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Predation by Sculpins on Fall Chinook Salmon, *Oncorhynchus tshawytscha*, Fry of Hatchery Origin

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NOTE

Until October 2, 1970, the National Marine Fisheries Service, Department of Commerce, was the Bureau of Commercial Fisheries, Department of the Interior. Throughout the body of this report, which was prepared for printing before October 2, the older term is used.

UNITED STATES DEPARTMENT OF COMMERCE
Maurice H. Stans, *Secretary*

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Philip M. Roedel, *Director*

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ABSTRACT

Predation was studied during migration of the fry towards the Columbia River from two hatcheries — the Elokomin River Hatchery (13 km. upstream from the Columbia) and the Oxbow Hatchery on Herman Creek (0.2 km. upstream). In the Elokomin River the estimated loss of hatchery salmon to sculpins, *Cottus* spp., was 3.9 percent of 1.5 million fry released in 1962 and 1.3 and 3.6 percent of 2.2 and 0.1 million fry, respectively, released in 1963. Loss was negligible among 2.3 million fry released in Herman Creek in 1962.

Sculpins that preyed on hatchery salmon were coastrange sculpin, *C. aleuticus;* prickly sculpin, *C. asper;* reticulate sculpin, *C. perplexus*, and torrent sculpin, *C. rhotheus;* in the Elokomin River and prickly and reticulate sculpins in Herman Creek. Predation was greatest by prickly sculpin (the largest species) and least by coastrange sculpin (a species with a comparatively small mouth).

Losses of salmon to sculpins may have been related to diet and to the size of the releases. In the Elokomin River, predation was greater on salmon fed a wet diet than on those fed moist pellets. The larger of the two releases in 1963 had the smaller percentage loss. Improvement of hatchery procedures is probably the best way to reduce losses of hatchery-reared salmon to sculpins.

INTRODUCTION

Artificial propagation of Pacific salmon, *Oncorhynchus* spp., in hatcheries has been effective in increasing their survival until time of release. Although the returns indicate economic success, the number of salmon accounted for (in the fishery and returning to a hatchery) represents only a small fraction of the fish released (Hublou, 1963). Biologists suspect that the major cause of the loss is predation.

Sculpins, *Cottus* spp., are known predators of Pacific salmon fry released from hatcheries. Hikita and Nagasawa (1960) reported about 5-percent predation of chum salmon, *O. keta*, by *C. nozawae* in a Japanese stream. Information on predation in North America is limited, but sculpins, salmon, and trout, *Salmo* spp., are known to readily consume artificially reared salmon.

I studied predation by sculpins on fry of fall chinook salmon, *O. tshawytscha*, that migrated into the Columbia River from two hatcheries — the Elokomin River Hatchery (operated by the State of Washington Department of Fisheries), which is 13 km. from the lower Columbia River, and the Oxbow Hatchery (operated by the State of Oregon Fish Commission, on Herman Creek, 0.2 km. from the Columbia River.

I analyzed the quantitative and qualitative aspects of predation in the Elokomin River in

1962 and 1963 and in Herman Creek in 1962. The data include the percentage of sculpins that ate salmon, the average number of salmon per sculpin, specific differences among sculpins as predators of salmon, and the comparative mortalities of salmon reared on wet diets and fortified diets.

MATERIALS AND METHODS

Elokomin River

Predation on hatchery chinook salmon was studied principally in the lower 13 km. of the Elokomin River (Wahkiakum County, Wash.), which empties into the Columbia River about 56 km. from the Pacific Ocean. The mean flows of the Elokomin River 2 km. above the mouth in May 1962 was 7.4 c.m.s. (cubic meters per second) and in 1963 was 6.3 c.m.s. The Elokomin River consists generally of riffles; it has moderate velocities over a rocky bottom and occasional pools, up to 91 m. long. Below km. 2, the river is influenced by tides and flow is reduced. The water was clear except for turbidity on May 22, 1963.

The diet of salmon reared in the Elokomin River Hatchery differed between the 1961 and 1962 brood years: the 1961 brood was fed beef liver, beef spleen, turbots, pasteurized salmon viscera, pasteurized salmon carcasses, and herring meal; the 1962 brood was fed the same diet for 6 weeks and then fed Oregon moist pellets (Hublou, 1963) for about 8 weeks.

At the time of release, the 1961 brood averaged 59 mm. fork length (range, 40-80 mm.) and averaged 469 salmon per kilogram; the 1962 brood averaged 60.1 mm. fork length (range, 38-79 mm.) and averaged 447 salmon per kilogram.

All fry were released into the Elokomin River after darkness. The 1961 brood, estimated at 1,493,000 fry by hatchery personnel, was released on May 24, 1962; the 1962 brood was released in three groups in May 1963 — 841,000 on May 21, 1,394,000 on May 22, and 127,000 on May 27. The group liberated on May 27 had been retained for treatment of disease, and I assumed these to have been of quality equal to the other released fish. The May 21 and 22 plantings were designated as the 1963A release; the May 27 release, as the 1963B.

Possible predators were collected by electrofishing (Patten and Gillaspie, 1966) at various times and locations in the Elokomin River. We also observed the movement, habitat, and behavior of prey and predators. In collecting, we moved upstream to avoid the capture of predators that might have consumed electronarcotized salmon fry which had drifted downstream. All sculpins 50 mm. or longer were retained.

Table 1 shows times and locations of sampling. We collected predators in the Elokomin River for 2 successive days after each release (extended to 3 days for the 1963A release made on May 21 and 22). A collection was made at 5:00 a.m. at km. 6.4 (designated 6.4A in the tables) on May 22, 1963, to determine if salmon released the previous evening had been preyed upon during darkness. Collections were made in the absence of released chinook salmon at km. 2.3 and 6.4 on May 21, 1963 (table 1), and at km. 16 on May 21 and 22, 1963 (table 1), to find the intensity of predation on wild coho salmon, *O. kisutch.*

Herman Creek

Predation on hatchery chinook salmon was studied secondarily on fish released into Herman Creek 0.2 km. from the Columbia River at Oxbow Hatchery, 6.4 km. above Bonneville Dam in Oregon. The chinook salmon were released into a diverted channel of Herman Creek, which enters the Columbia River through a 200-m. outlet channel about 23 to 46 m. wide and 4 m. deep. The water was clear, and velocity was negligible except at the diversion inlet.

