from the saturated model (there are no extra degrees of freedom), we used the estimates from the reduced models.

Because the number of northern elephant seal and harbor porpoise entanglements was so low, we fit this model to the entanglement data for pinnipeds and cetaceans combined, for pinnipeds only, and for California sea lion only. Of the 1541 observed net pulls, 83 had no value for either soak time or net length. There were 10 marine mammal entanglements observed for these net pulls. These observations were not included in the GLM fits. Table 8 summarizes the 5 effort measures and the number of entanglements for each of the 12 cells.

<u>Results</u>

Table 9 compares the normalized model deviances, the estimated dispersions, and the p-values for each of the seven fits, as well as the estimated coefficient, standard error, and p-value for each of the effort measures. In this analysis, the normalized deviance is a measure of how well the data fit a "Poisson-like" error model, and the estimated dispersion is a measure of how close the "best-fit" model is to Poisson (i.e., variance equal to mean). All but one of the estimated dispersion parameters were larger than 2, indicating that a standard Poisson model does not fit these data well.

In all three cases, number of net pulls and number of mackerel had the lowest model deviances. Of these two, net pulls had the lower estimated dispersion, indicating that the corresponding model has a smaller variance for a given mean kill rate. Mackerel fit the combined data as well as it did due to the large proportion of California sea lion entanglements, and in fact fit the sea lion data best. The number of days consistently had higher deviances and larger estimated dispersions than the number of net pulls, suggesting that net pulls may be a more useful unit of measure for predicting total mortality than days, which is currently the only measure of total fishing effort available. Net length had the lowest estimated dispersion in two of the three cases, however the deviances were among the highest. Soak time had among the highest deviances and estimated dispersions in all three cases. The number of halibut was not found as a significant predictor of California sea lion entanglement in the previous analysis, and it produced the highest model deviance in all three cases. However, it also produced among the lowest estimated dispersions.

Interestingly, (soak time * net length) as a predictor produced among the highest model deviances, and the largest estimated dispersion, in all three cases. This variable might be expected to be a more accurate measure of effort than net length or soak time alone, because it accounts for both temporal and areal extent of fishing effort. However, it is clearly not a good predictor for this dataset.

Of the seven variables tested, number of halibut consistently had the coefficient closest to 1, i.e., entanglements proportional to effort. One of the best predictors, number of halibut, had coefficients that were significantly different from 1 for a 2-tailed test at the 5% level. The number of net pulls and net length had coefficients that were not significantly different from 1 at the 5% level, however the p-values were fairly low in all three cases.

8. Total Fishing Effort Estimates

Data and Methods

In order to extrapolate from observed marine mammal kill to total kill, the total fishing effort must be estimated. The California Department of Fish and Game (CDFG) provided NMFS with quarterly and yearly (1 April through 31 March) estimates of fishing effort for both the halibut/angel shark set-net fishery and the shark/swordfish drift-net fishery. The unit of effort reported is one day of fishing for a single boat for a single target fishery. For the drift-net fishery, one day of effort is equivalent to a single net pull, and for the set-net fishery, one day of effort may represent several net pulls. The primary source of data for the effort estimates are daily fishing logs of commercial gillnet fishers. In addition, landing receipts of fish sales are used to account for unlogged effort. NMFS observer data are also used to verify logbook entries and landing receipts when possible. For a detailed description of the methods used to estimate total effort, see Beeson and Hanan (1991).

For the purpose of estimating total marine mammal kill, we treated the total effort estimates as known, even though they include at least three sources of uncertainty. First, much of the logbook data are reported by the fishers well after the fact, and it is not clear how accurate they are, both in terms of number of days and position. Second, a single landing receipt may represent more than the assumed one day of effort. Because all but two observed set-net trips were a single day, we have no way of estimating the average set-net trip length, and so cannot check the assumption of one day per landing receipt. Finally, the location for a significant percentage (15% of drift-net, 21% of set-net) of the estimated effort was specified only very grossly or not at all. Although this does not affect the total effort estimate, it introduces uncertainty for the purposes of stratification by area. We did stratify by area for the set-net fishery mortality estimate, and so the poorly- or unspecified days of effort were apportioned to the three area strata considered, according to the known percentages of the fully specified effort.

Because the data from 1990/1991 NMFS observer program cover a different time period than the CDFG yearly estimates (July-June vs. April-March), it was necessary to use the CDFG April-June quarterly estimates for both 1990 and 1991 along with the 1990/1991 yearly estimates to estimate total effort for the period of time covered by this report. Because the quarterly estimates are preliminary data only (and no final quarterly estimates were available), this may have introduced more inaccuracy into the effort estimates.

