INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION *

Appointed under a Convention
Between Canada and the United States for the
Protection, Preservation and Extension of
the Sockeye and Pink Salmon Fisheries
in the Fraser River System

PROGRESS REPORT

No. 42

WOUNDS, SCARS AND MARKS ON FRASER RIVER SOCKEYE SALMON WITH SOME RELATIONSHIPS TO PREDATION LOSSES

BY

PHILIP GILHOUSEN

COMMISSIONERS IN TRUST

ROLLAND A. SCHMITTEN C. WAYNE SHINNERS

VANCOUVER, B.C., CANADA
1989

*Dissolved December 31, 1985 by agreement of the Governments of Canada and the United States in accordance with Article XV of the Pacific Salmon Treaty.

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ABSTRACT

From 1971 through 1978, 13,861 sockeye salmon were examined for external parasite and/or injury incidence (1,228 smolts and 12,633 adults). Smolts were variably parasitized (Salmincola) by lake origin (maximum 2.8%), had very few injuries (0.6 to 6.3%), and no missing fins. Injuries and injury sources were described for adults. Frequent injury types were ascribed to sharks (5.1 - 21.1%) and Pacific lampreys (seasonal; 0.0 - 66.5%). Shark wound age varied from fresh (23.8% overall) to completely healed (56.9% overall). Slashes (shark-tooth cuts on only one side of the sockeye) were about 5 times as frequent as shark bites. Less frequent injuries were attributed to river lampreys (0.0 - 5.8%), porpoises (0.0 - 1.6%; apparently frivolous attacks), and troll hooks (seasonal; 0.0 - 5.6%). Troll fishery efficiency on sockeye was estimated at about 75% maximum (% boated of fish hooked). Damaged or missing fins (0.0 - 3.9% by month, varying with fin) and tooth scratches (2.2% overall) were attributed to sharks. Injury types without specific causes comprised scrape scars (2.1% overall) and unassigned (1.6% overall). A predation/wounding model was devised and used to suggest possible levels of predation. Sharks (predominantly the salmon shark) and river lampreys (more a predator than parasite) have potentially large predation rates. Wound location and orientation suggest that salmon sharks attack prey from below and behind; prey are disabled (slashes) as well as captured directly. Comparison of annual incidence of 5 types of injuries with annual sockeye abundance suggested that injuries were possibly more prevalent at higher sockeye abundance. It was concluded that the vast majority of salmon lost during both freshwater and marine life are killed by predators.

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INTRODUCTION

Injuries, both fresh and partially or completely healed, have long been observed on maturing sockeye salmon (Oncorhynchus nerka) en route to spawning grounds in the Fraser River. However, no systematic examinations have been available with which to determine the frequencies and causes of the various types of injuries. The nature of each injury yields clues to the identity of the animal or agent which caused it, and reasonable causes can be assigned to many wounds and marks. Reported herein are the results obtained via sampling of sockeye salmon captured by commercial fisheries in the lower Fraser River and marine approach routes, during 1971-78. Sockeye smolts captured in research nets in various locations in 1971-1979 were examined for comparison with adults. The observations shed light on the importance of certain predators, and indirectly, on the time during marine life when depredation associated with these predators may occur.

Two types of wounds caused by lampreys have been directly verified (Roos et al. 1973, Williams and Gilhousen 1968, Beamish and Williams 1976). Shark wound identification (Sano 1959a,b) is based on strong circumstantial evidence. Although the explanations given for other types of injuries may not be universally accepted, they are offered here as a starting point in assessing the significance of injuries on salmon.

On average, approximately 90% of all Fraser River sockeye die between lake exit as smolts and maturation as adults, approximately 2.3 years later. A significant but unmeasured fraction of this mortality has been assumed to be due to early predation by fish and birds (Ricker 1976). Sharks and marine mammals have been implicated in high seas predation of North Pacific salmon via stomach-content studies (Sano 1959a,b; Mathiesen et al. 1962; Anon. 1963; Spalding 1964; Perez and Bigg 1986), including sockeye (Bigg, pers. comm.). However, these sources did not estimate or apportion the marine mortalities attributable to the multitude of potential predators. The present study attempts a first approximation of the relative magnitude of coastal and open-ocean mortalities of Fraser River sockeye salmon.

MATERIALS AND METHODS

SAMPLING

Samples of both seaward-migrating smolts and maturing adults on their spawning migration were examined. Sampled smolts were predominantly age 1+ (one-year-in-lake), and were caught by purse seine or trap near the lake outlet, in the river immediately downstream, or in the lower Fraser River. Most of the sampled adults were from gillnet catches in the lower Fraser River, below New Westminster (Figure 1). A few samples were from gillnet catches in the Fraser River upstream from New Westminster, and from purse-seine and troll fisheries farther seaward: Strait of Georgia, Juan de Fuca Strait, Barkley Sound and the west coast of Vancouver Island.

Sampling emphasis, for adults, was placed on the Fraser River gillnet fishery because this fishery is the most consistent throughout the season and the catches are landed promptly at convenient locations. Moreover, as the River is the terminal commercial fishery, injuries originating close to, or in, the Strait of Georgia will be better represented in samples.

Adult samples (100-300 fish) were examined, as time permitted, at processing plants from scheduled samples of 250-300 fish, from which scales had been collected for age composition and stock delineation. Adult sockeye were primarily 4- and 5-years old (two or three years in the ocean), but one or two 3-year-old "jacks" (one year in the ocean) were sometimes included in a sample. In 1977, a special sample of jacks was examined to compare wound incidence with that of older sockeye. During August-September 1978, special samples were examined from sockeye caught by gillnet in the Fraser River during test-fishing operations while the commercial fishery was closed. Only troll-hook wounds were recorded from these fish.

Examination

Smolts, preserved in formalin, were examined at the laboratory under approximately 3X magnification. Injuries not deemed to have been caused by capture or post-preservation handling were described in verbal notes. External parasite infestation was included in descriptions.

FIGURE 1.

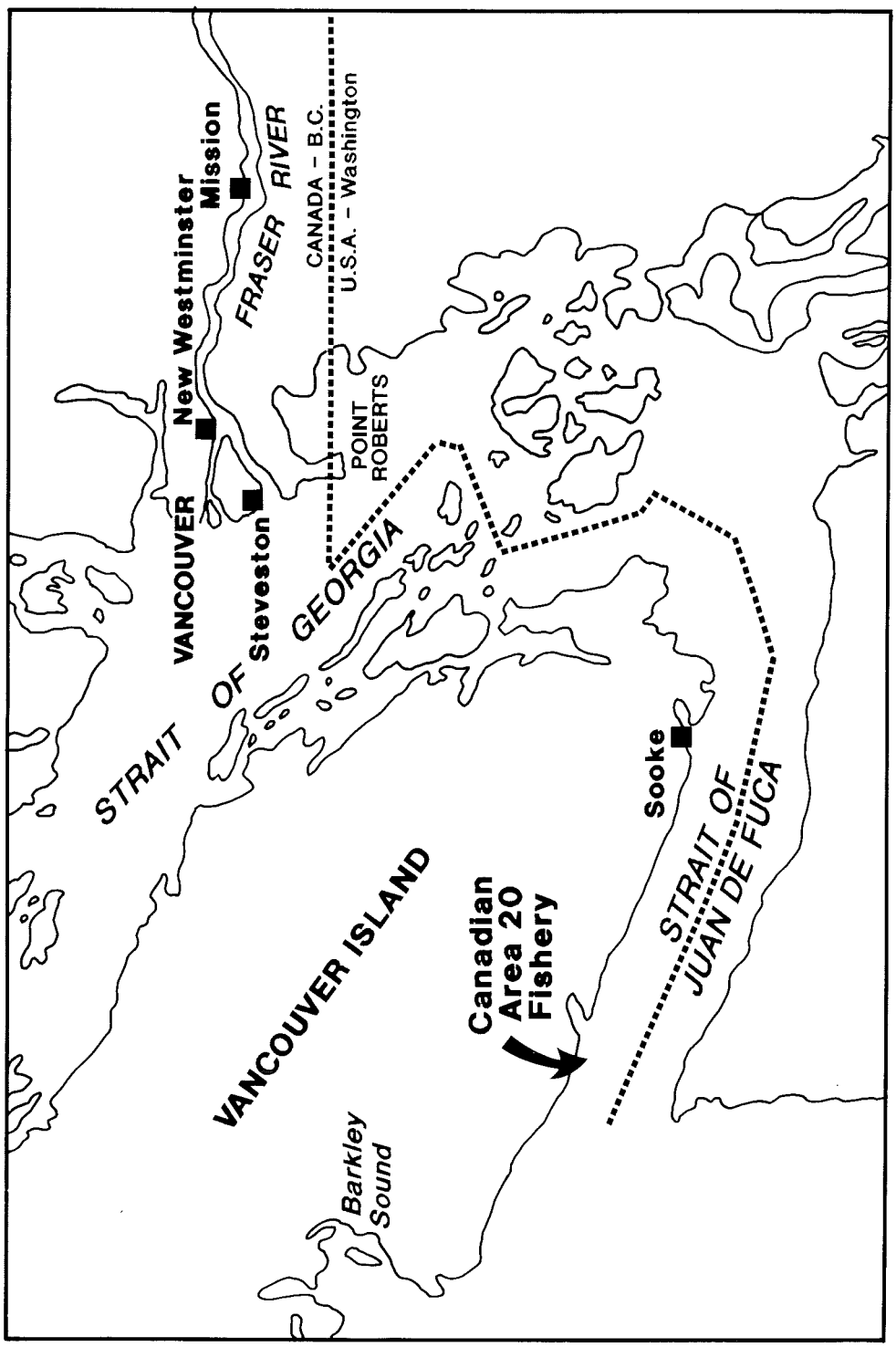

Figure 1. Commercial fishing areas for adult sockeye salmon in the waters of southern British Columbia and northern Washington State.

Adult examination in 1971, when the program began, was initially directed to the scaled areas of the fish. However, head injuries, presumably caused by the troll fishery, and numerous cut and damaged caudal fins noted late in the season, led to expansion of the examination. After 1971, the entire body of each specimen, including fins, was examined.

Adult sockeye were usually examined by a single observer who rotated the fish with one hand and recorded wounds, etc., with the other. No magnification was used. Minor injuries such as small areas of disrupted scales were ignored. Probably some other minor injuries were undetected. In 1971, wounds, scars and marks were recorded by frequency of occurrence, but with only a few categories of wounds and scars. From 1972 to 1974, sketches of wound and scar size and position were used, with notes to indicate wound age and severity. Beginning in 1973, this method was formalized to pre-printed outlines of each side of the fish on which all the wounds and scars on a single, and often more than one, fish were recorded. Coded notations were appended to show age and severity of injuries. In September, 1974, a code was prepared which covered all wounds, scars and marks, and included position and stage of healing. This latter procedure allowed more concise recording of injuries, and only certain uncoded details such as missing fins or wound direction needed to be recorded in words. However, the coding did not increase the efficiency of recording, and lacked some of the detail obtainable from sketches.

Injury classification

Wound age was recorded as fresh, about half healed, or nearly healed. Completely healed wounds were classified as scars. Severity was recorded as superficial (skin not penetrated), moderate (skin penetrated but with slight flesh damage), and severe (very large wound penetrations in skin, and extensive flesh damage). Healed wounds were classified by what they were assumed to be when fresh. No attempt was made to assign degrees of severity related to effect on subsequent survival. Post mortem wounds on sockeye caused by fish peughs, conveyor belts, etc., during commercial transfer and processing expose only the orange, bloodless flesh when the skin is penetrated. Wounds acquired by live sockeye in which flesh was exposed were in all cases covered by a thin, dark-red scab or by healing tissue.

Injury description

Pacific lamprey wounds

Photographs of wounds and marks caused by the Pacific lamprey (Lampetra tridentatus) were shown by Williams and Gilhousen (1968). Typical examples of wounds and marks observed on adult sockeye caught at the mouth of the Fraser River are shown in Figure 2. The diagnostic five teeth on the infra-oral tooth bar show in the superficial marks.

Shark-caused wounds/scars

Wounds and scars, clearly caused by very sharp agents, were attributed to the teeth of the larger species of predatory sharks. Such wounds occurred in all stages from fresh to completely healed. Four types of shark injuries were distinguished: slashes, bites, scratches, and damaged (or excised) fins.

Slashes, usually linear, were found on only one side of the body (Figure 3). They often occurred with, and graded into, superficial scratches on the skin. However, scratches also occurred alone. Slashes often extended onto the fins, although cut fins also occurred on fish lacking body injuries, particularly cut caudal fins. Slashes occurred as a single cut, branching cuts, or two or more parallel cuts. Rarely, a patch of skin was completely torn away. Severe anterior wounds occasionally penetrated the body cavity.

Bites mirrored the widely spaced teeth of large sharks (Figure 4). The teeth of both jaws made obvious injuries, normally involving both sides of the sockeye. Occasional bites showed the rounded-arch shape of both upper and lower shark jaws on only one side of the fish.

Most of the body scratches and fin injuries appeared to be caused by the sharp, widely spaced teeth of large sharks, but not all could be so explained. Scratches and fin injuries were therefore treated separately from shark-caused injuries.

Several species of sharks in the Pacific Coast region are potential causes of sockeye salmon wounds, based on tooth size, distribution, and stomach contents. Information in Hart (1973), suggests the following as potential predators:

FIGURE 2.

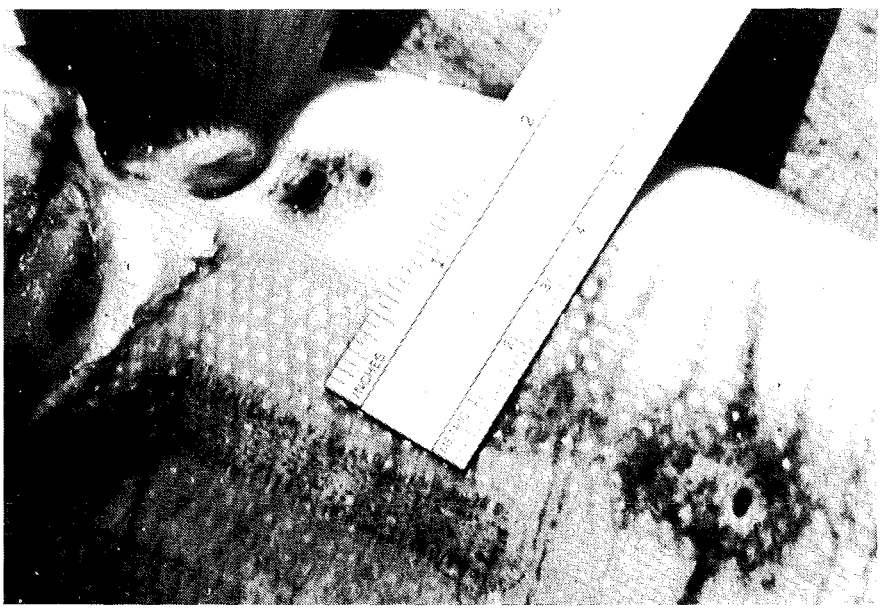

Figure 2. Wounds on adult sockeye caused by Pacific lamprey. More than one lamprey may have been responsible. The superficial mark (below end of scale) shows lamprey tooth structure.