The diet of chinook salmon reared at Oxbow Hatchery consisted of beef liver (20 percent), hog liver (20 percent), tuna viscera (10 percent), beef spleen (10 percent), and pasteurized salmon viscera (40 percent). The salmon had a mean fork length of 56.8 mm. (range, 45-64 mm.) at the time of release, and numbered 427 to the kilogram. The release totaled about 2.3 million fish and started at 9:00 p.m. on May 16, 1962, and was completed during darkness.

Table 1.—Numbers of fish taken in 1962-63 in the Elokomin River and Herman Creek, by time and area of sampling and species collected

Study area and year	Time of sampling: Day	Time of sampling: Hour	Distance from mouth of stream	Species: Rainbow trout	Cutthroat trout	Coho salmon	Coastrange sculpin	Prickly sculpin	Reticulate sculpin	Torrent sculpin
			Km.	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Elokomin R. 1962	May 25	7 p.m.	3.2	--	--	--	93	1	3	21
	May 26	8 a.m.	3.2	4	--	1	94	1	2	3
	May 25	9 p.m.	6.4	--	--	--	11	--	8	--
	May 26	2 p.m.	6.4	--	--	--	24	--	40	24
	May 25	8 p.m.	13.0	4	--	--	11	4	--	55
	May 26	12 noon	13.0	--	--	--	15	--	23	49
Total fish				8	--	1	248	6	76	152
Elokomin R. 1963	May 23	3 p.m.	2.0	2	3	6	--	8	--	3
	May 28	2 p.m.	2.0	1	2	2	1	22	5	--
	May 29	2 p.m.	2.0	2	3	10	--	26	21	--
	May 21	3 p.m.	3.2	1	--	1	44	--	5	11
	May 22	1 p.m.	3.2	8	1	7	41	1	5	15
	May 23	2 p.m.	3.2	7	2	5	44	12	5	10
	May 24	12 noon	3.2	5	2	5	79	5	9	23
	May 29	12 noon	3.2	3	8	9	--	--	--	--
	May 21	4 p.m.	6.4	1	--	3	26	--	--	54
	May 22	5 a.m.	6.4A	2	--	1	32	--	--	22
	May 22	11 a.m.	6.4B	--	--	--	33	--	6	55
	May 23	11 a.m.	6.4	1	--	2	10	1	17	49
	May 28	1 p.m.	6.4	2	--	3	15	--	19	23
	May 29	10 a.m.	6.4	1	5	2	93	9	17	52
	May 24	9 a.m.	13.0	--	1	2	26	--	22	39
	May 21	9 a.m.	16.0	--	--	--	--	--	3	7
	May 22	9 a.m.	16.0	1	--	--	--	--	3	16
Total fish				37	27	58	444	84	137	379
Herman Cr. 1962	May 17	8 a.m.	0.0	1	--	--	--	116	31	--

We made one collection of predators with electrofishing gear in Herman Creek in the outlet channel on the morning after release of the salmon. By this time all but a few salmon had moved into the Columbia River during the night. Fish observed or collected in the outlet channel included the hatchery chinook salmon fry; prickly sculpins, *C. asper*; reticulate sculpin, *C. perplexus*; and one rainbow trout, *Salmo gairdneri*.

Laboratory Procedure

The collected fish were preserved in Formalin. Data recorded were total length of sculpins, fork length of other fishes, and stomach contents; for specimens collected in 1962 in the Elokomin River and Herman Creek, the lateral gape of mouth (length measured by calipers with rounded fingers 3 mm. in diameter) was recorded.

Numbers of salmon in stomachs of predators were counted. When remains of salmon were present, I assumed that they were eaten within a 24-hour period. Supplementary field studies indicated that a sculpin could digest a salmon 60 mm. long in a 24- to 28-hour period. Lengths and species of salmon recovered from stomachs of predators were recorded when possible. Of 235 prey fish recovered from sculpins in the Elokomin River, 155 were chinook salmon, 2 were coho salmon, and 78 could not be identified. Prey species of salmon other than chinook were not observed in Herman Creek. The incidence refers to percentage of predators containing salmon; rate refers to occurence of a salmon per stomach; and intensity refers to incidence and rate.

SPECIES AND HABITAT IN THE LOWER ELOKOMIN RIVER

In addition to chinook salmon fry (presumed to be of hatchery origin), the species of fish collected (table 1) were coho salmon; rainbow trout; cutthroat trout, *S. clarki;* sculpins; largescale sucker, *Catostomus macrocheilus;* and longnose dace, *Rhinichthys cataractae.* Other species caught, but not considered to be predators, were the sand roller, *Percopsis transmontana;* peamouth, *Mylocheilus caurinus;* Pacific lamprey, *Lampetra tridentata;* and western brook lamprey, *L. richardsoni.*

Chinook salmon fry were the most abundant of the species observed throughout the lower 13 km. of the Elokomin River for 2 days after each release. On the second day after each release, fewer chinook salmon fry were observed at km. 13 and 6.4 than on the previous day; this observation suggested a downstream movement.

In 1963 we observed how chinook salmon behave when they move downstream. On May 22 at 5:00 a.m., the morning after the release at about 10:00 p.m. on May 21, chinook salmon were abundant at km. 6.4; therefore, they had moved downstream in the dark. On the same day at 7:00 a.m. at km. 3.2, schools of 5 to 30 chinook salmon each were seen drifting downstream tail first near the midstream surface in a riffle. The salmon passed km. 3.2 at an estimated rate of 200 to 300 per min. at 11:00 a.m. on May 22 and 100 per min. at 11:00 a.m. on May 23. No downstream movement was noted at km. 3.2 on May 24, but schools of salmon descended the river in the afternoon of May 24 at km. 2. A few were seen moving downstream at km. 3.2 the morning after the May 27 release; none were seen there on May 29. At any one time after the three releases, not all chinook salmon were moving downstream; some were observed maintaining their positions in low-velocity water.

