LOSS OF SALMON FROM HIGH-SEAS GILLNETTING WITH REFERENCE TO THE JAPANESE SALMON MOTHERSHIP FISHERY

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ABSTRACT

Studies by the National Marine Fisheries Service on the loss (i.e., dropouts, those salmon that become unmeshed or otherwise escape from drifting gill nets; and fallouts, those salmon observed falling from gill nets as the gear is hauled aboard the vessel) of salmon due to high-seas gillnetting were conducted in the North Pacific Ocean and Bering Sea from 1964 to 1969. Losses attributed to dropouts and to predators and scavengers, as determined by indirect methods, were estimated as 32% for immature salmon for fishing periods up to 12.5 h (1964) and 27% for maturing salmon for a 3-h fishing period (1965). Loss estimates derived from direct observations in 1966-69 were 6, 14, and 41% for fishing periods up to 1, 2½, and 11 h, respectively. Estimates of losses of immature salmon were 46% up to 11 h and 20% for maturing salmon for the same time period. No losses were recorded for fishing periods of 3 h in an inshore commercial gill net fishery in Puget Sound, Wash., in August 1967.

Losses attributed to fallouts from U.S. research vessels during 1965-70 amounted to about 1.4% of the total number of salmon landed, a figure similar to that reported for Japanese research vessels.

The estimated annual loss from dropouts (including predators and scavengers) by the Japanese mothership fishery would range from 5.5 to 10.8 million fish in applying an estimated average loss of 20% (for maturing salmon) to 33% (for maturing and immature salmon combined) to the average annual catch of 22 million salmon by the mothership fleet. It was estimated that an average of 0.6 to 1.8 million sockeye salmon, *Oncorhynchus nerka*, of Bristol Bay, Alaska, origin would be lost annually from the Japanese mothership fishery (depending on total catch). The estimated annual loss due to fallouts (1% of landings) would average over 200,000 fish each year, of which 25,000 sockeye salmon of Bristol Bay origin would be lost on the average.

The estimated large numbers of salmon lost from gill nets (and probable high mortality of those fish escaping) indicate a relatively large waste of resources due to a high-seas gill net fishery.

For many years, Pacific salmon, *Oncorhynchus* spp., with gill net marks have been observed in coastal waters and in spawning streams, indicating they had escaped from gill nets. Percentages of net-marked salmon in some river systems have been substantial. For example, from 1944 to 1952, counts of gill net-marked salmon at a weir near Brooks Lake, Bristol Bay, Alaska, showed 6.3% of the annual escapement of salmon were net-marked (Nelson and Abegglen, 1955). Hanson, Zimmer, and Donaldson (1950) reported about 4% of the sockeye, *O. nerka*, and 6% of the chinook, *O. tshawytscha*, salmon on the Columbia River showed gill net wounds and scars in 1946. Talbot (1950) showed that the percentage of net-marked sockeye salmon in the daily catch below Hells Gate on the Fraser River during 1943-47 ranged from 0 to 75%.

With the advent of the Japanese offshore gill net fishery in 1952, Japan and the USSR have reported net injuries to salmon in coastal waters. Thus, Petrova (1964) reported that up to 15% of the salmon ascending the Bolshaya River (USSR) in recent years had gill net injuries. She observed that these net-marked fish were less effective as spawners; net-marked chum salmon, *O. keta*, retained more than 20% of their eggs and many died before spawning. Konda (1966) noted that as early as 1934, drift net fishing off the Kuril Islands was caus-

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ing a problem of net-injured salmon in the streams of Hokkaido Island, Japan. He also reported that up to 5% of the salmon in some streams in 1960 were gill net-marked.

These net-marked or injured salmon that are observed in coastal waters or in river systems are, of course, only the surviving salmon that have encountered and escaped either a high-seas or an inshore gill net fishery. The loss or dropout of salmon from high-seas gill nets has been recognized as a potentially serious loss to the resource by scientists of all nations concerned; however, neither the rates of fish dropping from the nets nor the number which perish are known. Doi (1962), in experiments on the high seas, estimated the rate of dropouts from examination of the catch in gill nets at 30-min intervals. He concluded that the rate of dropouts is a function of the time the fish are in the nets; that is, dropouts increase with time in the net. In Doi's experiments, dropout rates ranged up to 55% for coho salmon, *O. kisutch*, and 47% for sockeye salmon after periods of 5½ h. Miyazaki and Taketomi (1963, as cited by Konda, 1966) estimated a 20% loss of pink salmon, *O. gorbuscha*, from gill nets. Semko (1964), in discussing the irrationality of a high-seas salmon fishery, stated that a large mortality is inflicted in salmon by the drift nets and that the loss may amount to 30% of the catch. Konda (1966), while commenting on the loss of salmon from gill nets during hauling, stated that the ratio of live to dead fish is closely related to the length of time needed to haul the net. He further stated ". . . not only when hauling in the set, but even while setting the gillnet, no small number of fish will leave the net after having once been gilled, . . . " and ". . . as is well known, the gillnet is effective for high seas salmon fishing, however, it is always accompanied with a large loss of resources." Ishida et al. (1969) found salmon dropout rates of 4.2 to 24.1% in four experiments in the Okhotsk Sea. Thus, there is recognition of loss of resources due to dropouts during the drift of gill nets and due to fallouts during hauling of the fishing gear.

Because of the possible deleterious effects on U.S. salmon stocks by the Japanese high-seas gill net fishery, the former Seattle Biological Laboratory of the Bureau of Commercial Fisheries (now National Marine Fisheries Service) undertook studies on the loss of salmon owing to a gill net fishery in 1964.

Progress on these studies has been reported in Annual Reports of the International North Pacific Fisheries Commission (French, 1966; French, Craddock, and Dunn, 1967; French, Craddock, Bakkala, Dunn, and Thorson, 1967; French et al., 1969, 1970, 1971). Progress on determining the fate of salmon which escape from gill nets has been reported by Thompson, Hunter, and Patten (1971); by Hunter, Patten, and Thompson (1972); and by Thompson and Hunter (1972)[2].

Reported here are the results of 6 yr of experiments to determine: (1) the rate of dropout; (2) the effect of varying length of fishing time on dropout loss rate; (3) the effect of different types of gill net materials and mesh sizes on dropout rates of maturing and immature salmon; and (4) rate of fallouts during hauling operations. Included are estimates of loss of salmon from high-seas and inshore gillnetting.

In this report we use the term "dropouts" as those salmon that become unmeshed or otherwise escape from drifting gill nets; the term "fallouts" is used to describe those salmon seen to fall from gill nets as the gear is hauled aboard the vessel.

EXPERIMENTAL METHODS

Dropout Studies

Experimental methods used in 1964 and 1965 differed from those used in 1966-69. The former methods were based on indirect observations of the fish, whereas, the more recent studies were based on direct observation of the fish. Experimental methods will be described separately below for the indirect and direct methods of observation.

[2] Thompson, R. B., and C. J. Hunter. 1972. Viability of adult sockeye salmon that disentangle from gill nets. *In* Investigations by the United States for the International North Pacific Fisheries Commission—1971, p. 95-105. Northwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, Wash. [Processed.]

Indirect Observations (1964 and 1965)

1964.—The 1964 studies of dropouts were carried out while conducting exploratory fishing for salmon in the western North Pacific Ocean in September and October. The method used to estimate the rate of dropouts was to determine the differences in numbers of salmon caught in gill nets fished for a long period compared to the cumulative catch of salmon caught in a series of short sets fished at the same time and place. Any decrease in catch of the nets fished continuously would be attributed to dropouts. In this procedure, gill nets were set, hauled, and reset at intervals throughout the night (Figure 1).

Conventional multifilament nylon gill nets (1 shackle was 91.5 m long and 7.3 m deep)[3] were fished in individual units of shackles, with each unit connected by a 55-m line. Each unit of gear consisted of 2 shackles of 114-mm and 2 shackles of 83-mm mesh—sizes that would capture most sizes of salmon present. There was a security snap on each gear unit for easy connection and disconnection of the units. Lighted buoys and radio buoys were attached to the net string to ensure finding the gear during hours of darkness.

The time and fishing procedure during the night were as follows:

2000 Set gear units No. 1, 2, 3, and 4.
2300 Haul unit No. 1, remove salmon, and reset.
0200 Haul units No. 1 and 2, remove salmon, and reset 2.
0500 Haul units No. 2 and 3, remove salmon, and reset 3.
0800 Haul unit No. 3 and the last unit, No. 4.

This fishing routine allowed comparison of the different 3-h periods during the night (2000-2300, 2300-0200, 0200-0500, and 0500-0800). Additionally, comparisons were possible for catches of nets fished continuously with the sum of the catches of the individual gear units for various time periods. For example, unit No. 4 fished for 12 h, from 2000 to 0800, and catches in these nets were compared to the cumulative catch of the four individual units hauled at the end of each 3-h period.

1965.—Procedures used in 1965 were extensions of those used in 1964 but on a larger scale employing two vessels full time. Fishing was conducted in the North Pacific Ocean (near long. 166°W) and in the Bering Sea (near long. 160°W) in June and early July, concentrating on maturing sockeye salmon.

Two experimental designs were used to estimate dropout rates of salmon. In the first design, the nets were fished at night; one unit of gear (four 91.5-m shackles of 133-mm mesh gill nets per unit) was fished for 6 h, a second unit for the first 3 h, and a third for the second 3 h (Figure 2). The fishing was repeated over three different time periods during the night. The dropout rate was computed by comparing the catch of the 6-h unit with those of similar

[3] Details of net construction (and fishing procedure) were given by Craddock (1969).
Multifilament nylon gill nets were 100% nylon—330 Starrlock type E (or equivalent) of plied or cable laid salmon twine and dark green in color. Ply size ranged from 3 to 12, depending on mesh size; numbers of body meshes ranged from 57 to 123 (plus guard meshes), depending on mesh size. Each shackle was 183-m long, stretched measure, so that each gill net made a full 91.5-m shackle when hung in 50% on the cork line. Monofilament nylon gill nets were of identical construction to multifilament nylon gill nets, except for net material. Monofilament nets were constructed of light green single strand filament, double selvage, with body meshes of 0.30-, 0.40-, 0.50-, and 0.50-mm diameter for mesh sizes 64, 83, 114, and 133 mm (stretched measure, knot to knot), respectively. [Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.]

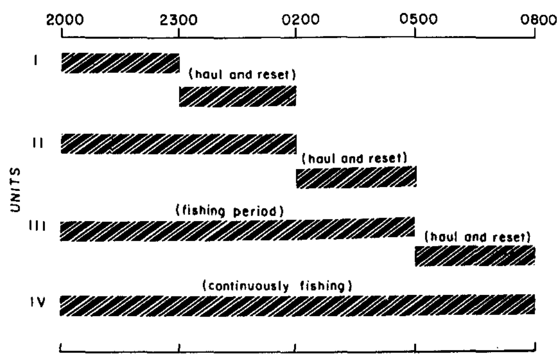

FIGURE 1.—Fishing plan for study of dropouts, 1964. Each unit of gear is identical; length of shaded area refers to fishing time.

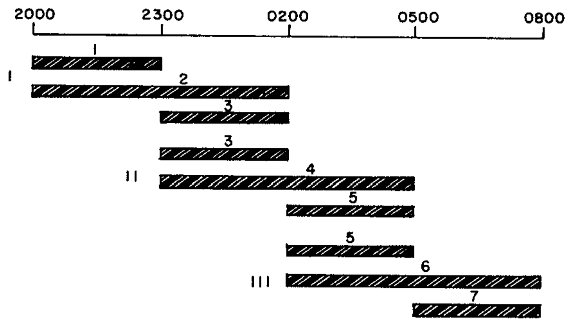

FIGURE 2.—Fishing plan (nighttime) for study of dropout, 1965. Each unit of gear is identical; length of shaded area refers to fishing time.

units fished during the first and second 3-h intervals. Loss of salmon from gill nets was estimated by regression analysis based on data from the catches in the various time periods (a 6-h catch vs. two 3-h catches).

In the second experimental design, four units of gill nets were set before daylight and fished for various lengths of time until noon. Additional units were fished concurrently as shown in Figure 3. In this design, we expected that in the event fish did not enter gill nets fished during daylight the dropout rate of fish caught before daylight could be measured directly by comparing catches of the gear units fished before daybreak with those units fished for various periods after daybreak.

The indirect methods described above have certain inherent limitations and potential sources of error. These methods assume that: a) each gill net is equally efficient; b) each net fishes the same amount of time; and c) the same number of fish are available to each unit of net.