FIGURE 3.

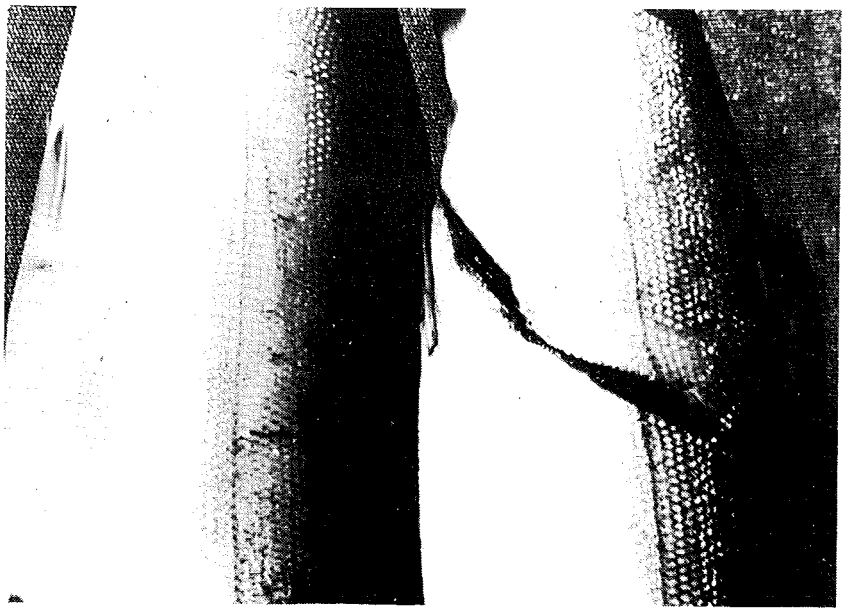

Figure 3. Slash wounds on adult sockeye attributed to salmon sharks. Wound on left fish is completely healed and probably several months old.

FIGURE 4.

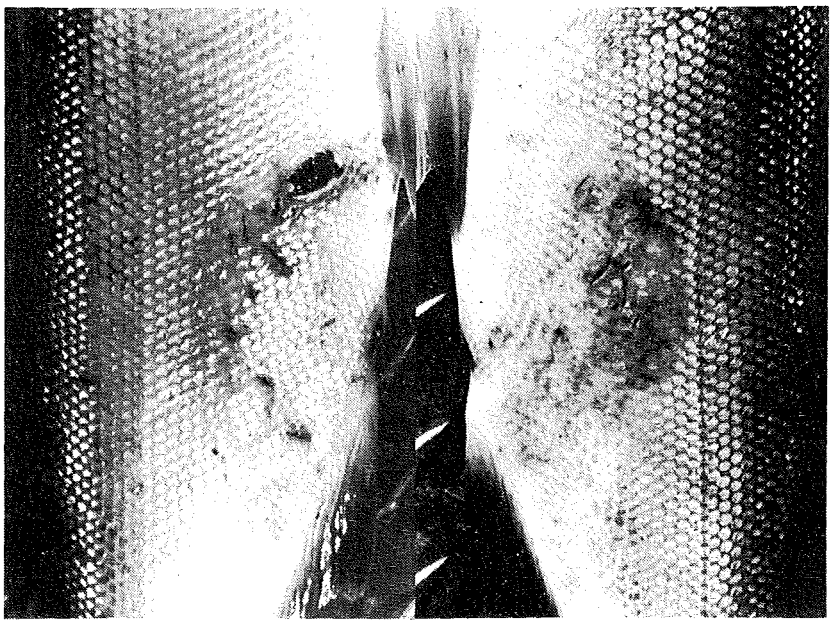

Figure 4. Fresh bite wound on adult sockeye (both sides shown) caused by a relatively small shark. A rounded jaw outline and sharp and irregular puncturing teeth are indicated.

Blue	*Prionace glauca*
Pacific sleeper	*Somniosus pacificus*
Salmon	*Lamna ditropis*
Sevengill	*Notorhynchus maculatus*
Sixgill	*Hexanchus griseus*
Soupfin	*Galeorhinus zyopterus*
Thresher	*Alopias vulpinus*
White	*Carcharodon carcharias*

Only the salmon, blue, and sixgill sharks (in order of presumed importance) are considered to be potentially serious predators on sockeye salmon. Among these, the salmon shark has the most extensive range in the North Pacific Ocean, and is prevalent throughout the year (Neave and Hanavan 1960). Blue sharks also have a relatively extensive range, but are more abundant near the coast of North America, and are seasonal (summer-autumn). The sixgill shark is locally abundant in the Strait of Georgia, and may feed on salmon, since this predator has been found in salmon traps (Clemens and Wilby 1961) and purse seines (Hart 1973).

Available evidence suggests that the salmon shark is the principal cause of the wounds noted on sockeye salmon sampled in this study. Tooth structure and scarcity eliminate most other shark species as serious predators on sockeye salmon. Most of these sharks have teeth adapted to shearing food, as exemplified by the overlapping, sickle-shaped teeth of the blue. Blue-shark attacks on salmon hooked on troll lures produce clean-cut removals of flesh (anecdotal evidence from fishermen). Shearing teeth appear to involve all-or-nothing results, and consequently few salmon would survive a bite by these teeth. The awl-like teeth (Figure 5) of salmon sharks are adapted as much to grasping as to cutting food, and are the most likely cause of slashes. Bites, on the other hand, may be caused by smaller shark species or smaller salmon sharks.

FIGURE 5

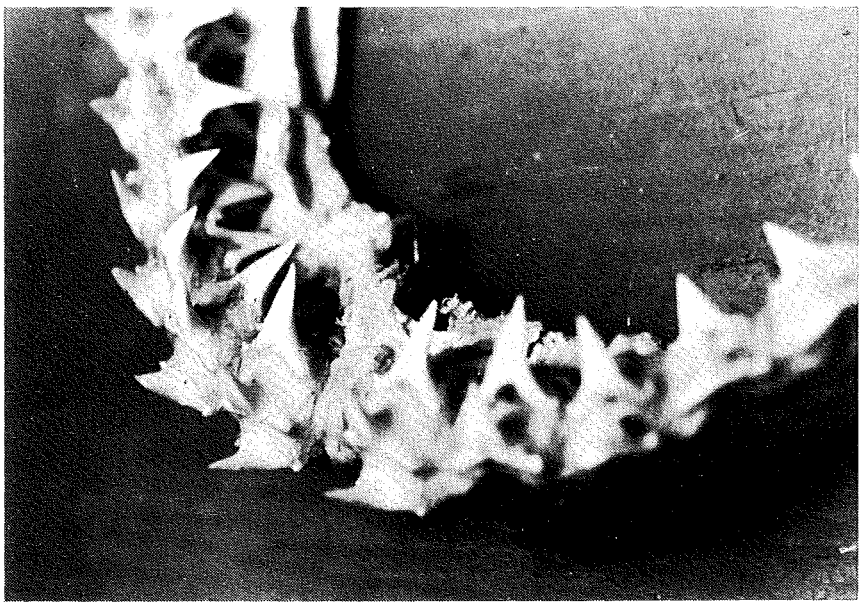

Figure 5. Lower jaw and teeth of a medium-size salmon shark, showing the awl-like teeth with minor cusps at the base. Note process of tooth succession with outward movement and protrusion before being shed.

River lamprey scars

Scars on adult sockeye salmon, attributed to the river lamprey (Lampetra ayresi), were healed wounds incurred by smolts shortly after entering the sea. Details of this predation were provided by Roos et al. (1973) and Beamish (1980). These scars ranged from a large patch of regenerated skin, bare or covered with small irregular scales (Figure 6), to a deep notch in the body outline (Figure 7) indicating incomplete regeneration of body tissue removed at the time of attack. Lamprey movement during feeding often created long wounds oriented lengthwise. Scar position was taken from the anterior end of the scar. Scar locations match, approximately, the usual location of fresh wounds found on migrating smolts, viz., close to the dorsal mid-line and ahead, close beside, or immediately behind the dorsal fin. River lamprey wounds graded into "scrape scars", with no clear dividing line.

Porpoise-caused injuries

Wounds produced by small, closely spaced teeth (Figure 8), sometimes no more than slight scratches, were ascribed to porpoise attacks. In almost all cases, the wounds appeared as approximately matched pairs on opposite sides of the body. Only slight healing was observed. Wounds of this description have sometimes been interpreted as gillnet marks. However, they may be distinguished by the evenly-spaced tooth marks which clearly do not encircle the body. When both sides of the jaws left marks, a long, narrow mouth was evident, which also distinguished these marks from those caused by other marine animals. A few porpoise marks exposed considerable areas of flesh.

Spacing of tooth scratches in typical porpoise marks is no more than 4-6 mm (0.25 in). The Dall porpoise (Phocoenoides dalli) is the only species having teeth this closely spaced. Indeed, according to Cowan (1944), its teeth are embedded in the gum, and the functional teeth are horny points between the tooth pockets. Observed weak tooth marks fit well with this description.

Some sets of tooth scratches indicative of coarser teeth may have been caused by other species of dolphin or porpoise. Infrequently, these graded into scratches classified as shark injuries; most such shark injuries were accompanied by cuts of greater severity.

FIGURE 6.

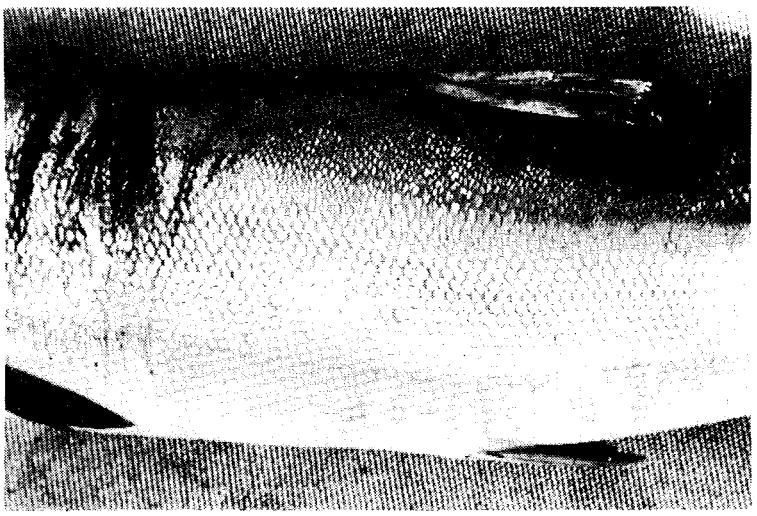

Figure 6. Regenerated scale pattern on adult sockeye resulting from attack by river lamprey at first entry of smolt into saltwater.

FIGURE 7.

Figure 7. Hollow in body outline of adult sockeye resulting from flesh removal during attack on smolts by river lamprey at first entry into saltwater.

FIGURE 8

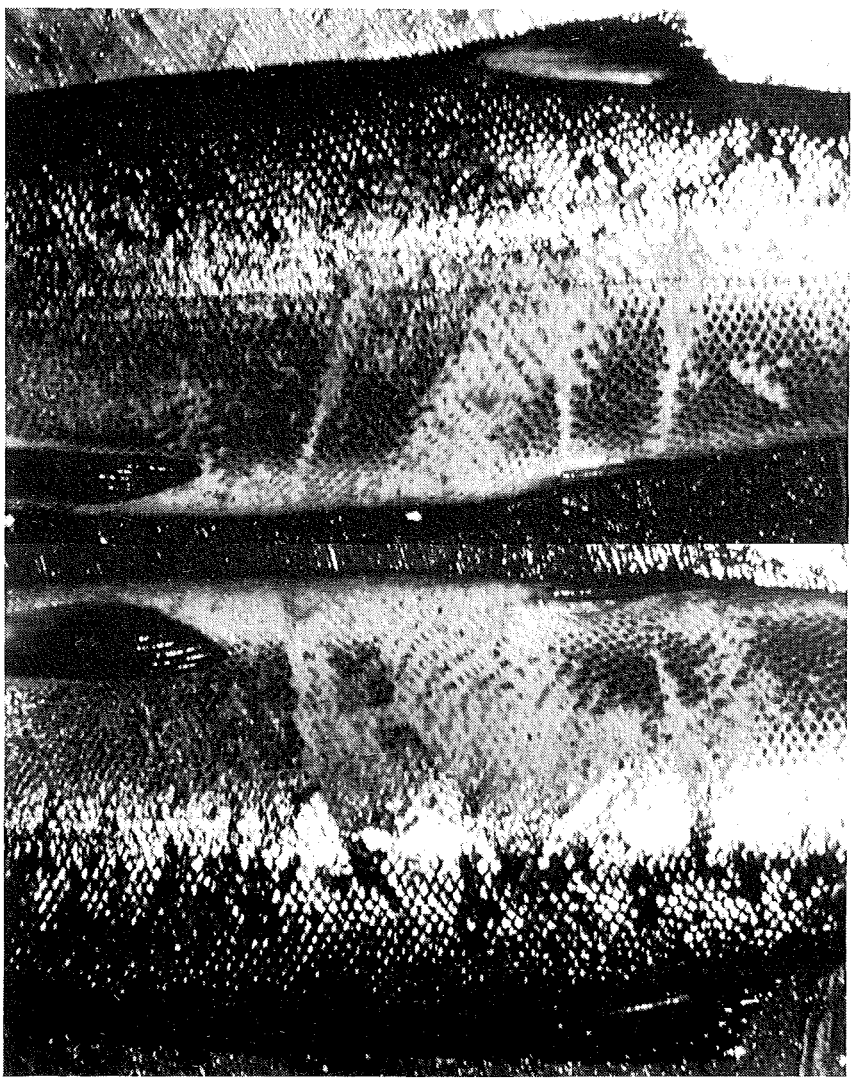

Figure 8. Presumed marks of a porpoise mouth on an adult, seine-caught sockeye (paired photographs of both sides of the same fish). Long, narrow jaws clamped on the sockeye from below, first ahead of pelvic fins, and then across them. Sockeye slipped from the jaws after second hold, leaving tooth-mark lines slanting down and backward as fish rotated in the porpoise's mouth prior to escape. Note small, closely-spaced teeth which did not penetrate skin, and absence of marks across the dorsal surface, typical of gillnet marks.