Trout, yearling coho salmon, and sculpins are known to eat salmon fry. These predators were abundant in the study area. Rainbow trout were more abundant than cutthroat trout, but both species were relatively scarce in the lower 16 km. of the river. In 1963 trout were most abundant at km. 3.2 probably because of releases from a trout hatchery near km. 4.8. Coho salmon fry and yearlings were abundant throughout the lower 16 km. of the river. Sculpins were distributed through the study

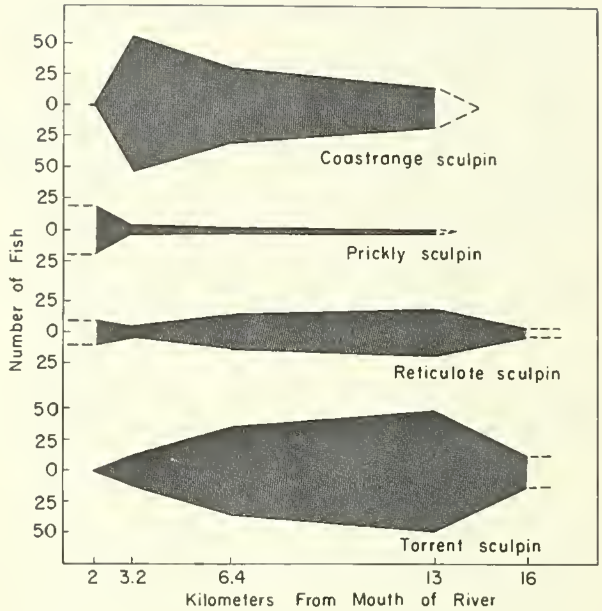

Figure 1.—Average numbers of four species of sculpin collected at five points in the lower 16 km. of the Elokomin River, 1962-63.

area and were the most abundant wild fish. The average number of sculpins collected at a site where sampling efforts were similar indicates differences in species distribution in the lower 16 km. of the river (fig. 1).

Six species of fish not known to prey on salmon fry were collected from the study area. Longnose dace were abundant in riffles from km. 3.2 to 13. Adult largescale suckers, which ascended the river to spawn, were observed during 1962. Many Pacific lampreys and smaller numbers of western brook lampreys spawned in the lower 13 km. in 1962 and 1963. One sand roller and one peamouth were taken at km. 2 in 1963.

The environmental niche occupied by salmon and trout, determined by underwater observation, appeared to be more a function of fish size than any other single observable factor. Coho salmon fry, 32 to 60 mm. long, were most common in water 1 to 10 cm. deep. Coho salmon and rainbow trout yearlings, 80 to 120 mm. long, were intermixed at depths greater than 18 cm. Rainbow and cutthroat trout over 130 mm. long were usually in water deeper than 40 cm. Salmon and trout were not observed in high-velocity riffles, except for chinook salmon that were actively migrating downstream. The greatest density of salmon and trout was where a riffle entered a pool. They were observed in a pool below a riffle at km. 3.2 before and after the first release in 1963. Trout over 130 mm. long maintained a central position below the swift current of the incoming riffle. Large trout usually remained close to the bottom and swam up quickly for food. Coho salmon and trout yearlings flanked the "large trout area" but were somewhat upstream in shallower water and distributed at all depths exceeding 18 cm. Thus the distribution of coho salmon and trout in a pool below the riffle appeared to be related directly to size of the fish. The largest fish were in a central location below the fast inflowing water; smaller fish were in shallower water upstream and shoreward from the larger individuals. At this same site, chinook salmon that were maintaining their positions were in still shallower water shoreward and somewhat upstream from the yearling coho salmon and rainbow trout.

The type of habitat occupied by sculpins was related to species rather than to size. Habitat preferences of the sculpins could not be determined by visual observation (sculpins hide among rocks and sometimes partially bury themselves in substrate) but were indicated by the results of electrofishing. Prickly and reticulate sculpins usually were taken from water of low velocity in pools near banks. Coastrange sculpins, *C. aleuticus*, appeared to prefer riffles, and torrent sculpins, *C. rhotheus*, were at the heads of riffles or throughout riffles of moderate velocity. Densities of sculpins within a "microhabitat" increased with increases in cover.

The distribution of hatchery chinook salmon within the river was so widespread that some of them passed near all potentially predaceous fish in the Elokomin River. Numbers of chinook salmon fry maintained their positions throughout the stream below the hatchery but were most numerous in pools below riffles. Others were distributed in other sections of pools or in low-velocity riffies, especially where cover was available. Piscivorous fishes, capable of eating chinook salmon fry, had ample (but not necessarily equal) opportunities to do so.

PREDATION ON CHINOOK SALMON FRY

Chinook salmon were found in the stomachs of salmon, sculpin, and trout. A brief account is given regarding predation by salmon and by trout. Predation by sculpins was studied more thoroughly. Reported here are the variations between species, the estimated numbers of salmon eaten, and prey-dependent factors.

By Sculpin

Variation between species of sculpins.—The numbers of salmon eaten (tables 2, 3, 4, and 5), the incidence (table 6) and rate of predation (table 7), and maximum numbers of salmon eaten by individuals (table 8) by the four species of sculpins showed the same trend. The prickly sculpin was the most intense predator, torrent sculpin was second, and reticulate sculpin was third; the coastrange sculpin was of little importance as a predator.

Reasons for variation in intensity of predation among species of sculpins may have been due to differences in: (1) habitat, (2) size of food items preferred, and (3) size of the sculpin. The present data contribute no

Table 2.—Number of salmon eaten by coastrange sculpins in the Elokomin River after releases of chinook salmon in May 1962 and 1963

Year	Sampling dates	Distance from mouth of river	Total sculpins examined	Sculpins with salmon in stomach	Salmon in stomach of sculpins
		Km.	*Number*	*Number*	*Number*
1962	May 25	3.2	93	--	--
	26	3.2	94	--	--
	25	6.4	11	--	--
	26	6.4	24	--	--
	25	13.0	11	5	9
	26	13.0	15	--	--
Total	fish		248	5	9
1963	May 21	3.2	44	--	--
	21	6.4	26	--	--
Total	fish		70	--	--
1963A	May 22	3.2	41	--	--
	23	3.2	44	3	3
	24	3.2	79	--	--
	22	6.4A	32	--	--
	22	6.4B	33	--	--
	23	6.4	10	--	--
	24	13.0	26	--	--
Total	fish		265	3	3
1963B	May 28	2.0	1	--	--
	28	6.4	15	--	--
	29	6.4	93	1	1
Total	fish		109	1	1

information on the first and second points. As for size, larger sculpins are, of course, better able to capture and swallow large pieces of

Table 3.—Number of salmon eaten by prickly sculpins in the Elokomin River and Herman Creek after releases of chinook salmon in May 1962 and 1963

