DEPARTMENT OF COMMERCE * UNITED STATES OF AMERICA *

NOAA Technical Memorandum NMFS-AFSC-55

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This document should be cited as follows:

> Pella, J., R. Rumbaugh, and M. Dahlberg. 1995. Incidental catches of salmonids in the 1991 North Pacific squid driftnet fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-55, 33 p.

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August 1995

ABSTRACT

In 1991, the National Marine Fisheries Service, as mandated by the U.S. Driftnet Impact Monitoring,. Assessment, and Control Act of 1987 and U.S. Public Law 101-627, developed methods to estimate the incidental catches (bycatch) of salmonids in the North Pacific squid driftnet fisheries of Japan, the Republic of Korea (ROK), and Taiwan. Two analytical approaches were used for the Japanese fishery: 1) simple expansion of average observed vessel-trip bycatch for total trips by the fleet, and 2) expansion of kernel-smoothed bycatch rates of monitored fishing effort among time and area strata to account for total fishing effort expended within strata. Bootstrap resampling was used to determine the reliability of all estimates. Total salmonid bycatch in the 1991 Japanese squid driftnet fishery was estimated to be 43,700 (vessel-trip method) or 32,100 fish (kernel technique). With an additional 6,000 (vessel-trip method) or 4,400 (kernel technique) salmon estimated to have dropped out of the driftnets during retrieval, total salmonid mortality (bycatch + dropouts) was estimated to be 49,700 (vessel-trip method) or 36,500 fish (kernel technique). Total salmonid bycatch in the squid driftnet fishery of the Republic of Korea was estimated at 13,500 fish using two-stage expansion. First, observed bycatch rate of each monitored time and area stratum was expanded by stratum effort to estimate the stratum bycatch. Second, the sum of these estimated bycatches for monitored strata was expanded for effort in unmonitored strata. Dropouts were estimated at 3,100 fish for a total mortality of 16,600 salmonids. Only 10 salmonids were observed in the squid driftnet fishery of Taiwan, and the total salmonid bycatch was evidently small. The salmonid bycatch in these legal squid driftnet fisheries was minor compared with catches of Alaskan coastal fisheries in 1991, as it was in 1989 (when U.S. monitoring began) and in 1990. The 1991 salmonid bycatch was also small compared with estimates of annual illegal catches of salmonids from the North Pacific Ocean in recent years.

CONTENTS

INTRODUCTION

In 1991, Japan,, the Republic of Korea (ROK), and Taiwan operated high-seas squid driftnet fisheries in the North Pacific Ocean. Fishermen from these three countries targeted various species of squid, especially neon flying squid *(Ommastrephes bartrami).* Many species of marine animals, including fishes, birds, and mammals, were incidentally caught. Salmonids - chinook *(Oncorhynchus tshawytscha),* chum (0. keta), coho (0. kisutch), pink (0. *gorbuscha),* cherry (0. *masou),* and sockeye (0. *nerka)* salmon and steelhead trout *(0. mykiss)* - were among the incidentally caught species.

In this, paper, we estimate the incidental catches (bycatch) of salmonids by the 1991 high-seas squid driftnet fisheries of Japan, the ROK, and Taiwan to meet requirements of the U.S. Driftnet Impact Monitoring, Assessment, and Control Act of 1987 and of U.S. Public Law 101-627. Estimated catch (in numbers), by species, taken by the fisheries of Japan and the ROK are provided. Our analysis used the methods developed by Pella et al. (1993) to estimate the 1990 salmonid bycatch of these fisheries. A complete description of these methods is included along with changes made for the 1991 data for the convenience of the reader. Only 10 salmonids were observed in the Taiwanese fishery and this bycatch was considered negligible for our analysis.

REGULATED FISHERIES *OF* JAPAN, REPUBLIC OF KOREA, AND TAIWAN

Legal Times and Areas of Squid Driftnet Fisheries

Japan, ROK, and Taiwan all had domestic regulations establishing boundaries within the North Pacific Ocean where their licensed squid driftnet vessels could legally operate. The legal boundaries of the Japanese high-seas squid driftnet fishery extended north from lat. 20°N, long. 170°E to 145°W, with the northern boundary changing monthly and longitudinally (Fig. 1). Monthly movement of the northern boundary was established to try to minimize the bycatch of salmonids. Japanese squid driftnet vessels were allowed to operate from June through December only.

Driftnet vessels from the ROK were allowed to fish between long. 160°E and 145°W. No southern boundary was established for the fishery. The northern boundary depended on longitude and month (Fig. 2). The ROK squid driftnet fishery was closed between long. 170°E and 145°W from January through April and in December; however, fishing was allowed from long. 160°E to 170°E during all months.

The Taiwanese Department of Agriculture also established legal areas where driftnet fishing was permitted by its licensed vessels. No southern or western boundaries other than 200-mile national Exclusive Economic Zones (EEZs) were

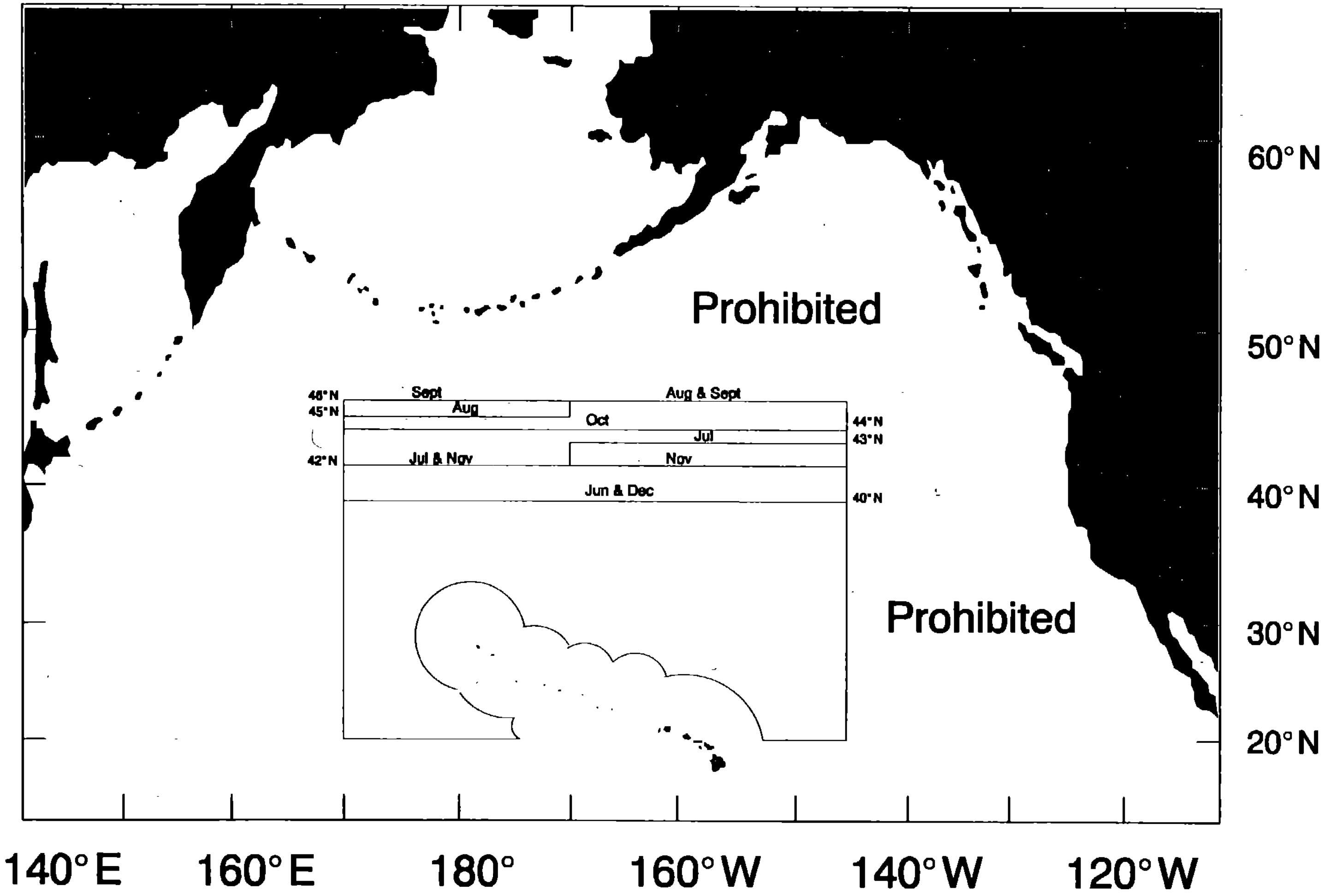


Figure 1.--Legal fishing area of the Japanese squid driftnet fishery. Northern boundary changed by month and longitude, but other boundaries were fixed (western, long. 170°E; eastern, long. 145°W; and southern, lat. 20°N and U.S. Exclusive Economic Zone). No fishing was allowed during January through May.

