INCIDENTAL AND ILLEGAL CATCHES
OF SALMONIDS
IN NORTH PACIFIC DRIFTNET FISHERIES

by

J. Pella¹, R. Rumbaugh¹, L. Simon¹,
M. Dahlberg¹, S. Pennoyer², and M. Rose³

¹Auke Bay Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
11305 Glacier Highway
Juneau, AK 99801-8626, U.S.A.

²Alaska Regional Office
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
POB 21668
Juneau, AK 99802, U.S.A.

³Office of Enforcement
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1335 East-West Highway
Silver Spring, MD 20910, U.S.A.

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ABSTRACT

We developed estimates of the legal incidental catch of salmonids in 1990 North Pacific driftnet fisheries. Analytical approaches for the Japanese fishery included (1) simple expansion of average observed 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. Bootstrap resampling was used to determine reliability of all estimates. Total salmonid bycatch in the 1990 Japanese squid driftnet fishery was estimated to be 210 000 fish by the vessel-trip method and 170 000 by the kernel estimation technique. An additional 21 000 (vessel-trip method) or 17 000 (kernel technique) salmon were estimated to have dropped out of the driftnets during retrieval. Total salmonid mortality (bycatch + dropouts) in the Japanese squid driftnet fishery was estimated to be 231 000 by the vessel-trip method and 187 000 by the kernel estimation technique. The total salmonid bycatch in the squid driftnet fishery of the Republic of Korea was estimated to be about 4000 fish. No estimate of salmonid bycatch was made for the driftnet fisheries of Taiwan as U.S. and Taiwanese observers saw only two salmonids caught. No salmonids were observed in the 1990 Japanese large-mesh fishery. Generally, legal bycatches have been relatively small since the monitoring programs began in 1989. However, substantial salmonid interception occurs as a result of illegal fishing, and resulting catches by non-salmon producing countries were estimated to be at least 10 000 metric tons (5.5 million fish) in 1988. There is concern that illegal catches of salmonids in the North Pacific could potentially affect endangered or threatened stocks.

INTRODUCTION

During 1990, three countries operated legal high seas driftnet fisheries in the North Pacific Ocean. Vessels of Japan and the Republic of Korea (ROK) both targeted squid, especially neon flying squid (Ommastrephes bartrami). Taiwanese vessels, on the other hand, targeted tuna, particularly albacore (Thunnus alalunga) and skipjack (Katsuwonus pelamis), and squid, particularly neon flying squid. Many species of marine animals, including mammals, birds, and fish, were taken incidentally to the target species. Salmonids—including chinook (Oncorhynchus tshawytscha), chum (O. keta), coho (O. kisutch), pink (O. gorbuscha), and sockeye (O. nerka) salmon, and steelhead trout (O. mykiss)—were among the incidentally-caught fish species. Each country determined time and area regulations for legal fishing by their licensed driftnet vessels; the incidental bycatch of salmonids by these vessels was legal while fishing for their target species.

In addition to legal bycatch of salmonids by regulated driftnet fisheries, substantial illegal salmonid catches were detected before and during 1990. These illegal catches were mainly from fishing operations by unlicensed vessels of non-salmon producing nations directed on salmonids outside the regulated squid fishing areas.

This paper covers four topics: the incidental and legal bycatch of salmonids by 1990 high seas driftnet fisheries of (1) Japan, (2) the ROK, and (3) Taiwan; and (4) the illegal catch of salmonids between 1988 and 1990 by non-salmon producing countries. Estimates of numbers of salmonids, by species, taken by these fisheries are provided when information was sufficient for such estimation.
REGULATED FISHERIES OF JAPAN, ROK, AND TAIWAN

LEGAL TIMES AND AREA

Japan, the Republic of Korea, and Taiwan all specify domestic regulations establishing boundaries within the North Pacific Ocean where their licensed driftnet vessels can legally operate.

The legal boundaries of the Japanese high seas squid driftnet fishery extend from 20°N, 170°E to 145°W, with the northern boundary changing monthly and longitudinally (Fig. 1). The moving northern boundary was established in an attempt to minimize the incidental bycatch of salmonids. Japanese squid driftnet vessels are allowed to operate from June through December only.

Driftnet vessels from the ROK are allowed to conduct fishing operations between 160°E and 145°W. No southern boundary is established. The northern boundary depends on longitude and month (Fig. 2). The ROK squid driftnet fishery is closed from 170°E to 145°W from January to April and in December; however, fishing is allowed from 160°E to 170°E during these months.

The Taiwanese governing agency has also established legal areas where driftnet fishing is permitted by its licensed vessels. No southern or western boundaries other than 200-mile EEZs were established; however, an eastern boundary of 145°W and moving monthly northern boundaries do delimit the fishery (Fig. 3). In contrast to the Japanese fishery, Taiwanese vessels can fish year round. Once again, the northern and eastern boundaries were established to restrict the incidental take of salmonids.

MONITORING PROGRAMS

In 1987, the United States Congress passed the Driftnet Monitoring and Control Act, which required that the United States 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 for the purpose of obtaining initial driftnet bycatch data on certain anadromous fish species, marine mammals, seabirds, and turtles. The initial program opportunistically placed observers on board driftnet vessels operating in the North Pacific Ocean. The data collected in 1989 were to be used to design a more comprehensive monitoring program for 1990.

An agreement signed on 19 March 1990 by the United States, Canada, and Japan established the 1990 observer program in the Japanese fishery. Under the agreement, scientific observers were placed on board Japanese driftnet vessels operating in the North Pacific Ocean from June through December. The 1990 observer program was expanded from the 1989 pilot program to include data collection on the incidental bycatch of all species of fish, marine mammals, seabirds, and turtles. Similar agreements were reached with the ROK and Taiwan to place observers on board their driftnet vessels.

Data to be collected by the scientific observers was part of and consistent among the three agreements. The observer data were of two types of information: header and catch. Header data described the physical aspects of the fishing operations. A fishing operation consists of the setting, soaking, and retrieval of up to twelve sections of driftnet. Time period (month, day, time), position (latitude and longitude), and oceanographic and environmental conditions (sea-surface temperature, wind direction, Beaufort state, and swell height) were recorded for the beginning and ending of net deployment and retrieval of observed operations. Catch information included the number of
sections deployed, length of each section, set direction, catch of the target species, and bycatch of all non-target species.

**DISTRIBUTION OF OBSERVED AND COMMERCIAL FISHING EFFORT**

The regulated squid driftnet fishing areas of Japan, the ROK, and Taiwan overlap to a considerable degree; however, the boundaries do not indicate where fishing actually takes place. Therefore, the commercial fishing effort data for 1990 were summarized by 1° x 1° statistical area. Statistical areas in which 10 or more commercial operations occurred were plotted for each of the three countries (Fig. 4). The data for Taiwan included both squid and large-mesh fishing effort because these categories were not reported separately.