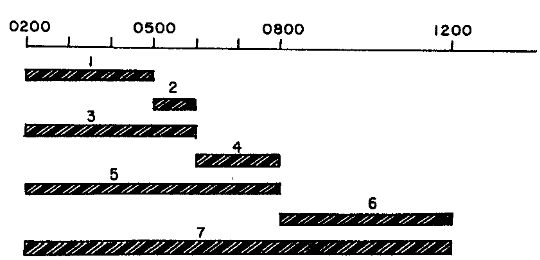

FIGURE 3.—Fishing plan (night-day) for study of dropout, 1965. Each unit of gear is identical; length of shaded area refers to fishing time.

Additionally, it is not possible to differentiate between losses due to dropout and losses due to predators and carrion eaters.[4] Thus, all losses of salmon from gill nets must be attributed to dropout and predation.

Direct Observations (1966-69)

Loss of salmon in gill nets was estimated by direct observation during experiments in 1966-69. The experimental procedure was to patrol the nets at night from small boats (when sea conditions permitted), mark the locations of gilled salmon, and determine their presence or absence at later patrols and when the gear was hauled in the morning. Portable spotlights were used to observe the salmon at night; reflected light made fish in the net visible. The position of an enmeshed salmon was noted by fastening a colored marker to the corkline directly over the fish.

The time and procedure are described below; some variation in timing occured during various sets.

- 2000 Put out 24-36 shackles of gill net.
- 2100 First patrol: Examine the nearest 7-14 shackles; mark positions of gilled salmon with colored pins.
- 2130 Second patrol: Repeat the patrol and record the presence or absence of salmon at locations marked at the first patrol; mark locations of newly observed salmon with pins of a second color.
- 2330 Third patrol: Repeat the above procedure, again marking locations of newly observed salmon with pins of a third color.
- 0800 Haul the gill net string; record presence or absence of salmon for all marked locations.

Variations in timing and frequency of observations occurred among years. For example, in 1967, an additional observation at 0230

[4] Total loss due to predators and carrion eaters is designated as loss due to predation in the remaining part of our report.

was made. Additionally, because the study required the use of small boats from the research vessel at night, some patrols were not made in rough seas.

These studies, with minor modifications, were conducted during high-seas gillnetting in 1966-69 and in Puget Sound in 1967. Details of these modifications are explained in the analysis section.

The direct method of observation also contained potential sources of error. For example, salmon marked on one patrol may drop out but be replaced by another fish, thus causing the observer to miss an actual dropout. Moreover, some fish may be inadvertently missed on subsequent patrols and erroneously recorded; upon hauling the net, the observer may then attribute the presence of a fish to replacement. Furthermore, as was the case with the indirect methods, it was not possible to differentiate losses due to dropout and losses due to predation.

Fallout Studies

Observations of the number of fish falling out of gill nets during net hauling operations (fallouts) were made from 1965 to 1970. Fish falling from nets of known mesh sizes were tallied and expressed as a percentage of the total catch. The number of fallouts are believed to be reasonably accurate, although some may have been missed during inclement weather or during very large catches.

SALMON DROPOUT RATES DURING GILLNETTING

Offshore Fishing

Indirect Observations (1964 and 1965)

1964.—Studies of the loss of salmon from gill nets by indirect methods were conducted in September and October. Four sets for these studies were made south of the western Aleutian Islands (one set along long. 178°W and three sets along long. 173°E); catches were principally of immature salmon.

The fishing procedure provided catch data for approximately four 3-h periods throughout the night and for approximately one 6-, 9-, and 12-h period. Precise gear hauling and setting schedules could not be maintained, and usually units of gear scheduled for a 3-h fishing period were fished for shorter time periods. Results of two experiments were unusable because of a combination of weather and tidal currents affecting the net string and because of the difficulty encountered in hauling the nets. The two successful experiments, however, provided data on catches in 6, 9, and 12 h compared to the cumulative catches in nets fished for 3-h periods.

The two sets caught 257 and 239 salmon, respectively. Catches were predominately age .1 immature sockeye salmon.[5] Catches by age and species of fish and by mesh size in each unit of gear are listed in Table 1.

The catches in gill net units fished continuously for periods of 6, 9, and 12 h, and the cumulative catch in individual units fished for short intervals (2.0-3.5 h) are compared in Figure 4. Less fish were landed each day in nets fished continuously for 9 and 12 h than for the 9- and 12-h cumulative catches of individual units fished for three and four short intervals. The catches each day were similar between fishing methods for approximately the first 6 h. Thereafter, in both experiments, the gear that fished continuously caught comparatively fewer fish.

The loss from the continuously fishing units (difference in total catch of the two fishing methods divided by the total catch during short intervals of fishing) for the two sets was 16 and 24% in 10 h and 43 and 20% in 12.5 h. No loss was shown after 6 h. The average for the two sets was 20% for 10 h and 32% for 12.5 h (Table 2). The loss was attributed to dropouts and predation.

1965.—In the spring of 1965, a concentrated effort was directed toward indirect methods of estimating the rate of dropout of salmon from gill nets. Two research vessels fished on maturing sockeye salmon (primarily

[5] Age designation follows that of Koo (1962); numerals indicate numbers of ocean annuli.

TABLE 1.—Catch of salmon by species, age of fish, and unit of gear, 30 September and 2 October 1964.

Sampling location	Date	Unit	Time fished	Total hours fished	Sockeye 83 mm .1	Sockeye 83 mm .2	Sockeye 114 mm .1	Sockeye 114 mm .2	Chum 83 mm .1	Chum 83 mm .2	Chum 114 mm .1	Chum 114 mm .2	Coho 83 mm .0	Coho 83 mm .1	Chinook 114 mm .1	Chinook 114 mm .2	Total catch
Lat. 50°10'N, long. 173°00'E	9/30	1	2025-2330	3.1	14	0	0	3	5	6	0	8	0	0	0	0	36
		2	2025-0230	6.1	20	0	0	1	5	17	0	9	0	0	0	0	52
		3	2025-0625	10.0	28	0	0	3	4	5	0	27	0	0	0	1	68
		4	2025-0855	12.5	29	1	0	3	6	15	0	4	0	0	0	0	58
		5	0010-0233	2.4	3	1	0	0	1	0	1	3	0	0	0	0	9
		6	0335-0535	2.0	8	0	0	4	1	1	0	1	1	0	0	0	16
		7	0635-0855	2.3	9	0	0	0	0	4	0	5	0	0	0	0	18
			Total		111	2	0	14	22	48	1	57	1	0	0	1	257
Lat. 50°10'N, long. 173°00'E	10/2	1	2000-2330	3.5	17	0	2	3	1	2	0	3	0	0	0	0	28
		2	2000-0250	6.8	25	0	3	3	4	5	0	7	0	0	0	0	47
		3	2000-0650	10.1	40	0	1	2	1	3	1	5	0	0	0	0	53
		4	2000-0825	12.4	47	2	1	2	2	7	1	3	0	0	0	0	65
		5	2350-0250	3.0	7	1	3	0	1	0	0	3	0	0	0	0	15
		6	0255-0525	2.5	14	0	0	1	1	2	1	0	0	0	0	0	19
		7	0630-0855	2.4	9	2	0	0	0	0	0	1	0	0	0	0	12
			Total		159	5	10	11	10	19	3	22	0	0	0	0	239

of Bristol Bay origin) south of the Alaska Peninsula and in the eastern Bering Sea in June and early July.

Fishing gear consisted of multifilament gill nets of 133-mm mesh. Four 91.5-m nets, 7.3-m deep, were joined together to form a basic unit of gear 366-m long. For some sets in areas where large catches were expected, the basic unit was reduced to 2 shackles (183 m).

Dropout of salmon from gill nets was estimated by regression analysis of catch ratio obtained from the catch for a 6-h period and the catches for the first and second halves of the same period (Figure 5). Assuming N_1 and N_2 are the numbers of fish available to the gill nets during the first and second halves of a given 6-h period, the expected catches of the three units of gear are:

$c_1 = s_0 u_1 N_1$ for the first 3-h unit,

$c_2 = s_0 u_1 N_2$ for the second 3-h unit,

$C = s_1 s_0 u_1 N_1 + s_0 u_2 N_2$ for the 6-h unit.

Where u_1 is the fraction of the fish available during a 3-h period which are captured by the unit of gear, s_0 is the fraction of those captured which are retained by the gear until the time of hauling, and s_1 is the fraction of the fish captured and retained by the 6-h unit of gear during the first half of the period, which are

TABLE 2.—Catch of salmon in gill nets fished continuously and in gill nets hauled at intervals, and estimated loss of salmon from nets fished continuously.

Nets fished continuously: Date and time period	Hours fished	Catch (no.)	Nets fished for short intervals: Time period	Hours fished	Catch (no.)	Cumulative catch (no.)	Catch[1] per hour	Adjusted cumulative catch[2]	Estimated loss[3] (%)
30 September									
2000-2300	3.1	36	2000-2300	3.1	36	36	11.6	36	
2000-0200	6.1	52	2300-0200	2.4	9	45	8.2	50	0.0
2000-0500	10.0	68	0200-0500	2.0	16	61	8.1	81	16.0
2000-0800	12.5	58	0500-0800	2.3	18	79	8.1	101	42.6
2 October									
2000-2300	3.5	28	2000-2300	3.5	28	28	8.0	28	
2000-0200	6.1	47	2300-0200	3.0	15	43	6.6	45	0.0
2000-0500	10.1	53	0200-0500	2.5	19	62	6.9	70	24.3
2000-0800	12.4	65	0500-0800	2.4	12	74	6.5	81	19.8

[1] Cumulative catch divided by cumulative hours fished.
[2] Adjusted to equal time period of nets fished continuously; catch per hour times number of hours fished of nets fished continuously.
[3] Total in adjusted cumulative catch for nets fished short intervals minus total for nets fished continuously, divided by adjusted cumulative catch.

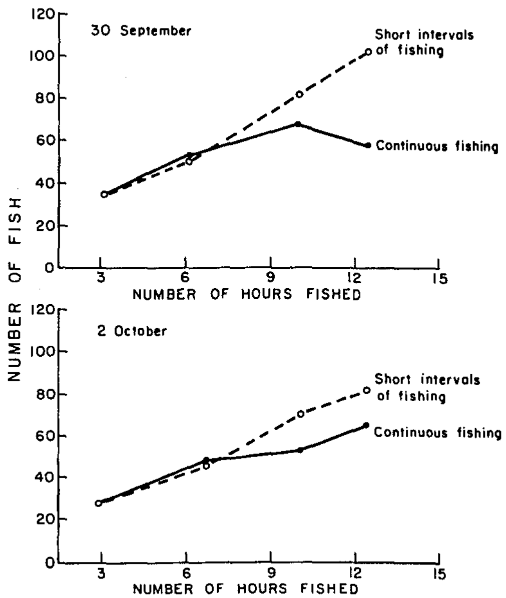

FIGURE 4.—Comparison of salmon catch in gill nets fished continuously with the cumulative catch in nets fished for short intervals (2.0-3.5 h), 1964. Data for short intervals of fishing have been adjusted to allow for comparable fishing hours.

also retained during the second half of the period. Rewriting C in terms of c_1 and c_2 we have

$$C = s_1 c_1 + (u_2/u_1)c_2$$

or

$$C/c_1 = s_1 + (u_2/u_1)\,(c_2/c_1).$$

By substituting the observed values of C, c_1, and c_2 for each 6-h fishing period, the regression of (C/c_1) on (c_2/c_1) will be linear with intercept equal to s_1 and slope equal to (u_2/u_1).

In the application of this model, it is assumed that over the totality of the 6-h-fishing periods, the average number of fish available to two units of gear fishing simultaneously is the same. The loss from gill nets, $1 - s_1$, applies to the fraction of fish disappearing from a gill net unit during a 3-h interval which is assumed to begin 1½ h after the fish enter the net. The loss from the time of entry to the beginning of the 3-h interval is not included in the estate of s_1.

Salmon catches (sockeye, chum, and pink salmon) by time periods and gear units of the usable experimental dropout sets are listed in Table 3. The total of column c_1 (the catches in the first 3-h unit) includes appropriate catches of c_2 where the second 3-h unit also constituted the first unit of the second or third time periods (see Figure 2). Sockeye salmon were the principal species taken in these sets; species totals were 4,327 sockeye, 353 chum, and 4 pink salmon.