Troll-hook injuries

Troll-hook injuries included split or separated mandibles, tongue and floor of mouth pulled loose from lower jaw, end of snout pulled off, and pieces of flesh torn from jaws or corner of the mouth (Figure 9). Damage also occurred to the eyes and to other structures close to the buccal cavity. Torn maxillaries were not recorded as troll-hook injuries since other causes were possible.

Sea lice

Sea lice (parasitic copepods; Lepeophtheirus salmonis) caused abraded areas on the posterior third of the body, principally above the anal fin and also in front of or behind the adipose fin. Scales were largely removed and bleeding sores often resulted from heavy infestations. These copepods were found on sockeye caught in saltwater and in the Fraser River shortly after the sockeye entered the river.

Miscellaneous injuries

Miscellaneous injuries were those not reasonably attributable to known or single causes, and rare or minor injuries of known or probable cause. They include damaged or missing fins, tooth scratches, and scrape scars.

Damaged or missing fins. These injuries comprised fins with rays removed, shortened or stunted fins, and missing fins with only a small stub or scar remaining. Damaged caudal fins were often split between fin rays; they usually occurred with tooth scratches.

Tooth scratches. These marks were self-evident, and were attributed largely to shark attacks, being clearly separable from the evenly spaced, porpoise-caused tooth scratches.

Scrape scars. These were defined as areas of regenerated scales which resulted from superficial wounds probably acquired as juveniles during lake residence, downstream migration, or early marine life. Their usual location was on the sides of the fish, either as opposed pairs or on one side only.

FIGURE 9.

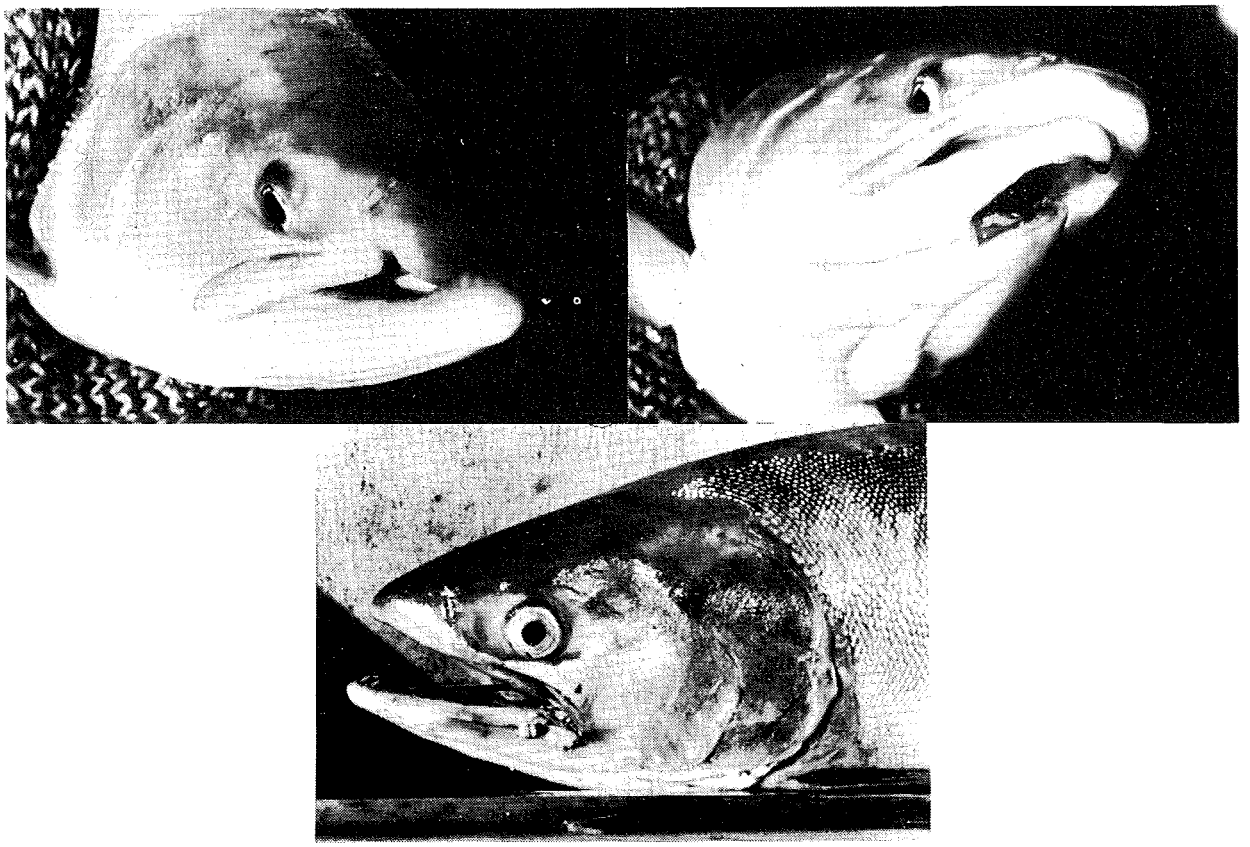

Figure 9. Troll-hook injuries sustained by pink salmon, to the upper jaw, lower jaw, and corner of mouth. Similar injuries occur on sockeye, and much more severe injuries are found on both species.

Gillnet marks were not recorded since some or all of the sockeye may have been captured by this gear. These marks were usually distinctive and offered no problem of differentiation from other injuries. However, extensive gillnet marks sometimes obscured other scars or marks. Damage to jaws and gill covers required careful examination since removal of sockeye from a gillnet sometimes caused injuries which resembled certain troll-hook injuries.

A few probable "old" gillnet marks were found. These may have been acquired in the gillnet fisheries in Juan de Fuca Strait or in the San Juan Islands. They were not analyzed since they could not be classified with certainty as to cause or age.

Bites clearly attributable to seals or sea lions were not found on sockeye examined in this study.

STATISTICAL TESTS

Chi-square tests (Snedecor 1946), mostly based on marginal totals, were applied, where appropriate, to quantify differences in injury incidence. Independence between certain injury types was tested for with 2x2 contingency tables, again by Chi-square. Analysis of variance was applied where within-year sample percentages were approximately normally distributed; logarithmic or arcsine transformations were not found to be advantageous.

RESULTS

GENERAL RESULTS

Numbers sampled

During 1971-79, 13,861 sockeye salmon were examined for parasite and/or injury incidence; 1,228 seaward-migrating smolts, and 12,633 landward-migrating adults (Table 1). Smolt specimens comprised 939 collected near the rearing lakes, and 289 in the lower Fraser River. Principal source of adult specimens was the gillnet fishery in and near the Fraser River (N = 11,215). Samplings seaward of the Fraser River totalled 1,087 specimens--261 from the troll fishery off the west coast of Vancouver Island; 826 from the purse-seine fishery in Juan de Fuca Strait (Canadian Statistical Area 20) or Barkley Sound; and 515 from the purse-seine fisheries in the Strait of Georgia (including the U.S. Point Roberts fishery).

Some non-Fraser River sockeye were included in the seaward area samples. Barkley Sound sockeye catches were entirely non-Fraser. June samples from Juan de Fuca Strait were more than half Lake Washington sockeye in both 1973 and 1974. The troll catches from the west coast of Vancouver Island in August, 1974, were almost entirely of Fraser River origin, however.

Injury/parasite incidence

Overall incidence[1] on smolts of wounds/scars was 2.3%, and of parasites (*Salmincola sp.*), 1.2% (Table 2).

Overall incidence on adults ranged from 0.0 - 66.5% for wounds/scars caused by Pacific lamprey (*L. tridentatus*) to 0.0 - 1.6% for porpoise-caused injuries (Table 2). Although 10 categories of injuries, including "unassigned", were identified, only two could be regarded as frequent -- those caused by Pacific lamprey and by shark (5.1 - 21.1%).

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[1] Epidemiological custom requires the use of "prevalence" to describe the proportion of parasites in sample, over time. However, "incidence", a more commonly used term elsewhere, is used here to avoid confusion.

Table 1. Numbers of sockeye salmon smolts and adults sampled for wounds, scars, and external parasites, by sampling location and time, and fishing gear, 1971-79.

Sampling location	Time		Fishing gear[1]	Numbers sampled
	Year	Month		
	Smolts			
Upper Fraser River	1971-79	Apr-May	PS/Tp	939
Lower Fraser River	1977-79	Apr-May	PS/Tp	289
Smolt Total				1228
	Adults			
W. Vancouver Island	1974	Aug	Tl	261
Barkley Sound	1974	Jun	PS	190[4]
Juan de Fuca Strait	1973/74	Jun	PS	360
(Area 20)	1977	Aug	PS	276[2]
Strait of Georgia	1971/74	Jul	PS	331[3]
Seaward Total				1418
Fraser River	1971/77	Jul-Oct	GN	8515
(and vicinity)	1974	Aug	PS	184
	1978	Aug-Sept	GN	2516[5]
Fraser River Total				11215
Adult Total				12633
Grand Total (Smolts + Adults)				13861

[1] GN = gillnet; PS = purse seine; PS/Tp = purse seine or trap; Tl = troll.
[2] Jacks only. (one-ocean fish)
[3] Pt. Roberts
[4] Sample contained no Fraser River sockeye.
[5] Special samples for troll-hook wounds only, while commercial season was closed.

Table 2. Range of incidence (%) within samples, by source/type and sample source, of injuries and parasites on juvenile (smolt), April-May, 1971-79, and adult sockeye salmon, June-October 1971-78.

Source/Type	Sample source: Fishing gear[1]	Sample source: Location[2]	Incidence in Samples (%)
	Smolts		
Wounds/scars	PS/Tp	Fraser River	0.6-6.3
Parasites	" "	" "	0.0-3.4
	Adults		
Pacific lamprey	PS/Tl	Seaward Areas	0.0
	GN	Fraser River	0.0-66.5
Shark	PS/Tl	Seaward Areas	5.1-13.0
	GN	Fraser River	6.5-21.1
River lamprey	PS/Tl	Seaward Areas	0.4-5.8
	GN	Fraser River	0.0-5.5
Damaged or missing fins:			
a. Unpaired Fins	PS/Tl	Seaward Areas	1.6-4.2
	GN	Fraser River	1.0-7.5
b. Paired Fins	PS/Tl	Seaward Areas	0.0-0.8
	GN	Fraser River	0.0-2.4
Tooth Scratches	PS/Tl	Seaward Areas	0.4-2.4
	GN	Fraser River	0.0-5.0
Scrape Scars	PS/Tl	Seaward Areas	0.4-4.9
	GN	Fraser River	0.0-5.8
Troll Hook	PS/Tl	Seaward Areas	0.0-0.4
	GN	Fraser River	0.0-5.6
Porpoise	PS/Tl	Seaward Areas	0.0-0.8
	GN	Fraser River	0.0-1.6
Unassigned	PS/Tl	Seaward Areas	0.0-2.2
	GN	Fraser River	0.0-0.6

[1] GN = gillnet; PS/Tl = purse seine or troll;
PS/Tp = purse seine or trap; one sample from Fraser River by purse seine.
[2] Seaward Areas include Area 20 (Juan de Fuca Strait), Barkley Sound and troll fishing areas on west coast of Vancouver Island.

SMOLT INJURIES AND PARASITES

In the upper Fraser River, 836 outmigrant smolts were sampled from Shuswap, Chilko, Quesnel, and Seton-Anderson lakes, captured during April and/or May 1971, 1975-77, and 1979 (Table 3). Overall incidence of fresh wounds was relatively low (0.4%), and ranged from 0.0 to 0.8% among lake stocks. No fresh wounds were recorded on smolts originating from Seton-Anderson (May 1979, N = 111), or Chilko (April - May 1977, N=411). Corresponding values for scars were 2.1%, and 0.0-6.3%. The only external parasite noted was Salmincola sp., and it was noted in upper river smolts only on juveniles originating from Shuswap Lake -- 4.2% overall and 2.4% with only the attachment remaining. Salmincola presence and attachments were also found in samples captured in the Lower Fraser River -- 1.1% overall and 0.7% with attachment only.

In the lower Fraser River, 289 smolts of mixed origin, captured during April-May 1977 (N = 178) and May 1979 (N = 111), were sampled (Table 3). No fresh wounds were recorded in either sample and no scars in the 1979 sample. Scar incidence was 1.7% in the 1977 sample. Salmincola were present in 0.6% of the 1977 sample and 0.9% in the 1979 sample (one specimen in each sample). Attachments were found in 2.8% of the 1977 sample while the 1979 sample contained none.

Results obtained concerning Salmincola compared well with those of Bailey (1984), who examined 1,330 sockeye smolts and presmolts from 15 rearing lakes in the Fraser River system, captured between 1971 and 1983. As in Table 3, he found no Salmincola in smolts from Quesnel, Chilko or Seton Lakes. In samples from the Shuswap Lake system, he reported an incidence of 2% (pooled 1971 and 1976 samples), compared with 4.2% total incidence in Table 3. Bailey did not mention attachments only; his results are close to the 1.8% presence of Salmincola, excluding attachments, reported in Table 3.

Bailey (ibid.) found Salmincola on juvenile sockeye captured in the Strait of Georgia, but as in the present study of inshore-migrating adults, he could find no evidence of these parasites occurring after ocean residence.

No specimens examined had missing fins, a significant difference from adults.

Table 3. Incidence (%) of wounds, scars, and external parasites on sockeye smolts collected in the Fraser River system, by sampling location and time, and age of specimens, April-May 1971-79. (Age = 1+, unless otherwise noted. Numbers observed in parentheses.)