The distribution of observed and reported 1990 commercial fishing effort was summarized by 1° x 1° statistical area and month for the Japanese and ROK squid and Taiwanese squid and large-mesh driftnet fisheries. The Japanese and ROK data were summarized by units of driftnet of length equal to 50 m (Japanese tans or Korean pokes), whereas the Taiwanese data were summarized by reported daily fishing operations, not units of driftnet. Plots of the monthly distribution of observed and reported fishing effort were constructed by plotting the scaled percentage of observed fishing effort on the ordinate and the scaled percentage of commercial fishing effort on the abscissa for each 1° x 1° statistical area (Figs. 5-7). If the observed and reported fishing effort were proportional, then the plot appears as a small square for the particular statistical area. If either the observed or reported fishing effort is disproportional, then the plot appears as a rectangle with either a vertical or horizontal skew.

Comparisons by month of the areas fished by vessels of the three nations showed differences in distribution of fishing effort. In May, the small amount of fishing effort by the Taiwanese fleet was generally distributed east of the area fished by the ROK; the Japanese squid driftnet fleet does not fish in May. In June, Taiwanese fishing effort was west of that of Japan and the ROK; Japanese fishing effort extended more from east to west than that of the ROK. In July, Japanese fishing effort was concentrated east of 180°, whereas the ROK fishing effort ranged from about 180° to 170°W and Taiwanese fishing effort was divided nearly equally east and west of 180°. In August, fishing effort for the three nations overlapped very little, with the Japanese fleet occupying two areas: 42°-44°N around 180° and 43°-45°N near 160°W-150°W. Taiwanese fishing effort was spread from 155°E to 175°W, generally south of where Japan fished. The ROK fishing effort was clustered around 145°E-155°E. In September, fishing effort of the ROK and Taiwan overlapped in the area 145°E-160°E. Japanese fishing effort east of 170°E was completely segregated from that of the ROK and Taiwan. In October, fishing effort by the ROK and Taiwan overlapped near 145°E-165°E, whereas nearly all Japanese fishing effort was east of 170°E. In November, fishing effort of the ROK and Taiwan again overlapped near 145°E, whereas Japanese fishing effort was concentrated near 170°E-175°W. Little fishing effort was reported for December, as most vessels had returned to port.

Although the percentage of observed fishing effort was sometimes low, the distribution of observed fishing effort appears roughly proportional to the reported fishing effort.
BYCATCH ESTIMATION

Japanese Squid Driftnet Fishery

From June through December 1990, scientific observers were aboard Japanese driftnet vessels in the North Pacific squid driftnet fishery as part of a joint effort of 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 incidental bycatch of non-target species could be evaluated.

Under the agreement, observers were placed on board 75 vessels, or 12% of the vessels operating in the squid driftnet fishery during 1990. Of the 75 observers, 10 were Canadian, 30 were Japanese, and 35 were from the United States. The observers were instructed to monitor daily operations of the vessels and record the number of individuals of the target and non-target species brought on deck entangled in the driftnets. In addition, data were also recorded on the number of individuals dropping out of the nets or shaken out by the fishermen during net retrieval (Fitzgerald et al., this symposium).

The main purpose of this section of the paper is to estimate the 1990 incidental bycatch of salmonids from the Japanese squid driftnet fishery. Two methods were employed: (1) a simple 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 method (2) 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).

Besides estimating salmonid bycatch, an estimate of the number of salmon that drop out of the nets during retrieval is also of interest. Ratio estimation was used to determine the number of dropouts for the entire fleet. Once again, the uncertainty of this estimate was evaluated by bootstrapping.

Methods

Expansion of Vessel-trip Bycatch—We estimated total salmonid bycatch for the 1990 Japanese squid driftnet fishery by stratifying vessel trips into those by small (25-35 m hull length) and large (>35 m hull length) vessels. During 1990, there were 263 small-vessel trips and 380 large-vessel trips (H. Hatanaka, National Research Institute of Far Seas Fisheries, Fishery Agency of Japan, Shimizu-shi, Shizuoka, Japan, pers. comm.). The 75 observers were placed on 23 small vessels (9% of the small-vessel trips) and 52 large vessels (14% of the large-vessel trips). Observers were on board the vessels for the entire trip duration of 21 of the 23 small vessels (91%) and 47 of the 52 large vessels (90%). The total 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 average vessel-trip bycatch estimates for the observed small- and large-vessel trips were not adjusted for the abbreviated presence of observers for seven trips. These estimated vessel-trip averages were then expanded by the corresponding total number of vessel trips made by small and large vessels to obtain an estimate of total salmon bycatch for the fishery for each vessel size. Finally, we combined the estimated salmon bycatch of both vessel sizes to obtain the total estimated salmon bycatch for the fleet.

Each vessel with an observer on board was considered an observed vessel trip. We treated observed vessel trips as though they were randomly sampled from the populations of vessel trips of the two vessel sizes. In actuality,
the vessels on which observers were placed were selected by the eleven local
driftnetters associations; the number of observers allocated to a given
association was approximately proportional to the size of the membership.
Each association chose which vessel trips among its members would host an
observer. The vessels from a given association do not operate in a similar
manner or as a group, so stratification by association was not necessary
(H. Hatanaka, pers. comm.). However, vessels of different sizes might be
expected to have different amounts of bycatch. Therefore, poststratification
by size (small and large) seemed appropriate.

A vessel trip was the primary sampling unit within the vessel size
strata. Operations were the secondary sampling units within a given vessel
trip. An operation was defined to be the deployment, soaking, and retrieval
of up to twelve sections of net. Each net section contained 90-170 tana of
50 m lengths. 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 a 24-hour
period. However, because of the unusually high squid abundance encountered
during 1990, sometimes all the driftnet that was deployed could not be
retrieved in a given day. In these instances, some net sections were left in
the water to soak an additional night. In a few cases, several sections of
net soaked an additional two days. Therefore, we had two kinds of operations:
daily (all nets deployed were retrieved the following day), and extended (some
nets soaked for one or two additional days). The two types of operations were
treated separately for estimating bycatch.

The daily operations of each month were further stratified into
approximately 10-day periods: days 1-10, 11-20, and 21-end of month. We refer
to these intervals as 10-day periods for brevity. There were 21 10-day
periods covering the duration of the fishery, from 1 June to 31 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, interruptions to
daily operations occurred because storms interrupted fishing operations for
one day to a week, depending on the time of year. Also, daily operations were
interrupted when a vessel changed locations within the fishery. Daily
operations were also disrupted when high squid catches caused an extended
operation. Therefore, a variable number of operations were observed during
each 10-day period of a vessel trip even though five of every six days were to
have been observed. We viewed the daily operations sampled within each 10-day
period as a random sample of the population of daily operations within the
10-day period. Although a systematic sampling scheme was originally planned,
in reality the daily operations observed within a 10-day period turned out to
be closer to a random sample because of the numerous, unpredictable
disruptions to the schedule.

Seventy-two percent of the observed vessel trips had extended operations;
the number of such operations during a vessel trip ranged from one to eight.
Each extended operation consisted of two to three days of net retrieval. We
distinguished those sections that soaked for one night from those that soaked
an additional 24 or 48 hours. Some of the days within a given extended
operation may not have been observed. Again, we treated the information as
though a random sample of days had been observed from each extended operation.
Given the unpredictability of occurrence of the extended operations and the
disruptions to scheduled observation because of storms, the assumption that
the observed days of an extended operation were a random sample of its total
duration seems reasonable.

