Wounding of Pacific Salmon by Predators in Gillnet Catches in the Russian Economic Zone in 2004

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Abstract: We describe data on wounds, scars, and marks on Pacific salmon caught during a gillnet survey by the R/V *Ecopacific* in the northwest North Pacific Ocean and southwest Bering Sea in summer–fall 2004. A classification scheme to systematize visual observations of various types of wounds caused by two major predator groups (piscivorous fish and seals) is suggested. Three general trends in the results apply to all species of salmon caught in gillnets during their prespawning migrations. First, wounding by fish and seals does not depend on salmon body size at either the intra- or inter-specific level. Second, the highest percentage of wounds were caused by seals and two piscivorous species, longnose lancetfish and North Pacific daggertooth (25–47% of wounds in North Pacific waters adjacent to Kamchatka). The percentage of wounds caused by lampreys was relatively low. Third, the percentage of healed wounds (scars) in mature salmon increased at the end of the prespawning migration, indicating that the energy expended to regenerate injured tissues may delay maturation. It was difficult to distinguish between natural wounds, which occurred before salmon were caught, and artificial wounds, which occurred after salmon were caught, particularly because of the length of fishing operations (~10 hr) and the ready availability of gillnet-caught salmon to predators. The results, however, can be used an indicator of general background conditions that influence natural predation of salmon during their prespawning migrations in the open ocean.

Keywords: salmon, gillnet, marine, predators, wounds, prespawning migration, Russia

INTRODUCTION

Assessment of the marine survival of Pacific salmon (*Oncorhynchus* spp.) is one of most important steps in forecasting the abundance of adult returns to spawning grounds. Accurate estimates of marine survival would significantly improve scientifically applied measures used to regulate commercial fisheries. Complexity in salmon stock assessments results primarily from the multi-factor character of salmon survival over the course of their ocean feeding migrations, as documented in numerous scientific publications. It is well known that the mechanisms of most abiotic and biotic processes influencing marine mortality cannot be controlled. The marine survival of Pacific salmon can fluctuate extensively, which, in turn, directly influences the quality of run forecasts. Contemporary research on this problem usually involves studies that provide information on various factors that may influence survival at different levels of salmon ecological interactions.

The results reported in this paper are also just one stage in the study of prey-predator interactions of Pacific salmon in the ocean. There are already many publications that provide insight into the variety (types) of wounds, scars, and marks caused by predators, as well as the effects of these wounds on the survival of salmon at different ocean life stages (Birman 1950; Sano 1960; Makhnyr' and Perlov 1988; Welch et al. 1991; Shuntov et al. 1993a,b; Radchenko and Semenchenko 1996; Melnikov 1997; Balanov and Radchenko 1998; Grishina 2000; Kaplanova and Zolotukhin 2002; Savinykh and Glebov 2003; Sviridov et al. 2004). Most of these studies, however, are species-specific and illustrate the influence of only a single predator. This is understandable because wider information is often limited, especially concerning information on the life histories of predators, particularly because the predators themselves are usually not the target of any marine fisheries.

Nevertheless, the need for data on the amounts and the rates of salmon removal by predators during their ocean feeding or prespawning migrations is urgent. Some observations have provided insight into the percentage of Pacific salmon consumed by different species of piscivorous fishes and marine mammals at sea (Sobolevsky 1983; Burkanov et al. 1991; Shuntov et al. 1993a,b; Melnykov 1997; Aschepkov and Radchenko 2000). Moreover, there are a number of local assessments of the effects of some pinnipeds on the abundance of particular salmon stocks during their prespawning migrations (Makhnyr' and Perlov 1988; Grishina 2000; Makoedov et al. 2000). The problem of prey-predator interactions is understandably much broader, concerning not only marine stages of Pacific salmon but also freshwa-

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ter stages, when juvenile and adult survival is influenced not only by fishes and pinnipeds, but also by birds, bears, and other mammals. Unfortunately, most existing assessments of the influences of predators on salmon survival are in the nature of expert opinions, rather than applied-scientific methods for management of Pacific salmon resources in the Russian Far East. This problem can be solved only through complex studies, involving collaboration with specialists from various fields of science.