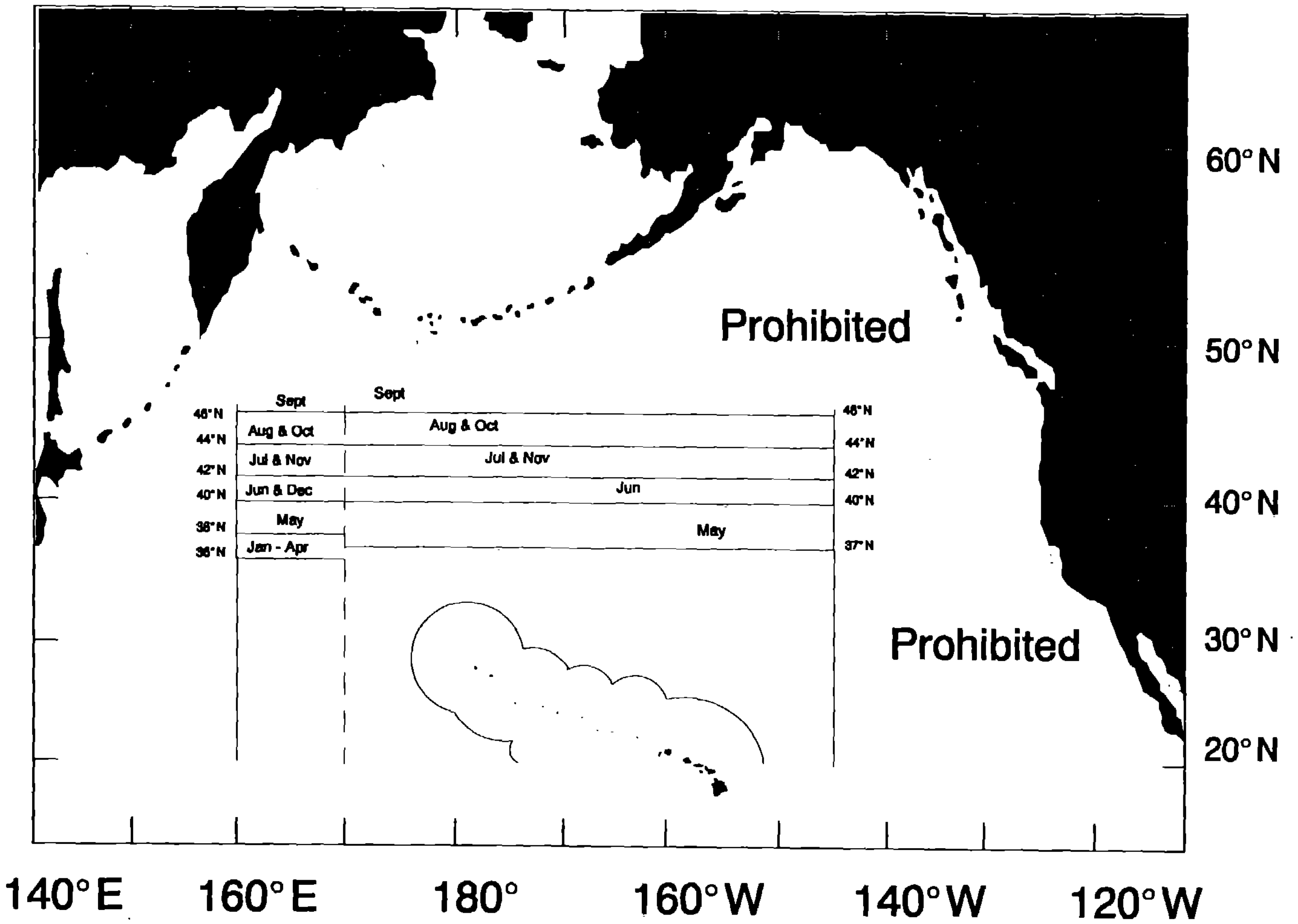


Figure 2.--portion of the legal fishing area of the Republic of Korea squid driftnet fishery northward of lat. 20°N (solid lines). Northern boundary changed by month and longitude; western (long. 160°E) and eastern (long. 145°W) boundaries were fixed. and *no* boundary to the south was imposed other than national Exclusive Economic Zones.

established; however, an eastern boundary of long. 145°W and changing monthly northern boundary delimited the fishery (Fig. 3). In contrast to the Japanese fishery, Taiwanese vessels could fish year-round. Once again, the northern and eastern boundaries were established to restrict the bycatch of salmonids.

Monitoring Programs

The U.S. Driftnet Impact Monitoring, Assessment, and Control Act of 1987 and U.S. Public Law 101-627 requires that the U.S. Department of State negotiate monitoring and enforcement agreements with nations that operate high-seas driftnet fisheries in the North Pacific Ocean. In 1989, the 'United States established pilot observer programs with Japan, the ROK, and Taiwan to obtain initial driftnet bycatch data on certain species of anadromous fish, marine mammals, seabirds, and turtles. In 1990 and 1991, more comprehensive observer programs were devised to collect data on the bycatch of all species of fish, marine mammals, seabirds, and turtles.

Data collected by the scientific observers in 1991 consisted of three types taken during each monitored vessel fishing operation (an operation comprised setting, soaking, and retrieval of the driftnet) : physical observations, environmental measurements, and catch. Physical data included time (month, day, time) and position (latitude and longitude). Environmental measurements comprised sea-surface temperature, wind direction, Beaufort state, and ocean swell height. Physical and environmental, data were recorded for the beginning and ending of net deployment and retrieval. Catch information included the number of sections deployed, length of each section, set direction, catch (in numbers) of the target species, and bycatch (in numbers of animals) of all non-target species.

Bycatch Estimation

Japanese Squid Driftnet Fishery

From June through early December 1991, observers were placed aboard Japanese vessels operating in the North Pacific squid driftnet fishery as part of a joint monitoring effort by the United States, Canada, and Japan. The objective of the observer program was to monitor the fishing operations of vessels so that the catch of target squid species, particularly neon flying squid, and the bycatch of non-target species could be estimated.

Observers were placed on board 59 vessels, or 14% of the vessels operating in the commercial fishery. Ten observers

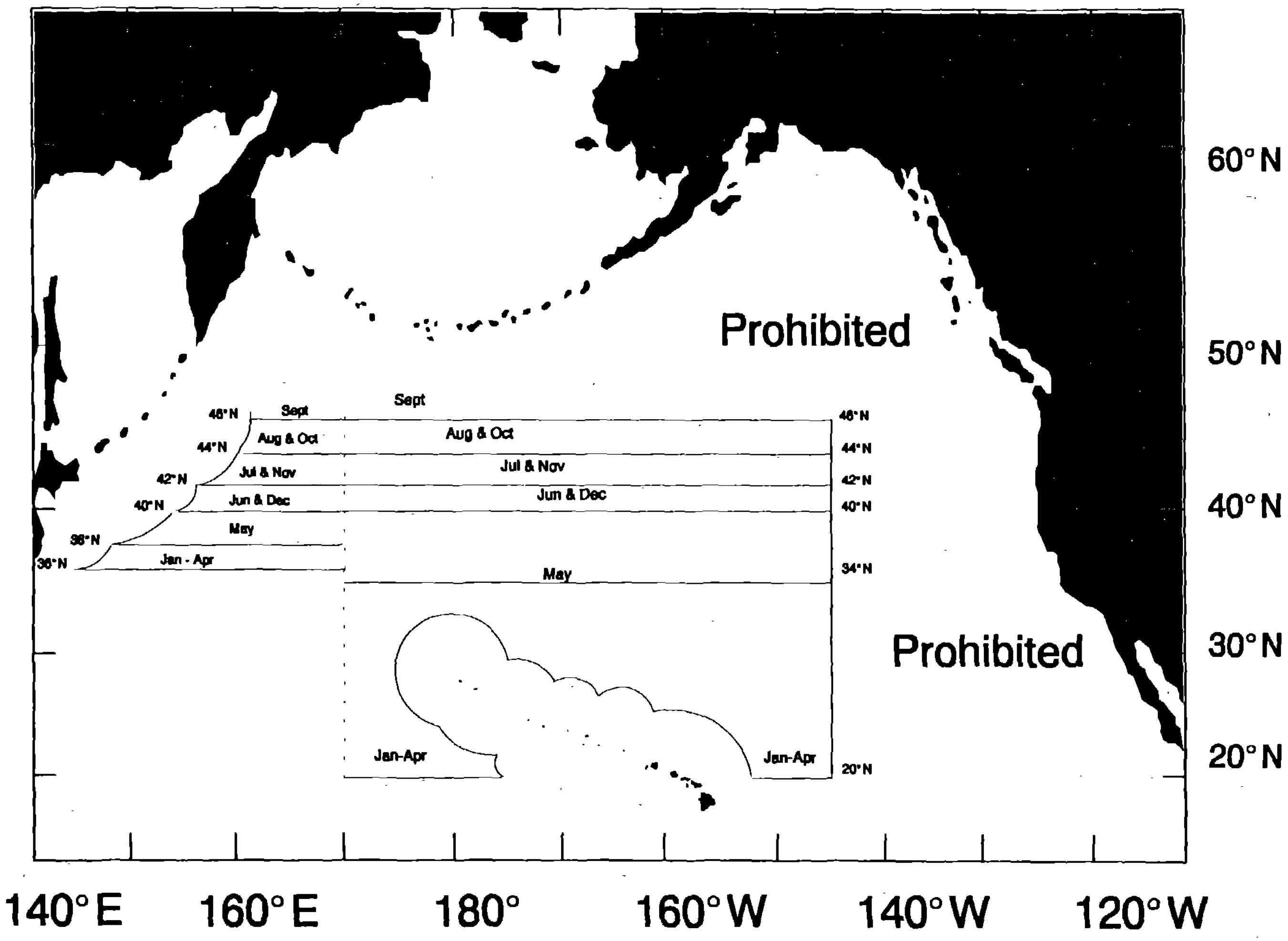


Figure 3.--Portion of the legal fishing area of the Taiwanese squid driftnet fishery northward of lat. 20°N and eastward of long. 140°E (solid lines). Northern boundary changedby month and longitude, eastern boundary (long. 145°W) was fixed; and no boundaries to the south or west were imposed other than national Exclusive Economic Zones.

were Canadian, 19 were Japanese, and 30 were from the United States. The observers were instructed to monitor daily vessel operations and record the number of individuals of the target and non-target species entangled and retrieved in the driftnets. They also recorded the number of animals dropping out or shaken out of the nets by fishermen during net retrieval.

Two methods were used to estimate the 1991 bycatch of salmonids in the Japanese squid driftnet fishery:
1) expansion of average observed vessel-trip bycatch for total trips by the fleet, and 2) expansion of kernel-smoothed bycatch rates of monitored effort among time and area strata to account for total fishing effort expended-within strata. Stratum bycatches of the second method were also allocated to species based on kernel-smoothed species composition estimates from samples of stratum bycatches. A measure of the uncertainty in the bycatch estimates was obtained in both cases by bootstrapping (Efron 1982). The bootstrapping procedures used slightly exaggerate the uncertainty in bycatch estimates because adjustments for finite populations sampled were not developed.

Besides the estimate of salmonid bycatch, an estimate of the number of salmon that drop out of the nets during retrieval (dropouts), was also desired. Ratio estimation was used to determine the number of dropouts for the entire fleet, and the uncertainty of this estimate was evaluated by bootstrapping.

Methods

***Expansion of Vessel-Trip* Bycatch.-** We estimated total salmonid bycatch for the 1991 Japanese fishery by classifying vessel trips into those made by small (25-35 m hull length) and large (>35 m hull length) vessels. In 1991, a total of 142 small-vessel trips and 286 large-vessel trips occurred (A. Yatsu, National Research Institute of Far Seas Fisheries, Fishery Agency of Japan, Shimizu-shi, Shizuoka, Japan, pers. commun., September 1992). Fifty-nine observers were placed on 15 small vessels (11% of the small-vessel trips) and 44 large vessels (15% of the large-vessel trips). Observers were on board the vessels for the entire trip of all 15 small vessels and 41 of the 44 large vessels (93%). The duration of vessel trips for which observers arrived or left at sea was unknown, and possibly some fishing during these trips was not monitored. The vessel-trip bycatch estimates were not adjusted for the abbreviated presence of observers for the three trips. The estimated vessel-trip bycatch averages for small and large vessels were expanded by corresponding total numbers of vessel trips to obtain an estimate of total salmonid bycatch for the fishery by each vessel size class.

Estimated total salmonid bycatch for the fishery equaled the sum of the bycatch estimates for both vessel size classes.

Vessel trips with an observer on board were treated as if randomly sampled from the "populations" of vessel trips of the two vessel sizes. Actually, 10 fishing ports were designated to host specified numbers of observers during the 1991 squid driftnet fishery, and the vessels that carried observers were selected through a lottery by the fishermen themselves. The allocation of observers to each fishing port was roughly proportional to the size of its fleet. Vessels from different fishing ports do not fish in distinctive manners, so vessels were not stratified by fishing port. However, vessels of different sizes might be expected to have different amounts of bycatch. Therefore, vessel trips were poststratified by size class (small and large).