Lake System	Time Year	Time Date	N	Injuries Fresh Wounds	Injuries Scars	Parasites[1] Present	Parasites[1] Attachment only
				Upper River			
Shuswap	1976	May 10-14	170	0.6	2.4	1.8	2.4
				(2)	(4)	(3)	(4)
Chilko	1977	Apr 26	103	0.0	1.0	0.0	0.0
				(0)	(1)	(0)	(0)
		Apr 28	106	0.0	1.9	0.0	0.0
				(0)	(2)	(0)	(0)
		Apr 28	99	0.0	1.0	0.0	0.0
				(0)	(1)	(0)	(0)
		May 12	103[2]	0.0	1.0	0.0	0.0
				(0)	(1)	(0)	(0)
Quesnel	1971	May 9-20	119	0.8	0.0	0.0	0.0
				(1)	(0)	(0)	(0)
	1975	May 7	128	0.8	3.1	0.0	0.0
				(1)	(4)	(0)	(0)
Seton-Anderson	1979	May 14	111	0.0	6.3	0.0	0.0
				(0)	(7)	(0)	(0)
Upper River Total			939	0.4	2.1	0.3	0.4
				(4)	(20)	(3)	(4)
				Lower River			
Mixed	1977	Apr 27-May 28	178	0.0	1.7	0.6	2.8
				(0)	(3)	(1)	(5)
	1979	May 7-25	111	0.0	0.0	0.9	0.0
				(0)	(0)	(1)	(0)
Lower River Total			289	0.0	1.0	0.7	1.7
				(0)	(3)	(2)	(5)
Grand Total			1228	0.3	1.9	0.4	0.7
				(4)	(23)	(5)	(9)

[1] Salmincola
[2] Age 2+

FREQUENT ADULT INJURIES

Pacific lamprey wounds

Beamish (1980) reported Pacific lamprey feeding on salmon off the west coast of Vancouver Island, in the migratory route of Fraser River sockeye. However, in the current study, Pacific lamprey wounds were only noted on sockeye caught by gillnet in the Fraser River (Table 2). Beamish (op. cit.) reported a minor proportion of attacks below the lateral line, based on field and laboratory observations of live lampreys. Non-lethal wounds may have been incurred below the lateral line, but none were recorded on adults in this study.

Within years, incidence was negligible, or zero, prior to August (Table 4), and was probably maximal in September (Figure 10). Beamish (op. cit.) concluded that Pacific lamprey congregate to feed on salmon in areas where the latter school prior to upriver migration. This would largely explain the timing of attacks on Fraser river sockeye, since stocks which delay at the river mouth begin to arrive in early August (Gilhousen 1960). The principal member of these stocks, Adams River, was abundant in 1967, 1971, and 1974 of the years with observations. Those stocks of Fraser River sockeye with peak arrival times prior to about August 10 tend to migrate directly into the river, and thus may be less vulnerable to attack by Pacific lamprey.

Among years, August incidences were relatively high in 1972 and 1977, while September incidences appeared to be relatively high in 1967 (Williams and Gilhousen 1968) and 1972 (Figure 10). However, 1967 samples were only collected in September, and other September samples were only collected in 1971, 1972, and 1974. Among-year incidences of injuries were evidently significantly different, and a Chi-square test, based on marginal totals (Table 5), supported this -- $X^2 = 665$; d.f. = 3; $P < 0.01$. General observations in years other than those sampled have also suggested significant differences between years.

Wound severity was primarily superficial on sockeye salmon sampled during September 1967, 1971-72 and August-September 1974 (Table 5) -- 61.5% overall, and 47.1-72.7% among years. Comparable values for moderate severity were 32.2% and 22.7-38.8%; and for severe, 6.3% and 4.6 - 14.1%. Numbers of wounds among years within severity criteria were heterogeneous ($X^2 = 25.05$; d.f. = 6; $P < 0.01$).

Table 4. First observations, by year and date, of Pacific lamprey wounds on gillnet-caught adult sockeye salmon sampled from the fishery in the vicinity of the Fraser River mouth, 1971-75 and 1977.

Year	First sample examined	First wound observed	
		Date	% wounded
1971	Aug 16	Aug 16	6.0
1972	Jul 18	Aug 21	1.6
1973	Jul 3	Aug 6[1]	0.0
1974	Jul 2	Aug 20	2.6
1975	Jul 21[2]	Jul 21	0.5[3]
1977	Jul 4	Aug 1 (Aug 10)	0.5[3] (2.4)

[1] Last sample.
[2] Only sample.
[3] Single fish, with single wound.

FIGURE 10.

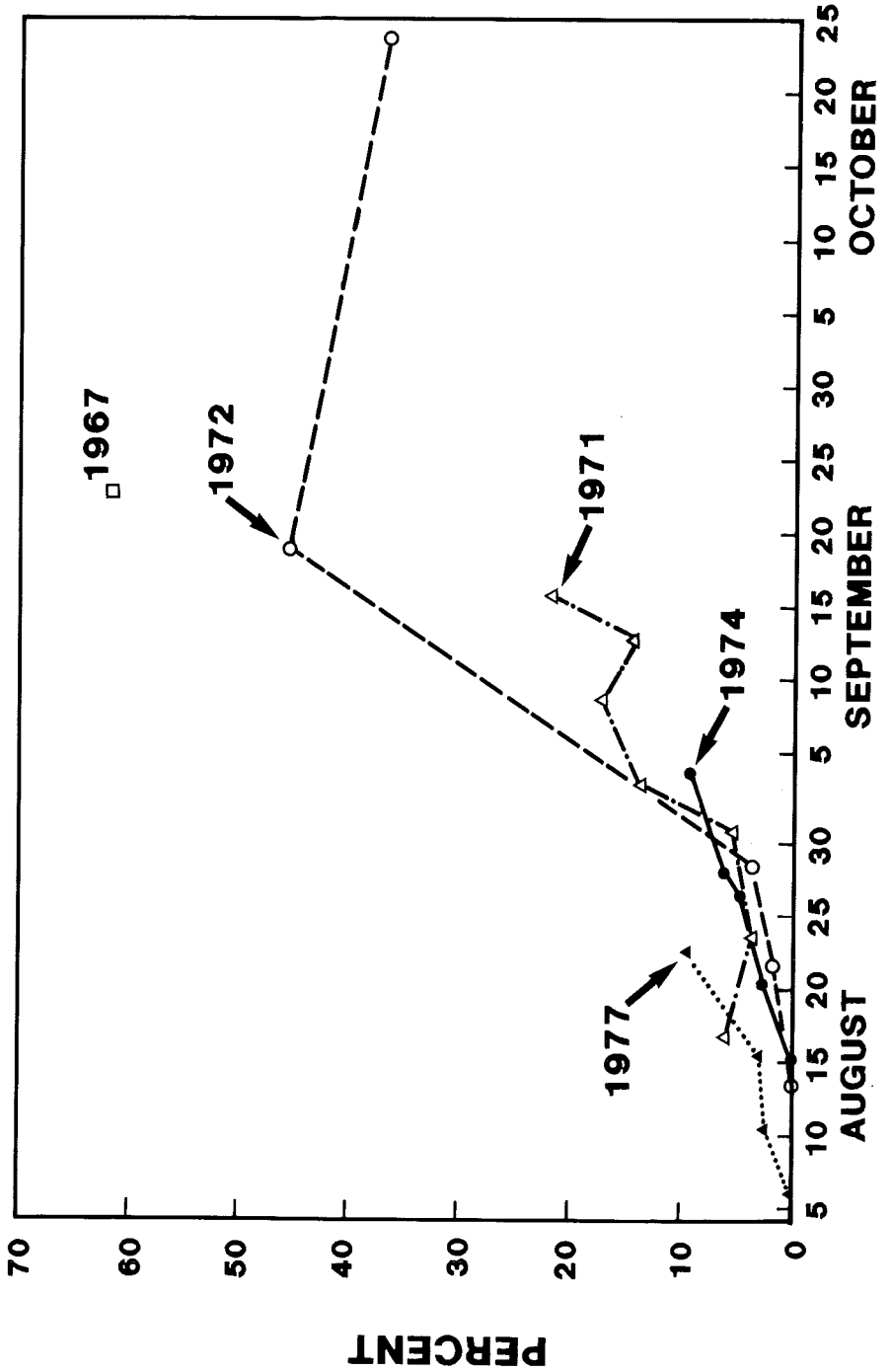


Figure 10. Incidence (%), by 7-day period, of wounds and marks, caused by Pacific lamprey, on adult sockeye salmon sampled from gillnet catches made in or near the mouth of the Fraser River in 1967 (Williams and Gilhousen 1968), 1971, 1972, 1974, and 1977.

Table 5. Annual incidence (%) of Pacific lamprey wounds, by wound severity and location, on gillnet-caught adult sockeye salmon sampled from the fishery in the vicinity of the Fraser River mouth, August-September 1967,1971-72, and 1974.

Year	Date (Sept)	N[2]	Severity	No. of wounds (%)	Wound location[1] Anterior vent (Nos. in parentheses)	Anterior dors	Posterior vent	Posterior dors
1967[3]	22-29	830 (66.5%)	Superficial	806 (61.9)	70.5 (568)	18.7 (151)	5.1 (41)	5.7 (46)
			Moderate	425 (32.6)	83.3 (354)	9.2 (39)	6.1 (26)	1.4 (6)
			Severe	71 (5.5)	80.3 (57)	11.3 (8)	2.8 (2)	5.6 (4)
			Total	1302 (100)	75.2 (979)	15.2 (198)	5.3 (69)	4.3 (56)
1971	8-16	635 (18.5%)	Superficial	90 (67.2)	62.2 (56)	14.5 (13)	14.4 (13)	8.9 (8)
			Moderate	33 (24.6)	87.9 (29)	6.1 (2)	6.0 (2)	-- (0)
			Severe	11 (8.2)	90.9 (10)	-- (0)	9.1 (1)	-- (0)
			Total	134 (100)	70.9 (95)	11.2 (15)	11.9 (16)	6.0 (8)
1972	18	176 (45.5%)	Superficial	57 (47.1)	86.0 (49)	7.0 (4)	5.3 (3)	1.7 (1)
			Moderate	47 (38.8)	87.3 (41)	2.1 (1)	8.3 (4)	2.1 (1)
			Severe	17 (14.1)	76.5 (13)	17.6 (3)	5.9 (1)	-- (0)
			Total	121 (100)	85.1 (103)	6.6 (8)	6.6 (8)	1.7 (2)
1974	3[4]	377 (8.0%)	Superficial	32 (72.7)	59.4 (19)	28.1 (9)	9.4 (3)	3.1 (1)
			Moderate	10 (22.7)	70.0 (7)	-- (0)	30.0 (3)	-- (0)
			Severe	2 (4.6)	50.0 (1)	-- (0)	50.0 (1)	-- (0)
			Total	44 (100)	61.4 (27)	20.4 (9)	15.9 (7)	2.3 (1)
Total		2018 (38.6%)	Superficial	985 (61.5)	70.2 (692)	18.0 (177)	6.1 (60)	5.7 (56)
			Moderate	515 (32.2)	83.7 (431)	8.1 (42)	6.8 (35)	1.4 (7)
			Severe	101 (6.3)	80.2 (81)	10.9 (11)	4.9 (5)	4.0 (4)
			Total	1601 (100)	75.2 (1204)	14.4 (230)	6.2 (100)	4.2 (67)

1 dors = dorsal; vent = ventral.
2 N = numbers of specimens examined. Number wounded in parentheses.
3 Williams and Gilhousen 1968.
4 Plus Aug 28.

Wound location, by body quadrant, was primarily antero-ventral--75.2% overall, and 61.4-85.1% among years, for severity categories combined (Table 5). Comparable values for the other three quadrants were: antero-dorsal, 14.4%, and 6.6-20.4%; postero-ventral, 6.2%, and 5.3-15.9%; and postero-dorsal, 4.2%, and 1.7-6.0%. Wound location exhibited no temporal trend either among, or by combined severity categories.

Pacific lamprey evidently attacked free swimming sockeye as well as fish enmeshed in gillnets. Predominant severity category was superficial, an unlikely event if only enmeshed fish were attacked. Furthermore, lamprey attacks were not closely related to gillnet fishing effort off the mouth of the Fraser River. For example, in 1967, only 3,800 gillnet-boat-days were expended when the incidence was 66.5%, while 8,000 gillnet-boat-days were expended in 1971 when the incidence was 18.5%.

Shark-caused wounds/scars

Shark-caused injuries were noted on sockeye salmon in every sample examined (Table 6).

Seaward Areas

Injury incidence (body + fins) for purse-seine and troll-caught sockeye was 9.2% in 1973, 9.5% to 13.0% in 1974, and 5.1% in 1977 (Table 6). The latter incidence was recorded for a single sample of jacks only (one-ocean-year sockeye). The lower rate for jacks may reflect their shorter ocean life. Most adult sockeye spend two or three years in the ocean.

Fraser River and vicinity

Mean shark injury incidence for gillnet-caught sockeye, among years, ranged from 9.6 to 16.0% without trend (Table 6). Similarly, weekly incidences exhibited no trend within years, but there were significant differences between years. Approximate normal distributions of percentages within years in Table 6 suggested an analysis of variance, which indicated significant differences between years ($p<0.05$) and within years (non-homogeneous variances; $p<0.01$). Evidently, shark attacks varied with time, from year to year and from week to week, but did not increase or decrease significantly during any season.

Table 6. Incidence (%), by catch location and 7-day periods, of shark-caused injuries (body + fins) on adult sockeye sampled during June-September 1971-75 and 1977 (most fin injuries were excluded in the 1971 data).

Catch date	1971	1972	1973	1974	1975	1977
			West Coast of Vancouver Island[1]			
Jul 28-Aug 3	--	--	--	13.0	--	--
Aug 4-10	--	--	--	13.0	--	--
			Barkley Sound[2]			
Jun 17-23	--	--	--	9.5	--	--
			Juan de Fuca Strait[3]			
Jun 17-23	--	--	9.2	10.8	--	--
Aug 4-10	--	--	--	--	--	5.1[4]
			Fraser River and Vicinity[5]			
Jul 1-6	--	--	6.5	15.2	--	11.7
7-13	--	--	--	14.9	--	21.1
14-20	--	8.6	--	17.2	--	9.3
21-27	--	8.7	7.7	9.9	13.2	8.8
Jul 28-Aug 3	--	12.9	9.3	13.4	--	11.1
Aug 4-10	--	9.2	15.0	12.2	--	12.0
						18.5
11-17	10.0	7.1	--	20.4	--	14.8
18-24	5.9	11.4	--	18.4	--	13.5
				18.5	--	--
25-31	10.0	15.9	--	19.5	--	--
	9.6			13.6*		
Sep 1-7	10.1	--	--	18.7	--	--
8-14	6.9	--	--	--	--	--
	20.8	--	--	--	--	--
15-21	19.0	18.8	--	--	--	--
Oct 19-25	--	10.7	--	--	--	--
Fraser River Mean[6]	11.5	11.5	9.6	16.0	13.2	13.4

[1] Troll fishery.
[2] Purse-seine fishery.
[3] Area 20 purse-seine fishery.
[4] Jacks only (one-ocean-year fish).
[5] Gillnet fishery, except for one purse-seine sample(*).
[6] Arithmetic mean of percentages.