A plot of the catch ratios, C/c_1 on c_2/c_1 is shown in Figure 5. In computing the regression constants, each point was weighted according to the weighting function shown in the Figure 5. This weighting function arose from two considerations. First, in those instances where the difference in catch between the 6-h unit and the sum of catches of the two 3-h units is large, there is some reason to suspect that the number of fish available to units of gear fishing simultaneously is not the same. Hence, those points should receive less weight in the regres-

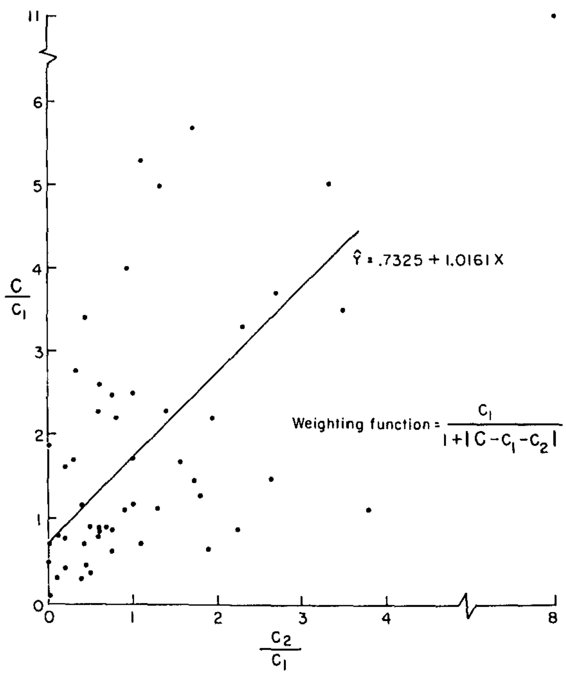

FIGURE 5.—Regression of C/c_1 on c_2/c_1. C is the catch in the 6-h unit, c_1, the catch in the first 3-h unit and c_2, the catch in the second 3-h unit.

TABLE 3.—Salmon catches by time periods, 1 June to 2 July 1965.

Research vessel and date	Sampling location		Time period (see Fig. 2)	Catch		
	Lat. N	Long. W		1st 3-h unit (c_1)	6-h unit (C)	2d 3-h unit (c_2)
RV *George B. Kelez*:						
6/6	53°23′	166°05′	I	8	1	0
			III	2	7	7
6/7	53°01′	166°03′	I	49	92	0
			III	18	50	6
6/8	53°06′	166°00′	I	13	69	14
			II	14	16	18
			III	18	21	7
6/14	53°07′	166°37′	I	38	44	38
			II	38	87	22
			III	22	38	6
6/15	52°55′	167°43′	I	100	107	91
6/22	55°50′	164°00′	I	73	65	36
			II	36	13	18
			III	18	9	0
6/23	56°10′	162°31′	I	22	49	17
			II	17	28	3
			III	3	17	5
6/25	57°01′	159°58′	I	25	57	35
			II	35	23	67
			III	67	112	105
7/2	56°24′	162°00′	II	44	40	30
			III	30	38	54
MV *Paragon*:						
6/1	53°43′	160°44′	I	3	10	7
			II	7	12	7
			III	7	24	3
6/7	53°20′	165°52′	I	167	129	19
			II	19	13	0
6/8	53°26′	165°57′	I	170	147	105
6/12	52°52′	166°12′	I	5	13	3
			II	3	15	4
			III	4	10	3
6/14	53°15′	166°38′	III	67	21	7
6/15	52°57′	167°41′	I	53	33	40
			II	40	160	37
			III	37	27	40
6/18	53°16′	166°15′	I	9	4	2
6/21	55°48′	160°31′	I	61	18	23
			II	23	20	14
			III	14	11	8
6/22	55°55′	164°00′	I	3	15	10
6/23	56°06′	162°30′	I	44	50	166
			II	166	130	31
			III	31	14	14
6/25	56°37′	161°30′	I	89	132	235
6/28	57°06′	161°56′	II	7	5	3
			III	3	11	8
6/29	56°47′	161°25′	I	15	22	26
7/1	56°30′	161°05′	I	1	11	8
			II	8	7	6
			III	6	15	6
7/2	56°17′	162°00′	II	8	7	18
			III	18	40	35
		Total	52	1,778	2,109	1,467

sion analysis. Secondly, since the measure of dropout refers to the fish which enter the 6-h unit during the first 3-h period and disappear during the second 3-h period, it seems reasonable to weight more heavily those points in which large numbers of fish entered during the first 3-h period.

The resulting weighted regression line is shown in Figure 5. In spite of the apparent wide scattering of points, the relation is significant at the 5% level ($t = 8.48$). The estimate of loss of salmon from the gill nets is 27% for the 3-h period; the 80% confidence interval is from 5 to 48%.

In the model used in estimating dropouts during a 3-h interval, we have assumed that salmon entered the nets 1½ h prior to the beginning of the second 3-h interval. If, on the other hand, we postulate that the majority of the salmon entered the nets either prior to or after the assumed 1½ h, an increased or decreased time interval is available for salmon to drop from nets during the 3-h period. Our estimate of dropouts now would be either lower or higher than that of the original model. A test of these hypotheses was inconclusive. Dropout rates were estimated at 15 and 35% for the two new assumptions of time of entry into the nets, but in neither instance was the rate significant.

When fishing the experimental dropout sets, we frequently observed northern fur seals, *Callorhinus ursinus*, and Steller sea lions, *Eumetopias jubatus*, swimming along the nets and taking fish. We frequently observed seabirds near the nets and we often took salmon sharks, *Lamna ditropis*, in the gill nets. Removal of fish from the nets by these animals was a factor we could not differentiate from actual salmon dropouts from the nets. Both factors, however, lead to loss of salmon from gill nets. As a matter of fact, the gill nets served to collect and hold salmon for predators and carrion eaters. We do not know if sea lions and fur seals could catch salmon as easily through their own efforts compared to having gill net-caught fish available. We concluded from these experiments, therefore, that there was loss of salmon from gill nets that was due to predation (removal of fish by predators and carrion eaters) and dropouts.

In the experiments to determine dropouts in 1964 and 1965, our technique involved indirect methods and assumptions of equal availability of salmon to units of gill nets fished during varying time periods and that all nets fished with equal efficiency. In 1965, the experiments were limited to estimates of dropouts over a 3-h period. To overcome these limitations, we attempted in subsequent experiments to observe salmon in the nets and determine dropouts by direct observation.

Direct Observations (1966-69)

1966.—In the summer of 1966, the loss of salmon from gill nets was estimated by direct observation. Three vessels fished with gill nets in July, August, and in early September along three sampling lines: long. 176°22′W, 167°W, and 158°W. In this technique, as outlined under the section of "Experimental Methods," we observed fish in the net from small boats, marked their position in the net with colored tags, and determined their presence or absence at subsequent time periods and at haul.

The experimental gill nets included 4 shackles of 133-mm, 3 of 114-mm, 4 of 83-mm, and 3 of 64-mm nets when the first 14 shackles of the string were observed. The net sequence was 133, 83, 114, 64 mm. In some sets not all nets were observed because of inclement weather or other factors. In any event, however, a range of mesh sizes was observed to include observations on age .1 immature salmon and on the larger .2 and older immatures.

In 1966 we made 28 observations for dropouts (Table 4). Each observation entailed one to three patrols of the net, some of which were not completed because of rough seas. There were 28 first patrols, 27 second patrols, and 16 third patrols.

Combining data from all observations, the overall dropout rate was substantial, 42.5% (95% confidence interval ±5.6) for periods up to 11 h (Table 5). After 1 h the rate was 3.7% (±5.1), and 14.9% (±7.9) for periods up to 2½ h. The rates for varying time periods were generally similar for the two combinations of mesh sizes. An exception was the 8% (±7.7) dropout rate of the large mesh sizes for periods up to 2½ h compared with 22.7% (±14.6) for the smaller mesh sizes. Typically, the large mesh nets take age .2 and older salmon with immature sockeye and chum salmon dominating catches in the summer. The small mesh sizes take mainly age .1 immature sockeye and chum salmon in the summer. Thus, overall dropout rates appeared to be about the same for small fish as for large fish.

The data suggested little difference in loss rates among the three vessels. The total rate of loss in the large mesh nets ranged from 42.3% (MV *Paragon*) to 48.1% (MV *St. Michael*). In the small mesh nets, overall loss rates were 39.6% for the *Paragon* and 45.7% for the *St. Michael* (and was 22.2% for RV *George B. Kelez*, but only 10 fish were marked).

TABLE 4.—Number of salmon marked and observed in gill nets over varying periods of time by mesh size, summer 1966.

Vessel and date	Sets	Position: Lat. N	Position: Long. W	Observation no.	114- and 133-mm mesh: No. fish marked	Number of fish observed after marking: Up to 1 h	Up to 2½ h	Up to 11 h[1]	64- and 83-mm mesh: No. fish marked	Number of fish observed after marking: Up to 1 h	Up to 2½ h	Up to 11 h[1]	Total marked fish	Total recovered fish
RV *George B. Kelez:*														
7/20	24	51°30′	166°59′	(a)	3	—	3	3	1	—	—	0	4	3
				(b)	2	—	—	2	1	—	—	1	3	3
7/29	32	51°31′	167°00′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	1	—	1	0	2	—	2	1	3	1
				(c)	0	—	—	—	0	—	—	—	0	0
8/19	48	49°29′	167°00′	(a)	0	—	—	—	3	3	—	3	3	3
				(b)	0	—	—	—	1	—	—	1	1	1
9/01	56	49°30′	167°01′	(a)	1	1	—	0	[2]2	2	—	1	3	1
				(b)	4	—	—	0	0	—	—	—	4	0
9/02	57	49°02′	167°04′	(a)	1	1	—	1	0	—	—	—	1	1
				(b)	1	—	—	1	0	—	—	—	1	1
MV *Paragon:*														
6/27	2	51°15′	176°22′	(a)	0	—	—	—	3	3	2	0	3	0
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	1	—	—	0	3	—	—	0	4	0
6/28	3	51°00′	176°22′	(a)	2	2	2	1	0	—	—	—	2	1
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	5	—	—	3	0	—	—	—	5	3
6/29	4	50°45′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	1	—	1	1	1	—	1	0	2	1
				(c)	3	—	—	3	1	—	—	1	4	4
6/30	5	50°30′	176°25′	(a)	0	—	—	—	1	0	0	0	1	0
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	0	—	—	—	2	—	—	0	2	0
7/14	15	50°22′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	2	—	2	0	4	—	3	1	6	1
				(c)	2	—	—	2	0	—	—	—	2	2
7/15	16	50°37′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	2	—	—	2	1	—	—	1	3	3
7/18	19	51°22′	176°22′	(a)	3	2	2	0	1	1	0	0	4	0
				(b)	1	—	0	0	4	—	3	0	5	0
				(c)	0	—	—	—	1	—	—	0	1	0
7/24	23	51°30′	176°22′	(a)	9	9	9	6	1	1	1	1	10	7
				(b)	0	—	—	—	1	—	1	0	1	0
				(c)	9	—	—	5	35	—	—	32	44	37
7/26	25	51°00′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	2	—	—	1	4	—	—	2	6	3
8/05	33	50°45′	176°22′	(a)	1	1	1	1	1	1	1	0	2	1
				(b)	1	—	1	0	1	—	1	1	2	1
				(c)	3	—	—	2	4	—	—	2	7	4

TABLE 4.—*Continued.*

Vessel and date	Sets	Position: Lat. N	Position: Long. W	Observation no.	114- and 133-mm mesh: No. fish marked	114- and 133-mm mesh: Number of fish observed after marking: Up to 1 h	Up to 2½ h	Up to 11 h[1]	64- and 83-mm mesh: No. fish marked	64- and 83-mm mesh: Number of fish observed after marking: Up to 1 h	Up to 2½ h	Up to 11 h[1]	Total marked fish	Total recovered fish
8/11	37	51°30′	176°22′	(a)	2	—	—	0	0	—	—	—	2	0
				(b)	2	—	—	0	1	—	—	1	3	1
8/12	38	51°15′	176°22′	(a)	1	—	1	0	5	—	4	4	6	4
				(b)	5	—	—	2	13	—	—	7	18	9
8/15	41	50°30′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	1	—	0	0	0	—	—	—	1	0
				(c)	2	—	—	0	0	—	—	—	2	0
8/16	42	50°15′	176°22′	(a)	7	7	7	7	3	3	3	1	10	8
				(b)	3	—	3	3	1	—	1	1	4	4
				(c)	3	—	—	3	2	—	—	1	5	4
8/17	43	50°00′	176°22′	(a)	2	2	—	2	3	3	—	3	5	5
				(b)	0	—	—	—	1	—	—	0	1	0
8/24	47	51°30′	176°22′	(a)	0	—	—	—	0	—	—	—	0	0
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	3	—	—	1	3	—	—	2	6	3
MV *St. Michael*														
7/18	6	49°20′	158°00′	(a)	1	1	—	1	0	—	—	—	1	1
				(b)	0	—	—	—	1	—	—	1	1	1
7/19	7	50°37′	158°01′	(a)	1	1	1	0	0	—	—	—	1	0
				(b)	3	—	—	2	1	—	—	1	4	3
				(c)	2	—	—	2	2	—	—	2	4	4
7/21	9	52°32′	158°00′	(a)	1	1	1	1	5	5	5	4	6	5
				(b)	1	—	1	1	2	—	1	1	3	2
				(c)	4	—	—	2	1	—	—	1	5	3
7/22	10	53°30′	158°00′	(a)	2	2	2	2	0	—	—	—	2	2
				(b)	0	—	—	—	0	—	—	—	0	0
				(c)	5	—	—	5	1	—	—	1	6	6
7/24	12	55°07′	158°00′	(a)	0	—	—	—	2	—	0	0	2	0
				(b)	18	—	—	0	7	—	—	0	25	0
8/25	28	52°00′	158°00′	(a)	9	—	8	7	6	—	5	3	15	10
				(b)	3	—	—	2	6	—	—	4	9	6
8/26	29	51°05′	158°00′	(a)	8	—	—	[3]3	13	—	—	[2]7	21	10

[1] A dash (—) indicates the net was not examined at the time interval.
[2] One tag missing at haul; treated as missing observation and not included in totals.
[3] Four tags missing at haul; treated as missing observation and not included in totals.