Study area & year	Sampling dates	Distance from mouth of river	Total sculpins examined	Sculpins with salmon in stomach	Salmon in stomach of sculpins
		Km.	*Number*	*Number*	*Number*
Elokomin River:					
1962	May 25	3.2	1	1	2
	26	3.2	1	1	4
	25	13.0	4	3	7
Total fish			6	5	13
1963A	May 23	2.0	8	1	3
	22	3.2	1	--	--
	23	3.2	12	6	17
	24	3.2	5	3	5
	23	6.4	1	--	--
Total fish			27	10	25
1963B	May 28	2.0	22	2	2
	29	2.1	26	1	1
	29	6.4	9	2	3
Total fish			57	5	6
Herman Creek:					
1962	May 17	0.0	116	44	73

Table 4.—Number of salmon eaten by reticulate sculpins in the Elokomin River and Herman Creek after releases of chinook salmon in May 1962 and 1963

Study area & year	Sampling dates	Distance from mouth of river	Total sculpins examined	Sculpins with salmon in stomach	Salmon in stomach of sculpins
		Km.	*Number*	*Number*	*Number*
Elokomin River:					
1962	May 25	3.2	3	--	--
	26	3.2	2	1	2
	25	6.4	8	--	--
	26	6.4	40	25	34
	26	13.0	23	2	2
Total fish			76	28	38
1963	May 21	3.2	5	--	--
1963A	May 22	3.2	5	--	--
	23	3.2	5	--	--
	24	3.2	9	--	--
	22	6.4B	6	--	--
	23	6.4	17	2	2
	24	13.0	22	6	6
Total fish			64	8	8
1963	May 21	16.0	3	2	2
	22	16.0	3	--	--
Total fish			6	2	2
1963B	May 28	1.6	5	--	--
	29	1.6	21	1	1
	28	6.4	19	1	1
	29	6.4	17	1	2
Total fish			62	3	4
Herman Creek:					
1962	May 17	0.0	31	4	4

Table 5.—Number of salmon eaten by torrent sculpins in the Elokomin River after releases of chinook salmon in May 1962 and 1963

Year	Sampling dates	Distance from mouth of river	Total sculpins examined	Sculpins with salmon in stomach	Salmon in stomach of sculpins
		Km.	*Number*	*Number*	*Number*
1962	May 25	3.2	21	5	7
	26	3.2	3	1	1
	26	6.4	24	14	18
	25	13.0	55	36	73
	26	13.0	49	3	4
Total fish			152	59	102
1963	May 21	3.2	11	--	--
	21	6.4	54	--	--
Total fish			65	--	--
1963A	May 23	2.0	3	--	--
	22	3.2	15	--	--
	23	3.2	10	1	1
	24	3.2	23	4	5
	22	6.4A	22	--	--
	22	6.4B	55	3	4
	23	6.4	49	7	7
	24	13.0	39	2	3
Total fish			216	17	20
1963	May 21	16.0	7	--	--
	22	16.0	16	--	--
Total fish			23	--	--
1963B	May 28	6.4	23	--	--
	29	6.4	52	3	4
Total fish			75	3	4

Table 6.—Incidence of predation on chinook salmon by sculpins, salmon, and trout for releases in the Elokomin River and Herman Creek

Species	Incidence of salmon in stomachs			
	Herman Creek	Elokomin River		
	1962	1962	1963A	1963B
	Percent			
Coastrange sculpin ...	--	2.0	1.1	0.9
Prickly sculpin	37.9	83.3	37.0	8.8
Reticulate sculpin	12.9	36.8	12.5	4.8
Torrent sculpin	--	38.8	7.9	4.0
Rainbow trout	100.0	37.5	32.0	0.0
Cutthroat trout	--	--	100.0	27.8
Coho salmon	--	0.0	10.7	0.0

Table 7.—Average numbers of chinook salmon fry per predator, after release in Elokomin River and Herman Creek

Species	Salmon fry per predator			
	Herman Creek	Elokomin River		
	1962	1962	1963A	1963B
	Number			
Coastrange sculpin ...	--	1.8	1.0	1.0
Prickly sculpin	1.7	2.6	2.5	1.2
Reticulate sculpin	1.0	1.4	1.0	1.3
Torrent sculpin	--	1.7	1.2	1.3
Rainbow trout	3.0	1.6	1.4	0.0
Cutthroat trout	--	--	3.7	2.4
Coho salmon	--	0.0	1.0	0.0

Table 8.—Maximum number of chinook salmon eaten by the most predaceous specimen of each predator species in the Elokomin River and Herman Creek

Stream	Species	Length	Salmon in stomach	Sampling
		Mm.	*Number*	*Year*
Elokomin River	Coastrange sculpin .	115	3	1962
	Prickly sculpin . . .	157	6	1963
	Reticulate sculpin .	83	3	1962
	Torrent sculpin . .	94, 122	5	1962
	Rainbow trout . . .	168	3	1963
	Cutthroat trout . . .	255	10	1963
	Coho salmon	93, 109	1	1963
Herman Creek	Prickly sculpin . . .	107	5	1962
	Reticulate sculpin .	66, 81	1	1962
	Rainbow trout . . .	160	3	1962

food. For example, the larger food items were consumed by the larger individual among mottled sculpins (Daiber, 1956) and among prickly and torrent sculpins (Northcote, 1954). Because salmon constitute relatively large food items, only the larger sculpins are predators on salmon fry. Prickly sculpins preyed most heavily on salmon and were also the largest species of sculpin.

Most of the prickly sculpin collected were over 110 mm. long — the largest was 221 mm. (fig. 2). Few reticulate (fig. 3) or torrent sculpins (fig. 4) were over 100 mm. long, and a few coastrange sculpin were over 110 mm. (fig. 5). The smallest prickly sculpin to prey on salmon was 103 mm. in the Elokomin River and 79 mm. in Herman Creek, compared to 73 mm. for reticulate sculpins in the Elokomin River and 66 mm. in Herman Creek, and to 73 mm. for coastrange sculpins and 68 mm. for torrent sculpins in the Elokomin River.

Body length of a sculpin does not entirely determine its capacity for seizing and swallowing large items of food because of different mouth sizes among species (fig. 6). For example, Northcote (1954) showed torrent sculpin to be more piscivorous and to feed on larger food items at shorter lengths than prickly sculpin and suggested that this difference was related to the larger mouth of the torrent sculpin.