A vessel trip was the primary sampling unit within the vessel size strata. Operations were the secondary sampling units within a given vessel trip. Up to 12 sections of net were fished during an operation, and each net section usually contained 100-150 net panels (tans) 50 m in length. The net (all sections) was deployed during late afternoon or evening, allowed to soak 8-12 hours, and then retrieved the following morning. With this scenario, one operation was usually conducted within 24 hours. Occasionally, extremely high abundances of squid were encountered such that all of the driftnet that was deployed could not be retrieved in a given day. Some net sections were then left to soak an additional night. In one case, several sections of net soaked an additional 2 days. Hence, two kinds of operations occurred: daily (all nets deployed were retrieved the following day) and extended (some nets soaked for up to two additional days). Extended operations were treated the same as the daily operations for estimating bycatch.

The daily operations of each month were stratified into approximate 10-day periods: days 1-10, 11-20, and 21-end of month. These intervals will be called 10-day periods for brevity. Fishing operations were monitored in each of 19 10-day periods covering the actual duration of the 1991 fishery, from 1 June to 10 December.

Not all operations of an observed vessel trip were monitored by the observers. To prevent fatigue, observers were instructed to skip the sixth day after observing operations for five consecutive days. Therefore; five of every six operations should have been observed. However, daily operations were interrupted by storms of l-9 days, with frequency depending on the time of year. Daily operations were also interrupted when a vessel changed locations within the fishery. Therefore, a variable number of operations were observed during 10-day periods of a vessel trip even though 5 of every 6 days were to have been observed. The observed daily operations by a vessel during each 10-day period were viewed as a random sample of all its daily operations for the period. Although a systematic sampling scheme was originally planned, in reality the daily operations observed within a 10-day period were closer to a random sample because of the numerous,, unpredictable disruptions to the schedule.

Finally, the ultimate sampling units for which observers recorded bycatch were individual net sections. A true random subset (6 or 7) of the total net sections deployed in an operation (6-12) was examined for bycatch during an observed retrieval. The number of sections monitored by an observer depended on the number of sections deployed. When 6-9 sections of net were deployed, observers were instructed to randomly monitor 6 sections. If 10-12 sections of net were deployed, observers monitored 7 sections. Therefore, the observed net sections of a daily operation were a simple random sample of the total sections.

To estimate the salmonid bycatch for an observed vessel trip, the daily operations were stratified into 10-day periods. The bycatch for a given daily operation was estimated by multiplying the observed salmonid bycatch rate (number of salmon per tan) by the number of tans deployed in the operation (observed and unobserved sections). Next, the average daily operation bycatch during each 10-day period of the given vessel trip was calculated. Then these averages were multiplied by the corresponding number of daily operations during the IO-day periods to estimate the bycatch for each 10-day period during the vessel trip. Finally, estimates of bycatch for each 10-day period were summed over 10-day periods to obtain the estimated bycatch during the vessel trip.

Once the estimated bycatch for each observed vessel trip was available, average bycatch per vessel trip by large and small vessels was computed. These averages were multiplied by the corresponding total numbers of vessel trips to estimate the total bycatch by each vessel size. The estimated bycatch for vessel size t, T_t, was

$$\hat{T}_t = N_t \cdot \bar{x}_t \ , \qquad (1)$$

where N_t was the number of vessel trips by vessels of size t and x_t was the estimated average vessel-trip bycatch of the observed vessels for size t. The estimates of bycatch for the two vessel sizes were then combined to obtain the estimate of bycatch for the entire fleet. The estimate of total bycatch for the entire fleet, T, was

$$\hat{T} = \sum_{t=1}^{2} \hat{T}_t \ . \qquad (2)$$

Precision of the estimate of total bycatch from the observed portion of the fleet was evaluated by bootstrap resampling (Efron 1982). First,, the observed daily operations within each 10-day period were resampled for each vessel trip. Then the sections within each daily operation included in the bootstrap sample were resampled. The resampled observations were then used to estimate the total bycatch of the observed vessel trips just as the original observations had been. The resampling was performed 1,000 times. For each repetition ($b = 1,2,\ldots, 1,000$) of the bootstrap, an estimate of salmonid bycatch (x^*_{bi}) for each vessel trip ($i = 1,2,\ldots,59$) was calculated.

The sampling distribution of the total bycatch estimate of the fleet, 9, was estimated by resampling vessel trips and using the previous bootstrapping results. Consider the b^{th} resampling. First, the observed trips of the 15 small vessels were resampled; independently, the observed trips of the 44 large vessels were also resampled. A typical sample omitted some observed vessel trips and repeated others. Then the bootstrap average bycatch for small (x^*_{b1}) and large (x^*_{b2}) vessels was computed from the previous estimates of vessel-trip bycatch (x^*_{b1}) included in the bootstrap sample of vessel trips. Finally, the b^{th} bootstrap estimate of total bycatch, T^*_b, was computed as

$$\hat{T}_b^* = \sum_{t=1}^{2} N_t \cdot \bar{x}_{bt}^* . \qquad (3)$$

One thousand values of T^*_b were computed in this fashion. The standard deviation of the T^*_b among the 1,000 resamplings is the' estimate of the standard error of the estimate of the total bycatch for the fleet, T. The, 5th and 95th percentiles of the 1,000 T^*_bs provide a 90% confidence interval (CI) .

This first approach to estimating total bycatch provides an estimate and a-measure of precision of this estimate which are simple to understand, and the basis seems a reasonable approximation to the sampling process. If the fishing activities of vessels were not affected by the presence of an observer, this estimate is unbiased even if imprecise. Some of the imprecision is due to the differences among vessel trips in the time of season and areas fished. To account for the time and area distribution of fishing effort by the fleet when estimating bycatch, a kernel estimation method was used.

***Kernel Estimation of* Bycatch by Time and Area** Strata.-Bycatch of the fleet during 1991 was estimated in three stages. First, bycatch rates of 'small and large vessels were estimated for every 1^{o} latitude X 1^{o} longitude area and 10-day period, hereafter referred to collectively as "strata," in which fishing effort was expended. Second, the bycatch by vessel size class for each stratum was estimated as the product of the estimated bycatch rate and the reported fishing effort expended by vessel size class in the stratum. Third, bycatch estimates were summed over vessel size class and time and area strata to obtain the total estimated bycatch for the fishery.

The amount of fishing effort (tans) expended by large and small vessels in each stratum, hereafter referred to as "effort," was available. A total of 1,038 strata were fished by the Japanese driftnet fleet, and of those, some fishing was monitored by observers in 561 strata (54%). Observer coverage of effort expended by large and small vessel size classes ranged from 0% to 100% and 0% to 76%, respectively, among the strata fished.

The strata in which some effort and associated bycatch was monitored provide estimates of bycatch rates. The spatial distributions of bycatch rates of large and small vessels for each lo-day period from 1 June to 10 December were revealing (Fig. 4). First, the highest salmonid bycatch rates occurred between 21 June and 10 July, mainly in the northwest corner of the fishing area. Second, a marked difference occurred in bycatch rates between large and small vessels, due in large part to their distinctive areal distributions. Small vessels crowded the western portion of the fishery, whereas large vessels spread out to the east.

Bycatch *rates by vessel size* class. The amount of monitored effort varied considerably among the 1^o X 1^o areas and 10-day periods, so the resulting variable precision of observed bycatch rates in the strata had to be considered when estimating-underlying bycatch rates. Effort in nearly one-half of the strata in which some fishing occurred was completely unmonitored, so corresponding bycatch rates were estimated from information gathered from monitored strata. The kernel method (Eubank 1988) was used to smooth observed bycatch rates to estimate the underlying bycatch rates by vessel size among strata. Kernel estimation was previously used by Larntz and Garrott (1991) to estimate bycatch rates of selected bird and marine mammal species in the 1989 Japanese squid fishery and by Pella et al. (1993) to estimate salmonid bycatch rates in the 1990 Japanese squid fishery.

The kernel estimate of bycatch rate by a vessel size class in a particular stratum during any of four monthly intervals of the fishing season - June, July, August, and September-December - used observed bycatch rates by the vessel size class from all strata in which observers monitored effort and bycatch in that monthly interval. However, the kernel estimate placed variable emphasis on different strata.' Observed bycatch rates in nearby strata, including the stratum