TABLE 5.—Number of salmon marked and observed in multifilament gill nets over varying periods of time by mesh size and area, 1966.

Nets and area (long.)	Vessel	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2½ h later	Up to 11 h later
114- and 133-mm mesh:					
176°W	MV *Paragon*	78	23 (24)	29 (32)	45 (78)
	Percentage loss		4.2	9.4	42.3
167°W	RV *George B. Kelez*	13	2 (2)	4 (4)	7 (13)
	Percentage loss		0	0	46.2
158°W	MV *St. Michael*	58	5 (5)	13 (14)	28 (54)
	Percentage loss		0	7.1	48.1
	Total	149	30 (31)	46 (50)	80 (145)
	Percentage loss and 95% confidence interval		3.2 ± 6.4	8.0 ± 7.7	44.8 ± 8.2
64- and 83-mm mesh:					
176°W	*MV Paragon*	101	12 (13)	21 (27)	61 (101)
	Percentage loss		7.7	22.2	39.6
167°W	RV *George B. Kelez*	10	5 (5)	2 (2)	7 (9)
	Percentage loss		0	0	22.2
158°W	MV *St. Michael*	47	5 (5)	11 (15)	25 (46)
	Percentage loss		0	26.7	45.7
	Total	158	22 (23)	34 (44)	93 (156)
	Percentage loss and 95% confidence interval		4.3 ± 8.6	22.7 ± 14.6	40.4 ± 7.7
	Grand total (both mesh sizes)	307	52 (54)	80 (94)	173 (301)
	Percentage loss and 95% confidence interval		3.7 ± 5.1	14.9 ± 7.9	42.5 ± 5.6

[1] Number of possible observations (figures in parentheses) for the time periods; difference from the number marked is because some observations were not made during rough weather.

1967.—Studies of loss from gill nets fished on the high seas were continued in 1967 in the same manner as in 1966. Because of inclement weather, only five gill net sets were observed for dropouts; however, the number of patrols during each set was increased over 1966.

Observations were made from one research vessel operating south of Adak Island (long. 176°W) in June-August. Eleven nets were patrolled: two each of 133-mm monofilament and 133-mm multifilament nets, two each of 114-mm monofilament and 114-mm multifilament nets, two 83-mm multifilament nets, and one 64-mm multifilament net. This combination of mesh sizes and net materials allowed comparisons of loss rates of small and large fish and comparisons between large mesh multifilament and monofilament gill nets. Not all of the 14 nets were patrolled during each set because of weather or mechanical problems. The large mesh multifilament nets were patrolled five times as opposed to three times for the small mesh nets.

Results of the dropout experiments in 1967 are listed in Table 6. Overall loss rates were nearly 11% (± 6.8) for periods up to 1 h, 17% (±10.1) for up to 2½ h, 58% (±18.0) for up to 5 h, and 64% (±9.7) for up to 10 h. The loss rates for large mesh nets (multi- and monofilament combined) were nearly 58% (for up to 10 h) as opposed to 83% for small mesh nets (although sample sizes for the latter were small).

The dropout rates of monofilament and multi-

TABLE 6.—Numbers of salmon marked and observed in gill nets of varying periods of time, July-August 1967.

Nets and set no.	Date hauled	Set position	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2½ h later	Up to 5 h later	Up to 10 h later
114- and 133-mm mesh nets (multifilament):							
6	6/29	Lat. 48°00'N	6	3	—	3	1
		Long. 176°22'W	1	1	—	1	1
			4	—	4	4	—
12	7/13	Lat. 50°45'N Long. 176°22'W	1	—	—	—	1
21	8/01	Lat. 51°40'N Long. 176°22'W	1	1	1	0	0
25	8/05	Lat. 50°45'N	2	2	1	—	0
		Long. 176°22'W	1	1	1	—	0
			3	3	3	—	0
			4	3	—	—	0
26	8/15	Lat. 51°30'N	2	2	2	—	0
		Long. 176°22'W	1	0	—	—	0
		Total	26	16 (21)	12 (13)	8 (12)	3 (22)
		Percentage loss and 95% confidence interval		23.8±17.9	7.7±15.2	33.3±26.8	86.4±11.2
114- and 133-mm mesh nets (monofilament):							
12	7/13	Lat. 50°45'N Long. 176°22'W	1	—	—	—	1
21	8/01	Lat. 51°40'N Long. 176°22'W	2	2	2	0	0
25	8/05	Lat. 50°45'N	2	2	1	—	1
		Long. 176°22'W	2	2	1	—	1
			1	1	1	—	0
			1	1	—	—	1
26	8/15	Lat. 51°30'N	9	9	8	—	6
		Long. 176°22'W	13	11	10	—	7
			2	2	—	—	2
			4	4	—	—	3
		Total	37	34 (36)	23 (29)	0 (2)	22 (37)
		Percentage loss and 95% confidence interval		5.6± 7.7	20.7±14.9	100	40.6±15.3
64- and 83-mm mesh nets (multifilament):							
21	8/01	Lat. 51°40'N	1	1	1	0	0
		Long. 176°22'W	4	4	—	0	0
25	8/05	Lat. 50°45'N	1	1	0	—	0
		Long. 176°22'W	4	3	3	—	0
			1	1	1	—	0
			2	2	—	—	0
26	8/15	Lat. 51°30'N Long. 176°22'W	5	5	5	—	3
		Total	18	17 (18)	10 (12)	0 (5)	3 (18)
		Percent loss and 95% confidence interval		5.6±10.9	16.7±21.0	100	83.3±12.8
		Grand total (all mesh sizes)	81	67 (75)	45 (54)	8 (19)	28 (77)
		Percentage loss and 95% confidence interval		10.7± 6.8	16.7±10.1	57.9±18.0	63.6± 9.7

[1] A zero (0) indicates that the net was examined, but no marked fish were observed; a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because some observations were not made in some periods.

filament nets are also listed in Table 6. Loss rates for fish observed up to 10 h were 86% in the large multifilament nets as opposed to 41% for monofilament nets of the same mesh size.

1968.—Studies on the loss of salmon from gill nets in 1968 were concentrated on maturing fish in May and June, south of Unalaska Island (long. 164°W). The procedures used to estimate loss of salmon were the same as used in 1966 and 1967. The net string consisted of five mesh sizes (64-, 83-, 98-, 114-, and 133-mm mesh) of multifilament net, all of which were observed for dropouts. Two shackles of monofilament nets (133-mm mesh) were also observed for comparison with multifilament nets.

Overall loss rates were zero up to 1 h, 4.7% (±6.3) up to 2 h, and 20.4% (±7.8) for up to 10 h (Table 7). Rates of loss for periods up to 10 h were nearly 18% (± 9.9) for multifilament nets and 22% (± 14.5) for monofilament nets; the difference was not significant. This similar loss rate for monofilament nets as opposed to multifilament nets contrasts to the loss rate of the two types of gear in 1967 on immature fish (41% loss for monofilament nets and 86% for multifilament nets).

Compared to the 1966 and 1967 studies of losses of primarily immature salmon, the dropout rates of maturing fish in 1968 were much smaller. Possibly this reduction in dropout rate in 1968 was due to unusually calm seas and partly to the fact that the experiments were on maturing fish taken in large mesh nets as opposed to immature salmon in large and small mesh nets in 1966 and 1967.

1969.—Studies of the loss of salmon from gill nets in 1969 were conducted in April and May on maturing salmon and in July on immature salmon.

Because of inclement weather in April and May, we were able to patrol the net string and mark the position of salmon in the nets in only four different sets. Eight nets were observed: one each of 114- and 133-mm monofilament nets and two each of 98-, 114-, and 133-mm multifilament nets (in one set, a single 64-mm multifilament net was also observed). Only 13 salmon were marked in the four sets; no loss was observed up to 1, 2, or 5 h (Table 8). A loss of two fish (15.4%) was recorded for periods up to 10 h.

In July, experiments on immature salmon were conducted south of Adak Island (long. 176°W) during three sets. Eight nets were patrolled: two 114-mm monofilament nets and three each of 114- and 133-mm multifilament nets. Comparison of loss rates was made between monofilament and multifilament nets (Table 9).

The loss rate in the monofilament nets was over twice that of the multifilament nets for the relatively small sample sizes (46% vs. 22% for periods up to 10 h). The combined loss was 35% (±14.8) up to 10 h; it was 15% (±13.6) up to 1 h and 25% (±21.4) up to 2 h. The total loss rate in the large nets was smaller than that observed in 1966 and 1967.

SUMMARY.—The total number of salmon marked and observed by direct methods over varying periods of time, by mesh size and year, are presented in Table 10. In 4 yr of experiments, 534 fish were marked. Overall loss rates for periods up to 11 h were about 41% (±4.0). Loss rates were about 6% (±3.4) up to 1 h and 14% (±4.4) up to 2½ h. The loss rate of about 52% (±16.2) for periods up to 5 h was greater than the rates for up to 11 h. However, this loss rate for up to 5 h was based on only 21 fish marked, whereas the loss rate for up to 11 h was based on 524 fish marked. The data indicated that losses of salmon continued with time in the net.

Losses from small mesh (64- and 83-mm) multifilament nets, which capture mainly the small age .1 immature salmon, were similar to losses from the large mesh multifilament nets (45% vs. 41%). Loss rates from the small mesh nets were similar to those of large mesh nets for periods up to 1 h (5 and 6%, respectively) and were greater than for the large mesh multifilament nets up to 2½ h (21 and 7%, respectively).

Comparisons of the loss rates of large mesh multifilament nets as opposed to large mesh monofilament nets indicated that, for periods

TABLE 7.—Number of salmon marked and observed in gill nets over varying periods of time, May and June 1968.