In this paper, we evaluate the effects of marine predators on salmon in gillnet catches in the open ocean. Traumas (wounds, scars, and marks) on Pacific salmon were observed and analyzed in fish caught in the northwest North Pacific Ocean and southwest Bering Sea during summer and fall 2004. Similar observations have been carried out by KamchatNIRO scientists during gillnet cruises since the mid 1990s. Nevertheless, all historical records of this research were brief, i.e., often one-word descriptions such as "bite", without further reliable identification and description of the characteristics of the wound. Therefore, we decided to develop a new method for systematizing field records of these observations based on data collected in 2004. In addition, we planned to develop a standard method of monitoring marine predators of Pacific salmon. Identification and assessment of wounds, scars, and marks on salmon are complex. There are always chances for error, especially in the identification of the species of predator that caused the wound. We took this problem into account during our work by classifying wounds to a higher taxonomic category, which reduced the possibility of mistaken identification of potential predators.

The objectives of our study were to develop a classification scheme for field identification of wounds caused by marine predators of Pacific salmon, and to use data from gillnet catches in 2004 to determine the incidence of wounded salmon in gillnet catches during their prespawning migrations.

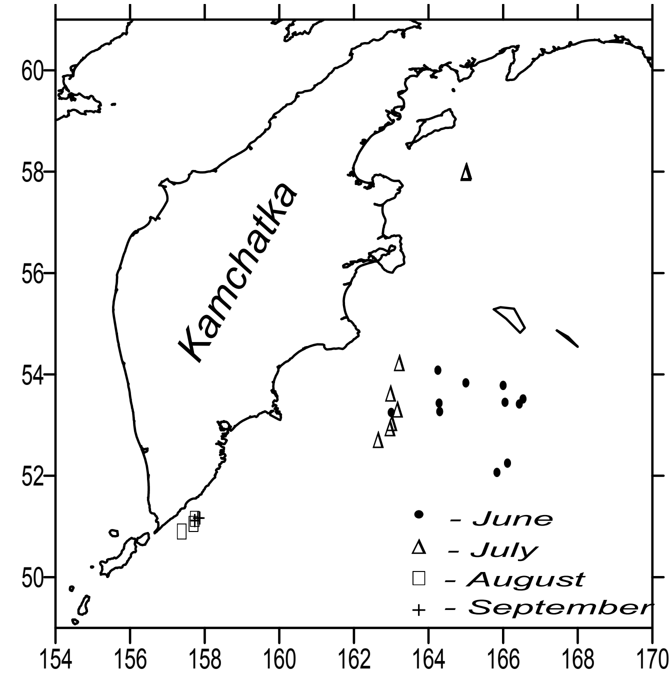

Fig. 1. Study area and locations of gillnet stations during the R/V *Ecopacific* survey of Pacific salmon in the northwest North Pacific Ocean and southwest Bering Sea in June–September 2004.

MATERIALS AND METHODS

Materials for this study were collected from June to September 2004 during gillnet research by KamchatNIRO scientists aboard the R/V *Ecopacific*. The research was carried out primarily in the northwest North Pacific Ocean (North Pacific waters adjacent to Kamchatka), where there were 27 salmon gillnet operations, and less extensively in the southwestern Bering Sea, where there were 4 gillnet operations (Fig. 1). All salmon caught by research (control) gillnets (square mesh size 55 mm; 20–30 nets per each diurnal operation) were analyzed. The length of one net was 50 m. Each fishing operation lasted 10 hours. In total, 2,202 Pacific salmon were examined, including 699 sockeye (*O. nerka*), 529 chum (*O. keta*), 714 pink (*O. gorbuscha*), 110 chinook (*O. tshawytscha*), and 150 coho (*O. kisutch*) salmon.