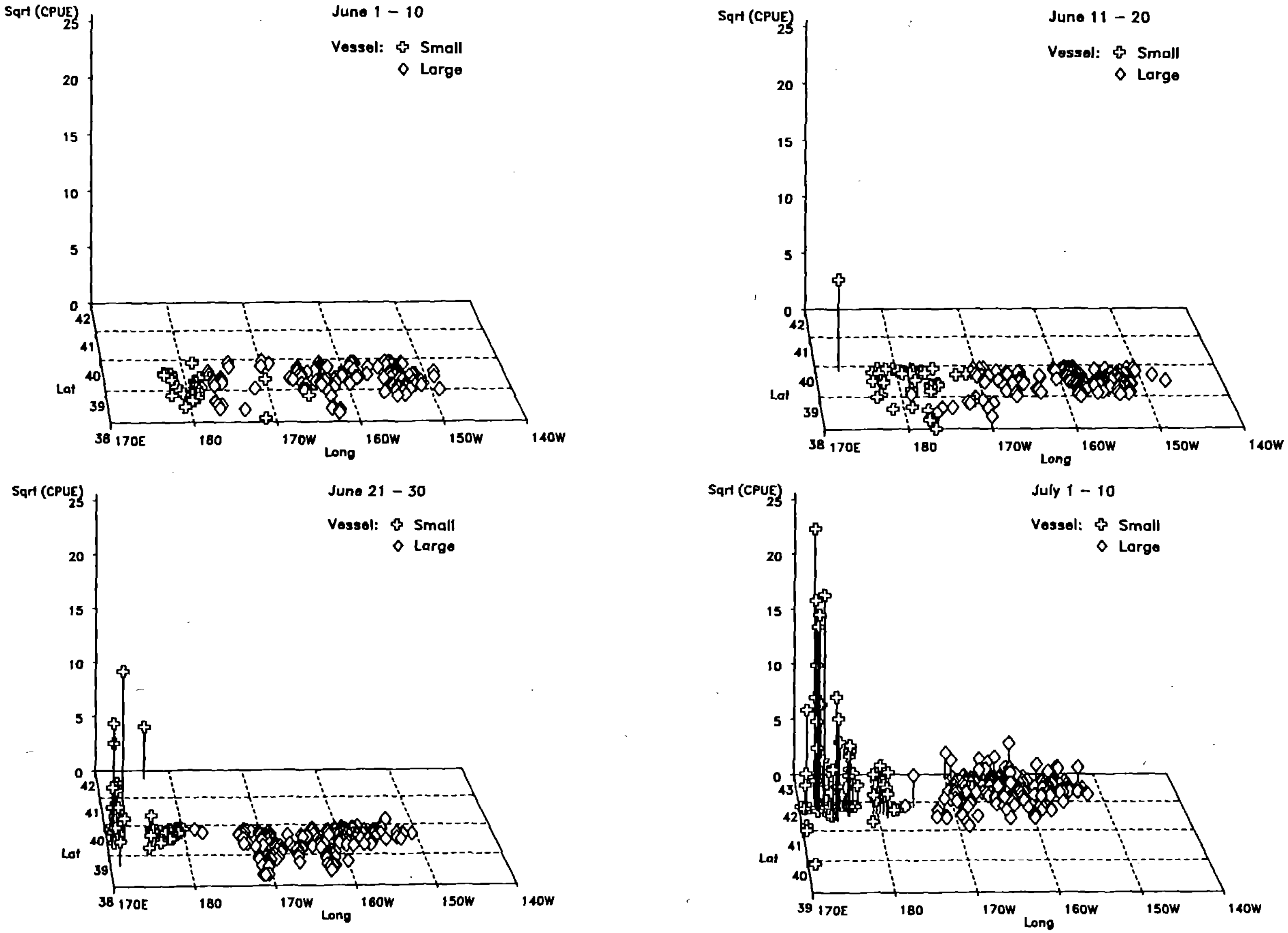
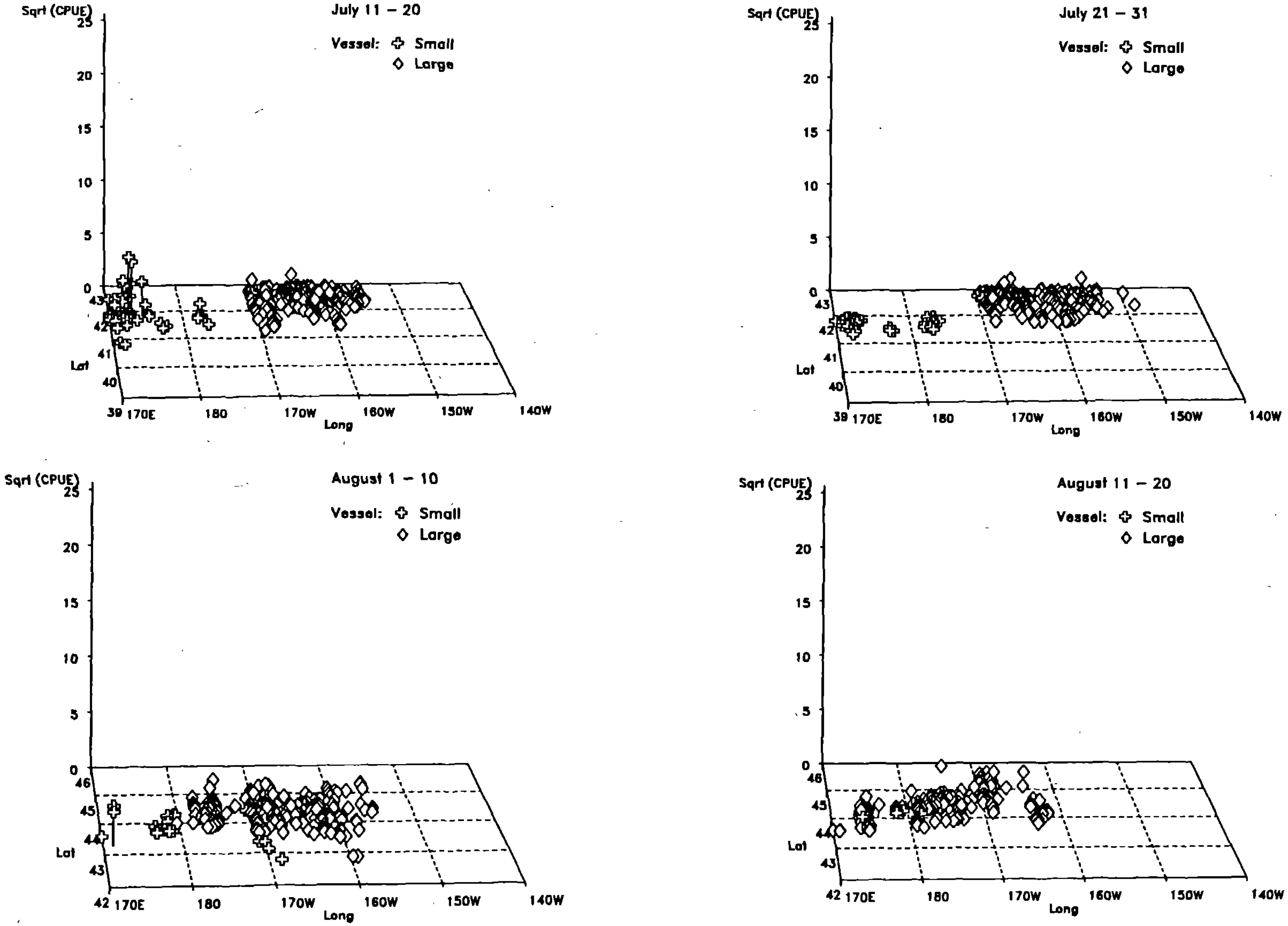


Figure 4.--Spatial distribution (1^o latitude [lat.] X 1^o longitude [long.]) of observed salmonid bycatch rates (shown as square root of bycatch [numbers of fish] per 1,000 tans) by vessel size class for 10-day periods from 1 June to 10 December.



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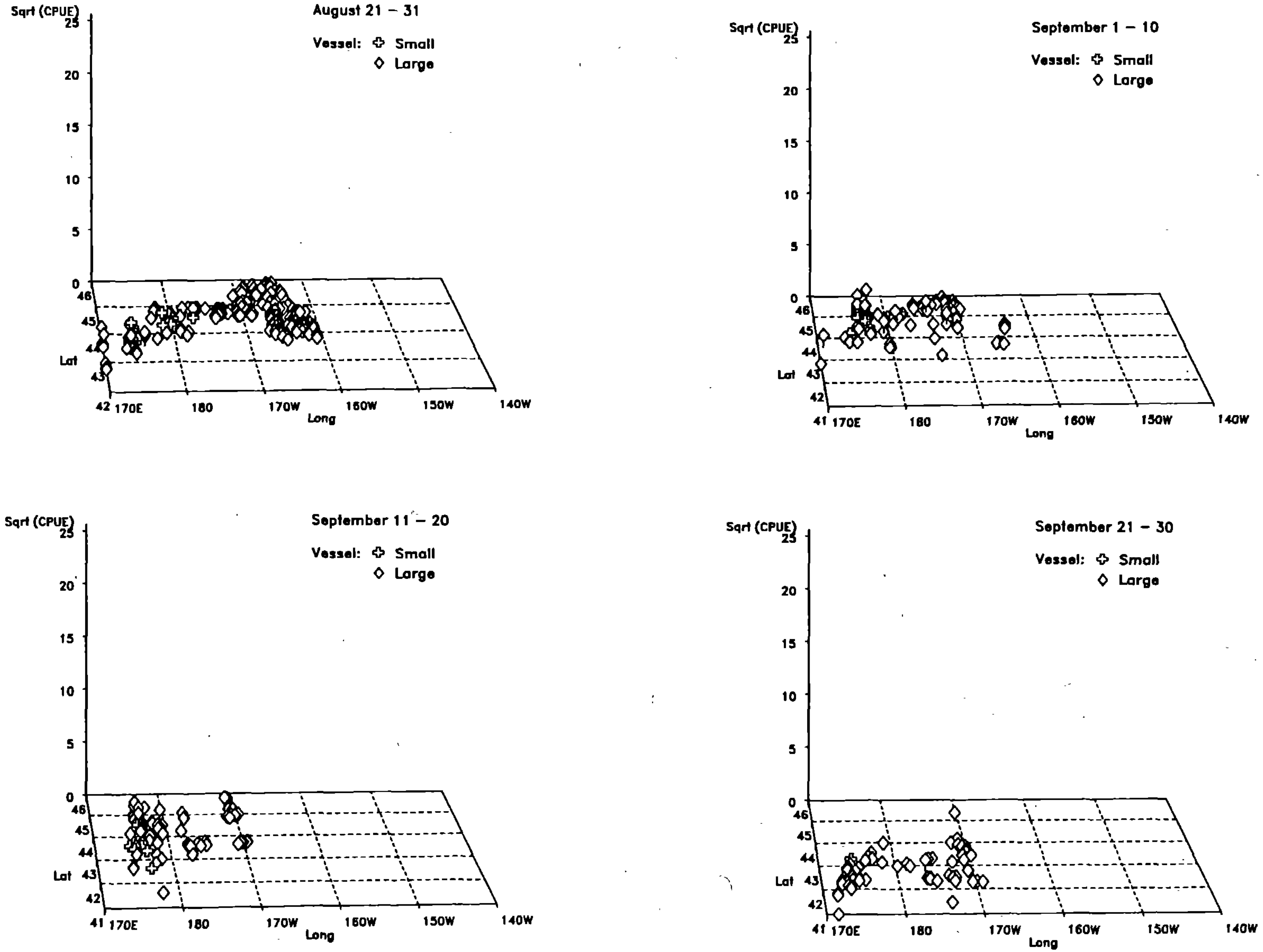

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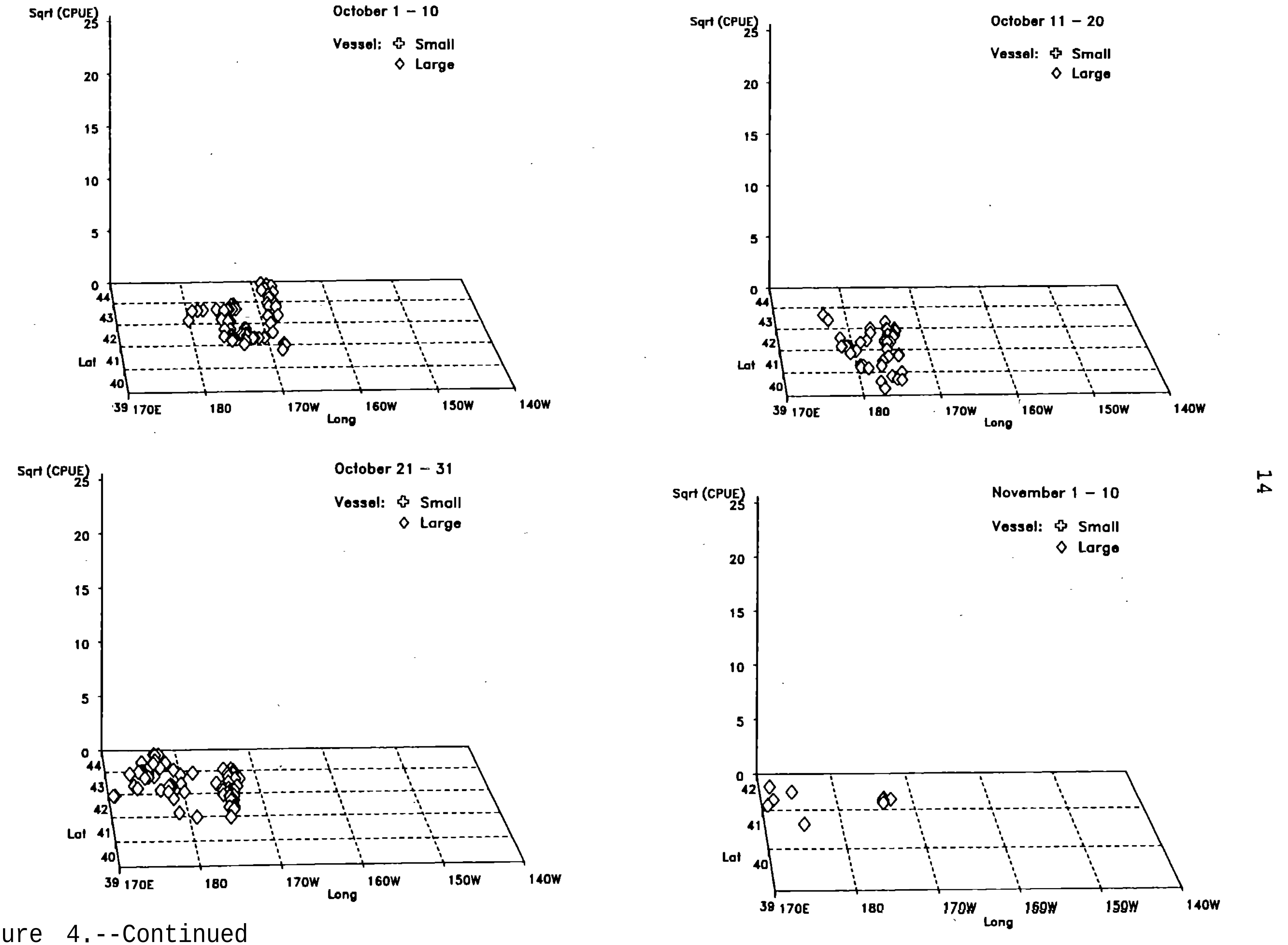