Nets and set no.	Date hauled	Set position	No. fish marked during patrols	Number of fish observed after marking[1]		
				Up to 1 h later	Up to 2 h later	Up to 10 h later
Multifilament nets (98-, 114-, and 133-mm mesh)[2]:						
17	5/28	Lat. 50°25′N	1	1	1	1
		Long. 168°43′W	3	3	3	3
19	5/31	Lat. 50°59′N	1	1	1	1
		Long. 164°01′W	3	3	—	3
			5	—	—	4
20	6/03	Lat. 52°58′N	3	3	—	3
		Long. 164°00′W	4	—	—	3
22	6/05	Lat. 53°30′N	15	15	15	12
		Long. 164°00′W	18	18	—	15
			4	—	—	2
		Total	57	44 (44)	20 (20)	47 (57)
		Percentage loss and 95% confidence interval		0	0	17.6± 9.9
Monofilament nets (133-mm mesh):						
17	5/28	Lat. 50°25′N Long. 168°43′W	1	1	—	1
19	5/31	Lat. 50°59′N Long. 164°01′W	1	1	1	1
20	6/03	Lat. 52°58′N Long. 164°00′W	5	—	—	3
22	6/05	Lat. 53°30′N	21	21	19	17
		Long. 164°00′W	2	2	—	2
			2	—	—	1
		Total	32	25 (25)	20 (22)	25 (32)
		Percentage loss and 95% confidence interval		0	9.1± 12.7	21.9± 14.5
Multifilament nets (64- and 83-mm mesh):						
17	5/28	Lat. 50°25′N	1	1	1	0
		Long. 168°43′W	1	1	—	1
19	5/31	Lat. 50°59′N Long. 164°01′W	1	—	—	1
20	6/03	Lat. 52°58′N Long. 164°00′W	1	—	—	0
		Total	4	2 (2)	1 (1)	2 (4)
		Percentage loss		0	0	50.0
		Grand total (all mesh sizes)	93	71 (71)	41 (43)	74 (93)
		Percentage loss and 95% confidence interval		0	4.7± 6.3	20.4± 7.8

[1] A zero (0) indicates that the net was examined, but no marked fish were observed; a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because some observations were not made in rough weather.
[2] Only one fish was marked in the 98-mm mesh nets.

up to 11 h, loss rates from the former exceeded the latter (41% vs. 33%) although the difference was not statistically significant.

Comparisons of rates of loss of immature and maturing salmon present some difficulty because we do not know the maturity status of those fish initially marked which are subsequently lost from the nets. We may rationally

TABLE 8.—Number of salmon marked and observed in gill nets over varying periods of time, April and May 1969.

Nets and set no.	Date hauled	Set position	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2 h later	Up to 5 h later	Up to 10 h later
98,-114-,and 133-mm mesh nets (multifilament):							
1	4/25	Lat. 55°10'N Long. 155°00'W	1	1	—	—	0
11	5/09	Lat. 51°00'N Long. 165°00'W	3	—	3	1	2
12	5/10	Lat. 52°10'N Long. 165°00'W	1	—	—	—	1
		Total	5	1 (1)	3 (3)	1 (1)	3 (5)
		Percentage loss		0	0	0	40.0
114- and 133-mm mesh nets (monofilament):							
1	4/25	Lat. 55°10'N Long. 155°00'W	1	—	—	—	1
9	5/07	Lat. 49°00'N Long. 165°00'W	3 1	3 —	3 —	— —	3 1
11	5/09	Lat. 51°00'N Long. 165°00'W	1	—	1	1	1
12	5/10	Lat. 52°10'N Long. 165°00'W	1	—	—	—	1
		Total	7	3 (3)	4 (4)	1 (1)	7 (7)
		Percentage loss		0	0	0	0
64- and 98-mm mesh nets (multifilament):							
9	5/07	Lat. 49°00'N Long. 165°00'W	1	—	—	—	1
		Total	1	— (—)	— (—)	— (—)	1 (1)
		Percentage loss		0	0	0	0
		Grand total	13	4 (4)	7 (7)	2 (2)	11 (13)
		Percentage loss		0	0	0	15.4

[1]A zero (0) indicates that the net was examined, but no marked fish were observed; a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because some observations were not made in rough weather.

assume, however, that the overwhelming majority of salmon caught in the small mesh nets (64- and 83-mm) are immature fish. The larger mesh nets (98-, 114-, and 133-mm), however, capture both maturing and immature salmon, depending on the season and availability of each group. The studies conducted in the spring of 1968 and 1969 were primarily on maturing salmon. By comparing the rate of loss of salmon from small mesh nets in 1966 and 1967 (and in July 1969) with the loss rates of salmon from large mesh nets in the spring of 1968 and 1969, we may effectively compare the loss rates of immature and maturing salmon (Table 11).

Overall loss rates for mature salmon were 0, 4% (±8.9), and 0 for three periods (1, 2½, and 5 h) and about 20% (±7.5) for periods up to 11 h (Table 11). Immature losses were 9% (±4.3), 17% (±5.6), 58% (±18.0), and 46% (±4.6) for the corresponding time periods. Overall loss rates were similar for mature fish in large mesh mono- and multifilament nets (19 and 18%), as were the rates for immature salmon in the same nets (48 and 42%, respectively). Loss rates of immatures in small mesh multifilament nets (45%) were also similar to the loss rates of immatures in the large mesh mono- and multifilament nets (42 and 48%, respectively).

TABLE 9.—Number of salmon marked and observed in gill nets over varying periods of time, July 1969.

Nets and set no.	Date hauled	Set position	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2 h later	Up to 10 h later
Multifilament nets (114- and 133-mm mesh):						
17	7/21	Lat. 51°32′N Long. 176°22′W	2	2	—	0
21	7/25	Lat. 50°10′N Long. 176°22′W	9 6	8 6	8 —	8 6
25	7/29	Lat. 51°35′N Long. 176°22′W	1	—	—	0
		Total	18	16 (17)	8 (9)	14 (18)
		Percentage loss and 95% confidence interval		5.9 ± 12.0	11.1 ± 23.7	22.2 ± 11.3
Monofilament nets (114-mm mesh):						
17	7/21	Lat. 51°32′N Long. 176°22′W	3	2	2	0
21	7/25	Lat. 50°10′N Long. 176°22′W	4 2	2 2	2 —	2 2
25	7/29	Lat. 51°35′N Long. 176°22′W	13	—	—	8
		Total	22	6 (9)	4 (7)	12 (22)
		Percentage loss and 95% confidence interval		33.3 ± 35.5	42.9	45.5 ± 19.8
		Grand total	40	22 (26)	12 (16)	26 (40)
		Percentage loss and 95% confidence interval		15.4 ± 13.6	25.0 ± 21.4	35.0 ± 14.8

[1] A zero (0) indicates that the net was examined, but no marked fish were observed: a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because, some observations were not made in some periods.

The results showed that for many of the 1-h and 2-h time periods the 95% confidence interval included zero indicating that the estimated loss rates were not significantly greater than zero. Similarly, the width of the confidence intervals indicated that the estimated losses for some adjacent time periods would not be considered to be significantly different. The point estimates, however, showed an increase in loss rates with time indicating that in general the longer the fish were in the nets the greater likelihood there was for the fish to drop out.

Because we could not determine species readily during the process of marking the location of salmon in the nets, we could not identify dropouts as to species. During the 1966-69 experiments, sockeye and chum salmon made up over 70% of the catches and thus these species most likely were the species escaping the nets. Undoubtedly, in a salmon gill net fishery, dropout rates would be applicable to those species which make up the bulk of the catches.

The above summary of dropout rates for all experiments includes losses due to predation as well as to dropouts. The effect on predation on dropout loss is examined in the next section.

Effects of Predation on Dropout Rates

The methods used in this study to estimate the loss of salmon due to gillnetting fail to differentiate between losses due to predation and losses due to disentanglement. The subject of losses due to predation apparently has not been considered by other authors (e.g., Doi, 1962; Konda, 1966; Ishida et al., 1969).

There is evidence, however, that predators

TABLE 10.—Total number of salmon marked and observed over varying periods of time by mesh size, material, and year, 1966-69.

Mesh size and year	Maturity	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2½ h later	Up to 5 h later	Up to 11 h later
98-, 114-, and 133-mm mesh (multifilament):						
1966	Immature	149	30 (31)	46 (50)	— —	80 (145)
1967	Immature	26	16 (21)	12 (13)	8 (12)	3 (22)
1968	Mature	57	44 (44)	17 (17)	— —	47 (57)
1969	Mature	5	1 (1)	3 (3)	1 (1)	3 (5)
	Immature	18	16 (17)	8 (9)	— —	14 (18)
	Total	255	107 (114)	86 (92)	9 (13)	147 (247)
	Percentage loss and 95% confidence interval		6.2 ± 4.4	6.5 ± 5.2	30.8 ± 27.1	40.5 ± 5.7
114- and 133-mm mesh (monofilament):						
1967	Immature	37	34 (36)	23 (29)	0 (2)	22 (37)
1968	Mature	32	25 (25)	20 (22)	— —	25 (32)
1969	Mature	7	3 (3)	4 (4)	1 (1)	7 (7)
	Immature	22	6 (9)	4 (7)	— —	12 (22)
	Total	98	68 (73)	51 (62)	1 (3)	66 (98)
	Percentage loss and 95% confidence interval		6.9 ± 5.4	17.8 ± 9.3	(66.7)	32.7 ± 9.0
64- and 83-mm mesh (multifilament):						
1966	Immature	158	22 (23)	34 (44)	— —	93 (156)
1967	Immature	18	17 (18)	10 (12)	0 (5)	3 (18)
1968	Mature	4	2 (2)	1 (1)	— —	2 (4)
1969	Mature	1	— (—)	— (—)	— (—)	1 (1)
	Total	181	41 (43)	45 (57)	0 (5)	99 (179)
	Percentage loss and 95% confidence interval		4.7 ± 6.5	21.1 ± 10.8	100	44.7 ± 7.1
	Grand Total	534	216 (230)	182 (211)	10 (21)	312 (524)
	Percentage loss and 95% confidence interval		6.1 ± 3.4	13.8 ± 4.4	52.4 ± 16.2	40.5 ± 4.0

[1] A zero (0) indicates that the net was examined, but no marked fish were observed; a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because some observations were not made in rough weather.

TABLE 11.—Total number of salmon marked and observed over varying periods of time by maturity, mesh size, material, and year, 1966-69.

Mesh size and maturity	Years	No. fish marked during patrols	Number of fish observed after marking[1] Up to 1 h later	Up to 2½ h later	Up to 5 h later	Up to 11 h later
Large mesh multifilament nets (98-, 114-, and 133-mm mesh):						
Mature	1968-69	62	45	20	1	50
			(45)	(20)	(1)	(62)
	Percentage loss and 95% confidence interval		0	0	0	19.4 ± 9.9
Immature	1966-67, 1969	193	62	66	8	97
			(69)	(72)	(12)	(185)
	Percentage loss and 95% confidence interval		10.1 ± 6.9	8.3 ± 6.5	33.3 ± 29.7	47.6 ± 6.9
Large mesh monofilament nets (114- and 133-mm mesh):						
Mature	1968-69	39	28	24	1	32
			(28)	(26)	(1)	(39)
	Percentage loss and 95% confidence interval		0	7.7 ± 10.7	0	17.9 ± 12.1
Immature	1967, 1969	59	40	27	0	34
			(45)	(36)	(2)	(59)
	Percentage loss and 95% confidence interval		11.1 ± 8.9	25.0 ± 14.3	100	42.4 ± 12.9
Small mesh multifilament nets (64- and 83-mm mesh):						
Mature	1968-69	5	2	1	—	3
			(2)	(1)	—	(5)
	Percentage loss		0	0	—	40.0
Immature	1966-67	176	39	44	0	96
			(41)	(56)	(5)	(174)
	Percentage loss and 95% confidence interval		4.9 ± 6.8	21.4 ± 10.9	100	44.8 ± 7.2
Total (all mesh sizes):						
Mature	1968-69	106	75	45	2	85
			(75)	(47)	(2)	(106)
	Percentage loss and 95% confidence interval		0	4.3 ± 8.9	0	19.8 ± 7.5
Immature	1966-67, 1969	428	141	137	8	227
			(155)	(164)	(19)	(418)
	Percentage loss and 95% confidence interval		9.0 ± 4.3	16.5 ± 5.6	57.9 ± 18.0	45.7 ± 4.6

[1] A zero (0) indicates that the net was examined, but no marked fish were observed; a dash (—) indicates that the net was not examined. Numbers in parentheses indicate number of possible observations for the time period; difference from the number marked is because some observations were not made in rough weather.

and carrion eaters could affect dropout rates. During the haul of gill nets, and in early morning hours, we often observe Steller sea lion, northern fur seal, and seabirds along the net string feeding on enmeshed salmon. Obviously, these animals could affect the results of the dropout experiments if they took marked salmon. An example of suspected sea lion predation was observed when, on one occasion in 1966, 25 salmon were marked between hours of 2254 and 2320; not a single salmon was present at the marked positions when the nets were hauled at 0730. Sea lions were observed along the nets on this occasion. On other occasions, while patrolling the gill nets at night during dropout studies, we have observed sea lions cruising the net and taking salmon.

Steller sea lions are probably the most flagrant predators. Although examination of their stomach contents has shown only occasional salmon (Pike, 1958; Mathisen, Baade, and Lopp, 1962; Thorsteinson and Lensink, 1962; Fiscus and Baines, 1966), there

TABLE 12.—Decoy loss rates in relation to distance from shore, spring and summer 1968-70.