Results

We estimated the total days of effort for the set-net fishery at 7513 days. This corresponds to 6321 days (427 days = 7% observed) for the southern California mainland area, 487 days (10 days = 2% observed) for the Channel Islands, and 705 days (79 days = 11% observed) for the central California area. We estimated the total days of effort for the drift-net fishery at 4734 days. This corresponds to 2613 days (128 days = 5% observed) for the southern California mainland area, 91 days (0 days observed) for the Channel Islands, and 2030 days (77 days = 4% observed) for the central California area.

9. Total Mortality Estimates

Set-Net - Methods

The total fishing effort data include only the total number of days of effort stratified by location and quarter. As discussed in the previous sections, area and month were found to be significant predictors of marine mammal entanglement. The estimated quarterly effects, however, are probably not accurate for areas other than southern California, and in addition, the specification of total effort by quarter is incomplete due to late reporting of effort by fishers. Thus, we stratified by area only to estimate the total mortality due to the set-net fishery.

In several recent reports (e.g., Hannan and Diamond, 1989), variances for kill rate estimates have been estimated using a bootstrap resampling estimator. In this paper, we have used an analytic variance estimator, based on the delta method (see Cochran, 1977). Comparison of these two estimators on a subset of the data analyzed in this paper indicates they have nearly identical results, at least for the type of data analyzed here[2].

Although net pulls were the sampling unit for the observer data, the total fishing effort is reported in days, and so we estimated the total mortality based on days as the unit of sampling. All but two of the observed set-net trips lasted a single day, and so we treated the observations as a random sample of days. We estimated the kill rate, $\hat{r}_a$, and the total set-net mortality, $\hat{m}_a$, in each area using a mean per unit (MPU) estimator, with days as the sampling unit. We could not use a ratio estimator based on net pulls, because the total number of net pulls is unknown. The MPU estimators and their estimated variances for each area are (see Cochran, 1977, or Lennert et al., 1991):

$$\hat{r}_a = (\Sigma k_{i,a}) \ / \ d_a$$

$$\hat{\sigma}_{r,a}^2 = (1-d_a/D_a)(1/d_a)\hat{\sigma}_{k,a}^2$$

$$\hat{m}_a = D_a\hat{r}_a$$

$$\hat{\sigma}_{m,a}^2 = D_a^2\hat{\sigma}_{r,a}^2$$

where $k_{i,a}$ is the observed kill per day, $\hat{\sigma}_{k,a}^2$ is the sampling variance of $k_{i,a}$, and d_a and D_a are the observed and total number of days of effort in the area. The estimates of kill rate, $\hat{r}$, and total mortality, $\hat{m}$, across all areas, and their variances, are then weighted averages:

$$\hat{r} = (\Sigma(D_a\hat{r}_a)) \ / \ D$$

$$\hat{\sigma}_r^2 = (\Sigma(D_a^2\hat{\sigma}_{r,a}^2)) \ / \ D^2$$

$$\hat{m} = D\hat{r}$$

$$\hat{\sigma}_m^2 = D^2\hat{\sigma}_r^2$$

where D is the total number of days of effort.

Set-Net - Results

Table 10 summarizes the estimated kill rates, $\hat{r}_a$, and kill, $\hat{m}_a$, in each area, as well as combined total estimates, $\hat{r}$ and $\hat{m}$, for the four species considered. The estimates for California sea

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[2] Lennert, C., Southwest Fisheries Science Center, P.O. Box 271, La Jolla CA 92038; personal communication.

lion mortality are based on kill data that include 5 unidentified sea lions - because no species other than California sea lion was identified entangled, these 5 were assumed to be California sea lions also. In addition, the observer data included 4 unidentified pinnipeds killed, as well as 1 California sea lion and 1 harbor seal released alive. We give total mortality estimates both with and without the unidentified individuals and the individuals released alive.

Drift-Net - Methods

As discussed in the previous sections, neither area nor month were significant as predictors of marine mammal entanglement, probably as a result of the small numbers of observed entanglements. Thus, we estimated a single, overall kill rate, rather than stratifying by area or month.

For the drift-net fishery, boats make a single net pull per day, thus days and net pulls are equivalent sampling units. However, as pointed out in Lennert et al. (1991), the assumption that the observed days are a random sample is not realistic. Drift-net sampling consisted of first selecting a boat, then observing all net pulls made during a single multi-day trip. Thus, the observed trips consist of clusters of days, and a mean per unit estimator based on days is not appropriate. Rather, we treated the trips as a random sample and estimated the mortality rate and the total drift-net mortality using a ratio estimator, with trips as the sampling unit, and days per trip as the auxiliary variable. The estimates of kill rate, $\hat{r}$, and total mortality, $\hat{m}$, and their variances, are (see Cochran, 1977, or Lennert et al., 1991):