Body length-mouth gape relations were studied for differences among species of sculpin. Fish from Elokomin River, Herman Creek, and other streams of the lower and upper Columbia River and Puget Sound drainage were included to obtain broad geographic coverage to lessen stream effects. After testing for fit the regressions of mouth gapes that progressively increased with length, I concluded that a straight line relation was best.

The D^2 (distance function as described by Rao, 1952)[1] statistics were used to measure

[1] The correlation of mouth gape with body length was removed by using body length as the first variable for part of the analysis. Treatment of the data by the D^2 method involves use of only the mouth gape as the independent variable.

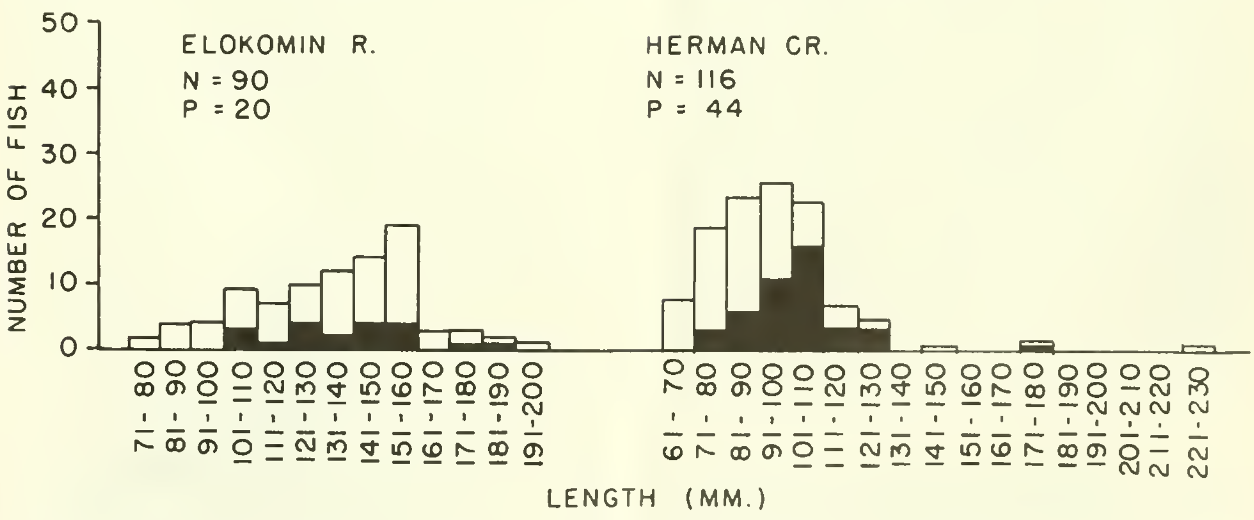

Figure 2.—Length frequencies of prickly sculpin collected after releases of salmon in the Elokomin River in 1962 and 1963 and in Herman Creek in 1962. Salmon predators are shaded, and nonpredators are unshaded. N = total number of sculpins in sample of which P = number of predators. Total number of sculpins is smaller than in Table 3 because Table 3 includes some sculpins taken prior to the release of hatchery reared salmon.

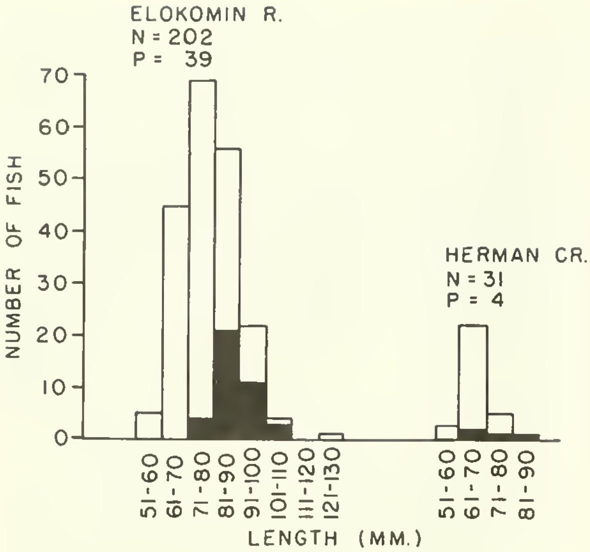

Figure 3.—Length frequencies of reticulate sculpin collected after releases of salmon in the Elokomin River in 1962 and 1963 and in Herman Creek in 1962. Salmon predators are shaded, and nonpredators are unshaded. N = total number of sculpins in sample of which P = number of predators. Total number of sculpins is smaller than in Table 4 because Table 4 includes some sculpins taken above the release site and prior to the release of hatchery reared salmon.

specific differences in mouth size of sculpins. Populations were examined from the Elokomin River (prickly, coastrange, reticulate, and torrent sculpins), Herman Creek (prickly and reticulate sculpin), and Abernathy Creek (a stream near the Elokomin River with the same composition of sculpins). Chi-square tests of the D^2 statistics showed that prickly, reticulate, and torrent sculpins are not separable on the basis of mouth size — but suggested that the coastrange sculpin has a smaller mouth than the other sculpins. Thus, the low intensity of predation by coastrange sculpins on salmon may be explained in part by the smaller mouths.