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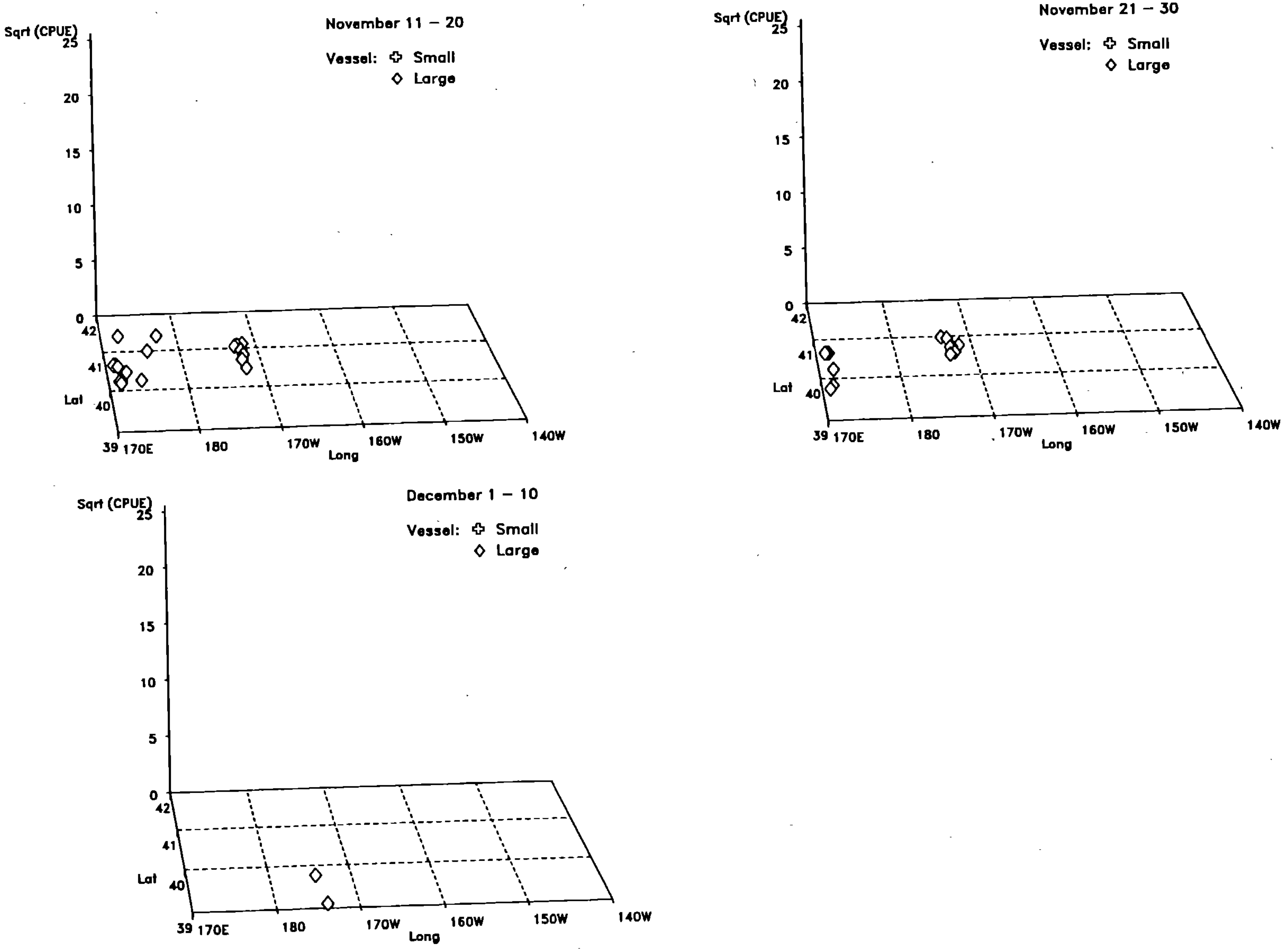

Figure 4.--Continued

of concern, were weighted more heavily than those of distant strata; and observed bycatch rates from strata in which larger amounts of effort were monitored by observers received greater weight as well. Specifically, the kernel estimate of the bycatch rate for vessels of size t in stratum s, I,,, was computed from the $S_{\max(t)}$ strata in which effort was monitored as follows:

$$\tilde{r}_{st} = \frac{\sum_{j=1}^{S_{\max(t)}} k(\mathbf{d}_{sj}) \cdot e_{jt} \cdot \ddot{r}_{jt}}{\sum_{j=1}^{S_{\max(t)}} k(\mathbf{d}_{sj}) \cdot e_{jt}}, \tag{4}$$

where e_{jt} is the monitored effort in stratum j of vessel size t,

r_{jt} is the observed bycatch rate (salmonids per tan) in stratum j for vessels of size t,

d_{sj} is the distance vector between stratum s and stratum j, and

k(.) is the kernel function.

The distance vector between stratum s and stratum j compared their values of three variables - latitude (α), longitude (β), and time period (γ)) - which defined every fished stratum. The variable value for latitude (α) equaled 1 at lat. 35°N, and increased by unit steps at each increase of 1° latitude until it equaled 11 at lat. 45°N. The variable value for longitude (β) equaled 1 at long. 170°E and increased in unit steps at each eastward change of 1° until it equaled 46 at long. 145°W. The variable value for time periods (γ) equaled 1 for 1-10 June and increased by unit steps until it equaled 19 for 1-10 December. The distance vector between strata s and j was defined as $d_{sj} = (|\alpha_s-\alpha_j|, |\beta_s-\beta_j|, |\gamma_s-\gamma_j|)$. Finally, the kernel function was defined as

$$k(\mathbf{d}_{sj}) = \rho_1^{|\alpha_s-\alpha_j|} \cdot \rho_2^{|\beta_s-\beta_j|} \cdot \rho_3^{|\gamma_s-\gamma_j|}, \qquad 0 \le \rho_1 \le 1,\ 0 \le \rho_2 \le 1,\ 0 \le \rho_3 \le 1. \tag{5}$$

Values of the three kernel function constants, p_l, p_Z, and p_3, determine how rapidly the weight given to observed strata bycatch rates diminishes with distance from the stratum of concern. The smaller the value for any one of these constants, the faster the weight decreases with distance along the corresponding variable - latitude, longitude, or time.

The observed bycatch rates by vessel size varied over time and area due to underlying variation in bycatch rates, as well as to sampling variation among vessels and operations in the strata. The possible sampling variation in average bycatch rate by vessel size for a stratum would have decreased as the proportion of expended effort in the stratum monitored by observers increased. For example, if nearly all the effort expended by the vessel size class in a stratum was observed, the observed bycatch rate was a very accurate and precise estimate of the bycatch rate. In the usual, less-favorable situations, some lesser fraction (possibly zero) of the expended effort was monitored, so the precision and accuracy of the observed bycatch rate as an estimate of bycatch rate of the total expended effort in any stratum would be degraded,

Bycatch rates in stratum s by vessel size class t were estimated using

$$\hat{r}_{st} = \phi_{st} \cdot \ddot{r}_{st} + (1-\phi_{st}) \cdot \tilde{r}_{st} , \qquad (6)$$

where ϕ_{st} is the fraction (e_{st}/E_{St}) of the total expended effort by vessel size class t in stratum s (E_{st}) accounted for by the monitored effort (e_{st}), and

$\tilde{r}_{st}$ and $\ddot{r}_{jt}$ were defined at Equation (4).

If all the bycatch and reported effort by a vessel size class were observed, $\hat{r}_{st} = \ddot{r}_{st}$; then the estimate of bycatch by the vessel size class in the stratum was presumably accurate. If none of the bycatch and effort were observed, $\hat{r}_{st} = \tilde{r}_{st}$, then the estimate of bycatch in the stratum was subject to the entire sampling error of the kernel estimate. Many strata had intermediate proportions of effort observed, so the level of sampling error fell between these extremes.

If some part of the effort was monitored in a stratum, the observed bycatch rate was included in the kernel estimate of the bycatch rate for the unobserved effort; that is, the kernel estimate Equation (4) included all strata in which effort was monitored. The inclusion of information from the stratum of interest was in contrast to the method next described, by which estimates of the kernel parameters were obtained.

The leave-one-out method of cross-validation was used to estimate the parameters, p_1, p_2, and p_3, for either vessel size class. The values of p_1, p_2, and p_3 that minimize the effort-weighted sum of squares of vessel size class t,

$$SS_t(\rho_1,\rho_2,\rho_3) = \sum_{s=1}^{S_{\max(t)}} e_{st} \cdot (\ddot{r}_{st} - \tilde{r}_{(s)t})^2 ,$$

$$\text{where } \tilde{r}_{(s)t} = \frac{\sum_{j \neq s}^{S_{\max(t)}} k(\boldsymbol{d}_{sj}) \cdot e_{jt} \cdot \ddot{r}_{jt}}{\sum_{j \neq s}^{S_{\max(t)}} k(\boldsymbol{d}_{sj}) \cdot e_{jt}} , \qquad (7)$$

were the cross-validation estimates. That is, the bycatch rate by vessel size class for each stratum was estimated by the kernel estimate (with selected values for p_1, p_2, and p_3) using only observed bycatch rates of other strata in which observers monitored bycatch and effort. A search for the minimizing values of the coefficients was accomplished by the conjugate gradient method (Press et al. 1986).