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) were 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 monitor 6 sections. If 10-12 sections were deployed, observers monitored 7 sections. Therefore, the observed net sections of a daily operation, or from a day of an extended operation, were a simple random sample of the total sections of net deployed.

To estimate the salmon bycatch for an observed vessel trip, we stratified operations into daily and extended operations. We estimated the salmon bycatch for a given daily operation by expanding the observed salmon bycatch per tan to account for tans fished in the unobserved sections. We then calculated the average observed daily operation bycatch during each 10-day period of the given vessel trip. We multiplied these averages by the corresponding number of daily operations during the 10-day periods to estimate the salmon bycatch for each 10-day period during the vessel trip. Once an estimate of salmon bycatch was determined for each 10-day period, we summed over 10-day periods to obtain the estimated salmon bycatch for daily operations during the vessel trip.

The exact number of daily operations fished within each 10-day period was known for the vessels with U.S. and Canadian scientific observers on board. These observers recorded which days were not fished (storms or transit days) and which days were fished but unobserved (i.e., un-monitored operations). For vessels monitored by Japanese scientific observers, the occurrence of un-monitored operations was not recorded. Therefore, for these vessels, we estimated the number of un-monitored operations during each 10-day period using the following conventions for a day with no reported operations: (1) If a storm was reported on the day by another vessel fishing near the vessel with the Japanese observer, we assumed the vessel in question was also affected by the storm and did not fish that day; (2) if the locations of the preceding operation and the following operation by the vessel in question differed, we assumed the vessel traveled on the unreported day, and therefore did not fish; and (3) finally, the remaining days without monitoring reports within the 10-day period were assumed fished but un-monitored by the Japanese observer.

Salmon bycatch was calculated for each day within an extended operation in the same manner as for a daily operation. The observed salmon bycatch per tan was multiplied by the total number of tans fished to estimate bycatch during a day. The estimated salmon bycatch for an extended operation was determined by summing the estimated bycatch for each day of the extended operation. When one day of an extended operation was un-monitored, the salmon bycatch for that day was estimated from another day within the extended operation. For example, if the first day of an extended operation was not observed, the bycatch was estimated from the second day, and vice versa. (By chance, the third day of an extended operation was always observed.) The bycatch for an un-monitored day of an extended operation was estimated by multiplying the salmon bycatch per tan for the observed day by the number of tans deployed during the un-monitored day.

The salmon bycatch for an observed vessel trip was then estimated by summing the bycatch for the daily operations and the extended operations. Once the salmon bycatch for each vessel trip was estimated, we calculated the average vessel-trip bycatch for either vessel size. We multiplied these averages by the corresponding total number of vessel trips to estimate the total salmon bycatch by either vessel size. The estimated bycatch for either vessel size $t$, $T$, was
where \( N_t \) was the number of vessel trips by vessels of size \( t \) and \( \bar{X}_t \) was the estimated average vessel-trip bycatch of the observed vessels for size \( t \). The estimates of salmon bycatch for the two vessel sizes were then combined to obtain the estimate of salmon bycatch for the entire fleet. The estimate of total salmon bycatch for the entire fleet, \( \hat{T} \), was:

\[
\hat{T} = \sum_{t=1}^{2} \hat{T}_t .
\]

Precision of the estimate of total bycatch by 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, as were the observed extended operations. To resample a sample, \( y_1, y_2, \ldots, y_n \), a simple random sample of size \( n \), \( y_1', y_2', \ldots, y_n' \), is drawn with replacement from the original observations; the resulting sample is called a bootstrap sample. Then the sections within each daily operation included in the bootstrap sample were resampled. For extended operations, the days within the extended operation were resampled and then the sections within each day 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 repeated 1000 times. For each repetition \( b = 1, 2, \ldots, 1000 \) of the bootstrap, we calculated an estimate of salmon bycatch \( (\hat{X}_{b1}) \) for each vessel trip \( i = 1, 2, \ldots, 75 \).

The sampling distribution of the total bycatch estimate of the fleet, \( \hat{T} \), can be estimated by resampling vessel trips and using the previous bootstrapping results. Consider the \( b \)th resampling. First, the observed trips of the 23 small vessels were resampled; independently, the observed trips of the 52 large vessels were also resampled. A typical sample omitted some of the observed vessel trips and repeated others. Then the bootstrap average bycatch for small \( (\hat{X}_{b1}) \) and large \( (\hat{X}_{b2}) \) vessels was computed from the previous estimates of vessel-trip bycatch \( (\hat{X}_{b}) \) included in the bootstrap sample of vessel trips. Finally, the \( b \)th bootstrap estimate of total bycatch, \( \hat{T}_b^* \), was computed as:

\[
\hat{T}_b^* = \sum_{t=1}^{2} N_t \cdot \bar{X}_{bt}^* .
\]

One thousand values of \( \hat{T}_b^* \) were computed in this fashion. The standard deviation of the \( \hat{T}_b^* \) among the 1000 resamplings is the estimate of the standard error of the estimate of the total bycatch for the fleet, \( \hat{T} \). The lower \( \alpha \cdot 100\% \) percentile and upper \((1-\alpha)\cdot 100\% \) percentile of the 1000 \( \hat{T}_b^* \)'s provide a \((1-2\alpha)\cdot 100\% \) confidence interval.

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, we turned to a kernel estimation method.

Kernel Estimation of Bycatch by Time and Area Strata—We estimated the bycatch of the fleet during 1990 in three steps. First, we estimated the bycatch rates of small and large vessels for every 1° x 1° area and 10-day period, hereafter referred to collectively as "strata", in which effort was expended. Second, we estimated the bycatch by vessel size for each stratum as the product of the estimated bycatch rate and the reported effort by vessel size expended in the stratum. Third, we summed bycatch estimates over sizes of vessels and time and area strata to obtain the total estimated bycatch for the fishery.

We had available for the entire fishery the amount of fishing effort (tans) expended by large and small vessels per stratum, hereafter referred to as "effort". The potential number of strata between the beginning, 1 June, and end, 31 December, of fishing within the legal fishing area is 22 092. A total of 1140 strata were actually fished by the Japanese driftnet fleet, and of those, some fishing was monitored by observers in 52% or 588 strata. Percent monitored of combined effort expended by both sizes of vessels per stratum ranged from 0 to 97% among the strata.

The strata in which some effort and associated bycatch was monitored provide estimates of bycatch rates. Figure 8 shows the spatial distribution of observed bycatch rates (vessel size was disregarded) for each 10-day period from 1 June to 30 September (notice the changing scales on which CPUE is plotted). Although observers were on board vessels through 10 December, no salmon were observed after 30 September. As can be seen from Fig. 8, the highest salmon bycatch rates occurred during July, with highest bycatch rates of that month in the northwest corner of the fishing area.