$$\hat{r} = (\Sigma k_i) / (\Sigma d_i)$$

$$\hat{\sigma}_r^2 = (1-d/D)(1/n)(1/d_{avg}^2)(\hat{r}^2\hat{\sigma}_d^2 + \hat{\sigma}_k^2 - 2\hat{r}\hat{\sigma}^2_{dk})$$

$$\hat{m} = D\hat{r}$$

$$\hat{\sigma}_m^2 = D^2\hat{\sigma}_r^2$$

where k_i and d_i are the observed kill and number of days for the ith trip, d_{avg} is the sample mean number of days per trip, $\hat{\sigma}_d^2$, $\hat{\sigma}_k^2$ and $\hat{\sigma}^2_{dk}$ are the sampling variances and covariance of d_i and k_i, d and n are the observed number of days and trips, and D is the total number of days of effort. We approximated the finite population correction (1-N/n), where N is the total number of trips, using (1-d/D), because the total number of trips is not known.

Drift-Net - Results

Table 11 summarizes the estimated kill rate, $\hat{r}$, and total kill, $\hat{m}$, for all the species for which kill was actually observed.

The estimates for California sea lion are based on kill data that include 2 unidentified sea lions - because no species other than California sea lion was identified entangled, these 2 were assumed to be California sea lions also. In addition, the observer data included 1 unidentified sea lion (assumed to be a California sea lion) released alive. We give total mortality estimates both with and without this individual.

The fact that no kill was observed (or estimated) for other species present in the fishing areas does not imply that there actually was no kill for those species. Due to the low kill rates and the low percentage of observed effort in the drift-net fishery, it is possible that, by random chance, kill for those species occurred but went unobserved. It is also possible that a sampling bias existed in the observation of trips. Thus, total kill for those species should not be assumed to be zero, and may be comparable to those listed in Table 11.

10. Discussion

Biases

The estimates of total pinniped mortality presented in the previous section may be biased for several reasons. Tables of the number of entanglements as well as the results of the GLM analyses show that pinniped entanglement rates are not homogeneous in either location and season. In order to estimate the total mortality for the fisheries covered in this paper more accurately, these effects need to be better quantified so that more fully stratified estimates may be explored. Specifically, the observation of net pulls needs to be more comprehensive and more balanced to better understand and more accurately estimate the areal and temporal variations in kill rates.

Another source of bias for the results in this report may be the sampling schemes used to place observers on fishing boats. We have modelled these as random, however the actual placement is clearly not random due to, among other things, unknown or unobservable boats, limited cooperation of some fishers, and safety considerations for the NMFS observers. For a detailed discussion of these problems, see Lennert et al. (1991). Nonrandom sampling may affect the analysis in two ways. First, the variance estimates for mortality are valid only for the assumed random samples, and so the computed estimates may not be accurate. More importantly, the entanglement rates, as well as the locations, times, and gear, may not be representative of the fishery as a whole if some segments of the fishery are undersampled or not sampled at all, e.g. distant fishing areas.

Finally, the data suggest that some mortality is due to a small number of trips with relatively high rates of entanglements, particularly multiday trips in the Channel Islands. With such low observed effort for those trips, it is not clear how accurate the estimated entanglement rates are.

Effort

The GLM analysis in Section 7 suggests that days may not be the best effort measure to use for estimating total mortality. More work needs to be done on more complete and balanced observer data to determine which measure of total effort is best (i.e., which one will estimate total mortality with the most accuracy), and what other variables should be used to stratify the effort to improve the accuracy of the mortality estimates.

In addition, we have assumed that the total effort is known exactly. This is clearly not the case, and the estimated variances for total mortality are almost certainly underestimated due to the uncertainty in the total effort. More analysis is needed to estimate the variances and examine the biases of the effort estimates.

Mortality Estimates

Lennert et al (1991) estimated total pinniped and cetacean mortality due to the same fisheries covered in this paper over the six month period July-December 1990. They used a subset (i.e. the July-December 1990 data) of the observer data used in this paper, and the same type of estimators. However, although their estimate of total set-net fishing effort (3041 days) was about half that estimated in this paper, their area stratification apportioned a larger percentage of the unspecified effort to central California and a smaller percentage to the Channel Islands. Also, no set-net effort was observed in central California during April-June 1991, and so only 2 more elephant seal kills were observed during the last six months covered by this paper. Almost all elephant seal kills and all harbor porpoise kills were observed in central California. Consequently, their estimate for elephant seal mortality (144, se=58) due to the set-net fishery is nearly equal to that presented in this paper, and their estimate for harbor porpoise mortality (44, se=25) is well over half of that presented in this paper. On the other hand, a large percentage of observed sea lion kills occurred in spring or in the Channel Islands. Consequently, their estimate of California sea lion mortality (847, se=134) is well under half of that presented in this paper. Their estimate for harbor seal mortality (392, se=83) is about half of that presented in this paper.