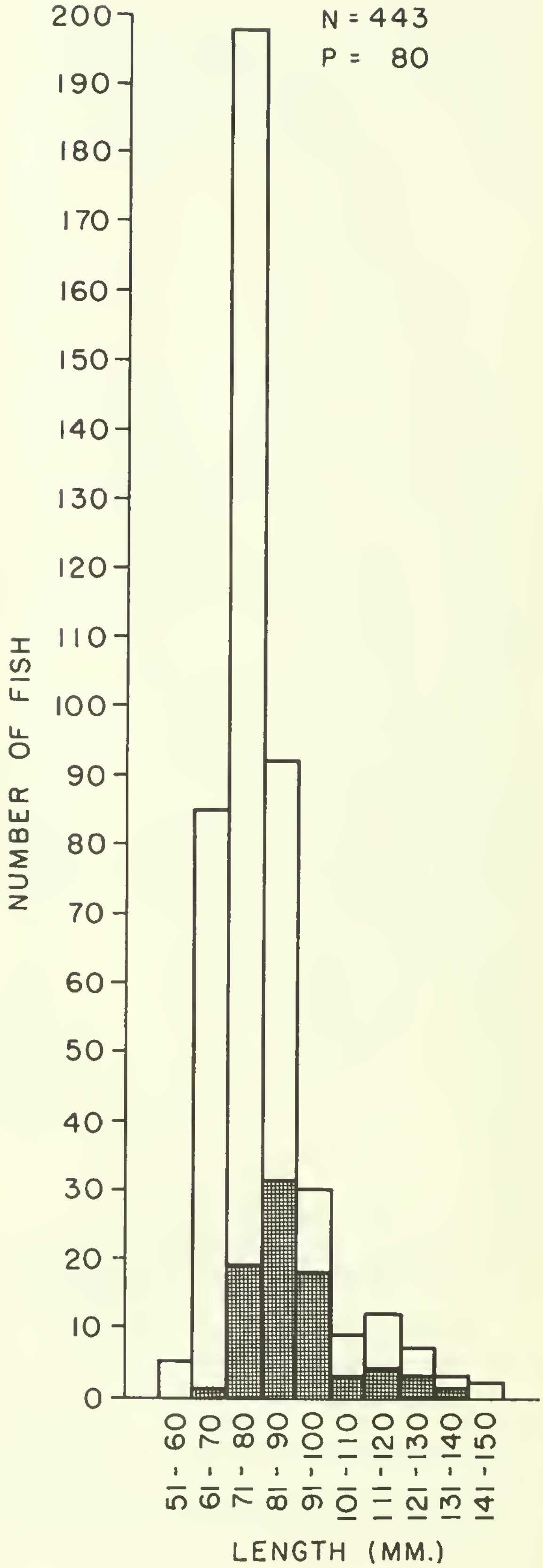

Figure 4.—Length frequencies of torrent sculpin collected after releases of salmon in the Elokomin River in 1962 and 1963. Salmon predators are shaded, and nonpredators are unshaded. N = total number of sculpins of which P = number of predators. Total number of sculpins is smaller than in Table 5 because Table 5 includes some sculpins taken above the release site and prior to the release of hatchery reared salmon.

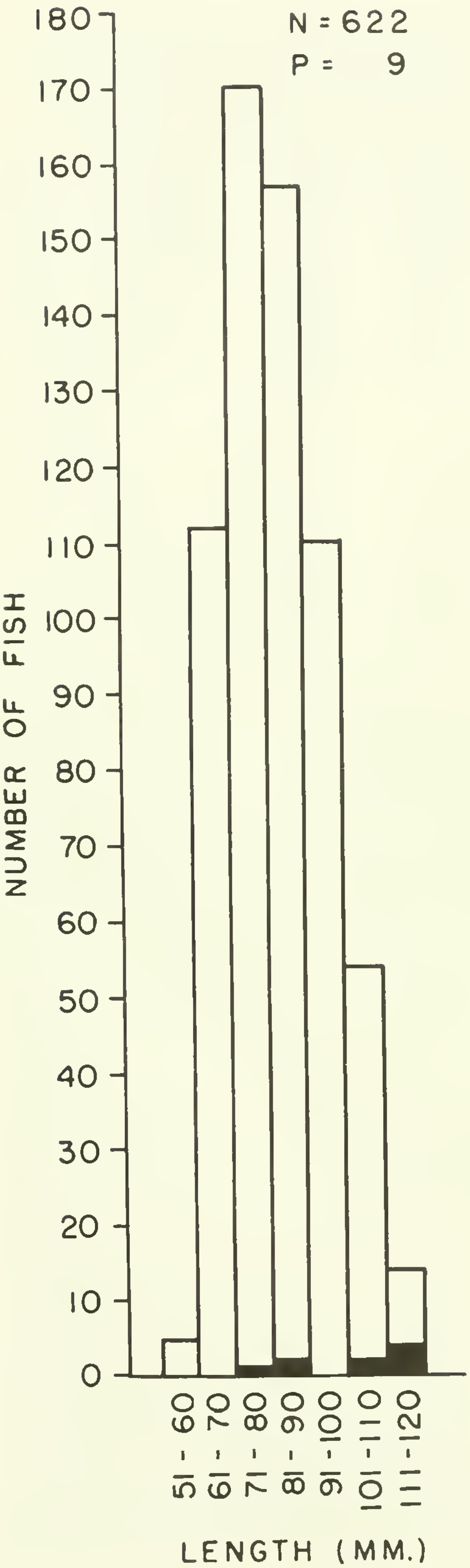

Figure 5.—Length frequencies of coastrange sculpin collected in the Elokomin River after releases of salmon in 1962 and 1963. Salmon predators are shaded, and nonpredators are unshaded. N = total number of sculpins in sample of which P = number of predators. Total number of sculpins is smaller than in Table 2 because Table 2 includes some sculpins taken prior to the release of hatchery reared salmon.

Estimation of loss of salmon. — The percentage of salmon lost from hatchery releases is the prime criterion in evaluating the gross effect of predation by sculpins in the Elokomin River — the smaller number of predators were not able to eat a significant number of salmon the one night they were available in Herman Creek. To compute the loss of salmon requires knowledge of number of predators, incidence and rate of predation, and duration of exposure to predation. The data available met

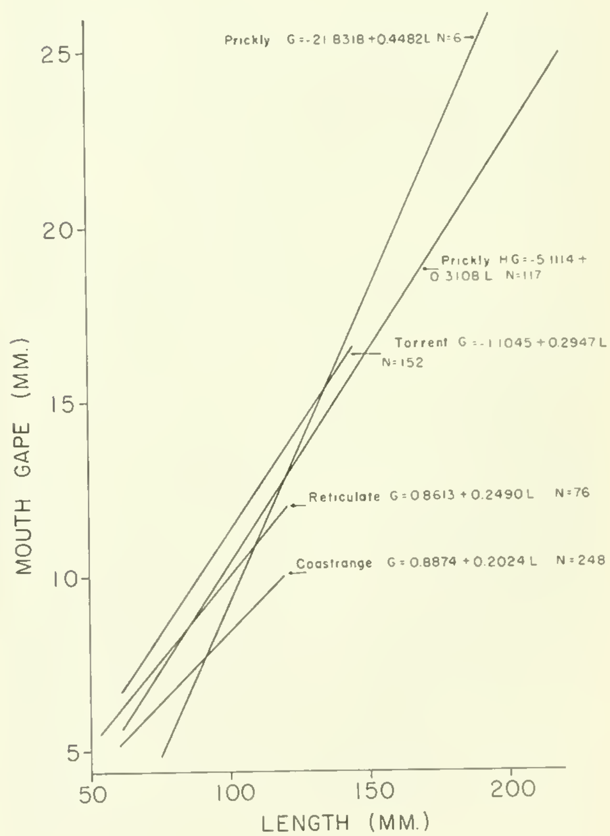

Figure 6.—Relation of length to mouth gape of sculpins from Elokomin River (G) and Herman Creek (HG). Regression lines show length range of sample.