The character of wounds, scars, and marks on each salmon was recorded during shipboard processing of specimens; afterward the possible predator that caused the wound was recorded. Wounds were identified either by referring to published data on the effects of different predators on Pacific salmon or by our own direct observations. All illustrative materials in this document were collected during our studies, except for materials by Sano (1960), that illustrate wounds caused by salmon sharks. We were not able to photograph salmon shark bites, because only one salmon with this type of wound was observed, even though salmon sharks were caught frequently in our nets.

RESULTS AND DISCUSSION

Identification of Wounds

Illustrations and descriptions of the different types of wounds classified in this document are shown in Fig. 2 and Table 1. The wounds of Pacific salmon were classified by division into two principal types. Type I wounds are those caused by fish or fish-like species, and include three subtypes: I–a longnose lancetfish (*Alepisaurus ferox*) and North Pacific daggertooth (*Anotopterus nikparini*), I–b lamprey and I–c salmon shark (*Lamna ditropis*). Type II wounds are those caused by seals (Pinnipedia). Our classification scheme provides only a general assessment of wounds on salmon caused by piscivorous fishes and seals. Additional work is needed to reliably identify predators to a particular species or group of species with similar hunting behavior and functional morphology.

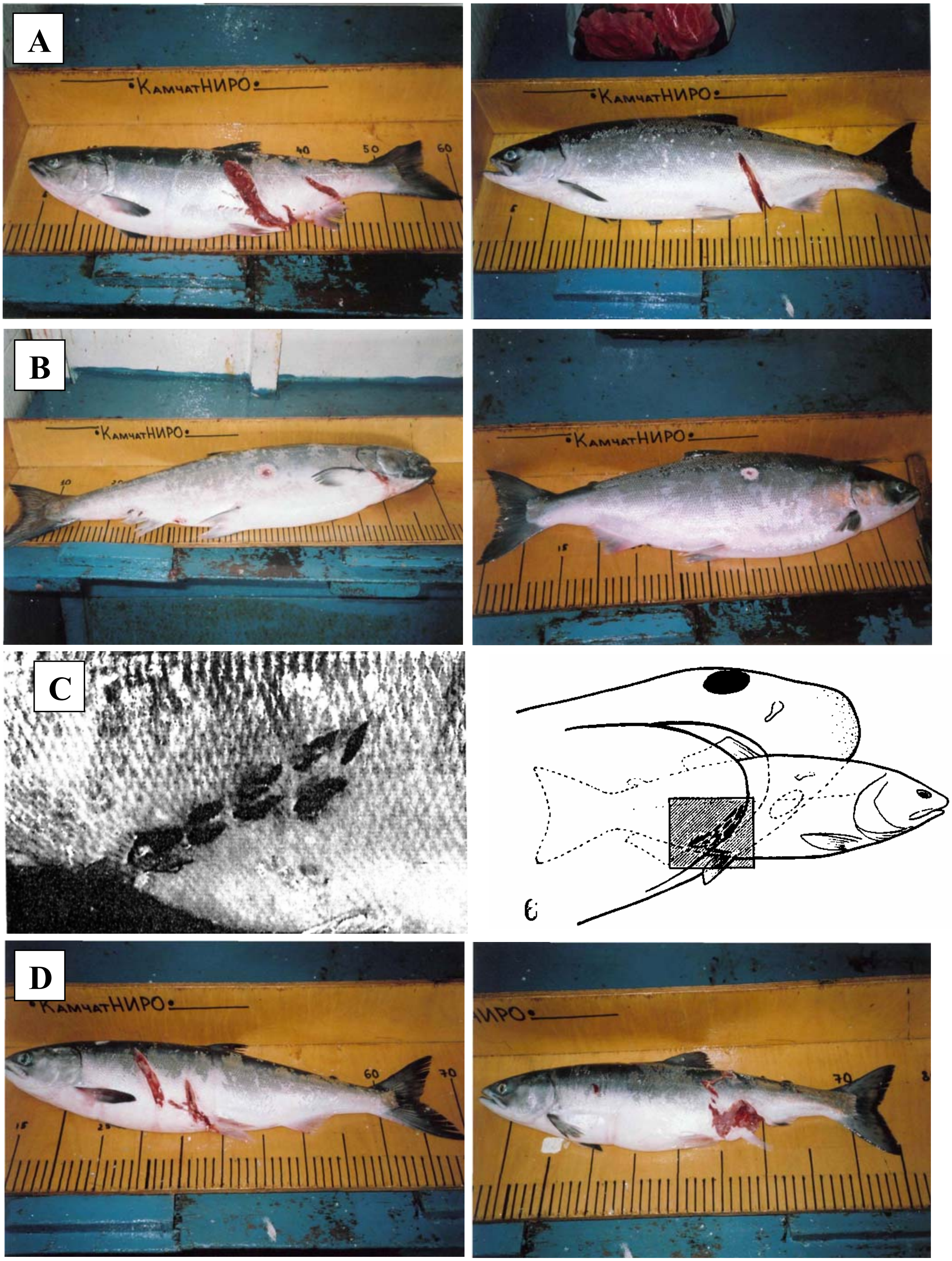

Fig. 2. Examples of the types of wounds caused by marine fish and mammal predators of Pacific salmon. (A) Type I – a (fish): lancetfish and daggertooth; (B) Type I – b (fish): lamprey; (C) Type I – c (fish): salmon shark (Sano, 1960); (D) Type II : seals.

Table 1. Classification scheme and description of characteristics of wounds on Pacific salmon.

Type of wounds	Predator	Characteristics of wounds
Type I (fish)	a) Lancetfish , daggertooth	Transversal cuts of various depths occur on one side of the fish, usually directed at a backward slanting angle to the vertical axis of fish. On the other side of the body, small lacerated wounds can be observed as a prolongation of a main cut. These wounds are most frequent in the area of anal fin.