Table 7. Annual incidence (%) of shark-caused body and fin injuries on adult sockeye sampled from the gillnet fishery in the vicinity of the Fraser River mouth, July-October 1971-75 and 1977.

Sampling time Year	Date	Nos. sampled	Body injuries Slash	Body injuries Bite	Fin injuries w/, w/o body injuries: with	Fin injuries w/, w/o body injuries: without	Total injuries[1]
1971	Aug 16-Sep 16	1548	8.6	1.9	(incomplete)		10.5 (11.7)[2]
1972	Jul 17-Oct 23	2044	8.4	1.7	1.9	1.5	11.6
1973	Jul 3-Aug 6	769	6.9	1.7	1.4	1.8	10.4
1974	Jul 2-Sep 3	2217	12.0	2.6	2.4	1.2	15.8
1975	Jul 21	219	7.8	3.6	0.5	1.8	13.2
1977	Jul 4-Aug 22	1902	8.9	2.5	2.6	1.7	13.1

[1] Excludes "fin injury with body injury" column.
[2] Corrected by addition of minimum observed value of fin injuries without body injuries (1.2% in 1974)

Among body injuries, incidence of slashes predominated over that of bites -- 6.9-12.0% v 1.7-3.6% (Table 7). About half the fin injuries occurred with body injuries. Incidences were 0.5-2.6% when associated with body injuries, and 1.2%-1.8% when not so associated; the two types were not independent (X^2 = 608.1, d.f. = 1, $p<0.01$), indicating shark involvement in many or most fin injuries.

Shark slash injuries predominated over bites in all samples (Table 8). For slashes, predominant "age" was "scar" (healed wound) -- 51.6% overall, and 32.0-58.0% among months. Comparable values for "healing" were 15.0%, and 8.0-23.7%; and for "fresh", 14.4%, and 4.4-32.0%. In general, incidences of "fresh" and "scars" varied inversely among months, within years, in 1972 and 1973, but not in 1974 or 1977. Incidences of "healing" injuries exhibited no consistent relationship with either of the other "ages". Incidences of the three "ages" showed borderline significant differences between years in July and August, as follows:

Month	X^2	d.f.	P
July	15.73	8	0.05
August	11.03	6	0.09

For bites, predominant "age" was "fresh" -- 9.2% overall, and 2.2-24.0% among months. Comparable values for "scars" were 5.3%, and 0.0-9.5%; and for "healing", 4.3%, and 0.0-10.0%. Incidences of "fresh", among months, varied inversely with those of "scars" in 1972-74, but not in 1977. "Healing" followed no particular pattern. Incidences of the three "ages" between years, by months, did not differ significantly as follows:

Month	X^2	d.f.	P
July	12.10	8	0.15
August	10.09	6	0.12

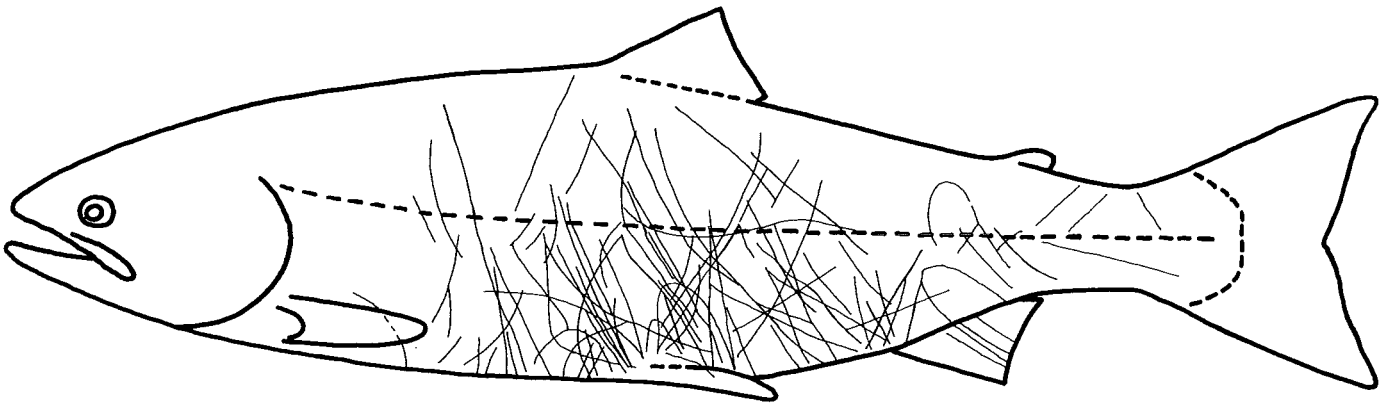
The linear cuts interpreted as shark slashes were not random in location and direction (Figure 11). Slashes were mainly oriented in anterior-dorsal: posterior-ventral directions, with only a small fraction lacking the vertical component. Slashes were found mainly on the lower half of the body and were most frequent just posterior to the center of the sockeye. Concentrations occurred in the vicinity of the anus and the pelvic fins, where the most severe wounds were generally located. The anus was often cut, apparently by catching the tip of a moving shark's tooth.

Table 8. Incidence (%), by month and age of wound, of shark-caused slashes and bites on adult sockeye sampled from the gillnet fishery in the vicinity of the Fraser River mouth, July-October 1972-75 and 1977.

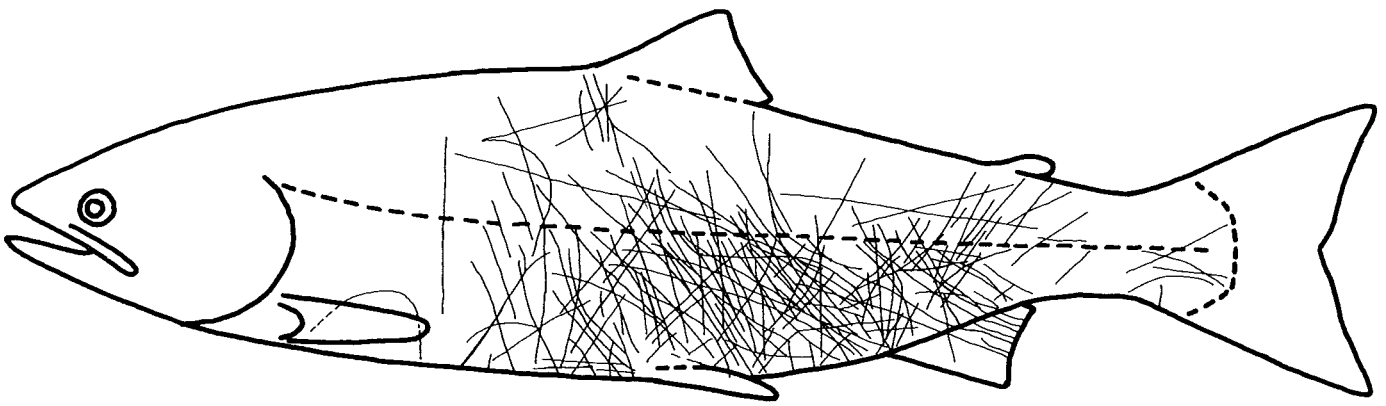
Year	Month	Nos. sampled	Injured fish		Nos. of injuries	Slash[1]			Bite[1]		
						Frsh	Hlng	Scar	Frsh	Hlng	Scar
			%	N		%	%	%	%	%	%
1972	Jul	475	8.0	38	38	21.1	23.7	39.5	10.5	2.6	2.6
	Aug	1206	9.9	118	118	15.3	20.2	46.0	9.3	5.1	5.1
	Sep-Oct	363	12.1	44	45	4.4	17.8	66.7	2.2	0.0	8.9
	Total	2044	9.8	200	201	14.0	20.3	49.3	7.7	3.4	5.3
1973	Jul	569	7.4	42	42	16.7	14.3	47.6	2.4	9.5	9.5
	Aug	200	12.0	24	24	12.5	12.5	58.3	8.3	4.2	4.2
	Total	769	8.6	66	66	15.2	13.6	51.5	4.5	7.6	7.6
1974	Jul	906	13.0	118	119	10.1	11.8	58.0	12.6	2.5	5.0
	Aug	1118	15.5	173	175	16.8	9.0	56.7	5.1	5.1	7.3
	Sep	193	15.5	29	30	10.0	13.3	53.4	13.3	10.0	0.0
	Total	2217	14.5	320	324	13.6	10.5	56.8	8.6	4.6	5.9
1975	Jul	219	11.4	25	25	32.0	8.0	32.0	24.0	4.0	0.0
1977	Jul	857	10.4	89	90	12.4	14.6	44.9	13.5	7.9	6.7
	Aug	1045	12.1	126	128	14.1	20.3	47.7	10.9	2.3	4.7
	Total	1902	11.3	215	218	13.4	18.0	46.5	12.0	4.6	5.5
Grand	Total	7151	11.6	826	834	14.4	15.0	51.6	9.4	4.3	5.3

[1] Frsh = fresh; Hlng = healing.

FIGURE 11.



Late June to early August, 1973 (889 sockeye examined; 9.9% wounded).



Early August to late October, 1972 (1,328 sockeye examined; 12.0% wounded).

Figure 11. Composite diagrams of linear wounds and scars on the body of sockeye attributed to shark attacks. Injuries include those on the right side of fish, projected to the equivalent location on the left side. Composites were transferred from diagrams of individual fish made in 1972 and 1973, from samples of Fraser River gillnet-caught sockeye.

INFREQUENT ADULT INJURIES

Infrequent adult injuries included river lamprey attacks, damaged or missing fins, tooth scratches, troll-hook injuries, porpoise attacks, sea lice attacks, and unassigned (Table 2).

River lamprey attacks

Incidence of scars attributed to river lamprey attacks, during the smolt seaward migration, was relatively low -- 0.0 to 5.0% in seaward areas; 1.8% in Georgia Strait; and 0.9-4.3% overall in the Fraser River and vicinity (Table 9). No temporal trend in incidence was evident in sockeye landed from the Fraser River gillnet fishery.

Observed scars were located above the lateral line on all sockeye sampled (Table 10). Overall, 36% were ahead of the dorsal fin; 23% beside the dorsal fin; and 41% behind the dorsal fin (Table 10). A similar pattern was evident for sockeye from all areas. For the Fraser River and vicinity, in 1972-74 and 1977, relative scar positions were not significantly different among years (X^2 = 5.56; d.f. = 6: P = 0.47). Scar location may have a relationship to mortality resulting from attacks by this lamprey.

River lamprey abundance is variable among coastal areas (Beamish and Williams, 1976), consequently individual sockeye stocks in different river systems will be variably affected by this lamprey. The Barkley Sound non-Fraser sockeye sample (June, 1974) had no recorded river lamprey scars. The Juan de Fuca samples of June, 1973 and 1974, had low incidences (0.8 and 0.4%, respectively) relative to the means of 4.3 and 2.4% for those years in the samples from the Fraser gillnet fishery. Since the two Juan de Fuca samples contained more than 50% non-Fraser sockeye (predominantly Lake Washington, U.S.A., stock), the Lake Washington sockeye, like Barkley Sound sockeye, appear to carry few if any river lamprey scars.

Damaged or missing fins

Fin damage (or excision) of both paired and unpaired fins was reported for sockeye sampled from all areas (Tables 11 and 12). Excision of fins of fingerling salmon has been used for cohort identification as adults, but there was no known use on sockeye of the brood years involved in the present study. Fin damage was therefore assumed to have been natural.

Table 9. Incidence (%), by 7-day periods, of river lamprey scars acquired during smolt seaward migration, on adult sockeye sampled in selected commercial fisheries during June-September 1971-75 and 1977.

Sampling period	1971	1972	1973	1974	1975	1977
			West Coast of Vancouver Island			
Aug 4-10	--	--	--	5.0[1]	--	--
			Barkley Sound[2]			
Jun 17-23	--	--	--	0.0	--	--
			Juan de Fuca Strait[3]			
Jun 17-23	--	--	0.8	0.4	--	--
Aug 4-10	--	--	--	--	--	1.4[4]
			Strait of Georgia[5]			
Jul 28-Aug 3	1.8	--	--	--	--	--
			Fraser River and Vicinity[6]			
Jul 1-6	--	--	5.0	0.6	--	3.4
7-13	--	--	--	3.5	--	1.9
14-20	--	0.0	--	2.6	--	2.2
21-27	--	2.4	5.5	2.5	2.7	2.8
Jul 28-Aug 3	--	1.2	3.2	4.3	--	1.9
Aug 4-10	--	0.0	4.0	3.7	--	5.0
	--	--	--	--	--	3.8
11-17	0.0	0.8	--	3.2	--	5.2
18-24	1.8	0.8	--	2.1	--	1.9
	--	--	--	2.6	--	--
25-31	1.0	0.8	--	1.1	--	--
	1.5	--	--	0.5	--	--
Sep 1-7	1.1	--	--	1.6	--	--
8-14	1.8	--	--	--	--	--
	1.4	--	--	--	--	--
15-21	2.4	1.7	--	--	--	--
Oct 23	--	1.1	--	--	--	--
Fraser River Mean[7]	1.5	0.9	4.3	2.4	2.7	3.1

[1] West Coast of Vancouver Island troll catch.
[2] Barkley Sound (Figure 1) purse-seine catch (non-Fraser sockeye).
[3] Area 20 purse seine fishery.
[4] Jacks only. (one-ocean-year fish)
[5] Point Roberts purse-seine fishery.
[6] Gillnet fishery (includes one sample caught by purse seine).
[7] Arithmetic mean of percentages.

Table 10. Location of river lamprey scars on adult sockeye (predominantly age-4), 1971-75 and 1977. (All scars were located above the lateral line.)