Year	Season	No. of sets	No. of decoys set	No. of decoys recovered	Percentage loss	% sets predators observed[1]
			≤145 km from shore			
1968	Spring	4	92	46	50.0	100
	Summer	21	394	71	82.0	81
1969	Spring	8	147	55	62.6	88
	Summer	34	663	317	52.2	94
1970	Spring	6	108	46	57.4	100
	Summer	16	320	209	34.7	94
Total		89	1,724	744	56.9	91
			>145 km from shore			
1968	Spring	10	183	149	18.6	80
	Summer	10	196	114	41.8	70
1969	Spring	13	260	195	25.0	77
	Summer	9	180	124	31.1	89
1970	Spring	14	266	215	19.2	93
	Summer	4	80	68	15.0	25
Total		60	1,165	865	25.8	78
Overall total or mean		149	2,889	1,609	44.3	86

[1]Potential predators or carrion eaters include: fur seal, sea lion, albatross, shark, porpoise.

TABLE 13.—Numbers of salmon marked and observed for varying periods of time for sets far offshore (>145 km).

Years	Number marked	Number observed after marking[1]			
		Up to 1 h	Up to 2½ h	Up to 5 h	Up to 11 h
1966-69	181	62 (66)	56 (62)	9 (12)	121 (173)
Percentage loss		6.1	9.7	25.0	30.1

[1] Number of possible observations for time period indicated in parentheses.

is evidence that sea lions rob salmon from gill nets and trolling gear (Pike, 1958; Thorsteinson, Nelson and Lall, 1961) and cause damage to gear. Furthermore, some authors (Mathisen, 1959; Tikhomirov, 1964) feel that sea lions may be attracted to areas where fishing boats are operating.

During our experimental gillnetting in the central Aleutians over a number of years, sea lions have been observed around gill nets much more frequently at inshore (within 145 km) than at offshore stations (Table 12). During studies of predation (French et al., 1970, 1971, 1972) in which frozen "decoy" salmon were tied to the nets when they were set and the numbers remaining counted at haul, the percentage loss of decoys was smaller at distances greater than 145 km than at stations closer to shore (26% vs. 57%, see Table 12).

These studies, though, were not conclusive when applied to the dropout data. For example, the mean decoy loss rate for all stations (44%) was similar to the average loss (40.5%) of salmon marked in gill nets (Tables 10, 12). In addition, the decoy loss rate beyond 145 km (26%) was similar to the dropout loss (30%) for the same area (Tables 12, 13).

As French et al. (1970, 1971, 1972) pointed out, the results of the decoy studies are difficult to relate to actual gill net catches. For example, the decoy fish normally were exposed to predators and carrion eaters from the time the gear was set (at about 2000 h) until completion of haul at about 1000 h, whereas salmon are not normally caught in gill nets on the high seas until dark and would, therefore, be subjected to predation for fewer hours than the decoy fish. The food preference of some animals may also vary between the dead decoy fish and the live gill net-caught salmon. Percentages of decoy fish removed by these animals therefore, may not be directly comparable to predation upon fish captured by gill nets. The possibility exists that the presence of decoy fish attached to the gill nets when they are set may attract predators and carrion eaters and, therefore, increase the incidence of predation.

To study further the relation between decoy losses and dropouts, we examined losses of decoys and salmon marked for dropout studies in 10 gill net sets in which dropout and decoy loss studies were conducted simultaneously. In these sets the decoys were generally attached near the distal end of the net string from the vessel, and salmon were marked for dropout studies at the proximal end of the string. Of these 10 sets, three showed no decoy loss but did have a mean total dropout loss of 11.8% (Table 14). The remaining seven sets had a mean total dropout loss of 27.3%, but also had a mean decoy loss rate of 36.4% (Table 14). Thus, if we accept a zero loss of decoy fish as evidence of no predation, we have evidence of dropout loss independent of predation.

Additionally, Thompson et al. (1971) studied the viability of salmon that disentangled from gill nets in a predator-free controlled environment. In the 1968 studies, nearly 46% of the 180 sockeye salmon exposed to the gill nets became disentangled.

Thompson et al. (1971) also studied the loss of dead salmon which became unmeshed from gill nets during high-seas fishing in 1968-69. These studies involved the placement of identifiable dead salmon in the net (i.e., "gill-ing" them in as natural a manner as possible) at the time of set and counting the retained carcasses when the net was hauled the following morning. Although it was not possible to establish whether a missing fish had dropped out of the net passively or had been extracted by an animal, these authors estimated the passive loss by comparing the loss of dead carcasses to the loss of decoy salmon during the same sets. The conditional estimate of passive loss (independent of predation) was 12.5%.

Admittedly, this is not extensive evidence. We must, therefore, attribute the loss of salmon from gill nets to both predation and disentanglement, and we cannot accurately separate the two.

It is pertinent, however, to draw analogies between the Japanese mothership fishery and our research vessel fishing. Both vessels fish gill nets in a similar manner, and both types of fishing would be subject to predation. The presence of Stellar sea lions in abundance in the area of the Japanese mothership fishery (from the central Aleutians to the Kuril Islands) has been documented (Mathisen, 1959; Tikhomirov, 1964). Estimates of abundance of Steller sea lions ranged up to 40,000 animals in the western Aleutians and up to 20,000 in the Kuril Islands (Kenyon and Rice, 1961; Tikhomirov, 1964).

Thus the estimates of loss of salmon from

TABLE 14.—Summary of loss from gill nets when "decoy" and dropout studies were conducted concurrently.

			Dropout studies			Decoy studies		
Year	Season	Set no.	Number marked	Number re-covered	Percent-age loss	Percent-age loss	Total catch	Distance offshore (km)
Loss from nets when no decoys were lost:								
1968	Spring	19	11	10	9.1	0	71	342
1969	Spring	12	2	2	0	0	23	161
	Summer	21	21	18	14.3	0	296	143
Total			34	30	11.8	0	—	
Loss from nets when decoys were lost:								
1968	Spring	17	7	6	14.3	47.6	58	228
	Spring	20	13	9	30.8	25.0	110	151
	Spring	22	62	49	20.9	47.4	283	100
1969	Spring	9	5	5	0	10.0	56	438
	Spring	11	4	3	25.0	5.0	50	255
	Summer	17	5	0	100.0	100.0	0	19
	Summer	25	14	8	42.9	20.0	154	15
Total			110	80	27.3	36.4	—	

gill nets (attributable to predation and disentanglement) based on research vessel data presented here would apply equally to the Japanese mothership fishery in areas where the fishery is exposed to sea lions. In other areas far offshore, loss of salmon attributable to predators would be minimal, but losses would still be expected from fish becoming disentangled.

Effects of Weather on Dropout Rates

Weather is one factor which should affect the dropout rate. Normally one would expect greater losses of fish from gill nets during strong winds and the resultant heavy seas.

The indirect methods of estimating losses from gill nets used in 1964 and 1965 allowed fishing in winds up to 35 knots. The design of the experiments, however, did not provide for an easy comparison of dropout loss and weather conditions, nor were detailed weather measurements recorded.

The direct methods of estimating loss from gill nets used in 1966-69 precluded observations in strong winds and heavy seas. Observations were normally not made in winds greater than 15 knots or in other than nearly calm seas. At times, however, winds would increase during the dropout observations, necessitating the canceling of the experiment.

Routine weather observations made aboard the vessel while setting and hauling the gill nets in 1966-69 included wind speed and direction, wave height, sea swell conditions, and barometric pressure. These data were compared to the percentage loss of salmon from gill nets (Table 15).

Because of the relatively small changes in most of the weather variables between set and haul times, no apparent relation with percentage loss of salmon was found. The weather measurement exhibiting the largest variation was wind speed at haul. This measurement was compared with the total loss of salmon (Figure 6), but little correlation was found ($r = 0.125$).

In a number of sets the loss rate was high (up to 40% or more) when wind speed at haul was 10 knots or less. In an attempt to determine whether or not these losses were due primarily

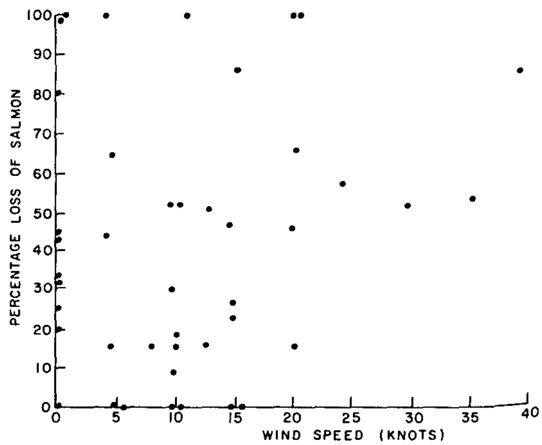

FIGURE 6.—Percentage loss of salmon in relation to wind speed at haul.

to predation as opposed to dropouts and, therefore, more independent of weather, all sets less than 145 km from shore were eliminated from further analysis to reduce the effects of predation. Twenty dropout sets remained for analysis; the correlation between percentage loss of salmon and wind speed at haul remained poor ($r = 0.362$).

Although it seems obvious that weather conditions (at least sea state) should influence the rate of loss of salmon from gill nets, the available data fail to demonstrate any relation. Effects of sea state must therefore remain as an unknown influence on the rate of salmon loss from gill nets. If, however, we assume that dropout of fish increased with increased agitation of the nets, the rates as measured (due to selectivity of experimental conditions) are probably low. Ishida et al. (1969) also were unable to evaluate the effect of sea state on dropout rate during their experiments from 1963 to 1967.

Inshore Fishing

The loss of salmon from gill nets fished on maturing salmon in inshore waters was studied by direct observation in Puget Sound in August 1967. The same basic experimental methods used on research vessels were applied to a commercial salmon fishing vessel. Because the commercial fishermen in Puget Sound

TABLE 15.—Loss of salmon from gill nets and weather conditions at set and haul, 1966-69.

							Weather conditions							
				Number of fish		Percentage loss	At set (2000-2200)				At haul (0800-1000)			
Year	Cruise	Set	Date	Marked	At haul		Barometer	Wind direction	Sea height	Swell height	Barometer	Wind direction	Sea height	Swell height
1966	37	24	7/20	7	6	14.2	30.02	SSE/5	0	1	30.00	S/10	1	1
		32	7/29	3	1	66.7	—	SW/15	2	6	30.01	SW/20	4	6
		48	8/19	4	4	0.0	30.02	SW/15	2	4	30.06	0	calm	—
		56	9/1	7	1	85.7	29.92	NW/5	2	5	29.94	W/15	2	6
		57	9/2	2	1	50.0	—	—	—	—	30.00	NW/35	5	6
1966	38	2	6/27	7	0	100.0	30.34	calm	0	2	30.37	calm	—	long
		3	6/28	7	4	42.9	30.25	NE/5	1	—	30.11	NW/5	1	long
		4	6/29	6	5	16.7	30.10	calm	—	—	29.89	NW/5	1	0
		5	6/30	3	0	100.0	29.81	calm	—	—	29.75	SW/20	2	—
		15	7/16	8	3	62.5	30.04	W/10	2	—	30.17	S/5	1	—
		16	7/17	3	3	0.0	—	—	—	—	30.90	S/5	1	—
		19	7/18	10	0	100.0	30.12	NE/5	—	—	30.14	0	—	—
		23	7/24	55	44	20.0	30.04	NE/5	2	—	29.88	0	—	—
		25	7/26	6	3	50.0	30.01	SW/15	2	—	30.05	SW/10	2	—
		33	8/5	11	6	45.5	29.90	calm	—	—	29.96	calm	—	—
		37	8/11	5	1	80.0	29.65	NE/10	2	4	29.69	calm	—	—
		38	8/12	24	13	45.8	29.65	W/10	2	low	29.58	W/30	6	8
		41	8/15	3	0	100.0	30.20	SW/5	1	low	30.20	W/5	1	—
		42	8/16	19	16	15.8	30.20	calm	1	—	30.26	W/20	3	—
		43	8/17	6	5	16.7	30.27	SW/10	3	—	30.20	SW/10	3	—
		47	8/24	6	3	50.0	30.12	W/5	calm	—	30.16	S/10	calm	—
1966	39	6	7/18	2	2	0.0	30.20	SE/5	calm	—	30.20	NE/5	calm	—
		7	7/19	9	7	22.2	30.17	NW/10	calm	—	30.16	NW/15	calm	—
		9	7/21	14	10	28.6	30.17	W/5	calm	—	30.16	W/10	calm	—
		10	7/22	8	8	0.0	30.20	NE/10	calm	—	30.22	E/15	choppy	—
		12	7/24	27	0	100.0	30.29	E/20	calm	—	30.23	E/20	choppy	—
		28	8/25	24	16	33.3	30.23	SW/5	calm	—	30.25	calm	—	—
		29	8/26	21	10	52.4	30.15	E/5	calm	—	30.14	SE/25	choppy	5-10
1967	41	6	6/29	11	6	45.5	30.20	calm	—	—	30.15	SE/15	4	5
		12	7/13	2	2	0.0	30.18	SW	1	3	30.10	SW/10	4	5
		21	8/1	8	0	100.0	30.07	SW/calm	2	5	30.04	0	1-2	4
		25	8/5	24	3	87.5	29.86	W/17	—	—	29.68	WSW/40	—	—
		26	8/15	36	21	41.7	29.59	SW/10	—	—	29.54	SW/20	—	—
1968	43	17	5/28	7	6	14.3	30.04	E/5	0	2	30.06	SE/10-15	1	2
		19	5/31	11	10	9.1	30.13	NNE/10-15	1	2	30.10	NNE/10	1-2	4
		20	6/3	13	9	30.8	29.59	WNW/5	1	3	29.63	calm	0	3
		22	6/5	62	49	20.9	29.85	ESE/10	1	3	29.87	ESE/15	1	3
1969	46	1	4/25	2	1	50.0	29.65	NW/10	—	3	29.63	NW/10-15	1	3
		9	5/27	5	5	0.0	29.91	0	—	3	29.93	E/10	1	3
		11	5/29	4	3	25.0	30.21	0	0	3	30.24	0	0	3
		12	5/30	2	2	0.0	30.28	W/10	1	3	30.18	SW/15	2	4
1969	47	17	7/20	5	0	100.0	30.15	NE/18	1	2	30.23	NE/12	1	2
		21	7/24	21	18	14.3	30.22	S/8	1	3	30.24	NE/8	1	3
		25	7/28	14	8	42.9	30.34	0	0	2	30.40	0	0	2