Bycatch *estimates.* Total bycatch in stratum s by vessels of size class t, T_{st}, was estimated as

$$\hat{T}_{st} = E_{st} \cdot \hat{r}_{st} , \tag{8}$$

and estimated total bycatch by the fishery was simply the sum of these estimates over vessel size class and the $S^*_{\max(t)}$ strata fished by vessel size class t,

$$\hat{T} = \sum_{t=1}^{2} \sum_{s=1}^{S^*_{\max(t)}} \hat{T}_{st} . \tag{9}$$

Sampling variation in estimated total bycatch, T, was computed by bootstrap resampling as if the observed vessel trips of each vessel size were a random sample of the corresponding total vessel trips during a monthly interval. The trips of large and small vessels were resampled with replacement. Let the b^{th} bootstrap resampling result in observed bycatch in stratum s of $c^*_{st(b)}$ taken by $e^*_{st(b)}$ tans of effort from vessel size class t. The bootstrap average observed bycatch rate in stratum s by vessels of size class t was computed as ; $\ddot{r}^*_{st(b)} = c^*_{st(b)}/e^*_{st(b)}$. The bootstrap observed average bycatch rates for the strata were used to recompute bycatch rates by vessel size class from Equations (4) - (7). Finally, the bootstrap estimate of total bycatch by the fleet, T^*_b, was computed using the bootstrap values in Equations (8) and (9). The time-consuming procedure was performed 25 times, as suggested by Efron and Tibshirani (1986) for obtaining reliable estimates of standard errors of estimates. The bootstrap estimates by vessel size class and combined fleet were plotted in histograms and examined for normality. Inasmuch as the bootstrap estimates appeared to be approximately normally distributed, confidence intervals were then calculated by normal approximation and the bootstrap standard errors.

Species ***composition of bycatch.*** Six- species of salmonids were present in the bycatch: chinook, chum, coho, pink, and sockeye salmon and steelhead trout. Scales were obtained from individual salmonids in the bycatch when possible so that species could be determined (see Koo 1962). When possible, observers also visually identified the species of salmonids brought on deck. A total of 1,359 salmonids identified to species were used to assess the species composition of bycatches, which was equivalent to 54% of the observed salmonid bycatch of the monitoring program. The species of 443 of the salmonids were identified by scales, and the species of the remaining 916 were visually identified.

Reliability of individual observers in species identification was evaluated by comparing species determinations from scales with the identification of the same fish from visual examination by the observers. Generally, if an observer's correct identification rate for a given species was high, their identifications of fish without scale samples for that species were accepted. If, for any given operation, 1) scales were available to identify species in the entire bycatch, 2) a reliable observer identified species in the entire bycatch, or 3) a combination of scales and a reliable observer provided species identifications of the entire bycatch, then the information was used to estimate the species composition of the bycatch for that operation. All samples were aggregated from operations in 1^o X 1^o areas and 10-day periods to provide an estimate of the species composition of the salmonid bycatch in that stratum. If species identified from scales were always correct, we expect about 14% of the 1,359 individual fish would be misidentified to species, based on misidentification rates of reliable observers. Probably many of these misidentification errors within the aggregated samples were self-compensating and had no effect on our estimation of species composition of bycatch; that is, a fish of species x was misidentified as species y but another fish of species y was misidentified as species x (e.g., see Myers and Bernard 1993).

Had the species of all the estimated salmonid bycatch in a stratum been determined from scales or reliable observers, the species composition of the stratum bycatch would presumably have been known essentially without error (ignoring occasional species misidentification by reliable observers). However, usually only a portion, possibly none, of a stratum bycatch was so determined. The species composition of the bycatch of each stratum was estimated by

$$\hat{\boldsymbol{p}}_{\boldsymbol{s}} = \hat{\gamma}_s \cdot \ddot{\boldsymbol{p}}_{\boldsymbol{s}} + (1-\hat{\gamma}_s) \cdot \tilde{\boldsymbol{p}}_{\boldsymbol{s}} \,, \tag{10}$$

where $\hat{\boldsymbol{p}}_{\boldsymbol{s}} = (\hat{p}_{1s}, \hat{p}_{2s}, \dots, \hat{p}_{6s})$ was the estimated vector of species proportions of bycatch from stratum s,

$\ddot{\boldsymbol{p}}_{\boldsymbol{s}} = (\ddot{p}_{1s}, \ddot{p}_{2s}, \dots, \ddot{p}_{6s})$ was the observed vector of species proportions of bycatch from stratum s,

$\tilde{p}_s = (\tilde{p}_{1s}, \tilde{p}_{2s}, \dots, \tilde{p}_{6s})$ was the kernel estimate of species proportions for bycatch of stratum s (described below), and

$\hat{\gamma}_s$ was the proportion of the estimated bycatch for stratum s for which the species were determined.

If species identification was available for all the estimated bycatch; then $\hat{p}_s = \ddot{p}_s$ and the estimate was presumably correct (again ignoring occasional misidentification by reliable observers). If species identification for none of the bycatch in the stratum was determined, $\hat{p}_s = \tilde{p}_s$. In this case, the estimate of species composition includes all the sampling error inherent in the kernel method of estimation. Most strata with large estimated salmonid bycatch levels had species compositions determined for portions of the bycatch, so the sampling error was intermediate between the two extremes.

The motivation for the kernel estimate of bycatch rate by stratum described earlier can also be applied to species composition. The kernel estimate of species composition in any stratum used observed estimates of species composition from all strata for which such information was obtained from scales and reliable observers. When estimating the species composition in a stratum, variable emphasis is given to the other strata, depending on their proximity to the target stratum. Species composition of bycatches from nearby strata were weighted more heavily than those of distant strata. Specifically, the kernel estimate of species composition of bycatch in stratum s, $\tilde{p}_s$, was computed from the C_{max} strata in which species composition was determined for a portion of the bycatch as follows:

$$\tilde{p}_s = \frac{\sum_{j=1}^{C_{max}} k(d_{sj}) \cdot \ddot{p}_s}{\sum_{j=1}^{C_{max}} k(d_{sj})}, \qquad (11)$$

where d_{sj} is the distance between stratum s and stratum j, and k(.) is the kernel function Equation (5).

The coefficients of the kernel function again were estimated by cross-validation, this time finding values of the coefficients which maximized a joint likelihood function for the aggregated species composition samples of our basic strata, 1^o x 1^o areas and 10-day periods. The likelihood function was maximized with respect to the unknown species proportions in the C_{max} strata of a monthly interval under the constraint that the proportions were smoothed by Equation (11). The joint likelihood function depends on two reasonable assumptions and one admitted simplification. First, the probability of the recorded frequencies of species in the aggregate sample of any stratum was assumed to be given by a multinomial probability function with parameters for aggregate sample size and unknown species proportions of the stratum bycatch. Second, aggregated samples among the C_{max} strata were assumed mutually independent. No account was taken of probable misidentifications of species, which simplified the analysis; the criteria used for inclusion of species-composition samples should have reduced the number of misclassifications to low levels. If x_{sh} ,was the number of fish of species h identified in bycatch of stratum s, the function maximized was

$$L(\rho_1,\rho_2,\rho_3) = \prod_{s=1}^{C_{max}} L_s(\tilde{\boldsymbol{p}}_{(s)}) \ , \tag{12}$$

$$\text{where} \quad L_s(\tilde{\boldsymbol{p}}_{(s)}) = \prod_{h=1}^{6} (\tilde{p}_{(s)h})^{x_{sh}} \tag{13}$$

$$\text{and} \quad \tilde{p}_{(s)h} = \frac{\sum_{j \neq s}^{C_{max}} k(\boldsymbol{d}_{sj}) \cdot \ddot{p}_{jh}}{\sum_{j \neq s}^{C_{max}} k(\boldsymbol{d}_{sj})} \ , \tag{14}$$

$$s = 1,2,\ldots,C_{max}\,; \quad h = 1,2,\ldots,6 \ .$$

Precision of the estimated species composition of bycatch from the kernel approach was evaluated by the bootstrap method. Each of the C_{max} species composition samples for each monthly interval was resampled with replacement to create bootstrap samples equal in size to those available. Cross-validation estimates of the kernel coefficients were obtained for the set of C_{max} bootstrap samples. Then the species proportions were computed for each stratum. The procedure was performed 25 times to match the earlier bootstrap resamplings for kernel estimates of bycatch by time and area strata. Resulting bootstrap estimates of species composition per stratum were used to allocate the corresponding bootstrap estimates of bycatch per stratum.

Estimation of Salmonid Dropouts. -During 1991, procedures were in place to estimate the number of "dropouts" - individual fish that were entangled when the net was brought out of the water and that dropped out or were shaken out of the net before reaching the deck. In each observed operation, two sections were randomly selected for dropout monitoring. For these two sections, in addition to recording landed bycatch, observers also recorded the number of dropouts. This recording procedure does not account for fish that were entangled in the net during the soaking period but dropped out unobserved before the net was retrieved.

The total dropout of salmonids for the entire fishery was estimated as

$$\hat{D} = \hat{R} \cdot \hat{T} , \tag{15}$$

where R was the observed ratio of total dropout to total landed for sections, monitored for dropouts and T was an estimate of the total landed salmonid bycatch, from the vessel-trip or the kernel method. Bootstrapping procedures were once again used to evaluate the precision of the estimates. The sections that were originally monitored for dropout were randomly resampled with replacement, and R was recalculated. This resampling and recalculation was performed 1,000 times (vessel-trip method) and 25 times (kernel method) to match previous numbers of independent resamplings for total salmon bycatch estimates. Each bootstrap ratio estimate (R) was multiplied by a previous bootstrap estimate of total salmon bycatch (T) to determine a sampling distribution for D. The standard deviation of the D among bootstrap repetitions was the estimate of the standard error of the estimates of dropouts for both the vessel-trip and kernel methods. A confidence interval for dropouts from the vessel-trip method was obtained using percentiles of the bootstrap distribution of D. The 25 bootstrap estimates of D from the kernel method were plotted in a histogram and examined for normality. Because the distribution appeared normal, normal approximation methods were used to calculate the confidence interval for the kernel estimate of dropouts.

Estimation* of *Salmonid Mortality. -Salmonid mortality' (M) is the total number of salmonids killed in the Japanese squid driftnet fishery (dropouts and bycatch combined). Salmonid mortality was estimated by summing the estimates of bycatch and dropouts obtained from the vessel-trip and kernel methods:

$$\hat{M} = \hat{T} + \hat{D} . \tag{16}$$

Bootstrap estimates of M were obtained by summing bootstrap estimates of dropouts and bycatch. Again, confidence intervals were calculated by the percentiles of the bootstrap distribution of M for the vessel-trip method and the normal approximation and the bootstrap standard error for the kernel method. As before, the 25 bootstrap estimates from the kernel method were examined for normality from a histogram of the data.

Results

Estimates of salmonid bycatch using the vessel-trip method were computed for small and large vessels. The point estimate of bycatch by the small vessel size class (T_1) was 42,600 (90% CI, 8,400 - 89,000; standard error [SE] = 25,700), and for the large vessel size class (T_2), 1,100 (90% CI, 700 - 1,900; SE = 400), yielding a total bycatch (T) of 43,700 (90% CI, 9,500 - 90,000; SE = 25,700). Stratifying by vessel size was appropriate, given the difference in bycatch between the two size classes. Estimated vessel-trip bycatch by observed small vessels was 0 - 2,236 fish, and by observed large vessels, 0 - 24 fish (Figs. 5 and 6). The 90% confidence intervals of average bycatch per vessel trip for small (u_l) and large (u_2) vessels emphasized the difference: $57 \leq u_1 \leq 625$ for small vessels and $2 \leq u_2 \leq 6$ for large vessels.