	b) Lamprey	The wound has a precise, rounded shape. In superficial wounds, diagnostic marks made by lamprey teeth can be observed. In serious wounds, there is a deep round hole that exudes semi-digested tissues.
	c) Salmon shark	Obvious marks or puncture wounds caused by placoid shark teeth. Characteristically, the bite has multiple rows of teeth marks.
Type II	Seals (Pinnipedia)	Lacerated wounds bearing the marks of pinniped canine or incisor teeth. As a rule, the wounds are deep, with tissues pulled out. Parallel scratches (pinniped claw rake abrasions) are frequently observed.

The wounds caused by longnose lancetfish and North Pacific daggertooth, which have similar hunting behavior, were combined into one group because reliable identification of species did not seem possible. The bites of these two species can possibly be differentiated by measuring the depth of the wound on the side opposite from the main cut site because longnose lancetfish have bigger teeth on the lower jaw than North Pacific daggertooth. To some extent, however, species identification from such measurements are unreliable because the shape and depth of the wounds correlate directly with the size and speed of movement of prey, as well as the size and the angle of attack of the predator. Despite these problems, many researchers have concluded that these types of wounds are caused only by North Pacific daggertooth (Welch et al. 1991; Radchenko and Semenchenko 1996; Melnykov 1997; Balanov and Radchenko 1998; Savinykh and Glebov 2003). Our criticism of this method does not pertain to well-documented incidents, e.g., when a daggertooth was taken from a net with its teeth inside a salmon. The origin of a bite in such a case is not in question, however, we assume that such cases are quite rare. There are published assessments of salmon wounds in which the bites of longnose lancetfish and North Pacific daggertooth were not differentiated by species (Shuntov et al. 1993a, b).