Because the drift-net fishery is closed from February to April, only 27 net pulls were observed during the last six months covered by this paper. A number of cetacean kills were observed during this period, including 9 common dolphins and 2 species not observed during the first six months. Our estimate of total drift-net fishing effort was only slightly larger than that estimated by Lennert et al. (4078 days) for July-December 1990. Consequently, their pinniped mortality estimates (sea lion=90, se=62; harbor seal=23, se=22; elephant seal=90, se=43) are essentially the same. For common dolphin mortality, however, because of the large number of observed kills in January and June 1991, their estimate of total mortality (203, se=82) was about half of that presented in this paper, even though the total effort estimates were relatively close. For the remaining cetaceans, their estimates range from none to the same as those presented in this paper, depending on the observed kill for January and June 1991.

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Table 1. Observed pinniped and cetacean entanglements stratified by area, species, and month for the set-net fishery. NP = net pull, EPNP = entanglements per net pull.

Southern CA:

	Observed Effort		California Sea Lion		Harbor Seal		Northern Elephant Seal		Unident. Pinniped	
month	obs days	obs NPs	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP
7/90	10	30	0	0.000	1	0.0333	0	0.000	0	0.000
8/90	19	55	0	0.000	0	0.000	0	0.000	0	0.000
9/90	15	39	0	0.000	1	0.0256	0	0.000	0	0.000
10/90	18[1]	53	1	0.0187	2	0.0377	0	0.000	0	0.000
11/90	18	43	3	0.0698	0	0.000	0	0.000	0	0.000
12/90	12	31	1[4]	0.0323	0	0.000	0	0.000	0	0.000
1/91	40[1]	123	9	0.0732	1	0.00813	0	0.000	0	0.000
2/91	45	147	5	0.0340	0	0.000	0	0.000	0	0.000
3/91	23	74	6[3]	0.0811	0	0.000	0	0.000	0	0.000
4/91	62	195	33[2,4]	0.169	20	0.103	1	0.00513	0	0.000
5/91	63	203	14	0.0690	3[2]	0.0148	1	0.00493	0	0.000
6/91	102	332	13	0.0392	4	0.0120	0	0.000	2	0.00600
	427	1325	85	0.0642	32	0.0242	2	0.00151	2	0.00151

Channel Islands:

	Observed Effort		California Sea Lion		Harbor Seal		Northern Elephant Seal		Unident. Pinniped	
month	obs days	obs NPs	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP
7/90	0	0	-	-	-	-	-	-	-	-
8/90	1	3	2	0.667	1	0.333	0	0.000	0	0.000
9/90	0	0	-	-	-	-	-	-	-	-
10/90	6[1]	12	7	0.583	1	0.083	0	0.000	1	0.083
11/90	0	0	-	-	-	-	-	-	-	-
12/90	0	0	-	-	-	-	-	-	-	-
1/91	1[1]	1	0	0.000	0	0.000	0	0.000	0	0.000
2/91	0	0	-	-	-	-	-	-	-	-
3/91	0	0	-	-	-	-	-	-	-	-
4/91	0	0	-	-	-	-	-	-	-	-
5/91	1	4	4	1.000	1	0.250	0	0.000	0	0.000
6/91	1	4	1[4]	0.250	0	0.000	0	0.000	0	0.000
	10	24	14	0.583	3	0.125	0	0.000	1	0.0417

notes:
1) includes 1 partial day
2) 1 individual released alive
3) includes 2 unidentified sea lions
4) includes 1 unidentified sea lion

Table 1 (cont.). Observed pinniped and cetacean entanglements stratified by area, species, and month for the set-net fishery. NP = net pull, EPNP = entanglements per net pull.

Central CA:

	Observed Effort		California Sea Lion		Harbor Seal		Northern Elephant Seal		Unident. Pinniped		Harbor Porpoise	
month	obs days	obs NPs	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP
7/90	1	4	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
8/90	5	15	7	0.467	0	0.000	0	0.000	0	0.000	1	0.0667
9/90	15	41	10	0.244	11	0.268	1	0.0244	1	0.0244	3	0.0732
10/90	14	29	19	0.655	6	0.207	6	0.207	0	0.000	0	0.000
11/90	19	37	15	0.405	6	0.162	5	0.135	0	0.000	0	0.000
12/90	6	14	3	0.214	1	0.0714	1	0.0714	0	0.000	0	0.000
1/91	9	25	4	0.160	0	0.000	0	0.000	0	0.000	0	0.000
2/91	6	17	2	0.118	0	0.000	0	0.000	0	0.000	0	0.000
3/91	4	10	3	0.300	0	0.000	0	0.000	0	0.000	3	0.300
4/91	0	0	-	-	-	-	-	-	-	-	-	-
5/91	0	0	-	-	-	-	-	-	-	-	-	-
6/91	0	0	-	-	-	-	-	-	-	-	-	-
	79	192	63	0.328	24	0.125	13	0.0677	1	0.00521	7	0.0365