Year	Nos. examined	Scar v dorsal fin			Total scars	
		Ahead	Beside	Behind	Nos.	%
		West Coast of Vancouver Island[1]				
1974	261	3	1	9	13	5.0
		Barkley Sound[2]				
1974	190	0	0	0	0	0.0
		Juan de Fuca Strait[3]				
1973	120	1	0	0	1	0.8
1974	240	0	0	1	1	0.4
1977	276[4]	2	0	2	4	1.4
Seaward Areas Total	1087	6	1	12	19	2.1
		Fraser River and Vicinity[5]				
1971	635[6]	3	2	7	12	1.9
1972	2044	7	5	7	19	0.9
1973	769	8	8	17	33	4.3
1974	2217	24	11	18	53	2.4
1975	219	4	1	1	6	2.7
1977	1902	20	18	21	59	3.1
Fraser River Total	7786	66	45	71	182	2.3
Grand Total	8873	72	46	83	201	2.3
	(%)	(36)	(23)	(41)	(100)	

[1] Troll fishery.
[2] Purse-seine fishery; non-Fraser sockeye.
[3] Area 20 purse seine fishery; June samples contain non-Fraser sockeye.
[4] Jacks only (one-ocean-year fish).
[5] Gillnet fishery, except for 1 purse-seine sample in 1974.
[6] Only the September 8-16 sampling period. Position not recorded in earlier sampling.

Table 11. Incidence (%) and numbers of injured, deformed or missing unpaired fins on adult sockeye caught in the Fraser River and vicinity, and in seaward areas, June-October 1971-75 and 1977.

Time			Nos.	Damaged or deformed fin			
Year	Date		sampled	Caudal	Dorsal	Anal	Adipose
			West Coast of Vancouver Island[1]				
1974	Aug 1-6	%		1.7	0.0	0.0	0.0
		N	261	7	0	0	0
			Barkley Sound[2]				
1974	Jun 20	%		1.6	0.0	0.0	0.0
		N	190	3	0	0	0
			Juan de Fuca Strait[3]				
1973	Jun 20	%		0.8	0.0	1.7	1.7
		N	120	1	0	2	2
1974	Jun 20	%		1.3	0.0	0.0	0.0
		N	240	3	0	0	0
1977	Aug 7/8	%		1.8	0.0	0.0	0.4
		N	276[4]	5	0	0	1
Seaward Areas							
Total		%		1.7	0.0	0.2	0.3
		N	1087	19	0	2	3
			Fraser River and Vicinity[5]				
1971	Sep 9-16	%		3.3	0.3	0.3	0.0
		N	635	21	2	2	0
1972	Jul-Aug	%		2.3	0.1	0.4	0.0
		N	1681	38	2	6	0
	Sep-Oct	%		3.9	0.0	1.1	0.0
		N	363	14	0	4	0
1973	Jul-Aug	%		2.5	0.4	0.4	0.0
		N	769	19	3	3	0
1974	Jul-Aug 5	%		1.6	0.0	0.5	0.4
		N	1095	17	0	5	4
	Aug 15-	%		3.8	0.2	0.4	0.4
	Sep 3	N	1122	43	2	4	5
1975	Jul 21	%		2.3	0.0	0.9	0.5
		N	219	5	0	2	1
1977	Jul	%		3.0	0.1	1.3	0.5
		N	857	26	1	11	4
	Aug	%		3.3	0.5	0.4	0.8
		N	1045	34	5	4	8
Fraser River							
Total		%		2.8	0.2	0.5	0.3
		N	7786	217	15	41	22
Grand Total		%		2.7	0.2	0.5	0.3
		N	8873	236	15	43	25

[1] Troll fishery; all Fraser sockeye.
[2] Purse-seine fishery; non-Fraser sockeye.
[3] Area 20 purse-seine fishery; contains non-Fraser sockeye.
[4] Jacks only. One-ocean-year fish, all Fraser sockeye.
[5] Gillnet fishery; one purse-seine sample (1974).

Table 12. Incidence (numbers of fins and %) of injured, deformed or missing paired fins on adult sockeye caught in the Fraser River and vicinity, and in seaward areas, June-September 1971-75 and 1977.

Year	Date	Nos. sampled	Pectorals (nos.)	Pelvics (nos.) Stunted/Cut L	R	L&R	Missing L	R	L&R	Total	%[1]
				West Coast of Vancouver Island[2]							
1974	Aug	261	--	-- 1	--	--	--	--	1	0.4	
				Barkley Sound							
1974	Jun	190	--	-- --	--	--	--	--	0	0.0	
				Juan de Fuca Strait[3]							
1973	Jun	120	--	1 --	--	--	--	--	1	0.8	
1974	Jun	240	--	-- --	--	1	--	--	1	0.4	
1977	Aug 7/8	276[4]	--	-- 1	--	--	--	--	1	0.4	
Seaward Areas Total		1087	0	1 2	0	1	0	0	4	0.4	
				Fraser River and Vicinity[5]							
1971	Sep	635	--	-- 1	--	--	--	--	1	0.2	
1972	Jul-Aug	1681	--	1 1	2	--	--	--	4	0.2	
	Sep-Oct	363	--	-- --	--	1	--	--	1	0.3	
1973	Jul-Aug	769	--	-- --	--	--	--	--	0	0.0	
1974	Jul-Aug 5	1095	--	1 2	--	1	--	4	8	0.7	
	Aug 6-Sep	1122	1	2 2	--	2	--	--	6	0.6	
1975	Jul 21	219	1	-- 1	--	--	--	--	1	0.5	
1977	Jul	857	--	3 2	2	--	--	--	7	0.8	
	Aug	1045	1	2 4	2	--	1	--	9	0.9	
Fraser River Total		7786	3	9 13	6	4	1	4	37	0.5	
Grand Total		8873	3	10 15	6	5	1	4	41	0.5	

[1] Incidence among total numbers sampled.
[2] Troll fishery; all Fraser sockeye.
[3] Area 20 purse-seine fishery; contains non-Fraser sockeye in June samples.
[4] Jacks only. One-ocean-year fish.
[5] Gillnet fishery (except one purse-seine sample).

Unpaired Fins

Overall injury incidence was 2.7% for the caudal fin, and 0.2, 0.5 and 0.3% for dorsal, anal and adipose fins respectively (Table 11). Incidence of caudal fin damage was 1.7% among the sockeye sampled from seaward areas and 2.8% from the gillnet fishery in the Fraser River and vicinity. Corresponding values were 0.2 and 0.5% for anal fins; 0 and 0.2% for dorsal fins; and 0.3 and 0.3% for adipose fins. No temporal trends were evident.

Paired Fins

Overall injury incidence to paired fins was 0.5% among the 8873 sockeye sampled from September, 1971 to 1977 -- 0.03% for pectorals and 0.5% for pelvic fins (Table 12). For the sockeye sampled from seaward areas, pectoral damage was nil, and for pelvics, 0.4%. Corresponding values for the Fraser River and vicinity were 0.04 and 0.5%, respectively. As with unpaired fins, no temporal trend was evident within years. However, incidence for pelvics was significantly less in 1971-73 than in 1974-75 and 1977, in the groupings of Table 12 (values do not overlap).

Injury classification incidence for pelvics was 76% stunted or cut and 24% were missing (Table 12). Injured fins (N = 41) were nearly equally divided between the left (36.6%) and the right (39.0%) sides - both fins were injured in 24.4% of cases. Missing fins (N=10) were more frequently noted on the left side (possibly a sampling artifact) - 50% v 10%, and 40% with both fins missing, overall.

Among the 29 sockeye with damaged or missing pelvic fins, sampled in 1974-75 and 1977, only 20.7% had no body injuries - 20.7% had fresh wounds and 58.6% had scars (Table 13). Pelvic injuries were not independent of body (shark) injuries; $X^2 = 139.3$, d.f. = 1, $p < 0.01$, N = 5163.

Damaged or missing fins were usually coincident with apparent shark injuries. Curtailed pelvic fins often had corresponding cuts on the body. Stunted pelvics normally had scars on the pelvic girdle (Table 13). Other fin injuries frequently had damage continuing from, or onto, the body.

Table 13. Numbers of Fraser River sockeye with pelvic fin defects, and associated injuries, sampled during 1974, 1975, and 1977. (5163 sockeye examined.)

Pelvic fin defect	Nos. with defect	Associated injuries[1]			
		Fresh wounds	Scars	None recorded	Wounds on pelvic girdle[2]
Stunted	12	--	10(11)[3]	2	8(9)[3]
Cut	10	3	4	3(4)[3]	1
Missing	7	3(5)[3]	3	1	1
Total	29	6	17	6	-
%	100.0	20.7	58.6	20.7	

[1] All attributed to sharks.
[2] Included in other injury categories.
[3] Number of fins; four fish with both fins injured/missing.

Tooth Scratches

Tooth scratches noted on sockeye, sampled during 1972-75 and 1977, varied from nil to 5.0% in the monthly groupings of all data (Table 14). Overall incidence was 2.2%; 1.3% associated with shark-caused body injuries and 0.9% not so associated. In the Fraser River gillnet fishery, yearly incidence of tooth scratches ranged from 0.8 to 5.0% without consistent trend within or between years. As with pelvic fins injuries, tooth scratches were not independent of shark-caused body injuries; $X^2 = 419.8$, d.f. = 1, $p < 0.001$. This adds to the list of probable shark-caused injuries.

Scrape scars

In yearly data divided into three temporal periods, scrape scar incidence ranged from 0.4 to 4.6% in the 9062 sockeye examined (Table 15). Overall incidence in the seaward area samples did not differ significantly from that of the Fraser River gillnet fishery samples; $X^2 = 0.21$, d.f. = 1, $p = 0.65$. Within the Fraser gillnet samples, there were no significant differences in mean scrape scar incidence between years -- analysis of variance of individual samples for 1971-74 and 1977; $F = 0.73$, $p = 0.58$.

More than a third of scrape-scarred sockeye bore opposing marks on each side of the body (Table 16). Opposing scars are interpreted as being caused by a bird beak or the mouth of a predatory fish early in the life of the sockeye, either just preceding or during down-stream migration as smolts or during early marine life, since the scars were more uniformly distributed among the samples than other injuries and because injuries and scars were found on smolts. Unfortunately, no study was made of the age of the scales on the regenerated scar to further define the scar age.

Troll-hook injuries

Troll-hook injuries were only reported for sockeye sampled (N = 3026) from the gillnet fishery in the Fraser River and vicinity because troll fisheries existed between the outer areas and the Fraser River mouth (Table 17). Overall incidence was 1.2%. Among-year values ranged from 0 to 4.4%, without trend. Among months, incidences generally increased temporally, indicating increased

Table 14. Incidence (%) of and numbers of shark-caused body injuries (wounds and/or scars), and tooth scratches (with and without shark-caused injuries), on adult sockeye in selected commercial fisheries, June-October 1972-75 and 1977.

Year	Month	Nos. examined	Shark-caused body injuries		Tooth scratches w/, w/o body injury				Total tooth scratches	
					With		Without			
			%	N	%	N	%	N	%	N
					West Coast of Vancouver Island[1]					
1974	Aug	261	11.5	30	0.4	1	1.1	3	1.5	4
					Barkley Sound[2]					
1974	Jun	190	8.4	16	0.5	1	1.1	2	1.6	3
					Juan de Fuca Strait[3]					
1973	Jun	120	9.2	11	1.7	2	0.0	0	1.7	2
1974	Jun	240	10.0	24	0.0	0	1.7	4	1.7	4
1974	Aug	276[4]	4.0	11	0.4	1	0.0	0	0.4	1
Seaward Area Total		1087	8.5	92	0.5	5	0.8	9	1.3	14
					Fraser River and Vicinity[5]					
1972	Jul	475	8.0	38	0.4	2	0.0	0	0.4	2
	Aug	1206	9.8	118	1.0	12	0.2	3	1.2	15
Sep-Oct		363	12.1	44	0.0	0	0.0	0	0.0	0
Jul-Oct		2044	9.8	200	0.7	14	0.2	3	0.9	17
1973	Jul	569	7.4	42	0.5	3	0.2	1	0.7	4
	Aug	200	12.4	24	0.5	1	0.5	1	1.0	2
Jul-Aug		769	8.6	66	0.5	4	0.3	2	0.8	6
1974	Jul	906	13.1	119	2.1	20	1.3	12	3.4	32
	Aug	1118	15.6	175	2.2	22	0.4	5	2.6	27
	Sep	193	15.5	30	2.1	4	1.0	2	3.1	6
Jul-Sep		2217	14.6	324	2.1	46	0.9	19	3.0	65
1975	Jul[6]	219	11.4	25	4.1	9	0.9	2	5.0	11
1977	Jul	857	10.5	90	1.1	9	3.0	26	4.1	35
	Aug	1045	12.2	128	1.7	18	1.1	11	2.8	29
Jul-Aug		1902	11.5	218	1.4	27	1.9	37	3.3	64
1972-77		7151	11.6	833	1.4	100	0.9	63	2.3	163
Grand Total		8238	11.2	925	1.3	105	0.9	72	2.2	177

[1] Troll fishery.
[2] Purse-seine fishery.
[3] Area 20 purse-seine fishery.
[4] Jacks only; one-ocean-year fish.
[5] Gillnet fishery.
[6] July 21 only.

Table 15. Incidence (%) and numbers of scrape scars on adult sockeye sampled from selected commercial fisheries, June-October 1971-75 and 1977.

Year	June-July			August			September-October			June-October		
	Nos. exam.	Scars		Nos. exam.	Scars		Nos. exam.	Scars		Nos. exam.	Scars	
		%	N		%	N		%	N		%	N
West Coast of Vancouver Island[1]												
1974	--	--	--	261	4.6	12	--	--	--	261	4.6	12
Barkley Sound[2]												
1974	190	1.6	3	--	--	--	--	--	--	190	1.6	3
Juan de Fuca Strait[3]												
1973	120	1.7	2	--	--	--	--	--	--	120	1.7	2
1974	240	0.4	1	--	--	--	--	--	--	240	0.4	1
1977	--	--	--	276[4]	0.7	2	--	--	--	276	0.7	2
Seaward Areas Total	550	1.1	6	537	2.6	14	--	--	--	1087	1.8	20
Fraser River and Vicinity[5]												
1971	--	--	--	--	--	--	824	2.7	22	824	2.7	22
1972	475	1.5	7	1206	1.7	21	363	2.8	10	2044	1.9	38
1973	569	1.6	9	200	1.0	2	--	--	--	769	1.4	11
1974	906	2.2	20	1118	2.3	26	193	4.1	8	2217	2.4	54
1975	219	2.3	5	--	--	--	--	--	--	219	2.3	5
1977	857	2.5	21	1045	1.4	15	--	--	--	1902	1.9	36
Total	3026	2.0	62	3569	1.8	64	1380	2.9	40	7975	2.1	166
Grand Total	3576	1.9	68	4106	1.9	78	1380	2.9	40	9062	2.1	186

[1] Troll fishery.
[2] Purse-seine fishery (non-fraser sockeye).
[3] Purse-seine fishery (June samples contain non-Fraser sockeye).
[4] Jack sockeye (one-ocean-year).
[5] Gillnet fishery.