Our estimates of bycatch based on vessel trips showed small vessels caught substantially greater numbers of salmonids than did large vessels. Although the difference in bycatch between vessel sizes was due in part to differences in areas fished, bycatch rates even within strata fished by both vessel sizes also appeared to differ. Bycatch rates of both vessel sizes were monitored in 53 strata. No bycatch by either vessel size was observed for 29 of these strata, but small vessels seemed to catch more salmon than large vessels in many of the remaining strata (Fig. 9). Finally, the distinction between vessel sizes was reinforced when we computed 1990 salmonid bycatch by methods similar to those about to be described, but based solely on small-vessel bycatch rates and then solely on large-vessel bycatch rates. Estimated 1990 bycatch using small-vessel rates was roughly 50-fold that using large-vessel rates. Therefore, we stratified the estimates of bycatch by vessel size.
Bycatch rates by vessel size—The amount of monitored fishing effort varied considerably among the 1° x 1° areas and 10-day periods, so the resulting variable precision of observed bycatch rates in the strata had to be considered in estimating underlying bycatch rates. Effort in nearly half the strata in which some fishing occurred was completely unmonitored, so corresponding bycatch rates were estimated from information of monitored strata. We chose the kernel method (Eubank 1988) for smoothing observed bycatch rates to estimate the underlying bycatch rates by vessel size among strata. (Kernel estimation was previously used to estimate bycatch of selected bird and mammal species in the 1989 Japanese squid fishery (Lanztz and Garrott 1991).) We divided the 10-day periods of the fishing season into four intervals: June, July, August, and September-December. The kernel estimate of bycatch rate by a vessel size in a particular stratum during a monthly interval utilized observed bycatch rates by the vessel size from all strata in which observers monitored effort and bycatch in that monthly interval. However, when estimating the bycatch rate, the kernel estimate placed variable emphasis on different strata, depending on their proximity to the target stratum, as well as the amount of effort monitored in each stratum. Observed bycatch rates in nearby strata, including the stratum 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 $s$, $\hat{P}_{st}$, was computed from the $S_{\text{max}}(t)$ strata in which effort was monitored as follows:

$$\hat{P}_{st} = \frac{\sum_{j=1}^{S_{\text{max}}(t)} k(d_{sj}) \cdot e_{jt} \cdot \hat{P}_{jt}}{\sum_{j=1}^{S_{\text{max}}(t)} k(d_{sj}) \cdot e_{jt}}$$

(4)

where

- $e_{jt}$ is the monitored effort in stratum $j$ of vessel size $t$,
- $\hat{P}_{jt}$ is the observed bycatch rate (salmonids per tan) in stratum $j$ for vessels of size $t$,
- $d_{sj}$ is the distance between stratum $s$ and stratum $j$, and
- $k(\cdot)$ is the kernel function.

The distance vector between stratum $s$ and stratum $j$ compared their values of three variables—latitude ($\alpha$), longitude ($\beta$), and time period ($\gamma$)—which defined each possible stratum of the fishery. The variable value for latitude ($\alpha$) equaled 1 at latitude 27°N, 2 at 30°N, 3 at 35°N, 4 at 37°N, and then increased by unit steps at each increase of 1° latitude until it equaled 12 at latitude 45°N. The variable value for longitude ($\beta$) equaled 1 at longitude 170°W and increased in unit steps at each eastward change of 1° until it equaled 45 at 145°W. The variable value for time periods ($\gamma$) equaled 1 for 1–10 June and increased by unit steps until it equaled 21 for 21–31 December.
The distance vector between strata \( s \) and \( j \) was defined as \( d_{s,j} = (|\alpha_s - \alpha_j|, |\beta_s - \beta_j|, |\gamma_s - \gamma_j|) \). Finally, the kernel function as defined by Larntz and Garrott (1991) was

\[
k(d_{s,j}) = \rho_1 |\alpha_s - \alpha_j|, \rho_2 |\beta_s - \beta_j|, \rho_3 |\gamma_s - \gamma_j|,
\]

\[
0 \leq \rho_1 \leq 1, 0 \leq \rho_2 \leq 1, 0 \leq \rho_3 \leq 1.
\]

The observed bycatch rates by vessel size varied over time and area due to underlying variation in bycatch rates, as well as from 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 in a stratum was observed, we had a very accurate and precise estimate of the bycatch rate based on the observed 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 for bycatch rate of the total expended effort in any stratum will be degraded.

We estimated bycatch rates in stratum \( s \) by vessel size \( t \) using

\[
P_{st} = \phi_{st} \cdot P_{st} + (1 - \phi_{st}) \cdot \hat{P}_{st},
\]

where

\[\phi_{st} \text{ is the fraction of the total expended effort by vessel size } t \text{ in stratum } s, \]

\[E_{st}, \text{ accounted for by the monitored effort, } e_{st}, \text{ i.e., } \]

\[\phi_{st} = e_{st}/E_{st}, \text{ and } \]

\[P_{st} \text{ and } \hat{P}_{jt} \text{ were defined at equation (4).} \]

If all the bycatch and reported effort by a vessel size were observed, \( P_{st} = \hat{P}_{st} \), then the estimate of bycatch by the vessel size in the stratum from the product of the estimate of bycatch rate and reported effort was presumably accurate. If none of the bycatch and effort were observed, \( P_{st} = \hat{P}_{st} \), then the estimate of bycatch in the stratum was subject to the entire sampling error of the kernel estimate. Most strata had intermediate proportions of effort observed, so the level of sampling error fell between these extremes.

Notice that 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, i.e. the kernel estimate at (4) included all strata in which effort was monitored. The inclusion of information from the stratum of concern was in contrast to the method next described by which estimates of the kernel parameters were obtained.

We used the leave-one-out method of cross validation to estimate the parameters, \( \rho_1, \rho_2, \) and \( \rho_3 \), for either vessel size. The values of \( \rho_1, \rho_2, \) and \( \rho_3 \) which minimize the effort-weighted sum of squares of vessel size \( t \),
were the cross-validation estimates. That is, the bycatch rate by vessel size for each stratum was estimated by the kernel estimate (with selected values for \( p_1 \), \( p_2 \), and \( p_3 \)) using the observed bycatch rates of the 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). The procedure determined an optimal (in this effort-weighted least-squares sense) estimate of the unobserved bycatch rate by vessel size in a stratum for which no effort was monitored.

**Bycatch estimates**—Total bycatch in stratum \( s \) by vessels of size \( t \), \( F_{st} \), was estimated as

\[
\hat{F}_{st} = E_{st} \cdot \hat{f}_{st},
\]

and estimated total bycatch by the fishery was simply the sum of these estimates over vessel size and strata fished by vessel size,

\[
\hat{F} = \sum_{t=1}^{L} \sum_{s=1}^{S} \hat{F}_{st}.
\]

Sampling variation in the estimated total bycatch was computed by bootstrap resampling as though the observed vessel trips of each vessel size were a random sample of the corresponding total vessel trips during a monthly interval. The vessel trips of large and small vessels were resampled with replacement. Let the \( b \)th bootstrap resampling result in observed bycatch in stratum \( s \) of \( c_{st(b)}^s \) taken by \( e_{st(b)}^s \) tons of effort from vessel size \( t \). The bootstrap average observed bycatch rate in stratum \( s \) by vessels of size \( t \) was computed as \( F_{st(b)}^s = c_{st(b)}^s / e_{st(b)}^s \). The bootstrap observed average bycatch rates for the strata were used to recompute bycatch rates by vessel size using equations (6) and (7). Finally, the bootstrap estimate of total bycatch by the fleet, \( F_{b} \), was computed using the bootstrap values in equations (8) and (9). The time-consuming procedure was repeated 25 times, as suggested by Efron and Tibshirani (1986) for obtaining reliable estimates of standard errors of estimates. The bootstrap estimates by vessel size and combined were plotted in histograms and examined for normality. The large-vessel bycatch estimates did not appear to be normally distributed, so the estimates were log transformed. Approximate confidence intervals were then calculated using 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. Also, when possible, observers visually identified the species of salmonids brought on deck. A total of 3316 salmonids identified to species were used in our assessment of the species composition of bycatches, equivalent to 35% of the observed salmonid bycatch of the monitoring program. The species of 721 of the salmonids were identified by scales, and species of the remaining 2595 were identified by reliable observers.