In most studies, identification of species of predators from wounds, scars, and marks on salmon has relied heavily on the subjective perceptions of scientists and field technicians. Thus, some errors are likely. In support of our suggestion to combine the assessment of wounds caused by longnose lancetfish and North Pacific daggertooth, we note that in 2004 longnose lancetfish were observed more frequently than North Pacific daggertooth in the bycatch of the R/V *Ecopacific* commercial nets (65-mm mesh). This may be related to the large size of longnose lancetfish (up to 5–7 kg); it is also possible that a large proportion of smaller daggertooth may have escaped the 65-mm mesh nets. We cannot provide reliable information on the dynamics of catches of these piscivorous fishes, however, because no data were recorded on these species in the catches of control nets (55-mm mesh). Although our information from commercial catches is anecdotal, longnose lancetfish and daggertooth are known to feed actively in the waters of the North Pacific Ocean adjacent to Kamchatka and the Kuril Islands, and their estimated biomass from trawl surveys in this region is as high as 2,000 tonnes (Shuntov et al. 1993a, b; Melnikov 1997).

Among the lampreys, three species occur in the Far Eastern section of the Russian Economic Zone: Pacific lamprey (*Entosphenus tridentatus)*, Arctic lamprey (*Lethenteron camtschaticum)* and far eastern brook lamprey (*L. reissneri)*, according to the revised classification (Moiseev and Tokranov 2000). We classified all wounds, marks, and scars made by these species as "lamprey" because identification to species from the number of teeth was not possible. This problem was primarily due to the effects of the digestive enzymes of lamprey, which masked the traces of teeth marks. Nevertheless, among all species of lamprey mentioned the Arctic lamprey is the most significant predator of salmon in our study area.

The salmon shark is one of the most active predators of Pacific salmon in the North Pacific Ocean. In most cases, however, a salmon shark attack results in the death of the salmon before it can be caught in a net, e.g., during our cruise we caught only one salmon with a shark bite.

Among pinnipeds the most active consumers of Pacific salmon in this region are spotted seals (*Phoca larga*), Bering ringed seals (*P. hispida krasheninnikovi*), and Okhotsk Sea ringed seals (*P. hispida ochotensis*) of the family Phocidae, and Northern fur seals (*Callorhinus ursinus*) and Steller sea lions (*Eumetopias jubatus*) of the family Otariidae. The percentage of salmon in the diets of pinniped species varies and depends on the time of year. During their prespawning period, salmon become readily available to seals and sea lions in areas along traditional marine migration routes where salmon concentrations are highest. Accordingly, the wounding of Pacific salmon in gillnet catches by pinnipeds can be very significant.

Northern fur seals are probably the most important cause of wounding of salmon in gillnets, as indicated by our multiple observations of their behavior during gillnet retrieval. Fur seals were observed stealing and eating salmon directly

Table 2. The incidence (% of N) of mature Pacific salmon in gillnet catches with wounds caused by some species of predators. N = number of fish.