Estimates of bycatch using the kernel approach are given in Tables 1-3, for small vessels, large vessels, and combined, respectively. The combined estimates indicate low bycatch during June (about 2,000), maximum bycatch during July (about 29,000), and little bycatch from August through December (< 800). An estimated total of 32,100 salmonids (90% CI, 6,100 - 58,100) were taken as bycatch in the Japanese squid driftnet fishery during the season: small vessels caught 31,100 (90% CI; 5,100 - 57,100), and large vessels 1,000 (90% CI, 760 - 1,200). Approximate 90% confidence intervals were calculated from the point estimates and standard errors given in Tables 1-3. The bycatch was mostly coho (85%), followed by chum (10%) and pink (3%) salmon.

Most salmonid bycatch occurred in the western half of the fishery, mainly in the northwestern corner, between long.. 170°E and 180° (Fig. 7). During June, most bycatch occurred between long. 171° and 173°E and between lat. 39° and 40°N. During July, most of the bycatch occurred between long. 170°E and 180° and lat. 41° and 42°N. In August-December, bycatch was much reduced, yet remained concentrated near the northwestern corner of the fishery.

Total dropouts equaled 13.7% of the total brought on deck, for net sections monitored for both dropouts and landed salmonids. The point estimate for total dropouts in the 1991 Japanese squid driftnet fishery was 6,000 fish (90% CI, 1,300 - 12,500; SE = 3,500) (vessel-trip method) and 4,400 fish (90% CI, 1,100 - 7,700; SE = 1,900) (kernel method). Total salmonid mortality in the 1991 Japanese squid driftnet fishery was estimated to be 49,700 fish (90% CI, 10,600 - 102,700) by the vessel-trip method and 36,500 fish (90% CI, 7,600 - 65,400) by the kernel method.

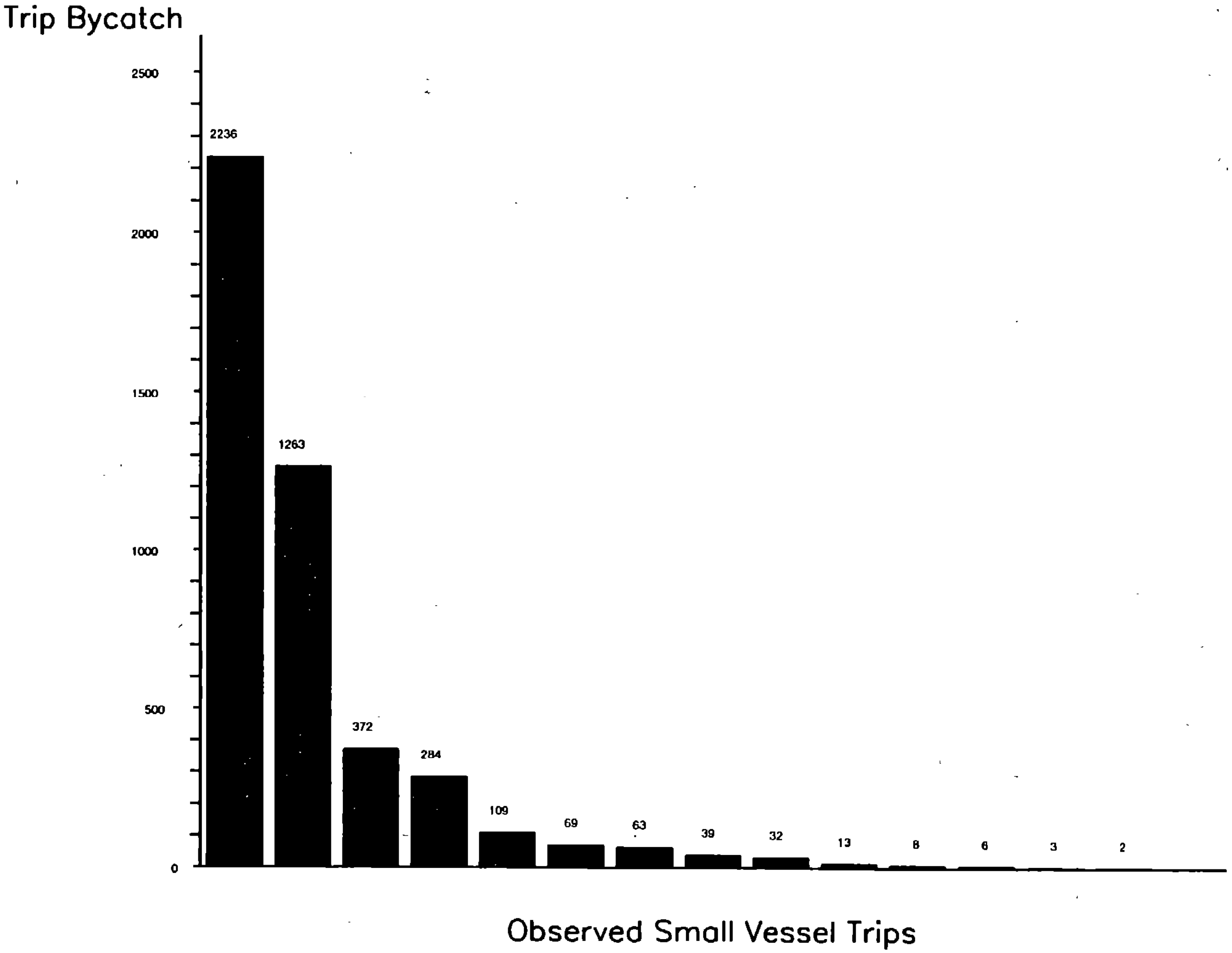

Figure 5. --Ranked estimated salmonid bycatches (numbers of fish) for observed vessel trips--small vessels. (Does not include one vessel trip with zero bycatch.)

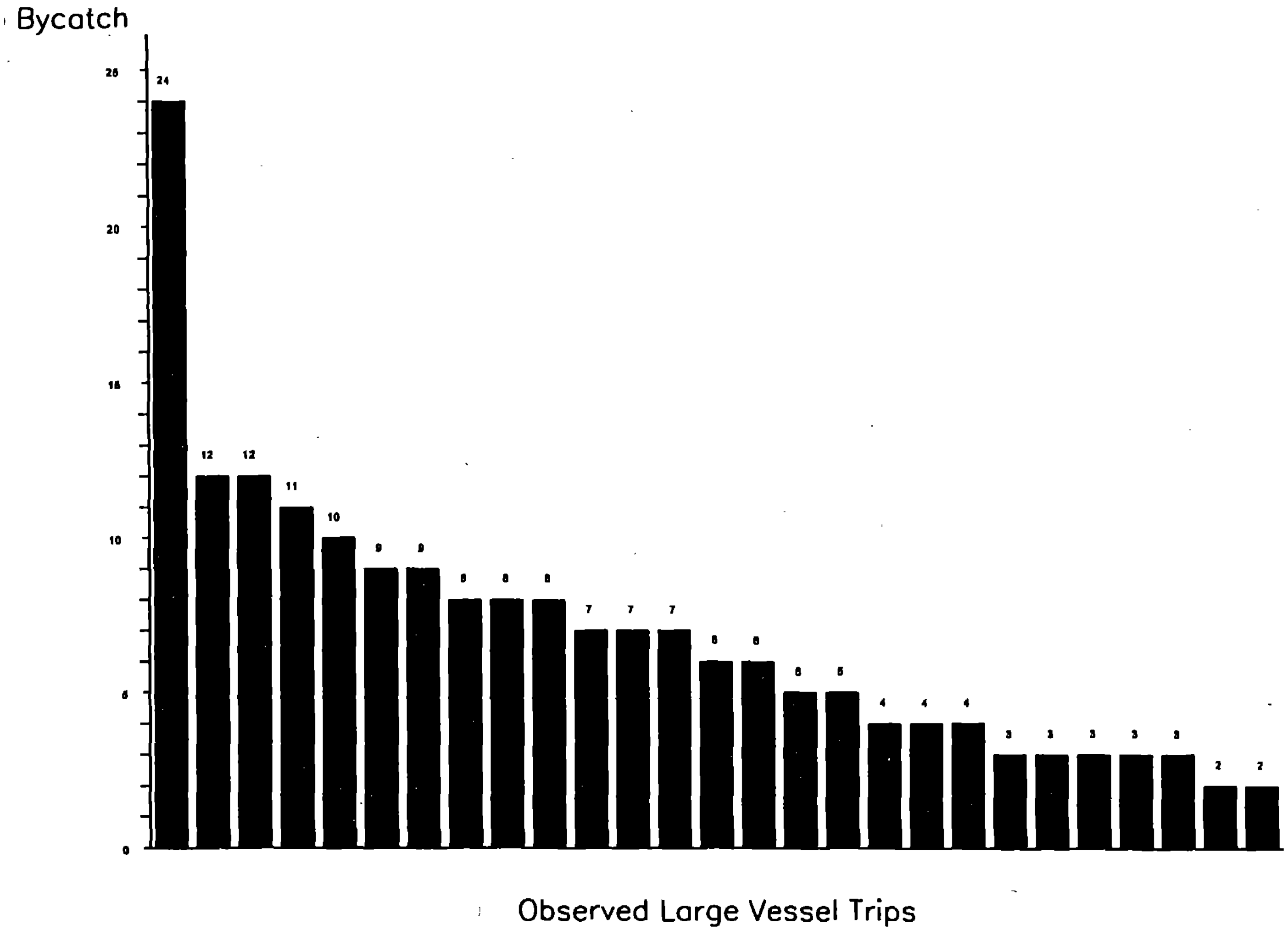

Figure 6. --Ranked estimated salmonid bycatches (numbers of fish) for observed vessel trips--large vessels. (Does not include 3 vessel trips with bycatch of one and 14 vessel trips with zero bycatch.)

Table I.-Estimated monthly salmonid bycatch (N) and bootstrap standard errors (SE), by species, for small vessels of the 1991 Japanese squid driftnet fishery. Slight inconsistencies in totals are due to rounding.

Species	June		July		August		Sept-Dec		Total	
	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE
Chinook	0	0	20	10	10	30	0	0	30	30
Chum	940	330	2,100	870	60	80	0	0	3,100	850
Coho	1,200	390	25,600	12,300	140	190	0	0	27,000	12,200
Pink	0	0	950	3,700	10	40	0	0	960	3,700
Sockeye	0	0	0	0	50	60	0	0	50	60
Steelhead	0	0	0	0	0	0	0	0	0	0
Total	2,100	710	28,700	15,300	270	350	0	0	31,100	15,200

Table 2.-Estimated monthly salmonid bycatch (N) and bootstrap standard errors (SE), by species, for large vessels of the 1991 Japanese squid driftnet fishery. Slight inconsistencies in totals are due to rounding.

Species	June		July		August		Sept-Dec		Total	
	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE
Chinook	0	0	0	0	20	5	40	10	60	10
Chum	0	0	80	20	30	5	90	40	200	40
Coho	30	10	240	60	120	30	50	20	440	70
Pink	0	0	100	30	40	10	20	5	160	30
Sockeye	10	5	40	10	30	10	20	5	100	20
Steelhead	0	0	40	20	10	5	10	10	60	20
Total	40	20	500	120	250	50	230	80	1,000	140

Table 3.-Estimated monthly salmonid bycatch (N) and bootstrap standard errors (SE), by species, for all vessels of the 1991 Japanese squid driftnet fishery. Slight inconsistencies in totals are due to rounding.