Reliability of individual observers in species identification was evaluated by comparing species determinations from scales with those of the same fish from visual examination by the observers. Generally, an observer whose visual identifications agreed with greater than 80% of scale determinations was classified as reliable. If, for any given operation, (1) scales were available to identify the entire bycatch, (2) a reliable observer identified the species in the entire bycatch, or (3) a combination of scales and a reliable observer provided species identification of the entire bycatch, then we used the information to estimate the species composition of the bycatch for that operation. All such samples were aggregated from operations in 1° x 1° 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 only about 7% of the 3316 individual fish of species composition samples were misidentified to species, based on misidentification rates of individual reliable observers and numbers of salmonids each identified. Probably many of these misidentification errors within the aggregated samples were compensating and of no effect on our estimation of species composition of bycatch, i.e., 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, in press).

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. We estimated the species composition of the bycatch of each stratum by

$$\mathbf{p}_s = \gamma_s \cdot \mathbf{p}_s + (1 - \gamma_s) \cdot \mathbf{p}_s,$$

where

- $$\mathbf{p}_s = (p_{1s}, p_{2s}, \ldots, p_{68})$$ was the estimated vector of species proportions of bycatch from stratum s,
- $$\mathbf{p}_s = (p_{1s}, p_{2s}, \ldots, p_{68})$$ was the observed vector of species proportions of bycatch from stratum s,
- $$\mathbf{p}_s = (p_{1s}, p_{2s}, \ldots, p_{68})$$ was the kernel estimate of species proportions for bycatch of stratum s (described below), and
- $$\gamma_s$$ was the proportion of the estimated bycatch for stratum s for which the species was determined.
If species identification was available for all the estimated bycatch, then \( b_s = b_s \), 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, \( b_s = b_s \). In this case, the estimate of species composition includes all the sampling error inherent to 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 utilized 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 \( s \), \( b_s \), was computed from the \( C_{\text{max}} \) strata in which species composition was determined for a portion of the bycatch as follows:

\[
b_s = \frac{\sum_{j=1}^{C_{\text{max}}} k(d_{sj}) \cdot b_s}{\sum_{j=1}^{C_{\text{max}}} k(d_{sj})},
\]

where \( d_{sj} \) is the distance between stratum \( s \) and stratum \( j \), and \( k(\cdot) \) is the kernel function. The kernel function was defined earlier (see equation (4)).

We again estimated the coefficients of the kernel function 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° x 1° areas and 10-day periods. The likelihood function was maximized with respect to the unknown species proportions in the \( C_{\text{max}} \) strata 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 equal to aggregate sample size and unknown species proportions of the stratum bycatch. Second, aggregated samples among the \( C_{\text{max}} \) strata were assumed mutually independent. No account was taken of probable misidentifications of species, which simplified the analysis; the criteria we 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 \( s \), we maximized
Precision of the estimated species composition of bycatch from the kernel approach was evaluated by the bootstrap method. Each of the \( C_{\text{max}} \) 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 \( C_{\text{max}} \) bootstrap samples. Then the species proportions were computed for each stratum. The procedure was repeated 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 Salmon Dropouts

During 1990, procedures were implemented to estimate the number of "dropouts"—individual fish which were entangled when the net was brought out of the water, but which dropped out or were shaken out of the net before reaching the deck (Int. North Pac. Fish. Comm. 1991). In each observed operation, two sections were randomly selected for dropout monitoring. For these two sections, in addition to recording decked 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.

We estimated the total dropout of salmon for the entire fishery using a ratio estimate \( \hat{D} \), calculated as

\[
\hat{D} = \hat{R} \hat{T},
\]

where \( \hat{R} \) was the observed ratio of total dropout to total decked for sections monitored for dropouts and \( \hat{T} \) was an estimate of the total decked salmon bycatch, from either 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 \( \hat{R} \) was recalculated. This resampling and recalculation was performed 1000 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 (\( \hat{R} \)) was multiplied by a previous bootstrap estimate of total salmon bycatch (\( \hat{T} \)) to determine a
sampling distribution for \( \hat{D}_1 \). The standard deviation of the \( \hat{D}_1 \) among bootstrap repetitions was the estimate of the standard error of the estimates of salmon dropouts for both the vessel-trip and kernel methods. A confidence interval was obtained for estimated dropouts from the vessel-trip method using percentiles of the bootstrap distribution of \( \hat{D}_1 \). The 25 bootstrap estimates of \( \hat{D}_1 \) 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 Salmon Mortality**—We define mortality to be total number of salmonids killed in the Japanese squid driftnet fishery (dropouts and bycatch combined). We estimate salmonid mortality \( \hat{N} \) by summing the estimates of bycatch and dropouts obtained from the vessel-trip and kernel methods:

\[
\hat{N} = \hat{T} + \hat{D}_1.
\]

We obtained bootstrap estimates of \( \hat{N} \) by summing independent bootstrap estimates of dropouts and bycatch. Again, confidence intervals were calculated using the percentiles of the sampling distribution of \( \hat{N} \) 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 checked for normality by examining a histogram of the data.

**Results**

**Expansion of Vessel-Trip Bycatch**—The point estimate of salmonid bycatch by small vessels \( \hat{T}_1 \) was 200,000, and for large vessels \( \hat{T}_2 \), 10,000, yielding a total salmon bycatch \( \hat{T} \) of 210,000. We calculated 90% confidence interval for the total salmon bycatch for the fleet and by vessel size using the bootstrapping procedures outlined in the methods section. The 90% confidence interval for the total salmon bycatch by small vessels \( \hat{T}_1 \) was 37,000 ≤ \( T_1 \) ≤ 377,000. The 90% confidence interval for the total salmon bycatch by large vessels \( \hat{T}_2 \) was 3000 ≤ \( T_2 \) ≤ 12,000. The 90% confidence interval for total salmon bycatch by the entire fleet was 44,000 ≤ \( T \) ≤ 383,000. The estimated standard error of \( \hat{T} \) was 107,000.