Species	Region	Period in 2004	CPUE (fish/tan)	N	Mature in catch (%)	Length (cm)	Incidence of wounds (%)				Total incidence (%)
							Type I (fish)			Type II (seal)	
							a	b	c		
Sockeye	Northwest Pacific Ocean	June 11-29	1.44	188	95	57.4	3.2	0.5	0.5	7.4	11.6
		July 8-18	4.88	102	50	55.8	4.9	0	0	12.7	17.6
		August 16-21	2.47	19	21	57.0	5.3	0	0	10.5	15.8
		September 12-14	6.50	-	-	-	-	-	-	-	-
		Average	3.8	309	42	56.7	3.4	0.1	0.1	7.7	11.3
	Southwest Bering Sea	July 1-5	0.60	50	100	57.9	0	0	0	10.0	10.0
		Average	0.60	50	100	57.9	0	0	0	10.0	10.0
Chum	Northwest Pacific Ocean	June 11-29	2.23	167	76	58.7	1.2	0	0	3.6	4.8
		July 8-18	2.92	102	68	58.7	2.9	1.0	0	4.9	8.8
		August 16-21	3.03	62	76	57.6	1.6	1.6	0	6.5	9.7
		September 12-14	0.70	16	100	55.6	25.0	12.5	0	6.3	43.8
		Average	2.2	347	80	57.7	7.7	3.8	0	5.3	16.8
	Southwest Bering Sea	July 1-5	2.60	54	87	58.9	0	1.9	0	3.7	5.6
		Average	2.60	54	87	58.9	0	1.9	0	3.7	5.6
Pink	Northwest Pacific Ocean	June 11-29	5.50	355	100	44.1	1.7	0	0	2.5	4.2
		July 8-18	3.33	129	100	47.1	0.8	2.3	0	9.3	12.4
		August 16-21	0.53	30	100	50.8	10.0	3.3	0	20.0	33.3
		Average	3.0	568	100	47.3	4.2	1.9	0	10.6	16.6
	Southwest Bering Sea	July 1-5	27.53	200	100	44.7	0	0.5	0	4.5	5.0
		Average	27.53	200	100	44.7	0	0.5	0	4.5	5.0
Chinook	Northwestern Pacific Ocean	June 11-29	0.01	25	61	69.6	4.0	0	0	12.0	16.0
		July 8-18	0.02	2	12	54.5	0	0	0	50.0	50.0
		August 16-21	0.08	-	-	-	-	-	-	-	-
		September 12-14	0.03	-	-	-	-	-	-	-	-
		Average	0.04	27	18	62.1	1.0	0	0	15.5	16.5
	Southwest Bering Sea	July 1-5	0.01	6	75	65.2	0	0	0	0	0
		Average	0.01	6	75	65.2	0	0	0	0	0
Coho	Northwest Pacific Ocean	July 8-18	0.43	42	100	58.4	4.8	0	0	9.5	14.3
		August 16-21	2.13	80	100	57.8	1.3	0	0	7.5	8.8
		September 12-14	1.20	28	100	57.3	7.1	0	0	10.7	17.8
		Average	0.9	156	100	57.8	4.4	0	0	9.2	13.6

from the nets in front of the fishing vessel. Fur seals often take only one bite instead of eating the entire fish, which greatly reduces the final quality of salmon in commercial catches. Moreover, the importance of fur seal predation on salmon in the northwest North Pacific Ocean and southwest Bering Sea can be confirmed indirectly by assessments showing their recent high level of abundance in the Commander Islands (up to 200,000 individuals; Kuzin 2003). We do not have any records of the occurrence of fur seals or other species of pinnipeds in our gillnets in 2004, although dead fur seals usually have not been observed in the nets. We cannot exclude other species of pinnipeds as potential consumers of salmon during drift gillnet fishing. For this reason, we classified all seal bites as Type II because accurate identification to species did not seem possible.

Other types of predators affecting salmon during drift gillnet fishing should also be considered. In general, seabirds (mostly fulmars and albatrosses) try to attack fish caught by gillnets, particularly fish caught near the upper rope of the gillnet. Usually, seabirds peck at salmon flesh in several different places, which further reduces the commercial value of the catch. This feeding behavior often leads to seabird mortality, if the birds become entangled in the nets.

Cetacean species are another potential cause of wounds on salmon. The most frequent cetacean in salmon gillnet bycatch is Dall's porpoise (*Phocoenoides dalli*). Unfortunate-

Table 3. The incidence (% of N) of immature Pacific salmon in gillnet catches with wounds caused by some species of predators. N = number of fish.