All Areas Combined:

	Observed Effort		California Sea Lion		Harbor Seal		Northern Elephant Seal		Unident. Pinniped		Harbor Porpoise	
month	obs days	obs NPs	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP
7/90	11	34	0	0.000	1	0.0294	0	0.000	0	0.000	0	0.000
8/90	25	73	9	0.123	1	0.0137	0	0.000	0	0.000	1	0.0137
9/90	30	80	10	0.125	12	0.150	1	0.0125	1	0.0125	3	0.0375
10/90	38	94	27	0.287	9	0.0957	6	0.0638	1	0.0106	0	0.000
11/90	37	80	18	0.225	6	0.0750	5	0.0625	0	0.000	0	0.000
12/90	18	45	4[4]	0.0889	1	0.0222	1	0.0222	0	0.000	0	0.000
1/91	50	149	13	0.0872	1	0.00671	0	0.000	0	0.000	0	0.000
2/91	51	164	7	0.0427	0	0.000	0	0.000	0	0.000	0	0.000
3/91	27	84	9[3]	0.107	0	0.000	0	0.000	0	0.000	3	0.0357
4/91	62	195	33[2,4]	0.169	20	0.103	1	0.00513	0	0.000	0	0.000
5/91	64	207	18	0.0870	4[2]	0.0193	1	0.00483	0	0.000	0	0.000
6/91	103	336	14[4]	0.0417	4	0.0119	0	0.000	2	0.000	0	0.000
	516	1541	162	0.105	59	0.0383	15	0.00973	4	0.00260	7	0.00454

notes:
1) includes 1 partial day
2) 1 individual released alive
3) includes 2 unidentified sea lions
4) includes 1 unidentified sea lion

Table 2. Observed pinniped and cetacean entanglements stratified by species and month for the drift-net fishery. This fishery is closed from February through April. Other cetaceans includes northern right whale dolphin, Pacific white-sided dolphin, Risso's dolphin, Dall's porpoise, mesoplodont beaked whale, and short-finned pilot whale. NP = net pull, EPNP = entanglements per net pull.

	Observed Effort	California Sea Lion		Harbor Seal		Northern Elephant Seal		Common Dolphin		Other Cetaceans	
month	obs NPs	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP	obs entgl.	mean EPNP
7/90	9	0	0.000	0	0.000	0	0.000	0	0.000	1	0.111
8/90	23	2	0.0870	0	0.000	0	0.000	2	0.0870	1	0.0435
9/90	18	0	0.000	0	0.000	0	0.000	4	0.222	1	0.0556
10/90	55	0	0.000	0	0.000	3	0.0545	2	0.0364	1	0.0182
11/90	29	0	0.000	1	0.0345	1	0.0345	0	0.000	0	0.000
12/90	44	2[2]	0.0455	0	0.000	0	0.000	0	0.000	2	0.0455
1/91	17	1[1,2]	0.0588	0	0.000	0	0.000	7	0.412	4	0.235
2/91	-	-	-	-	-	-	-	-	-	-	-
3/91	-	-	-	-	-	-	-	-	-	-	-
4/91	-	-	-	-	-	-	-	-	-	-	-
5/91	0	-	-	-	-	-	-	-	-	-	-
6/91	10	0	0.000	0	0.000	0	0.000	2	0.200	2	0.200
	205	5	0.0244	1	0.00488	4	0.0195	17	0.0829	12	0.00488

notes: 1) this individual released alive
2) unidentified sea lions

Table 3. Deviances for the log-linear model fits to the set-net data. Each model shown includes all of the preceding effects in the table, e.g., the third model includes grand mean, area, and soak time effects. df = degrees of freedom, p = significance level from an approximate F-test for the change in deviance normalized by the model dispersion estimated from the full model.

California Sea Lion

Model	Deviance	df	change	p
Grand Mean	565.5	1435		
+Area	490.6	1433	74.9	0.0000
+Soak Time	475.8	1432	14.9	0.0002
+Quarter	468.3	1429	7.4	0.0001
+Mackerel	463.3	1428	5.0	0.0249
+Depth	461.2	1427	2.1	0.1497
+Net Length	460.1	1426	1.1	0.2910
+Halibut	460.1	1425	0.0	0.8643
+Obs. Type	460.1	1424	0.0	0.9105

Harbor Seal

Model	Deviance	df	change	p
Grand Mean	315.6	1435		
+Area	290.0	1433	25.6	0.0000
+Quarter	268.0	1430	22.0	0.0000
+Depth	262.2	1429	5.7	0.0168
+Soak Time	258.4	1428	3.9	0.0498
+Halibut	253.9	1427	4.5	0.0344
+Mackerel	253.0	1426	0.9	0.3481
+Net Length	252.6	1425	0.4	0.5302
+Obs. Type	252.5	1424	0.1	0.7485

Table 4. Estimated coefficients and dispersion parameter for the log-linear model fits to the set-net data. These estimates include only those effects that were significant at the 5% level. The coefficient for the first class of each categorical effect was constrained to be 0. se = standard error.