Stratifying by vessel size was appropriate, given the apparent difference in bycatch between the two sizes. Estimated vessel-trip bycatch by observed small vessels ranged from 0 to 9173, and by observed large vessels, from 0 to 195 (Figs. 10 and 11). The 90% confidence intervals of average salmon bycatch per vessel trip for small \( \mu_1 \) and large \( \mu_2 \) vessels emphasized the difference. These confidence intervals were 142 ≤ \( \mu_1 \) ≤ 1435 for small vessels and 7 ≤ \( \mu_2 \) ≤ 31 for large vessels. The great uncertainty in salmon bycatch for small vessels resulted in large part from the estimated vessel-trip bycatch of a single vessel of 9173 salmon, roughly six times that of the next-largest estimated vessel-trip bycatch among small vessels. During seven
successive observed days, daily observed catches by this vessel ranged from 170 to 1455 salmonids and averaged 671.

Differences in the average salmon bycatch between the two vessel sizes was partly due to areas fished. Tracks of small and large vessels illustrate a different fishing pattern. Small vessels spent the majority of their time in the western portion of the fishery (west of 180°), whereas large vessels roamed the entire fishery (170°E to 145°W) (Fig. 12). As a result, 81% of the observed operations by small vessels were in locations west of 180°, whereas the corresponding value for large vessels was 12%.

**Kernel Estimation of Bycatch by Time and Area Strata**—Estimates of salmonid 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 4000), maximum bycatch during July (about 118 000), reduced bycatch in August (48 000), and further decline to very low levels from September to December (<1000). An estimated total of 170 000 salmonids was taken as bycatch in the Japanese squid fishery during the season, with small vessels catching 164 000, and large vessels 6000. Approximate 90% confidence intervals were calculated for both small- and large-vessel bycatch, along with their combined bycatch, using the point estimates and standard errors given in Tables 1-3. The 90% confidence interval ranged from 13 200 to 315 200 for small vessels, and from 4900 to 7600 for large vessels. The 90% confidence interval for salmonid bycatch of combined vessel sizes ranged from 19 200 to 321 300. The species composition of the bycatch was mostly coho (ca. 80 000) and chum (ca. 40 000) salmon.

Most salmonid bycatch occurred in the western half of the fishery, mainly in the northwestern corner, between 170°E to 180° longitude and within 2° latitude of the monthly northern boundary (Fig. 13). During June, the bycatch occurred in the western half of the fishery near 39°N latitude. During July, bycatch was more concentrated in the northwestern corner, with 80 000 fish estimated caught between 171°E and 172°E at 44°N latitude. In August, bycatch was more dispersed with longitude (170°E - 180°), yet concentrated near the northern boundary. Finally, most of the small bycatch of September-December occurred again in the northwestern corner.

**Estimation of Salmon Dropouts**—Total salmon dropouts equaled 10.2% of the total brought on deck, for net sections monitored for both dropouts and decked salmon. The point estimate for total salmon dropouts in the 1990 Japanese squid driftnet fishery was 21 000 fish (vessel-trip method) and 17 000 fish (kernel method). A 90% confidence interval for the total number of salmon dropouts based on the vessel-trip method ranged from 4100 to 41 000, and from 1700 to 33 000 based on the kernel method. The standard error of the estimate of total salmon dropouts was 12 000 (vessel-trip method) and 10 000 (kernel method).
Estimation of Salmon Mortality—We estimated total mortality in the 1990 Japanese squid driftnet fishery to be 231,000 salmonids using the vessel-trip method and 187,000 using the kernel method. The 90% confidence interval for mortality ranged from 47,000 to 478,000 for the vessel-trip method and from 21,000 to 354,000 using the kernel method.

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 during 1990. From May through December, 24 observers (11 U.S. and 13 ROK nationals) were placed on board ROK squid driftnet vessels. Once again, the purpose was to monitor fishing operations and record the catch and bycatch of target and non-target species.

Using this information, we estimated the number of salmon incidentally caught in the ROK high seas squid driftnet fishery of the North Pacific Ocean during 1990. Uncertainty in the estimate was evaluated using bootstrapping methods (Efron 1982).

Methods

The observed salmonid bycatch in the Korean fishery was much less than in the Japanese fishery. Only 77 salmonids were observed as bycatch in the Korean fishery during 1990, and of these, 55 were caught during November within a single 1° by 1° statistical area. Interpretation of species identification was even less a problem in the Korean fishery than it was in the Japanese fishery. Species of 87% of the total observed salmonids (57 of 77 fish) in monitored ROK bycatch were identified from scales, and an additional 4% of the observed salmonids (3 of 77) were identified to species by reliable observers. Reliable observers correctly identified species in 97% of cases (58 of 60 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 negligible effect on our analysis.

Due to rarity of observed bycatch among strata, kernel smoothing was not practical for estimating salmonid bycatch in the Korean fishery. Instead, we divided the fishery into time and area strata (1° latitude by 1° longitude by month) and estimated salmon bycatch, by species, for each stratum by multiplying the observed species bycatch rate by the number of poks (50 m) fished in that stratum. The observed stratum bycatch rate for each species was calculated by dividing the total observed number of 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 1990. Although driftnet vessels fished in 702 time and area strata, only 164 strata had observed operations. However, the 164 observed strata
accounted for 62% of the total pokes fished during 1990. 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 1.61 \((1 + 0.62)\).

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. This resampling was repeated 1000 times. A \((1-2\alpha)\cdot100\%\) confidence interval was obtained from the 1000 estimates by the percentile method.

Results

Point estimates and 90\% confidence intervals were calculated for the bycatch of each species of salmon in the 1990 ROK squid driftnet fishery in the North Pacific Ocean (Table 4). Chum and coho salmon were most abundant in the bycatch.

Taiwanese Squid and Large-Mesh Fisheries

We did not attempt to estimate the incidental catch of salmonids in the driftnet fisheries of Taiwan because (1) only two salmonids were observed caught in the 1990 Taiwanese driftnet fisheries, and (2) the commercial fishery statistics report pooled fishing-effort data from the squid and large-mesh fisheries. A U.S. observer sampled scales from one of these two salmonids which confirmed that it was a pink salmon caught on 19 July at 41°N, 177°W in the squid fishery. An unidentified salmonid was recorded by a U.S. observer on 1 July at 40°N, 176°W in the large-mesh fishery. Commercial fishing-effort data available from Taiwan was not differentiated into squid and large-mesh categories; therefore, expansion of bycatch rates was not realistic because the mesh sizes used in the Taiwanese squid and large-mesh fisheries are drastically different (85 mm and 205 mm, respectively). Additionally, fishing effort was reported as vessel days rather than length of driftnet fished. The number of tans deployed in observed daily operations ranged from 100 to more than 900 in the squid fishery and from 150 to 750 in the large-mesh fishery.

Examination of the distribution of observed and reported Taiwanese fishing effort (Fig. 7) indicates that the fisheries were monitored roughly in proportion to the amount of reported fishing effort in most months and most areas within a month. Thus, the observed bycatch of two salmonids is probably representative of the reported fishing effort, and we conclude that few salmonids were taken in the 1990 driftnet fisheries of Taiwan.
ILLEGAL CATCHES OF SALMONIDS

Preceding sections of this paper dealt with the considerable research effort expended to estimate legal salmonid bycatch in North Pacific driftnet fisheries. Salmonid mortality from illegal catches, however, was not estimated in our scientific program. The potential for such mortality is high: large-scale pelagic driftnets are capable of efficiently catching salmonids, and salmon and steelhead have been reported in commercially exploitable numbers just north (within 30 nmi (56 km)) of the current monthly legal boundaries (see salmonid catch at Station 6, Table 1, in Kawasaki et al. 1989).