Table 16. Incidence (%) of scrape scars on one side and both sides of adult sockeye sampled from the gillnet fishery in the vicinity of the Fraser River mouth and from seaward area fisheries, 1971-75 and 1977.

Year	Nos. examined	Incidence (%) One side	Both sides	Total
	West Coast Vancouver Island[1]			
1974	261	1.5	3.1	4.6
	Barkley Sound[2]			
1974	190	1.0	0.5	1.5
	Juan de Fuca Strait[3]			
1973, '74, '77	636	0.6	0.0	0.6
Seaward Area Total	1087	0.9	0.8	1.7
	Fraser River and Vicinity[4]			
1971	824	1.7	1.0	2.7
1972	2044	1.2	0.7	1.9
1973	769	1.0	0.4	1.4
1974	2217	1.1	1.3	2.4
1975	219	1.4	0.9	2.3
1977	1902	1.2	0.7	1.9
Fraser River Total	7975	1.2	0.9	2.1
Grand Total	9062	1.2	0.9	2.1

[1] Troll fishery.
[2] Purse seine fishery (non-Fraser sockeye).
[3] Area 20 purse seine fishery (contains some non-Fraser sockeye).
[4] Gillnet fishery (includes one purse seine sample).

Table 17. Incidence (%) and numbers, by year and month, of troll-hook wounds on adult sockeye sampled from the Fraser River gillnet fishery, June-October 1971-75 and 1977-78.

Year	June-July			August			September-October			June-October		
	Nos. exam.	Wounds		Nos. exam.	Wounds		Nos. exam.	Wounds		Nos. exam.	Wounds	
		%	N		%	N		%	N		%	N
1971	--	--	--	--	--	--	635	1.1	7	635	1.1	7
1972	475	0.0	0	1206	0.0	0	363	0.3	1	2044	<0.1	1
1973	569	0.0	0	200	0.0	0	--	--	--	769	0.0	0
1974	906	0.0	0	1118	0.1	1	193	0.0	0	2217	<0.1	1
1975	219	0.0	0	--	--	--	--	--	--	219	0.0	0
1977	857	0.0	0	1045	0.2	2	--	--	--	1902	0.1	2
1978	--	--	--	1893	4.0	75	623	5.6	35	2516	4.4	110
Total	3026	0.0	0	5462	1.4	78	1814	2.4	43	10302	1.2	121

vulnerability of later timed sockeye stocks to troll capture. Among month-year cells, incidences only exceeded 0.3% in September-October 1971 (1.1%), August 1978 (4.0%), and September-October 1978 (5.6%). June-July and August incidences (excepting August 1978) agree with the incidence of well under 1% found by DiDonato (1967).

Approximately 5% of the 1978 late-run sockeye entering the Fraser River bore troll-hook injuries. The 1978 troll fishery harvest was almost 13% of the late-run sockeye (unpublished data), the therefore about 4.35% of the total (unfished) run (5% of 87%) would have been troll-hook marked. Thus, of the estimated 17.35% (13% + 4.35%) of unfished sockeye which were hooked, 13% were boated, and 4.35% escaped with a discernible hook wound. This suggests an injury rate of 25% (4.35/17.35) by sockeye escaping from the hook. Maximum possible troll-fishing efficiency is therefore about 75%, viz., the ratio of fish boated to fish hooked. Post-hooking (cryptic) mortality of escapees would lower estimated efficiency further (Ricker 1976).

Porpoise injuries

Porpoise-caused injuries were reported for sockeye sampled from the purse-seine and troll fisheries in seaward areas (N = 881), and the gillnet fishery in the Fraser River and vicinity (N = 3026)(Table 18). Overall incidence was 0.3% both for sockeye from seaward areas and for sockeye from the Fraser River and vicinity.

Seaward area samples exhibited porpoise-caused marks only among the troll-caught sockeye on the west coast of Vancouver Island and among purse-seine caught sockeye from Point Roberts. The August 1975 sample of 276 jacks from Juan de Fuca Strait yielded one specimen (0.4%) with a porpoise-caused mark. A significant but unevaluated incidence was noted among trap-caught sockeye at Sooke (Figure 1) in June, 1957.

For Fraser River samples, overall incidences by year ranged from 0 to 1.4%, with a possibly rising trend during 1972-74. Among months, overall, incidences were 0.2% in June-July, 0.4% in August, and 0.3% in September-October.

Table 18. Incidence (%) and numbers of porpoise-caused marks on adult sockeye caught by year and month, June-October 1971-75 and 1977.

Year	June-July Nos. exam.	June-July Marks %	June-July Marks N	August Nos. exam.	August Marks %	August Marks N	September-October Nos. exam.	September-October Marks %	September-October Marks N	June-October Nos. exam.	June-October Marks %	June-October Marks N
				West Coast Vancouver Island[1]								
1974	--	--	--	261	0.8	2	--	--	--	261	0.8	2
				Barkley Sound[2]								
1974	190	0.0	0	--	--	--	--	--	--	190	0.0	0
				Juan de Fuca Strait[3]								
1973	120[4]	0.0	0	--	--	--	--	--	--	120	0.0	0
1974	240[4]	0.0	0	--	--	--	--	--	--	240	0.0	0
1977	--	--	--	276[5]	0.4	1	--	--	--	276	0.4	1
				Strait of Georgia[6]								
1971	331	0.3	1	--	--	--	--	--	--	331	0.3	1
Seaward Areas Total	881	0.1	1	537	0.6	3	--	--	--	1418	0.3	4
				Fraser River and Vicinity[7]								
1971	--	--	--	724	0.1	1	824	0.1	1	1548	0.1	2
1972	475	0.2	1	1206	0.5	6	363	0.6	2	2044	0.4	9
1973	569	0.2	1	200	1.0	2	--	--	--	769	0.4	3
1974	906	0.2	2	1118	0.7	8	193	0.5	1	2217	0.5	11
1975	219	1.4	3	--	--	--	--	--	--	219	1.4	3
1977	857	0.0	0	1045	0.0	0	--	--	--	1902	0.0	0
Fraser River Total	3026	0.2	7	4293	0.4	17	1380	0.3	4	8699	0.3	28
Grand Total	3907	0.2	8	4830	0.4	20	1380	0.3	4	10117	0.3	32

[1] Troll fishery; all Fraser sockeye.
[2] Purse-seine fishery; non-Fraser sockeye.
[3] Area 20 purse-seine fishery.
[4] Majority are non-Fraser sockeye.
[5] Jacks only. One-ocean-year fish.
[6] Point Roberts purse-seine fishery.
[7] Gillnet fishery.

Sea lice

Sea lice occurred on almost all sockeye examined, but infestation on individual fish was slight during June-August. Extensive parasitism was only observed during September-October 1971 on late-run sockeye. These sockeye were heavily infested with sea lice, and large, abraded areas were noted on the posterior third of many of the fish. Open sores were often noted, caused by removal of scales and the outer layers of skin. Sea lice must be sloughed shortly after the sockeye enter freshwater. None have been observed on sockeye caught in the Fraser River at Hells Gate.

Unassigned injuries

Unassigned injuries were reported with greater incidence for sockeye sampled in 1971 (Table 19) because in that year this category included injuries reported separately in following years sampling. Overall incidence was 1.3% for sockeye from seaward areas, and 1.6% for sockeye from the Fraser River and vicinity.

For the Fraser River, overall, yearly incidences ranged from 0.9 to 3.6%, with no temporal trend. Among months, incidences increased steadily from 1.0% in June-July to 2.2% in September-October.

Table 19. Incidence (%) and numbers, by year and month, of wounds and scars of unassigned cause on adult sockeye sampled from selected commercial fisheries, June-October 1971-75 and 1977.

Year	June-July			August			September-October			June-October		
	Nos. exam.	Marks %	Marks N	Nos. exam.	Marks %	Marks N	Nos. exam.	Marks %	Marks N	Nos. exam.	Marks %	Marks N
West Coast Vancouver Island[1]												
1974	--	--	--	261	1.5	4	--	--	--	261	1.5	4
Barkley Sound[2]												
1974	190	1.6	3	--	--	--	--	--	--	190	1.6	3
Juan de Fuca Strait[3]												
1973	120	0.0	0	--	--	--	--	--	--	120	0.0	0
1974	240	0.4	1	--	--	--	--	--	--	240	0.4	1
1977	--	--	--	276	1.1	3	--	--	--	276	1.1	3
Point Roberts[4]												
1971	331	2.1	7	--	--	--	--	--	--	331	2.1	7
Seaward Areas Total	881	1.2	11	537	1.3	7	--	--	--	1418	1.3	18
Fraser River and Vicinity[5]												
1971	--	--	--	724	4.3	31	824	2.9	24	1548	3.6	55
1972	475	0.2	1	1206	1.5	18	363	0.6	2	2044	1.0	21
1973	569	1.2	7	200	0.5	1	--	--	--	769	1.0	8
1974	906	1.1	10	1118	1.4	16	193	2.1	4	2217	1.8	30
1975	219	0.9	2	--	--	--	--	--	--	219	0.9	2
1977	857	1.3	11	1045	1.1	12	--	--	--	1902	1.2	23
Fraser River Total	3026	1.0	31	4293	1.8	78	1380	2.2	30	8699	1.6	139
Grand Total	3907	1.1	42	4830	1.8	85	1380	2.2	30	10117	1.6	157

[1] Troll fishery.
[2] Purse-seine fishery; non-Fraser sockeye.
[3] Purse-seine fishery; June samples contain non-Fraser sockeye.
[4] Purse-seine fishery; Strait of Georgia.
[5] Gillnet fishery.

DISCUSSION

Most causes of injury to sockeye at any stage of their free-swimming life will be sources of mortality. Presumably, most observed injuries are the result of predator action.

PREDATION/WOUNDING MODEL

A model of predation and wounding can be devised if certain simplifications are assumed. A predator will not always be successful in attacks on sockeye; in a proportion of those attacks, it will wound rather than capture the intended victim, which will escape and in some cases survive. Attacks which contact the intended victim, resulting in death or in leaving a permanent, discernable mark, will be defined as "contacting attacks". A relatively constant rate of capture by contacting attacks, "r", and a resulting instantaneous wounding rate, "w", are assumed.

If M is the instantaneous mortality rate resulting from contacting attacks by the predator in question for the period of ocean residence, and A is the fraction of salmon removed during the period, then

$$A = 1 - e^{-M}$$

and

$$r = M/(M + w), \quad \text{or} \quad w = M\,(1 - r)/r$$

The final proportion of injuries, W, in a sockeye population will be:

$$W = 1 - e^{-w} = 1 - e^{-M(1 - r)/r}$$

Differential vulnerability of wounded sockeye to further predation is assumed to be irrelevant. Increased rates of removal of wounded sockeye relative to unwounded is equivalent to a larger mortality rate, M, and an equivalent decrease in the wounding rate, w, in above equations. Similarly, death of wounded sockeye without predator consumption will merely add another component to M.

Predation and wounding are cumulative. Regular seasonal variation in the rates will not affect the final result, because the equations represent an average over the marine life of an annual sockeye return migration. Significant differences between years in the final incidence of injuries due to a specific predator should therefore indicate differences in predation between years.

Final percentages of injured sockeye (W) for an array of total mortalities (A) and efficiencies of contacting attacks (r) were calculated from the above relationships (Table 20). Diagonal lines for 1, 5, 10, and 20% incidence of injuries were interpolated; these approximate the range of injuries observed in the present study. Clearly, for a given incidence of injury, high mortality rate occurs with high attack efficiency, and also the converse.

POSSIBLE SOCKEYE PREDATION LOSSES

Likely predators will include various birds and fish during sockeye freshwater life; and many species of birds, fish and mammals during marine life. Positive or tentative identification of Pacific and river lampreys, Dall porpoise and salmon sharks has been made herein.

Pacific lamprey

Incidence of wounds caused by the Pacific lamprey was substantial in some years, but these attacks were primarily limited to late-run sockeye during migration delay in the vicinity of the Fraser River. Most of the marks were rated "superficial", consequently efficiency of contacting attacks would be low.

Mortality of sockeye from Pacific lamprey attacks cannot be accurately estimated on the basis of wound incidences from a single location. Williams and Gilhousen (1968) estimated a small mortality rate in 1967 by comparing wound incidence observed in the lower and upper parts of the Fraser River system. Davis (1967) found a significant (but unevaluated) proportion of fish with wounds penetrating the coelom in the 1967 late-run sockeye caught off the mouth of the Fraser, whereas few sockeye subsequently caught within the River exhibited this injury. Presumably, few sockeye survived such injuries.

Table 20. Hypothetical relationship between predation mortality (A), efficiency of contacting attacks(r), and resulting percentage of wounds and scars (W) (diagonal contours). Efficiency column headings are arbitrary, nonlinear values to partially straighten contour lines.

Predation mortality(A)	Efficiency of contacting attacks(r)						
	.10	.40	.65	.77	.85	.90	.93
0.90					.334	.226	.159
0.80				.382	.247	.164	.114
0.70				.302	.191	.125	.087
0.60			.389	.239	.149	.097	.067
0.50			.311	.187	.115	.074	.051
0.40			.240	.142	.086	.055	.038
0.30		.414	.175	.101	.061	.039	.026
0.20	.866	.284	.113	.064	.039	.024	.017
0.10	.613	.146	.055	.031	.018	.012	.008
0.05	.370	.074	.027	.015	.009	.006	.004
0.02	.166	.030	.011	.006	.004	.002	

River lamprey

River lamprey are probably more a predator than a parasite on juvenile salmon (and herring), since Beamish (1980) found that this lamprey removed as much as 75% of the victim's flesh and concluded that most small fish died during or shortly after attack. Beamish (op. cit.) noted that a minority (unstated) of river lamprey attacks occurred on the ventral surface of victims, but no ventral scars attributable to this lamprey were observed on sockeye in the present study; possibly some of the unassigned scars were so caused, but they would probably have been relatively superficial, since typical hollow scars would not have gone unnoticed. The lack of ventral scars on adult sockeye infers a mortality component for juveniles attacked by river lamprey.