California Sea Lion

variable	est. coef	se(coef)
Grand Mean	-6.279	0.9166
Southern CA	0	-
Channel Islands	2.530	0.3583
Central CA	1.544	0.2997
Soak Time	0.8473	0.2435
Jan - Mar	0	-
Apr - Jun	0.6736	0.3012
Jul - Sep	0.2150	0.3653
Oct - Dec	0.5657	0.3005
Mackerel	0.1820	0.07255

est. dispersion 1.389

Harbor Seal

variable	est. coef	se(coef)
Grand Mean	-4.719	1.641
Southern CA	0	-
Channel Islands	1.616	0.6931
Central CA	1.901	0.5331
Jan - Mar	0	-
Apr - Jun	3.713	1.163
Jul - Sep	3.191	1.164
Oct - Dec	2.688	1.147
Shallow Water	0	-
Deep Water	1.234	0.4166
Soak Time	-0.8685	0.3630
Halibut	0.4043	0.1899

est. dispersion 1.215

Table 5. Deviances for the log-linear model fits to the drift-net data. Each model shown includes all of the preceding effects in the table, e.g., the third model includes grand mean, depth, and soak time effects. df = degrees of freedom, p = significance level from an approximate F-test for the change in deviance normalized by the model dispersion estimated from the full model.

Model	Deviance	df	change	p
Grand Mean	115.5	204		
+Depth	110.1	203	5.4	0.0209
+Soak Time	107.6	202	2.6	0.1078
+Season	107.0	201	0.6	0.4612
+Area	107.0	200	0.0	0.9880

Table 6. Estimated coefficients and dispersion parameter for the log-linear model fits to the drift-net data. These estimates include only those effects that were significant at the 5% level. The coefficient for the first class of the depth effect was constrained to be 0. se = standard error.

variable	est. coef	se(coef)
Grand Mean	-1.386	0.2204
Shelf/Slope	0	-
Deep Water	-1.112	0.5617

est. dispersion 1.606

Table 7. Estimated coefficients for the test for significance of observation type effect in the set-net fishery. se = standard error. p = approximate significance level for the estimated coefficient. Significance levels for Post-Set coefficients are for a 1-tailed z-test. All other p-values are for a 2-tailed z-test.

	Pinnipeds & Cetaceans			Pinnipeds Only		
	est. coef	se(coef)	p	est. coef	se(coef)	p
Grand Mean	-8.495	1.380	0.0000	-8.197	1.4369	0.0000
Jan - Mar	0	-	-	0	-	-
Jul - Sep	2.216	0.5022	0.0000	2.057	0.5160	0.0001
Oct - Dec	2.169	0.4825	0.0000	2.141	0.4899	0.0000
Soak Time	1.497	0.3227	0.0000	1.438	0.3369	0.0000
Pre-Set	0	-		0	-	
Post-Set	0.4945	0.2931	0.0458	0.439	0.2985	0.0705

Table 8. Cell counts of effort and entanglement used in log-linear model to compare measures of fishing effort in the set-net fishery.

		Effort Per Cell						Number of Entanglements			
Area	Qtr	Sets	Days	Soak Time (hours)	Net Lgth (fathoms)	Halibut Caught	Mackerel Caught	Pin. & Cet.	Pin. Only	CSL Only	HS Only
Southern CA	Jan-Mar	333	106	10339	91020	1716	908	21	21	20	1
	Apr-Jun	670	214	21433	175028	2779	4950	85	85	57	26
	Jul-Sep	119	42	3302	28717	343	317	2	2	0	2
	Oct-Dec	125	47	3340	31819	368	349	7	7	5	2
Channel Is.	Jan-Mar	1	1	21	250	11	0	0	0	0	0
	Apr-Jun	8	2	192	2070	18	7	6	6	5	1
	Jul-Sep	3	1	57	900	13	0	3	3	2	1
	Oct-Dec	12	6	259	2500	57	22	9	9	8	1
Central CA	Jan-Mar	52	19	3381	19665	182	2	12	9	9	0
	Apr-Jun	0	0	0	0	0	0	0	0	0	0
	Jul-Sep	58	20	1929	14420	151	274	33	29	17	11
	Oct-Dec	77	37	3345	21025	251	497	59	59	36	11

Table 9. Deviances for the log-linear model to compare measures of fishing effort in the set-net fishery. Each model shown includes grand mean, area and quarter effects as well as the effort effect listed in the table, e.g., the third model includes grand mean, area, quarter, and soak time effects. p = approximate significance level for the normalized deviance or the estimated effort coefficient. The model deviances are normalized by the estimated dispersion, and the significance levels are from an approximate F-test. The significance levels for the estimated coefficients are from an approximate z-test. se = standard error.