Illegal catches of salmonids could potentially affect endangered or depleted Columbia River stocks. Illegal salmon fishing in the North Pacific before 1977 has been documented as far east at 153°W (Fredin et al. 1977), and more recently as far east as 144°30'W (U.S. Coast Guard 1987). Columbia River stocks have been detected near areas of suspected illegal fishing. During a Japanese tagging experiment, a steelhead trout was captured and released at 42°30'N, 175°30'W and recovered in the Columbia River (see Tag No. BB0964 in Ogura 1990). Four coded-wire tags from Columbia River steelhead were recovered in the 1990 Japanese squid driftnet fishery. These fish were all caught in August within 2° of the squid driftnet northern boundary between 152°W and 160°W (calculated from data in Dahlberg et al. 1991 and Int. North Pac. Fish Comm. 1991). The southernmost distribution of Columbia Basin origin steelhead is documented at 40°58'N, 159°39'W by Burgner et al. (1992); three coded-wire tagged steelhead were recovered from sampling done with a Canadian research vessel (LeBrasseur et al. 1987). A coded-wire tag from a coho salmon of the lower Columbia River basin was recovered in the 1991 Japanese driftnet fishery during August at 44°44'N, 175°30'W. Two tagged coho from the Pacific northwest, but not of Columbia River origin, were also recovered (McKinnell et al. 1991). The status of 76 stocks of Columbia Basin origin salmonids has been classified as high risk, moderate risk, or of special concern (Nehlsen et al. 1991) and one stock (Snake River sockeye salmon) has been declared endangered (Federal Register 1991). Even nominal illegal catches from threatened or endangered stocks could impair their survival.

Although the amount of illegal salmonids taken outside driftnet boundaries is unknown, some estimates are as great as 40,000 metric tons (t) per year (Beamish et al. 1990). Full documentation of illegal harvest is not possible, but minimal estimates of its magnitude can be made through the following sources: official trade statistics regarding salmon imports from countries without legal access to Pacific salmon fishing grounds, investigations of illegal salmon transactions, and enforcement efforts on the high seas.

ESTIMATES OF ILLEGAL HARVEST BASED ON OFFICIAL TRADE STATISTICS

Available official trade statistics on imports of frozen and canned Pacific salmon from countries without legal access to Pacific salmon fishing
grounds indicate their exports totaled at least 10,000 t in 1988 (Table 5). Other sources (Steinbock and Jamieson 1991) document that a total of 6106 t of fresh, frozen, and canned salmon was exported during 1990 from countries believed to be involved in the illegal trade of salmon. Steinbock and Jamieson (1991) indicate that most of the illegally harvested salmon from Taiwan is re-exported through the Asian countries of Thailand, Malaysia, Singapore, Hong Kong, and the People's Republic of China (PRC) and that most of this illegal salmon is supplied to the world markets through Thailand and Malaysia. The Republic of Korea may also be involved in the trade of illegally caught salmon, but the ROK legally imports large quantities of salmon from the United States for processing and re-export, making it very difficult to determine the extent of mingling that occurs between legitimate and illegitimate product. The principal importers of illegally traded salmon during 1990 were Japan (2500 t), Netherlands (1502 t), and France (845 t) (Steinbock and Jamieson 1991).

U.S. INVESTIGATIONS AND DRIFTNET ENFORCEMENT

Working with the U.S. Department of Justice, the U.S. Customs Service, and the Canadian Department of Fisheries and Oceans, investigations by U.S. National Marine Fisheries Service Special Agents have been directed at three major areas: (1) illegal high seas fishing, (2) domestic laundering and illegal sales, and (3) international illegal trade and distribution of salmonids. The investigations reveal that fishing fleets (30 to 90 vessels each) illegally target salmonids six months of the year (April-October) in the North Pacific. Over the past five years, more than 1 million pounds (453 t) of salmon has been seized that was imported illegally into the United States from Singapore, Hong Kong, and other far eastern ports; nearly 10 million pounds (4536 t) of illegally taken salmon was documented to have been smuggled through the United States and subsequently sold in Japan; and additional illegal salmon was trans-shipped at sea and delivered directly to Japan. International smuggling rings involving parties in Hong Kong, Singapore, Taiwan, the PRC, Thailand, Chile, Japan, and the U.S. have been uncovered. To date, 34 U.S. and foreign fish brokers and associated companies have been federally indicted, charged, and convicted. (Wayne Lewis, National Marine Fisheries Service, Office of Enforcement, Pacific Area Operations Division, Seattle, WA, pers. comm., 1991.)

In addition to U.S. investigations of illegal trade in salmonids, enforcement data support the allegation of illegal harvest in the North Pacific. Sources of enforcement data are summaries of electronic surveillance by satellite transmitters, aircraft observations of fishing activities by personnel of the U.S. Coast Guard and Canadian Maritime Forces, and boardings and surveillance from U.S. Coast Guard cutters. Illegal fishing observed outside legal squid fishing areas—defined in either domestic law or international agreement—occurred 1) near boundaries, presumably by vessels targeting squid, but which may nevertheless have had unobserved bycatch because of fishing in areas of probable salmon presence, and 2) farther north of boundaries by vessels probably targeting salmon.
Overall statistics on vessels sighted by country during 1990 and 1991 are provided (Fig. 14); unidentified vessels did not have visible national markings. Forty-seven vessels were seen 30-94 nmi (56 and 174 km) north of the legal squid fishing areas, and 69 vessels were seen ≥100 nmi (185 km) outside the authorized area (Figs. 15, 16). (Figures 14-16 are based on Sonar Technician First Class (ST1) Lyle E. Phillips, U.S. Coast Guard, Office of Law Enforcement, 17th District, Juneau, AK 99802, pers. comm., 1991.)

SUMMARY OF ILLEGAL CATCHES

Information collected over the past five years shows substantial illegal harvest of salmon. Accurate estimates of the magnitude of this illegal harvest cannot be made; however, if all salmon exported by harvesting and transit countries (without legal access to Pacific salmon fishing grounds) were taken illegally as seems reasonable, then the number of salmon killed illegally in a recent year was at least 10 000 t (5.5 million fish). Some of this illegal harvest may be bycatch in out-of-area squid driftnet operations—a large number of vessels have fished well outside the boundaries of the squid fishing area. However, evidence has been gathered of illegal directed fishing for salmon by international criminal enterprises which aim at placing this illegal product on world markets. Any assessment of the impacts on salmonid stocks of high seas large-scale pelagic driftnetting needs to acknowledge the potential impact of this illegal fishing effort on some stocks, particularly those threatened or endangered.

ACKNOWLEDGMENTS

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REFERENCES


TABLES AND FIGURES
Table 1. Estimated monthly salmonid bycatch and bootstrap standard errors, by species, for small vessels of the 1990 Japanese squid driftnet fishery. Slight inconsistencies in totals are due to rounding.