Beamish and Williams (1976) observed that the majority (unevaluated) of attacks on small salmon and herring were initiated dorsally and anteriorly, whereas the present study indicated that almost two-thirds of the scars originated either beside or behind the dorsal fin. This infers a second component to the mortality caused by the river lamprey.

The low incidence of observed river lamprey scars (maximum 5.2%, average about 2.5%; Table 9) does not necessarily indicate low mortality resulting from river lamprey attacks. If efficiency of contacting attack were extremely high, a substantial mortality would be indicated (Table 20).

Porpoise

Injuries attributed to the Dall porpoise were almost entirely superficial, and presumably would seldom cause mortality, because the teeth of this animal are too weak to reduce sockeye to ingestible pieces, and the gullet is too narrow to allow a sockeye to be swallowed whole (Cowan 1944). Attacks by this porpoise on riverward migrating sockeye are therefore judged to be frivolous. However, this porpoise is abundant in the North Pacific Ocean (I.N.P.F.C. 1988) and it may be a predator on juvenile sockeye shortly after ocean entry.

Tooth scratches noted in the present study may have been caused in part by other species of porpoise (or dolphin) with larger teeth than the Dall. Such attacks may indicate a possible source of mortality, but no information is available in this regard.

Other predators

Predators which cause the scrape scars, apparently during juvenile life, are unidentified but may include many diving birds, probably in freshwater as well as saltwater. Large scrape-scars may be predominantly of freshwater origin, since Bouck and Smith (1979) found a high mortality among coho smolts placed in sea-water after having 10% or more of the body surface descaled, but negligible mortality when retained in freshwater. This probably would apply to sockeye also. The incidence of such scars is low, but as with river lamprey, a substantial mortality may be imposed by this predation if attack efficiency is high.

Troll fishing may be considered predation in that some sockeye escape capture and bear discernable wounds as a consequence. The 5% troll-hook wound incidence in 1978 (equivalent to W, % wounds and scars) and the calculated 13% harvest rate, when entered into Table 20, yield an estimated efficiency for "contacting attacks" (i.e., hook taking) for the fishery of about 75%, in agreement with the value calculated by previous analysis.

Sea lice, Lepeophtheirus, do not appear to cause death in Fraser River sockeye, although White (1940) found evidence of death caused by an extreme case of parasitism in Atlantic salmon.

Salmon sharks

Salmon sharks appear to be the prime predator of sockeye and other salmon in the North Pacific Ocean. This was first reported by Sano (1959 a,b), who noted a 2% incidence of slash-marked sockeye in the gillnet catches of the Japanese high-seas fishery near the Aleutian Islands. Slash-marked sockeye were also found in the stomachs of salmon sharks caught in the same nets. Usual numbers of sockeye per stomach were 1 - 3, and 70% of the stomachs contained sockeye. The 30% of stomachs without sockeye were from sharks caught outside the area of shark abundance.

Larkins (1964) reported on the various fish species caught in gillnets during 1955-61 by United States research vessels operating in the Bering Sea and North Pacific Ocean. Among the species caught were 172 salmon sharks, 877 blue sharks, and 20,371 sockeye salmon. Macy et al. (1978) reported that the order of importance of salmon in these salmon shark stomachs was: sockeye; chum (O. keta); pink (O. gorbuscha); coho (O. kisutch); and chinook (O. tshawytscha).

Paust and Smith (1986) provide an excellent summary of information on the salmon shark.

Paucity of quantitative information on salmon shark abundance and stomach contents precludes estimation of consumption of sockeye by these predators. However, the large percentage of shark wounds and scars sustained by Fraser River sockeye suggest a relatively large mortality; all observed incidences fall between 5% and 21%, approximately.

Efficiency of contacting attacks has not been evaluated, but is expected to be relatively high. Most sharks are solitary predators (Costeau 1970), and such predators, which pursue mobile prey, limit attacks to situations where chance of success is reasonably high (Curio 1976). Indeed, the location and orientation of shark-caused wounds (Figure 11) suggests attack from below and behind, i.e., "evaluated" choice of target prey.

Slashes by the salmon shark, occurring on but one side of sockeye, are probable evidence of disabling tactics made possible by the protruding teeth of the shark. However, the prime purpose of attacks is presumably to bite and ingest the salmon; disabling slashes, the result of failed bite attacks, would allow greater predation success.

Only Major (1978, 1979) has reported quantified estimates of the incidence in fish of predator-wounding of prey, although based on fish confined to enclosures. In 42 pen experiments on Hawaiian anchovy (Stolephorus purpureus), with the jack (Caranx ignobilis) as predator, jacks caught and ate 37% of the prey and injured less than 2%. While the results of pen experiments cannot be directly applied to fish in the open ocean, the possibility of high attack efficiency is evident.

Estimated mortality of Chilko Lake sockeye salmon cohorts, between lake exit as smolts and return to the coast as adults, has ranged from 80% to 98%, over 24 years of evaluation (unpublished data). Ricker (1962) estimated open-ocean mortality for sockeye in general as 66%, with the caveat that this estimate was biased toward the high side. The difference between this value and that for Chilko Lake smolts is generally attributed to variable mortalities during river migration, estuarial residence, and coastal residence. If a 50% open-ocean mortality rate is arbitrarily assumed for Chilko smolts, mortality ascribed to these latter factors would range from 54% to 96%.

Natural causes of open-ocean mortality, other than sharks, are as far as is known, unimportant. If a 50% mortality is imposed by sharks, a contacting attack efficiency of 70% to 95% would encompass shark-injury incidences of 5% to 21% in Table 20.

VARIATION IN INCIDENCE OF INJURIES

Comparison of data on annual sockeye abundance with the annual incidence of five injury types showed only weak relationships between them (Table 21). A lower incidence of injuries might be hypothesized for large sockeye populations, based on dilution of relatively constant predator populations. However, the correlations of Table 21 are all positive, perhaps indicating that predators are attracted to concentrations of salmon. Other reasons for these contrary results may lie partly in deficiencies in the sampling of injuries but also may have resulted from annual variation in the total abundance and distribution of salmon in the North Pacific Ocean, since Fraser River sockeye distribution overlaps, but is not identical to, that of other stocks and species.

Shark-caused injuries varied significantly both within and between years, although variation was not extreme, suggesting factors which caused rate of predation to vary over different parts of an annual population and between years. Because salmon sharks are apparently solitary predators, and salmon appear to be solitary or swim only in small groups (Thurow 1968, Suzuki and Sonoda 1972, Hartt 1975), encounters between sharks and sockeye would be essentially random. The population of salmon sharks is assumed to be stable, based on the general longevity of elasmobranchs. A reasonably uniform shark-caused mortality, and a similarly uniform injury incidence in any sockeye population would therefore be expected, unless salmon abundance pushed shark food-intake beyond the satiation level. A non-uniform injury incidence might result from uneven shark distribution or variation in water clarity or illumination.

Observed within-season injury variability reflected both sampling variation and, for Pacific lamprey wounds and marks at least, changes in the rate of attack as well. However, it was not possible to relate changes in any injury rate to levels of sockeye abundance within seasons, mainly because the sampling was not uniformly applied over the whole season in the years sampled.

Table 21. Comparisons between annual incidence (%) for five types of injuries suffered by Fraser River sockeye and the annual numerical return of adult Fraser sockeye to coastal waters. Samples from Fraser River gillnet fishery only.

		Type of injury				
Year	Total return	Shark Shark	River lamprey	Scrape scars	Porpoise	Tooth Scratches
	(millions)	(%)	(%)	(%)	(%)	(%)
1971	7.61	11.7	1.5	2.7	0.1	---
1972	3.61	11.6	0.9	1.9	0.4	0.9
1973	6.55	9.6	4.3	1.4	0.4	0.8
1974	8.40	16.0	2.4	2.4	0.5	3.0
1977	5.64	13.4	3.1	1.9	0.0	3.3
Correlation coefficient		0.42	0.29	0.51	0.07	0.49
Probability		0.49	0.64	0.38	0.91	0.51

INJURIES IN OTHER SALMON SPECIES

Only a few references have been made to injuries on Pacific salmon. A sea-run cutthroat trout with apparent porpoise-teeth marks was pictured by Giger (1972). The "fresh-run" pink salmon illustration in Hart (1973) also bore probable porpoise teeth marks. Flain (1981) reported a New Zealand quinnat (chinook) salmon with "mammalian teeth marks --, possibly dolphin (porpoise) or seal".

Foerster (1935) noted missing fins on coho, chum and (principally) sockeye salmon. His observations included notes of pelvic and pectoral fins "probably bitten off". These suggest the results of shark attacks, as concluded for the damaged and missing fins reported herein.

Few references to shark-caused injuries were found, despite the severity of many of these wounds. Giger (1972) showed a wounded sea-run cutthroat trout "perhaps wounded by a marine mammal", but the fish was more likely wounded by a shark. Worthington (1964) reported that in the Scottish salmon-net fisheries, "at least 6% of the total catch of (Atlantic) salmon bear claw or tooth marks", and attributed them to the grey seal. Probably part, perhaps most, of these "claw and tooth marks" were caused by sharks, likely the porbeagle (Lamna cornubica), the Atlantic counterpart of the salmon shark.

Jewel (1962) noted scars on 30% of chum salmon caught in Puget Sound, Washington, in 1961. Fiscus (1964) reported further sampling of Washington State chum salmon in several areas, with the incidence of scarred fish varying from 11.3-15.5%. Neither author offered an explanation for the scars, but their photos indicate that shark-attacks were the probable cause. The scar frequencies exceed those found on Fraser River sockeye (Table 8) and, with the apparent lack of fresh wounds, suggest that the later-timed migration of chum salmon and possible differences in areas of ocean residence might account for the difference.

Shark slashes have only been considered in some detail by Sano (1959 a,b), for pink and chum salmon as well as for sockeye. More recently, observations (unpublished) of injuries on chinook and coho salmon by the Alaska Department of Fish and Game were followed by a Canadian study of healing of artificial wounds on chinook, simulating injuries noted on troll caught fish (I.N.P.F.C. 1984). Superficial wounds (apparently like those caused by porpoises) healed

slowly, while deep wounds into the musculature healed almost completely in 64-70 days. If the results apply to sockeye, shark-slash scars may be at the minimum less than 3 months of age, and porpoise teeth-marks may be acquired in the open ocean as well as in coastal waters.

FINAL REMARKS CONCERNING PREDATION MORTALITIES

Attempts have been made to correlate measures of environmental variability -- such as air, river and ocean temperatures, salinity and stream flow -- with smolt-to-adult survival in Fraser River sockeye, in part on the premise that these factors are closely related to planktonic food abundance or availability and therefore to growth and consequently survival (Henry 1961; I.P.S.F.C. 1974, 1977-79, 1981). If significant, these correlations may, alternately, be comparing secondary factors that affect either sockeye availability to predators (e.g. the distribution of alternate prey), or the abundance of predators (e.g. the river lamprey, which may have non-constant abundance in salt water due to variable survival or variable metamorphosis from the stream dwelling stage).

Although knowledge of the sources and time of occurrence of predation would be valuable in the modelling of growth of salmon biomass and of productivity, direct measurement is not feasible. Nevertheless, it is likely that the vast majority of individuals lost from a salmon population in the freshwater, coastal and oceanic areas of the eastern North Pacific Ocean are killed by predators.

SUMMARY

1. The present observations of wounds, scars and marks on Fraser River sockeye extends previously reported work involving a limited set of injury types.

2. Injury types are described and illustrated for the causal agents Pacific lamprey, sharks, river lamprey, porpoise, troll hooks and sea lice. Other injury types, unassigned as to specific cause, are also included.

3. Sockeye examined for injuries and marks comprised 12,633 landward-migrating adults (caught mainly in gillnets) and 1,228 seaward-migrating smolts. Samples were taken during 1971 - 1979.

4. Samples of adults varied from 100 to over 300, examined at circa-weekly intervals when possible, from June to October.

5. Incidence of smolt injuries, classified as fresh, varied from 0.0-0.8% between lakes of origin; scars ranged from 0.0-6.3%. Parasites (Salmincola sp.) varied from 0.0-4.2% between lakes; none were noted on returning adults.

6. Pacific lamprey wound incidence (primarily anterior-ventral body quadrant) varied widely between years. Occurrence, observed only on sockeye caught near the Fraser River mouth, was first noted in early August and thereafter increased to a maximum in September or October (66.5% in 1972). Of years sampled (1967, '71, '72, '74), 1967 and 1972 had the highest incidence.

7. Shark-caused injuries were observed in all samples, varying from 5.1% incidence in one-ocean-year sockeye (jacks) to a maximum of 21.1% in 2-3 ocean-year adults. Significant differences occurred between and within years, but no trends were found within years.

8. River lamprey attack seaward migrating Fraser River sockeye in coastal waters. Resulting scars on returning adults ranged in incidence from 0.0-5.5% in individual samples.

9. Incidence of fin injury (or excision) was greatest for the caudal fin (2.7% overall) and less than 1% in other fins. Pelvic injuries (next most common) were not independent of body (shark) injuries.

10. Tooth scratches, varying in incidence from 0.0-5.0% in circa-monthly sample groupings, were also not independent of body (shark) injuries.

11. Scrape-scars, ascribed in part to unsuccessful fish or bird predation in early life, varied from 0.4-4.6% incidence by year and area of catch.

12. Troll-hook injuries were of low incidence in year and circa-monthly periods (maximum 1.1%) except in 1978 (maximum 5.6%). Data from 1978 suggested a maximum troll-fishing efficiency of about 75%.

13. Porpoise-caused injury incidence (predominantly Dall porpoise) was 0.3% overall and ranged from 0.0-1.4% by year.

14. A predation/wounding model was devised (assuming a constant success rate for contacting attacks by predators) to aid in limiting mortality estimates.

15. Mortalities caused by the several agents could not be evaluated but appear to be low for Pacific lamprey and porpoise, possibly large in river lamprey, highest for sharks and unknown for bird and fish predators.

16. An open-ocean mortality of sockeye of the order of 50% due to salmon sharks is possible. Mode of attack appears to be stalking from below and behind, with disabling tactics (slashes) involved as well as direct capture.

17. Wounds and marks have been previously noted on sockeye and other salmon species, and were sometimes misinterpreted or not assigned as to cause.

18. Correlation of sockeye mortality rates with physical variables in the environment may index variable predator-prey interactions as well as variation in food and of consequent growth affecting survival. Regardless, predation probably accounts for most salmon mortalities.

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