Pinnipeds and Cetaceans

model	normalized deviance	est. dispersion	p	est. coef	se(coef)	p
Sets	3.78	2.13	.11	1.68	.385	.15
Days	4.35	3.15	.092	1.42	.416	.37
Soak Time	4.35	3.82	.092	1.65	.565	.31
Net Length	4.35	1.99	.092	1.97	.450	.097
Halibut	4.53	2.08	.086	1.22	.283	.48
Mackerel	3.98	3.69	.10	.486	.157	.031
net len * soak	4.42	4.88	.090	1.78	.749	.36

Pinnipeds Only

model	normalized deviance	est. dispersion	p	est. coef	se(coef)	p
Sets	3.67	2.63	.12	1.71	.432	.18
Days	4.17	3.69	.098	1.43	.451	.39
Soak Time	4.23	4.40	.096	1.66	.606	.34
Net Length	4.24	2.45	.095	2.00	.503	.12
Halibut	4.34	2.51	.092	1.24	.313	.49
Mackerel	3.76	3.46	.11	.533	.162	.045
net len * soak	4.35	5.42	.092	1.79	.787	.37

California Sea Lion

model	normalized deviance	est. dispersion	p	est. coef	se(coef)	p
Sets	5.02	2.11	.074	1.76	.451	.17
Days	5.26	3.06	.068	1.47	.474	.38
Soak Time	5.24	3.47	.069	1.68	.612	.33
Net Length	5.42	2.14	.065	2.03	.542	.13
Halibut	5.45	2.33	.066	1.27	.350	.48
Mackerel	4.75	3.41	.080	.520	.180	.056
net len * soak	5.19	4.36	.070	1.78	.792	.38

Table 10. Estimated pinniped and cetacean kill rates and total kill, stratified by area and species, in the California halibut/Pacific angle shark set-net fishery, for the period July 1990 through June 1991. Estimates of total kill are reported to the nearest individual. Estimates of kill rates are reported to 3 significant digits. Estimated standard errors are included in parentheses, and are reported to 3 significant digits. KPD = kill per day.

		Southern CA		Channel Islands		Central CA		Total	
Days of Effort		6321		487		705		7513	
California Sea Lion[1]:	est. KPD	.197	(.0288)	1.40	(.575)	.797	(.127)	.331	(.0460)
	est. kill	1243	(182)	682	(280)	562	(89.9)	2487[2]	(346)
Harbor Seal:	est. KPD	.0726	(.0155)	.300	(.151)	.304	(.0784)	.109	(.0179)
	est. kill	459	(97.9)	146	(73.6)	214	(55.3)	819[3]	(134)
N. Elephant Seal:	est. KPD	.00468	(.00319)	0	(0)	.165	(.0667)	.0194	(.00681)
	est. kill	30	(20.2)	146	(73.6)	116	(47.0)	146[4]	(51.2)
Harbor Porpoise:	est. KPD	-	-	-	-	.0886	(.0387)	.0886	(.0387)
	est. kill	-	-	-	-	62	(27.3)	62	(27.3)

notes:
1) includes 5 unidentified sea lions.
2) including the 1 individual released alive and the 4 unidentified individuals increases this kill estimate to 2590 (se=354).
3) including the 1 individual released alive and the 4 unidentified individuals increases this kill estimate to 921 (se=139).
4) including the 4 unidentified individuals increases this kill estimate to 233 (se=73.4).

Table 11. Estimated pinniped and cetacean kill rates and total kill, stratified by area and species, in the shark/swordfish drift-net fishery, for the period July 1990 through June 1991.. Estimates of total kill are reported to the nearest individual. Estimates of kill rates are reported to 3 significant digits. Estimated standard errors are included in parentheses, and are reported to 3 significant digits. KPD = kill per day.