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Table 2. Estimated monthly salmonid bycatch and bootstrap standard errors, by species, for large vessels of the 1990 Japanese squid driftnet fishery. Slight inconsistencies in totals due to rounding.

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<td>3100</td>
<td>940</td>
<td>2200</td>
</tr>
</tbody>
</table>
Table 3. Estimated monthly salmonid bycatch and bootstrap standard errors, by species, for all vessels of the 1990 Japanese squid driftnet fishery. Slight inconsistency in totals due to rounding.

<table>
<thead>
<tr>
<th>Species</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Sept-Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>$se$</td>
<td>$n$</td>
<td>$se$</td>
<td>$n$</td>
</tr>
<tr>
<td>Chinook</td>
<td>310</td>
<td>140</td>
<td>250</td>
<td>300</td>
<td>3900</td>
</tr>
<tr>
<td>Chum</td>
<td>530</td>
<td>240</td>
<td>25 000</td>
<td>18 000</td>
<td>38 600</td>
</tr>
<tr>
<td>Coho</td>
<td>2500</td>
<td>1200</td>
<td>71 400</td>
<td>54 900</td>
<td>82 400</td>
</tr>
<tr>
<td>Pink</td>
<td>210</td>
<td>100</td>
<td>6 900</td>
<td>5 000</td>
<td>8 500</td>
</tr>
<tr>
<td>Sockeye</td>
<td>0</td>
<td>0</td>
<td>9 600</td>
<td>7 400</td>
<td>15 900</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0</td>
<td>0</td>
<td>4 500</td>
<td>3 900</td>
<td>14 100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3600</td>
<td>1600</td>
<td>117 700</td>
<td>88 700</td>
<td>170 300</td>
</tr>
</tbody>
</table>

Table 4. Point estimates and 90% confidence intervals of salmon bycatch, by species, for the 1990 ROK squid driftnet fishery.

<table>
<thead>
<tr>
<th>Species</th>
<th>Point estimate</th>
<th>90% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unidentified salmonids</td>
<td>165</td>
<td>0-254</td>
</tr>
<tr>
<td>Chinook</td>
<td>21</td>
<td>0-52</td>
</tr>
<tr>
<td>Chum</td>
<td>3656</td>
<td>52-4481</td>
</tr>
<tr>
<td>Coho</td>
<td>106</td>
<td>11-190</td>
</tr>
<tr>
<td>Pink</td>
<td>0</td>
<td>0-0</td>
</tr>
<tr>
<td>Sockeye</td>
<td>53</td>
<td>0-320</td>
</tr>
<tr>
<td>Steelhead</td>
<td>35</td>
<td>0-79</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4036</td>
<td>243-5029</td>
</tr>
</tbody>
</table>
Table 5. 1988-1990 trade in frozen and canned Pacific salmon involving countries without legal access to salmon fishing grounds. Product weight in metric tons and value in thousands of U.S. dollars.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data source</td>
<td>Import Qty</td>
<td>Value</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>(1)</td>
<td>1,673</td>
<td>7,189</td>
</tr>
<tr>
<td>Singapore</td>
<td>(1)</td>
<td>2,302</td>
<td>24,772</td>
</tr>
<tr>
<td>Taiwan</td>
<td>(1)</td>
<td>3,336</td>
<td>9,514</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>10,311</td>
<td>41,475</td>
</tr>
</tbody>
</table>

Harvesting and transit countries' exports:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Republic of Korea</td>
<td>(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Major processing country imports:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>(4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>(5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>(6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>(7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(U.K.)</td>
<td>(8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Imports by major consumer countries:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1,673</td>
<td>7,189</td>
<td>1,364</td>
</tr>
<tr>
<td>France</td>
<td>2,302</td>
<td>24,772</td>
<td>1,429</td>
</tr>
<tr>
<td>Japan</td>
<td>3,336</td>
<td>9,514</td>
<td>3,440</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1,302</td>
<td>9,514</td>
<td>1,429</td>
</tr>
<tr>
<td>(U.K.)</td>
<td>848</td>
<td>3,872</td>
<td>950</td>
</tr>
<tr>
<td>Totals</td>
<td>10,311</td>
<td>41,475</td>
<td>10,633</td>
</tr>
</tbody>
</table>

a Product weights are frozen product or frozen product equivalents (40% recovery rate from canned product) except where noted.
b Harvesting and transit countries without legal access to Pacific salmon fishing grounds.
c Incomplete data.
d Import figures without parentheses are for quantities and values of frozen product imported from countries without legal access to Pacific salmon grounds whereas those in parentheses are quantities and values of total imports from all countries. Export figures are totals and include product from all sources.
e January-November 1990.
f Figures are product imported from processing countries without legal access to Pacific salmon fishing grounds. Product weight is primarily of canned salmon.
g July 1988-June 1990.

The above table was compiled by Hilton Rose, NMFS Office of Enforcement, from the following sources:

(1) Trade statistics of importing countries.
(3) Foreign Trade Department, Thai Ministry of Commerce.
Figure 1.--Legal boundaries for the Japanese squid driftnet fishery.
Figure 2.—Legal boundaries for the ROK squid driftnet fishery.
Figure 3.—Legal boundaries for the Taiwanese squid driftnet fishery.
Figure 4.—Major concentrations of driftnet fishing by Japan, ROK, and Taiwan. Areas outlined include only those 1° x 1° statistical areas that contained 10 or more operations.
Figure 5.—Proportionality of observer effort to commercial effort for the Japanese squid driftnet fishery.
Figure 6.--Proportionality of observer effort to commercial effort for the ROK squid driftnet fishery.
Figure 7.--Proportionality of observer effort to commercial effort for the Taiwanese squid and large-mesh fisheries.
Figure 8, Part 1

Salmon CPUE

June 1 - 10

June 11 - 20

June 21 - 30

July 1 - 10

July 11 - 20

July 21 - 31

Max rate includes 2 operations with catch rates of 78 and 94.

Max rate includes 3 operations with catch rates of 263, 326, 532, 654, 725, 914, 1223 and 1988.

Max rate includes 4 operations with catch rates of 267, 326, 531 and 1983.
Figure 8.—Spatial and temporal distribution of observed salmon bycatch rates (bycatch rate = salmon caught per 1000 tans).
Figure 9.—Plot of bycatch rates for small versus large vessels for strata that included effort by both size classes (values plotted are the square root of the actual bycatch rates).
Figure 10.—Ranked estimated bycatches for observed vessel trips—small vessels. (Does not include three vessel trips with zero bycatch.)
Figure 11.—Ranked estimated bycatches for observed vessel trips—large vessels. (Does not include 5 vessel trips with bycatch less than three, and 19 vessel trips with zero bycatch.)
Figure 12.--Percentage of total observed operations from the Japanese squid driftnet fishery for each vessel size by latitude and longitude.
Figure 13.—Estimated salmon bycatch by 1° x 1° statistical areas using the kernel approach.
Figure 14.—Number of foreign driftnet sightings outside of authorized fishing areas.
Figure 15.—1991 driftnet sightings. Vessels operating 30 to 94 nautical miles north of authorized area.
Figure 16.--1991 driftnet sightings. Vessels operating greater than 100 nautical miles out of authorized area.