Species	June		July		August		Sept-Dec		Total	
	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE	$\hat{N}$	SE
Chinook	0	0	20	10	30	30	40	10	90	30
Chum	940	330	2,200	870	90	80	90	40	3,300	850
Coho	1,300	390	25,800	12,300	260	200	50	20	27,400	12,200
Pink	0	0	1,000	3,700	50	50	20	5	1,100	3,700
Sockeye	10	5	40	10	90	60	20	5	160	60
Steelhead	0	0	40	20	10	5	10	10	60	20
Total	2,200	710	29,100	15,300	530	370	230	80	32,100	15,200

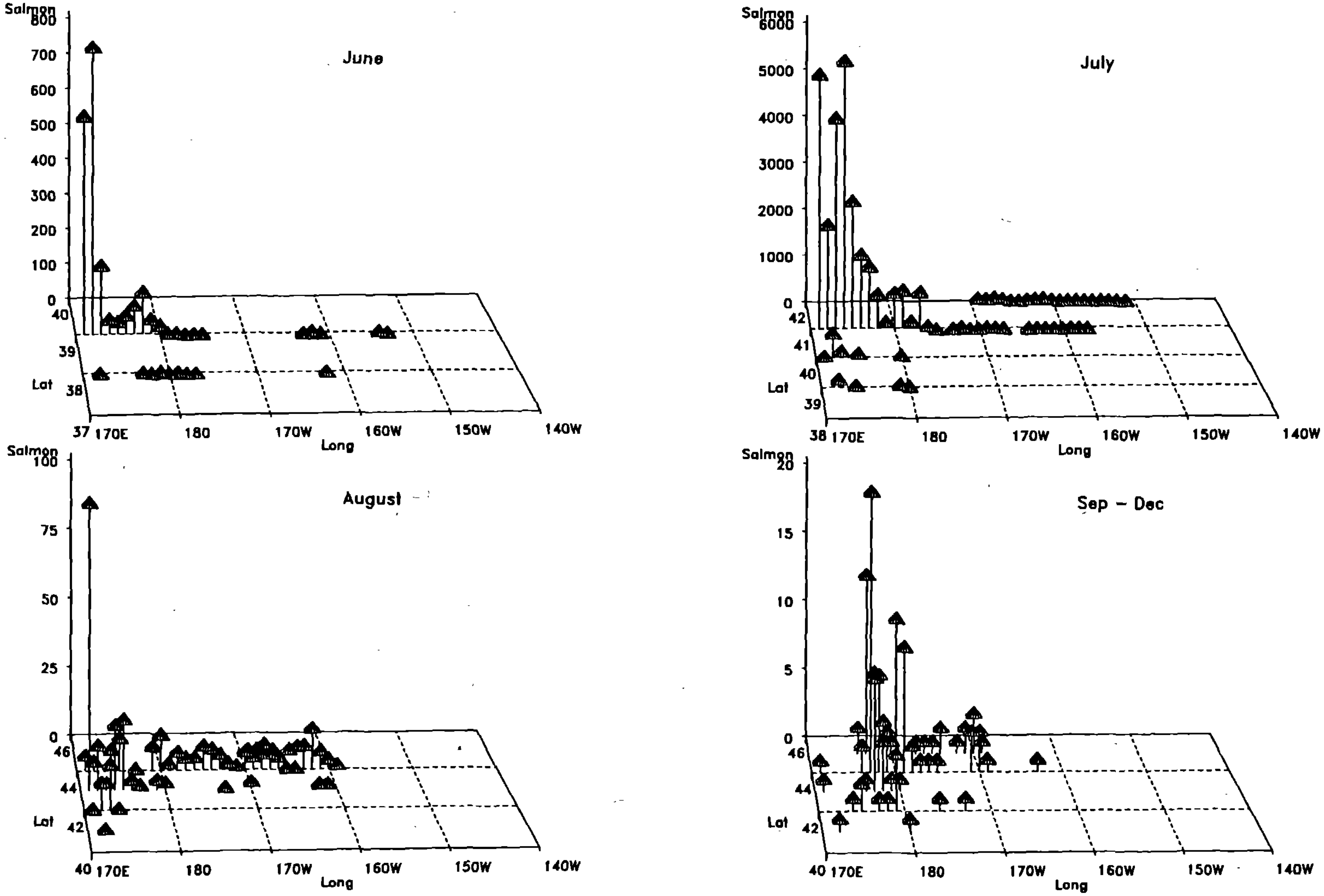

Figure 7.--Estimated (kernel method) salmonid bycatch (numbers of fish per 1° latitude [lat.] X 1° longitude [long.] statistical areas) in the 1991 Japanese squid driftnet fishery.

Republic of Korea Squid Driftnet Fishery

As with Japan, the United States and the ROK entered into an agreement to place scientific observers on board ROK squid driftnet vessels operating in the North Pacific Ocean in 1991. From May through December, 23 observers (10 U.S. and 13 ROK) were placed on board ROK squid driftnet vessels to monitor fishing operations and record the catch and bycatch of target and non-target species. Using this information, the bycatch, dropouts, and total mortality of salmonids in the 1991 ROK high-seas squid driftnet fishery were estimated.

Methods

The observed salmonid bycatch in the ROK fishery was less than in the Japanese fishery. In 1991, 258 salmonids were observed as bycatch in the ROK fishery; 110 were caught within a single 1^{o} latitude X 1^{o} longitude statistical area in July. Interpretation of species identification was much less a problem in the Korean fishery than it was in the Japanese fishery. Only 2% of all salmonids observed were not identified to species. Sixty-two percent of the total observed (159 of 258 fish) were identified from scales. An additional 36% (93 of 258) were identified to species by reliable observers, and 90 of these were pink salmon identified by one observer who correctly identified pink salmon in 100% of the cases (24 fish) for which scales provided a check on observer accuracy. No further account was taken of possible species misidentification because probable errors would have had a negligible effect on our analysis.

Due to the rarity of observed bycatch among strata, kernel smoothing was not practical for estimating salmonid bycatch in the Korean fishery. Instead, the fishery was divided into time and area strata (1° latitude X 1^{o} longitude by month), and bycatch, by species, was estimated for each stratum by multiplying the observed species bycatch rate by the number of 50-m long net panels (poks) fished in that stratum. The observed stratum bycatch rate for each species was calculated by dividing the total number of observed salmon of each species by the corresponding number of poks deployed for their capture. Estimated total species bycatch in strata monitored by observers was obtained by summing over all strata.

Numerous strata within the ROK fishery had no observed operations during 1991. Although driftnet vessels fished in 501 time and area strata, only 162 strata (32%) had observed operations. However, the 162 observed strata accounted for 74% of the total poks fished during 1991. Observed effort was assumed to be a random sample of total effort fished. Total bycatch for the ROK fishery was estimated by multiplying estimated total bycatch in observed strata by 1.35 (1 / 0.74).

Uncertainty in the species bycatch estimates was evaluated by bootstrap resampling. Vessels were resampled with replacement. An estimate of total bycatch of each species for the entire fishery was calculated from each resampling in the same manner as the original estimate. Resampling was performed 1,000 times. A 90% confidence interval was obtained from the 1,000 estimates by the percentile method.

The numbers of salmonid dropouts and salmonid mortality for the ROK squid driftnet fishery were also estimated. Dropout procedures followed by the observers of the ROK fishery were identical to those described earlier for the Japanese fishery.

Methodology used to estimate dropouts and mortality (and precision of estimates) for the ROK fishery was the same as for the Japanese fishery. The ratio estimator, D, Equation (15) was used to assess the number of salmonid dropouts from point and bootstrap estimates of total bycatch described above.. Salmonid mortality (M) was estimated as the sum of the estimates of bycatch and dropouts.

Results

Point estimates and 90% confidence intervals were calculated for the bycatch of each salmonid species in the 1991 ROK squid driftnet fishery (Table 4.). The total estimated bycatch of salmonids in the 1991 ROK squid driftnet fishery was 13,500 (90% CI, 2,600 - 16,300). Most of the bycatch consisted of chum and pink salmon. Total dropouts equaled *23%* of the total brought on deck, for net sections monitored for both dropouts and landed salmonids. Estimated total dropouts in the 1991 ROK squid driftnet fishery was ***3,100*** fish (90% CI, 590 ***- 5,800;*** SE = 1,700). Total salmonid mortality in the 1991 ROK squid driftnet fishery wasestimated to be 16,600 fish (90% CI, 3,200 - 21,400).

Table 4.-Point estimates, standard errors, and 90% confidence intervals of salmonid bycatch, by species, for the 1991 Republic of Korea squid driftnet fishery. Slight inconsistency in total are due to rounding.

Species	Point estimate	Standard error	90% Confidence interval
Unidentified salmonids	660	270	0 - 860
Chinook	160	100	0 - 260
Chum	6,800	3,300	1,100 - 9,300
Coho	430	230	40 - 800
Pink	5,400	3,000	40 - 7,100
Cherry	40	20	0 - 60
Total	13,500	4,200	2,600 - 16,300

Taiwanese Squid Driftnet Fishery

Estimation of the bycatch of salmonids in the squid driftnet fishery of Taiwan was not attempted because only 10 salmonids (8 coho, 1 pink, and 1 unidentified) were observed caught, thereby indicating negligible bycatch. The low salmonid bycatch was due to concentration of the Taiwanese fleet in areas away from high salmonid abundance and use of gill nets with mesh size too small to be as effective for salmonids as the larger mesh used by the Japanese and ROK fisheries. Taiwanese driftnet vessels fished in 858 strata (1° latitude X 1° longitude and 10-day period), and observers monitored fishing operations in 158 (18%) of these strata. The 158 monitored strata accounted for 40.5% of the total piens (50-m net panels) fished by Taiwanese driftnet vessels. A total of 343 (5.5%) of 6,280 operations were monitored by observers.

CONCLUSION

Since the beginning of U.S. monitoring in 1989, the observed salmonid bycatch by the legal squid driftnet fisheries of Japan, ROK, and Taiwan was small compared with commercial catches in Alaskan coastal fisheries (Rigby et al. 1991). In 1991, Alaska landings were 188 million salmon as compared with our estimated total bycatch by legal squid driftnet fisheries (Japanese bycatch from vessel-trip method + ROK bycatch) equal to 57,200 fish. In 1990, Alaska landings were 155 million salmon as compared with 214,000 by the legal driftnet fisheries (Pella et al. 1993); and in 1989, Alaska landings were 154 million salmon as compared with the bycatch of 2,600 salmon by the legal driftnet fisheries (Ignell et al. 1994). However, the salmonid bycatch by illegal driftnet fishing in the North Pacific Ocean in recent years apparently has been much greater, although the quantity is more difficult to ascertain. For example, Pella et al. (1993) used 1988-90 official trade statistics on imports from countries without legal access to Pacific salmon fishing grounds to infer substantial illegal catches in these years: the estimated catch during 1988 was at least 5.5 million salmonids. Pella et al. (1993) further noted that illegal catches could affect endangered or depleted Columbia River stocks which occur in areas of suspected illegal fishing.

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