Days of Effort		4734
California Sea Lion[1]:	est. KPD	.0195 (.0135)
	est. kill	92[2] (63.7)
Harbor Seal:	est. KPD	.00488 (.00468)
	est. kill	23 (22.1)
Northern Elephant Seal:	est. KPD	.0195 (.00949)
	est. kill	92 (44.9)
Common Dolphin:	est. KPD	.0829 (.0327)
	est. kill	393 (155)
N. Right Whale Dolphin:	est. KPD	.0146 (.0108)
	est. kill	69 (51.1)
Pac. Whited-Sided Dolphin:	est. KPD	.0146 (.00821)
	est. kill	69 (38.9)
Risso's Dolphin:	est. KPD	.00976 (.00662)
	est. kill	46 (31.4)
Dall's Porpoise:	est. KPD	.00976 (.00638)
	est. kill	46 (30.2)
Mesoplodont Beaked Whale:	est. KPD	.00488 (.00475)
	est. kill	23 (22.5)
Short-Finned Pilot Whale:	est. KPD	.00488 (.00468)
	est. kill	23 (22.1)

notes: 1) includes 3 unidentified sea lions.
2) including the 1 individual released alive increases this kill estimate to 115 (se=66.4).

Figure 1: Observed net pull data for the halibut/angel shark set-net fishery from July 1990 to June 1991.

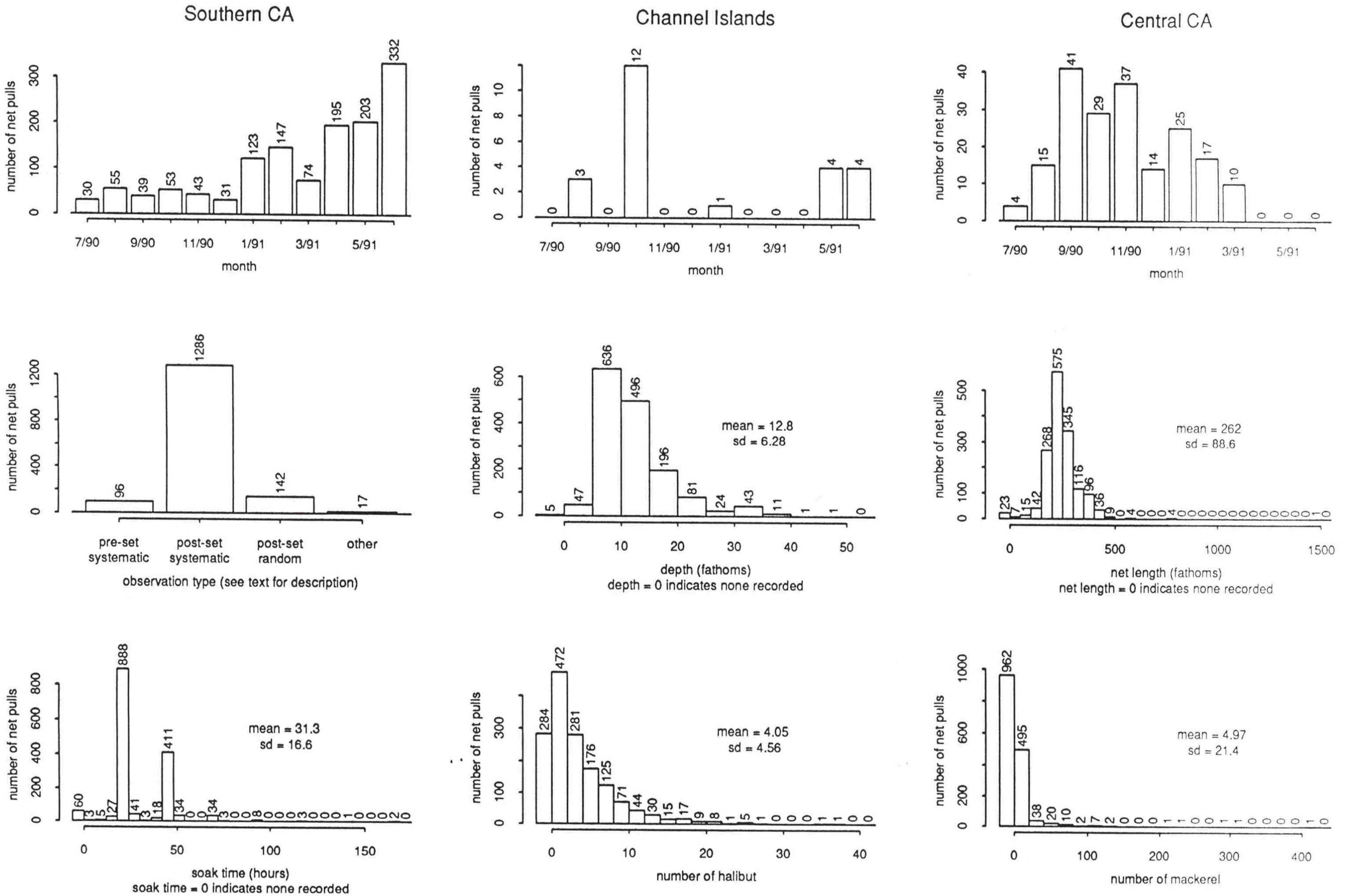

Figure 2. Observed net pull data for the shark/swordfish drift-net fishery from July 1990 to June 1991.