generally do not drift longer than 3 h at a time, our inshore observations were limited to a maximum of 3 h. These inshore observations provided a basis of comparison with loss rates determined on the high seas.

Commercial salmon gill nets used in Puget Sound were 549 m long and about 15 m deep. Our observations covered the entire string. Mesh sizes used were 130 mm and 143 mm.

Observations were conducted during eight sets (Table 16). Fifty-nine fish (primarily sockeye and pink salmon) were marked. No dropouts were recorded for periods up to 3 h. Although the observations were limited, it appears that loss of salmon from gill nets of 130- and 143-mm mesh is not a serious problem in the commercial fishery of Puget Sound.

Similar conclusions were reached by the Washington State Department of Fisheries after studies on dropouts in Puget Sound in 1968 and 1969.[6] During 2 yr of experiments, 245 salmon were observed or marked in commercial type gill nets; only 3 of these (1.2%) were dropouts. In a special experiment involving sockeye salmon native to Lake Washington (near Seattle, Wash.), 38 fish were marked (located by observation in the nets), and 11 (29%) had dropped out by the time the gear was hauled. In this experiment, however, the gill nets used were 121 to 140 mm in mesh size and were considered too large for the salmon which averaged less than 5 lb. per fish.

These studies in Puget Sound, in a gill net fishery generally conducted in comparatively calm and protected waters, show that dropouts were much reduced from dropout rates on the open seas. They further indicate that dropouts from gill nets may be mainly related to open-seas fishing.

[6] Jewel, E. D. 1970. Gill net dropout study. Wash. Dep. Fish., Prog. AFC-14, 5 p. [Unpubl. Rep.]

TABLE 16.—Numbers of salmon marked and observed in gill nets (130- and 143-mm mesh) over varying periods of time, Puget Sound, Wash., August 1967.

Set	Number of fish marked during patrols	Number of fish observed after marking: Up to 1 h later	Up to 2-3 h later
1	1	—	—
2	2	2	—
	2	2	—
3	8	8	—
	2	—	—
4	2	—	—
	1	—	—
5	3	3	—
	3	—	—
6	3	—	3
	2	2	2
	5	—	—
7	9	9	9
	4	—	4
	9	9	9
8	3	3	3
Total	59	38 [1](38)	30 [1](30)
Percentage loss		0	0

[1] Number of possible observations for the time period; different from the number marked because some net drifts were of short duration and observations were not made over the entire period. Dash (—) indicates no observation.

SALMON FALLOUTS FROM GILL NETS DURING HAUL

In the process of hauling gill nets aboard fishing vessels during high-seas salmon fishing, salmon are frequently observed falling from the nets before they can be taken aboard. These fish have been termed fallouts to distinquish them from the dropouts or those salmon that become disentangled from the gill nets during fishing. We have examined the catch records of research vessels from 1965 to 1970 to determine the number of fallouts by season of fishing, size of vessel, and mesh size.

The total number of fallouts during hauling of gear amounted to about 1.4% of the total number of salmon landed (Table 17). The greatest number of fallouts occurred on the RV *Miller Freeman*, the vessel having the highest lift of the nets from the water surface to the net roller where the nets are brought aboard the vessel; the least number occurred on the chartered vessels *Paragon* and *St. Michael*, vessels with the shortest lift distance between the water and roller. The fallouts from the *George B. Kelez*, with an intermediate distance from water to roller, were intermediate between those of the smaller and larger vessels.

Only one vessel, the *George B. Kelez*, fished over the four seasons. Results of fallout tabulations indicated relatively little difference by

TABLE 17.—Salmon fallouts from gill nets during hauling operations, by vessel and season.

Vessel	Vessel length (m)	Height from water to net roller (m)	Season	Number of fish falling out of nets	Total number of fish landed	Percent fallout of number of fish landed
RV *George B. Kelez*	54	2.4-3.0	Summer	264	18,725	1.41
			Fall	11	1,012	1.09
			Winter	67	3,357	2.00
			Spring	116	7,880	1.47
RV *Miller Freeman*	65	7.0-9.0	Summer	141	6,739	2.09
MV *Paragon*	27	1.5-2.0	Spring	20	3,492	0.57
MV *St. Michael*	23	1.5-2.0	Summer	25	3,611	0.69
Total				644	44,816	1.44

season of fishing, although slightly more fallouts were observed during the winter cruises—the season of generally poor weather and rough sea conditions.

Results of tabulating fallouts by mesh size are given in Table 18. In winter there was not a large difference in fallouts by mesh size with the exception of the 133-mm mesh. In general, however, during winter fishing operations (1967, 1969, 1970), the large salmon (predominantly sockeye) that were normally taken by 133-mm mesh nets in the spring were not as numerous as the smaller salmon. In the spring, when maturing salmon predominated in the catches and the catches were primarily in the large meshes (98, 114, and 133 mm), fallouts were mainly from those mesh sizes. Summer catches were primarily of immature salmon (sockeye and chum); the largest number of fallouts were from the small meshes (64 and 83 mm).

Konda (1966) examined data from Japanese research vessels for 1961-63 and estimated the escapement of salmon from gill nets during haul at 2%, a figure similar to our findings for U.S. research vessels. He further concluded that the number of fish surviving from falling out of the nets at haul is related to the length of time needed to haul the nets and that in commercial operations most fish will die because of the large number of gill nets fished in a day.

We concluded from our experimental fishing that the number of fallouts was small in relation to the number of fish hauled aboard the vessels and that there was little difference in percentage of fallouts by size of vessel.

If our findings are comparable to the catch and fallout of a large high-seas gill net fleet and unless remedial action is taken to retrieve lost fish, a sizeable number of salmon would be lost by the fleet over a season.

POTENTIAL LOSS OF SALMON RESOURCES FROM HIGH-SEAS GILLNETTING

The evidence of loss of salmon from gill nets (due either to dropouts, predation, or both) fished on the high seas in test fishing by research vessels indicated that the potential for substantial waste of the resource was due to the harvesting technique. Although the mortality of salmon escaping from gill nets (dropouts) is not known, there is evidence in the literature that losses are relatively large. Nelson and

TABLE 18.—Salmon fallouts according to mesh size.

Season	Sample size[1]	Percent fallouts by mesh size					
		51 mm	64 mm	83 mm	98 mm	114 mm	133 mm
Winter	71	18.6	18.6	22.5	18.3	17.9	4.2
Spring	114		8.8	13.9	38.6	26.2	12.5
Summer	459		30.4	36.6		17.9	15.1

[1] Totals by mesh size are equated to equal number of shackles of each mesh size as fished by season in 1970.

Abegglen (1955) studied the survival and spawning of sockeye salmon marked by gill nets in the Karluk Lagoon (Alaska). In experiments on maturing salmon entering Karluk River, fish were induced to enter gill nets, tagged, and recovered at upriver weirs or on the spawning grounds. Nelson and Abegglen estimated that from 10 to 20% of the gill net-marked fish escaping commercial gill nets die because of injuries inflicted by the webbing.

More conclusive evidence of high mortality of salmon which escape from gill nets in salt water comes from controlled experiments in 1968 and 1970. These experiments indicated that an average of 73% of the dropouts died in 6 days compared with 10% for control fish (Thompson and Hunter, see footnote 2).

Recoveries in inshore areas of gill net-caught salmon which had been tagged and released at sea have been far fewer than recoveries of gill net-caught fish tagged in rivers or estuaries. For example, from 1952 to 1957, Japanese scientists tagged 6,155 salmon that had been captured in gill nets on the high seas; only 26 (0.4%) were recovered (Fisheries Agency of Japan, 1959). In another example, U.S. scientists tagged 378 salmon captured with gill nets on the high seas, and none were recovered. At the same time as these experiments, salmon were captured by longlines and purse seines and were tagged and released; recoveries amounted to 7.3%. From inshore tagging during these same series of experiments (fish were captured in gill nets and tagged primarily in Bristol Bay, east of long. 165°W), recoveries were 6.9%, whereas recoveries from fish captured with longline and purse seines averaged 29% (Lander et al., 1967). The poor recovery of tagged salmon led Japanese, Canadian, and United States scientists to abandon gill nets as a means of capturing salmon for tagging experiments.

There is evidence, on the other hand, that recoveries of salmon captured in gill nets and tagged in fresh water may be relatively high. Salmon captured in gill nets at Hells Gate (Fraser River, B.C.) were tagged in 1939 and 1940; upstream recoveries were 40% in 1939 and 31% in 1940 (Thompson, 1945).

If we assume similar care in handling fish for offshore and inshore experiments and assume that the fish were in the nets for approximately equal time periods, these examples illustrate that salmon upon reaching estuaries and fresh water are likely to be much hardier than their offshore counterparts and apparently are much more able to survive the effects of gillnetting.

From the evidence of tagging experiments and from studies on the viability of salmon escaping gill nets, we concluded that the survival of salmon escaping gill nets on the high seas is relatively low. Furthermore, we may assume that losses of salmon due to predation result in 100% mortality of the extracted fish. Therefore, the potential loss of salmon and waste of the resource due to dropouts and predation amount to large numbers of salmon.

Japan engages in a major high-seas gill net fishery for Pacific salmon in the North Pacific Ocean and Bering Sea. The Japanese mothership fishing area, governed by agreements with Canada and the United States (International North Pacific Fisheries Convention) and with the USSR (International Convention for Northwest Pacific Fisheries), lies west of long. 175°W and extends generally from lat. 46° to 60°N (International North Pacific Fisheries Commission, 1968). In addition, a land-based gill net fishery for salmon is pursued by Japan in areas of the North Pacific Ocean south of the mothership fishing area (Figure 7).

Fukuhara (1971) analyzed the Japanese mothership fishery, the details of which follow. The fishing effort of the fleet since 1961 has numbered 11 motherships and 369 catcher boats, fishing between 5 and 7.5 million tans[7] (cumulative effort) of nylon gill nets during a season. West of long. 170°E, the maximum allowable number of tans per boat is 264 and 330 east of that longitude. On a given day, therefore, the fleet is capable of fishing 4,900 to 6,100 km of gill nets, depending on its east-west distribution. Two sizes of mesh are used, 121 mm and 130 mm, stretched measure. The ratio of large mesh to small mesh must be 6:4 west of long. 170°25′E and may be 4:6 east of

[7] A tan is approximately 50 m long.