Table 9.—Estimates of chinook salmon eaten by sculpins in the lower 13 km. of the Elokomin River in 1962-63

Species	Species composition	Predator-sized individuals	May 25-26, 1962			May 22-23-24, 1963A			May 28-29, 1963B		
			Average daily predation	Average number of salmon in stomachs of sculpins	Total fry eaten in 48-hour period	Average daily predation	Average number of salmon in stomachs of sculpins	Total fry eaten in 72-hour period	Average daily predation	Average number of salmon in stomachs of sculpins	Total fry eaten in 48-hour period
	Percent	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*
Coastrange sculpin ...	34	14,348	2	1.8	1,033	1	1.0	287	1	1.0	287
Prickly sculpin	18	7,596	83	2.6	33,179	37	2.5	21,077	9	1.2	1,640
Reticulate sculpin	18	7,596	37	1.4	7,869	13	1.0	2,960	5	1.3	988
Torrent sculpin	30	12,660	39	1.7	16,787	8	1.2	3,645	4	1.3	1,646
Total		42,200			58,868			27,969			4,561
Estimated number of salmon released					1,493,483			2,235,475			127,305
Percentage of salmon release eaten					3.9			1.3			3.6

all the requirements; except for number of predators, this number was estimated from catches by electrofishing.

On the basis of the number of sculpins collected and observed during electrofishing, I estimated that the minimum number of sculpins over 65 mm. long per 30 m. of stream was 100. Thus, the total population of predatory sculpins for the lower 13 km. of the Elokomin River was about 42,000.

The number of chinook salmon consumed by sculpins in the Elokomin River is estimated (table 9) from the product of the estimated sculpin population, the average daily incidence of predation (table 6), the average number of salmon eaten by sculpins (table 7), and the duration of predation.

The estimated loss is roughly indicative of salmon mortalities from sculpin predation, although it is minimal for at least two reasons. First, populations of sculpins of predatory size are probably greater than the estimate (electrofishing caught slightly more than 1,000 sculpins over 65 mm. long in 1963). This catch indicates that 1/42 of the sculpins of a predatory size were collected. Considering the small area shocked, the short duration of shocking (electric current was on a total duration of 1 hour and 50 minutes for the 15 collections), and the inefficiency of shocking for sculpins (Patten and Gillaspie, 1966), it is inconceivable this effort removed 1/42 of the larger sculpins from 13 km. of a stream as large as the Elokomin River. Second, predation on a few salmon fry continued beyond the 48- or 72-hour period of observation because some fry remained in the Elokomin River beyond this time. This study indicates only the losses during the period of the heaviest mortalities.

Total loss estimates for the respective releases of salmon are not directly comparable because of differences in numbers released. A percentage loss computation provides a better evaluation. Sculpins ate an estimated 3.9 percent of the 1962 chinook salmon release, 1.3 percent of the 1963A release, and 3.6 percent of the 1963B release.

Prey-dependent factors.—The variation in losses of salmon to sculpins for the different releases (table 9) suggests that prey-dependent factors are important. The factors that should be considered, in addition to the obvious one of rate of downstream migration, are: (1) density, (2) size, and (3) ability to escape predators.

The intensity of predation by sculpins for the three releases (table 9) showed no consistent relation to the density of salmon (numbers released on a given date). The total mortalities in 1962 were twice those for 1963A despite the longer observation period in 1963. Also, the percentage loss was three times greater for the 1962 release than for 1963A. The difference between the 1963A and 1963B releases was also large. Although the total numbers of fry eaten by sculpins reflected the smaller numbers of salmon in the 1963B release, the percentage of this release lost was almost three times greater than that for 1963A.

The average length of salmon recovered from stomachs of sculpins was smaller than the average length of those released. The mean length of the salmon released from the Elokomin Hatchery was 59 mm. in 1962 and 60 mm. in 1963; lengths of salmon from stomachs of predators averaged 43 mm. in 1962 and 42 mm. in 1963 (differences were similar in Herman Creek). Also, the more capable salmon predator, prickly sculpin, fed on the same sized prey as smaller species of sculpins. It seems clear that the sculpins preyed selectively on the smaller salmon in the releases.

The hatchery salmon varied in alertness and agility between 1962 and 1963. The 1962 and 1963 releases of chinook salmon fry and wild coho salmon fry differed in their ability to evade capture in the stream by a dipnet. It was more difficult to catch chinook salmon in 1963 than in 1962; it was almost impossible to capture wild coho salmon fry in either year by this method. Chinook salmon released in 1962 were not as responsive to movements above the surface as those liberated in 1963, which instantly sounded at slight movements above the surface. The greater alertness and agility of the salmon in 1963 may have contributed to the less intense predation in that year than in 1962.

By Salmon and Trout

Although the primary aim of my study was to examine predation by sculpins on fry of chinook salmon, I examined stomachs of some trout and yearling coho salmon collected in the Elokomin River after the releases of chinook salmon fry in 1963 (one rainbow trout was collected in Herman Creek in 1962). Salmon were found in the stomachs of 3 of 58 yearling coho salmon, in 11 of 44 rainbow trout from the Elokomin River, and in 14 of 27 cutthroat. Tables 6, 7, and 8 show the incidence, rate, and maximum numbers of salmon eaten by salmon and trout predators. The rainbow trout from Herman Creek had eaten three salmon.

INFLUENCE OF HATCHERY TECHNIQUES ON SALMON LOSS

The damage by fish predators to chinook salmon fry released in the Elokomin River was rather extensive. The extent of this damage from the predatory activities of certain stream fishes depends partly on the availability and susceptibility of hatchery fish. Controlling the predators might reduce the damage. The cost of control of sculpins, however, is difficult to justify, and attempts to control predation at an early point in the life of salmon in poor condition would be of little value because the pressures of survival would surely eliminate them later. If cultural practices were known to be developed to a point where the quality of the fish approached the maximum attainable and heavy predation still continued, predator-control measures would be worth considering. Because hatchery practices are still improving, it is not justifiable now to recommend control measures on fresh-water sculpins or other predatory fish. Indeed, predation on hatchery salmon has always been a major concern of fish-culturists and the results of this study provide data that are important for the improvement of techniques of culture and release of salmon.

Factors Related to Methods of Fish Culture

Cultural techniques that better enable salmon to cope with the natural environment are clearly desirable, as salmon released from hatcheries will always be exposed to many predators. Good physical condition and large size are recognized as qualities for which culturists should strive.

Fitness of hatchery salmon may be attained by physical conditioning and proper diets. Survival of hatchery fish has been improved by exercising (Burrows, 1964) and by predator-avoidance conditioning (Thompson, 1966[2]). Data from this paper lend support to the hypothesis that proper diets can decrease losses from predation.

[2] Richard B. Thompson. 1966. Effects of predator avoidance conditioning on the post-release survival rate of artificially propagated salmon. Ph.D. Thesis, Univ. Wash., Seattle, 155 pp. Typescript.

The lower estimated percentage loss in 1963 than in 1962 of chinook salmon in the Elokomin River through predation by sculpins (table 9) could conceivably be attributed in part to the change from a "wet" diet in 1962 to the Oregon moist pellet in 1963. It has been shown that the return of adult hatchery salmon is consistently higher from fish reared on the Oregon moist pellets than from those fed a "wet" diet (Hublou, 1963). The energy reserves of rainbow trout fed another fortified pellet in Canada were also superior to those of fish reared on a wet diet (Miller, Sinclair, and Hochachka, 1959). Because wet diets seem to be less desirable than some fortified pellets or the diets of wild fish, hatchery salmon fed the wet diet may be weakened by the requirements of stream life and have such small energy reserves that predators can catch them more easily. Many factors apparently contribute to differences in loss of chinook salmon to sculpins; data for the 1962 and 1963 salmon releases, however, suggest that reduced losses in 1963 resulted in part from the dietary change from "wet" diets to the Oregon moist pellet.

The specific reason for the apparent relation between losses from predation and the size of chinook salmon at release is not known. It is clear, however, that at certain sizes salmon are too large for certain predators; possibly more important is the fact that larger individuals of a release may be salmon of higher quality. That is, the larger salmon in a release may be more healthy, agile, and alert than smaller fish and therefore be less vulnerable to predators.

Factors Related to Release Techniques

Although the physical condition of cultured salmon is important in reduction of mortality, the manner in which they are released can also be significant — especially the use of methods that reduce exposure to intensive predation. The three statements which Neave (1953) used to describe predation on fry of wild pink salmon, *O. gorbuscha,* and chum salmon apply to the release of hatchery-reared chinook salmon fry: (1) percentage mortality increases with the distance the fry travel; (2) percentage mortality decreases with increasing number of migrants; and (3) percentage mortality increases during the progress of the run.

Neave's first point indicates that location of the release point is important because it determines the length of the route the salmon must travel and the duration of exposure to predation. Salmon released from the Oxbow Hatchery reached the Columbia River with fewer mortalities than those released from the Elokomin River Hatchery. Ellis and Noble (1960) reported that losses were less for juvenile chinook salmon transported 65 km. downstream from the Klickitat River Hatchery than for fish released at the hatchery. The transporting of juvenile salmon past concentrations of predators, however, did not seem to affect the percentage of adult fish that returned to the hatchery; the proportion of transported fish that returned to the hatchery was smaller than the proportion of returning fish that were not transported. In the Elokomin River, chinook salmon traveled 13 km. near numerous predators and were generally subjected to predation for about 2 days. If Elokomin River salmon were transported and released below km. 2, they would be, initially at least, subjected to fewer predators for a shorter period. Semko (1954) also theorized that more hatchery salmon fry would be saved if they were released below concentrations of predators.

Neave's second point indicates that percentage mortality from predation will be least if large numbers of migrants are released at the same time. Results from the 1963A and 1963B releases were consistent with this principle. The 1963A release of chinook salmon into the Elokomin River was larger than the 1963B liberation. The calculated percentage of the first release consumed by sculpins was about one-third that of the smaller second release and suggests that the percentage of a release eaten by sculpins increases as the number of fish liberated decreases. On the other hand, the percentage of salmon eaten by sculpins was similar for the 1962 and 1963B releases despite a much greater number of salmon released in 1962. Fish were cultured differently in these 2 years, however, and I attribute much of the loss of salmon in 1962 to their diet.

The third point by Neave suggests that the duration of exposure to predation should be minimized, which is already being accomplished by the hatchery practice of holding salmon until they are at a migratory stage.

SUMMARY

Chinook salmon fry reared in a hatchery and released into the Elokomin River in May 1962 and 1963 were available to predators for about 2 days. Fourteen species of fish were collected, but the predator species were limited to four sculpins, two trout, and one salmon.

Sculpins were significant predators; the extent of salmon loss, however, varied within and between the species of sculpin. The tendency of sculpins to prey on salmon increases with body size and mouth width. Because of the large size it attains the prickly sculpin is extremely predatory and inflicted the greatest estimated mortality on chinook salmon fry. Torrent and reticulate sculpins were of less importance as predators. Despite having the largest population, the coastrange sculpin was an insignificant predator. Estimates of chinook salmon fry eaten by sculpins were 58,868 out of a release of 1.5 million in 1962 and 27,969 out of 2.2 million and 4,561 out of 127,000 in 1963; respective percentage losses were 3.9, 1.3, and 3.6. The mean length of the chinook salmon released was about 60 mm., but the mean length of those found in sculpins was about 43 mm.

Salmon released from Oxbow Hatchery were little affected by predation from sculpins in the 0.2 km. of stream to the Columbia River, because numbers of predators and intensity of predation were low and the duration of predation was short.

In Herman Creek the prickly sculpin was generally more predaceous, larger, and more abundant than reticulate sculpin. The data support the theory that improvement of hatchery techniques tends to reduce predation more effectively than control of predators. Chinook salmon fed the Oregon moist pellet in 1963 appeared to be of higher quality at release and had lower mortality following release in the Elokomin River than those fed a wet diet in 1962. Liberating chinook salmon en masse at night apparently reduces percentage predation. The proximity of migrating salmon fry to predators and the high rate of predation in streams suggest that the transport of hatchery fish around concentrations of predators may be of value.

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