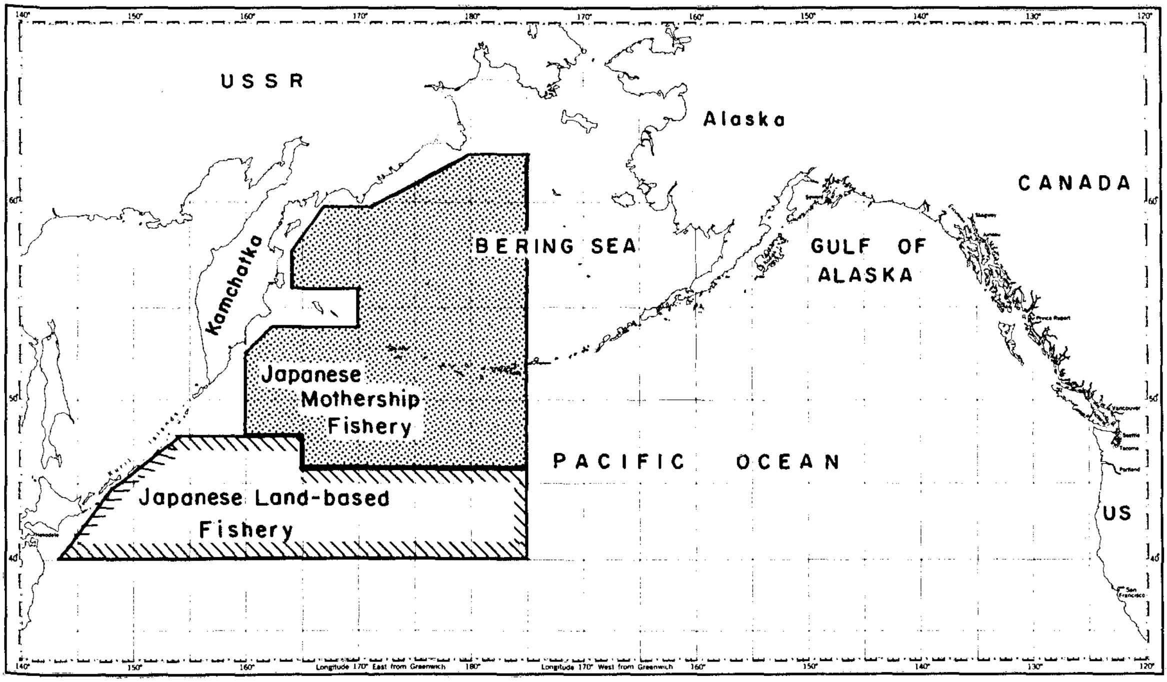

FIGURE 7.—Fishing area of Japanese mothership and land-based fishery.

long. 170°25′E. In recent years the fleet has been changing the gill nets to monofilament netting in lieu of multifilament netting. Our most recent information is that most, if not all, of the catcher boats now use the monofilament gear.

Although our experiments on dropouts and fallouts have been conducted on research vessels, the results are applicable to fishing practices as carried out by the mothership fleet. The webbing for the gill nets used by our research vessels originated from Japan, and construction of the gill nets was generally copied from the construction of Japanese gear. The leadline of the Japanese gear has heavier cordage and is slightly shorter than the corkline, whereas in the U.S. gear the corkline is slightly shorter than the leadline and is of heavier cordage; therefore, while the gear is soaking and during the hauling, the tension is on the leadline in Japanese commercial gear and on the corkline in U.S. research gear. The mesh sizes of 114 mm and 133 mm, as used by our research vessels for capturing maturing salmon and the larger immature salmon were similar in size to the mesh sizes (121 and 130 mm) of the commercial nets of the fishing fleets. The modal selection length for 114-mm and 121-mm meshes are 53 cm and 56 cm, respectively, and for 130 mm and 133 mm, 60 and 62 cm, respectively, which is a very slight disparity in selection lengths (Fukuhara, 1971).

Salmon catches by the Japanese mothership fleet have ranged from about 19 to 26.5 million fish and have averaged about 22 million salmon annually for 1960 through 1968 (International North Pacific Fisheries Commission, 1965-1968). An annual estimated average of about 2.5 million sockeye salmon (maturing and immature) of Bristol Bay origin have been taken by the mothership fishery; the catch has ranged from approximately 0.3 to 7.2 million fish for 1956-69 (Fredin and Worlund).[8] Loss

[8] Fredin, R. A., and D. D. Worlund. 1972. Estimates of the catches of sockeye salmon of Bristol Bay origin by the Japanese mothership salmon fishery, 1956 to 1970. Northwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, Wash., 82 p. [Unpubl. Manuscr.]

rates as determined from the dropout studies, therefore, indicated substantial numbers of salmon lost during high-seas gillnetting.

To summarize the loss rates obtained, for large mesh nets of monofilament construction, the percentage loss of immature and mature salmon was approximately 33% (Table 10). For mature fish and for multifilament and monofilament nets the loss rate was about 20% (Table 11). These estimates of loss due to gillnetting are similar to those reported by Semko (1964) and by Miyazaki and Taketomi (1963, as cited by Konda, 1966), are smaller than those reported by Doi (1962), and are somewhat larger than the losses reported by Ishida et al. (1969).

Applying a loss rate of 33% to the average catch of 2.5 million sockeye salmon of Bristol Bay origin taken by the Japanese mothership fleet results in an estimated average of about 1.2 million sockeye salmon lost from the gill net fishery annually, with a range of 0.15 to 3.5 million fish yearly, depending upon the size of the catch. A loss rate of 20% would indicate that 0.6 million Bristol Bay sockeye salmon are lost annually on the average (with a range of 0.08 to 1.8 million fish).

Calculation of the total loss of salmon (of North American and Asian origin) from the mothership operation, based on annual catches, resulted in an estimated loss of about 10.8 million salmon at a 33% loss rate and 5.5 million fish at a 20% loss rate. The range of losses, depending upon the annual catch by the mothership fleet, was from 9.4 to 13.1 million fish and 4.8 to 6.6 million fish for the two respective loss rates.

In experiments in which no decoys were lost and in which losses from gill nets were attributable only to dropouts (Table 14), the disentanglement rate of about 12% also indicated substantial losses of salmon. This loss rate applied to the average annual catches by the mothership fishery, resulted in estimated annual losses of 0.3 million sockeye salmon of Bristol Bay origin (with a range of 0.04 to 1.0 million fish, depending upon the catch) and an average total loss of 3.0 million salmon of all origins (range of 2.6 to 3.6 million fish depending upon catch).

We have no way of determining the actual mortality of salmon lost from gill nets. We know that some fish survive as evidenced by net-marked salmon observed in spawning streams. In the experiments on viability of adult sockeye salmon that disentangle from gill nets, which were carried out in an enclosed area in relatively calm waters of Puget Sound, it was shown that approximately 73% of fish that disentangled from gill nets died within 6 days compared with 10% for control fish. These particular fish were held in a protected enclosure throughout the experiments; mortalities of gill net dropouts could be even greater in the open ocean. Therefore, at any likely mortality level that we might assign to salmon dropping out of gill nets on the high seas, the resultant waste of the resource is substantial.

In addition to losses due to dropouts and predation, there is the attendant loss of salmon during the haul of gear aboard vessels. It was estimated for U.S. research vessels that about 1.4% of the number of fish landed fell out of the gill nets at haul. If we consider a 1% fallout rate (the approximate fallout rate of the smallest of U.S. research vessels), the resultant loss of salmon during the Japanese mothership fishery would average over 200,000 fish annually. The estimated loss of sockeye salmon of Bristol Bay origin by the mothership fishery would amount to an average annual loss of 25,000 fish.

From the indirect methods of determining rates of losses, we obtained rates of approximately 32% for immature fish and 27% for maturing fish. Either of these rates indicated losses of salmon on the order of or even greater than that estimated from direct observation. As with the majority of direct observations, however, we were unable to differentiate the effect of predators on dropout rates and losses were considered as due to a combination of dropouts and predation.

The estimated large numbers of salmon lost from gill nets in a high-seas fishery and the probable large mortality of these salmon indicate the relatively large waste of part of the resource. In contrast, inshore experiments in Puget Sound indicated that there is not the loss of salmon from gill nets or potential waste of the resource as associated with an open sea fishery.

SUMMARY AND CONCLUSIONS

Studies by U.S. scientists on the loss of salmon from gill nets fished on the high seas commenced in 1964. The indirect methods of determining losses used in 1964 and 1965 resulted in the estimates of loss of immature salmon of 32% for periods up to 12.5 h in 1964 and an estimated average loss of maturing salmon of 27% for a 3-h period in 1965. These losses were attributed to disentanglement and to extraction by predators.

Direct methods of observation were initiated in 1966. These studies permitted estimates of rate of loss of salmon for periods up to 1, 2½, and 3 h (and in some years up to 5 h) as well as periods up to 10-11 h. These studies were directed toward both maturing and immature salmon; comparisons were also made between large and small mesh gill nets and between monofilament and multifilament gill nets.

In the 4 years' experiments, 534 salmon were marked. Overall loss rates for periods up to 11 h was 41%. Loss rates were nearly 6% up to 1 h and 14% up to 2½ h, and it was shown that losses continued with time in the net.

Losses from small mesh (64- and 83-mm) multifilament nets, which capture mainly the small age .1 immature salmon, were similar to losses from large mesh nets (45% vs. 41%). Loss rates from the small mesh nets were similar to those of large mesh multifilament nets for periods up to 1 h (5 and 6%, respectively) and greater than the losses in large mesh multifilament nets for periods up to 2½ h (21 and 7%, respectively).

Comparisons of the loss rates of large mesh (98-, 114-, and 133-mm) multifilament nets as opposed to large mesh (114- and 133-mm) monofilament nets indicated that for periods up to 11 h, loss rates from the multifilament nets exceeded the monofilament nets (41% vs. 33%), although the difference was not statistically significant.

The loss rates of primarily immature salmon in the summers of 1966 and 1967 were compared with the catches of primarily maturing salmon in the spring of 1968 and 1969. Loss rates for the immatures for the three time periods (1, 2½, and 11 h) were 9, 17, and 46%; for maturing salmon the loss rates for the three time periods were 0, 4, and 20%.

It was not possible to determine accurately species during the process of marking the locations of fish in the nets. It was concluded that dropout rates would be applicable to those species which make up the bulk of the catches (sockeye and chum salmon made up over 70% of the catch during these experiments).

The losses were attributed to both disentanglement (dropout) and to extraction by predators. Attempts at differentiating between losses due to dropout and losses due to predation were not entirely conclusive. Estimates of the loss of salmon due only to dropout was about 12%, although the data from which this estimate was derived are limited. It was concluded that the estimates of losses from gill nets based on research vessel data apply equally to the Japanese mothership fishery because of similarity of fishing methods, gill net construction, and susceptibility to predation.

Weather (wind and sea state) was expected to influence gill net loss, but the available data failed to demonstrate any relation, primarily because the experiments were generally conducted in comparatively calm weather.

Direct observation of the loss of maturing salmon from gill nets was extended to an inshore fishery (Puget Sound) in August 1967. No losses were recorded for periods up to 3 h. Subsequent studies by the Department of Fisheries, State of Washington, also failed to demonstrate significant losses, suggesting that losses from gill net fisheries were mainly related to high-seas fishing.

Additional losses in high-seas gillnetting were attributed to fallouts, those salmon lost while hauling the nets aboard the vessel. Examination of U.S. research vessel catches from 1965 to 1970 indicated that fallouts amounted to about 1.4% of the total number of salmon landed. There was relatively little difference in percentage of fallouts by size of vessel. Although the number of fallouts did not form a substantial part of the total number of salmon landed, if the percentage loss was similar in a large gill net fishing fleet, substantial numbers of salmon would be lost over a fishing season.

Based on the data reported herein, it was concluded that a substantial loss of salmon could occur in the Japanese high-seas fishery. Applying an estimated loss of from 20% (for maturing salmon) to 33% (for maturing and immature salmon combined) to the average annual catch of 22 million salmon by the mothership fishery, the estimated annual loss from gill nets would range from 5.5 to 10.8 million fish. Of this loss, it was estimated that an average of 0.6 to 1.8 million sockeye salmon of Bristol Bay origin would be lost annually by the Japanese mothership fishery.

In addition to losses due to dropouts, there is an attendent loss due to fallouts. If 1% of the total landings of the Japanese mothership fleet were lost, this would average over 200,000 fish each year, of which 25,000 sockeye salmon of Bristol Bay origin would be lost on the average.

Although the ultimate fate of salmon dropping out of gill nets is not known, evidence from the literature suggests that the mortality of salmon escaping from gill nets is high. The potential loss of salmon (due to dropout and predation) and waste of the resource, therefore, amount to substantial numbers of salmon.

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