Species	Region	Period in 2004	CPUE (fish/ tan)	N	Immature in catch (%)	Length (cm)	Incidence of wounds (%)				Total incidence (%)
							Type I (fish)			Type II (seal)	
							a	b	c		
Sockeye	Northwest Pacific Ocean	June 11-29	1.44	10	5	49.9	0	0	0	0	0
		July 8-18	4.88	101	50	48.5	0	0	0	4.0	4.0
		August 16-21	2.47	73	79	49.3	2.7	1.4	0	2.7	6.8
		September 12-14	6.50	156	100	48.9	2.6	1.3	0	1.9	5.8
		Average	3.8	340	58	49.2	1.3	0.7	0	2.2	4.2
	Southwest Bering Sea	July 1-5	0.60	-	-	-	-	-	-	-	-
		Average	0.60	-	-	-	-	-	-	-	-
Chum	Northwest Pacific Ocean	June 11-29	2.23	53	24	53.6	0	0	0	0	0
		July 8-18	2.92	47	32	50.7	2.1	0	0	8.5	10.6
		August 16-21	3.03	20	24	51.1	5.0	0	0	0	5.0
		September 12-14	0.70	-	-	-	-	-	-	-	-
		Average	2.2	120	20	51.8	1.8	0	0	2.1	3.9
	Southwest Bering Sea	July 1-5	2.60	8	13	53.4	0	0	0	0	0
		Average	2.60	8	13	53.4	0	0	0	0	0
Chinook	Northwest Pacific Ocean	June 11-29	0.01	16	39	70.5	0	6.3	0	0	6.3
		July 8-18	0.02	15	88	66.9	0	0	0	0	0
		August 16-21	0.08	23	100	66.0	0	0	0	8.7	8.7
		September 12-14	0.03	21	100	61.3	9.5	0	0	4.8	13.3
		Average	0.0	75	82	66.2	2.4	1.6	0	3.4	7.1
	Southwest Bering Sea	July 1-5	0.01	2	25	69.5	0	0	0	0	0
		Average	0.01	2	25	69.5	0	0	0	0	0

ly, we did not have enough data to identify wounds caused by cetaceans. Nevertheless, attempts to assess this problem have already been undertaken by other researchers. According to observations by Kaplanova and Zolotukhin (2002), the Amur River salmon have wounds identified as the bites of white whales (*Delphinapterus leucas*). However, we did not observe such bites during our study. Recently, the first information was received from fishermen about killer whale (*Orcinus orca*) attacks on salmon in gillnets near the northern Kuril Islands. This problem is currently becoming serious enough to create a threat to the commercial longline fishery for halibut and cod in the Sea of Okhotsk.

During the cruise of the R/V *Ecopacific* in 2004, there were no recorded cases of fish with secondary net marks. We expected to see secondary net marks because gillnet fishing occurs in open waters of the North Pacific Ocean and the Bering Sea during the initial stages of commercial fisheries along salmon migration routes. The problem of secondary net marks is characteristic of offshore and river fisheries.

We also recorded the condition of wounds as "fresh" and "healed". These data are not provided in this document, because 80–90% of all wounds observed during the cruise were obviously "fresh." In addition, fresh and healed wounds do not provide insight into losses caused by predators. Many of the fresh wounds on salmon in gillnets are a direct consequence of increased availability of net-caught fish to predators. Wounding among fish in gillnet catches is several times higher than that in nature, e.g., as in the case of fur seal activity. Thus, if a wound occurred shortly before the fish was caught in a driftnet, the wound was considered "natural" and "fresh." A major problem in the analysis of wounded salmon caught in gillnets is that the differentiation of wounds into "natural" and "not natural" is never absolute.

We emphasize that the results of our analysis are only an indicator of the possible influence of predators on the abundance of salmon. In essence, our results can be interpreted as background monitoring helpful to analysis of the situation as a whole. Perhaps data from trawl catches may be more informative than gillnet data, because the time of predator-prey contact in trawl gear is limited. Moreover, investigations of wounded salmon caught in trawl gear have already been undertaken (Sviridov et al. 2004). At present, all that is needed to advance to the applied stage is the standardization of methods and organization of field data records.

Northwest North Pacific Ocean

Most of our observations were made in the northwest North Pacific Ocean (Tables 2 and 3). The large volume

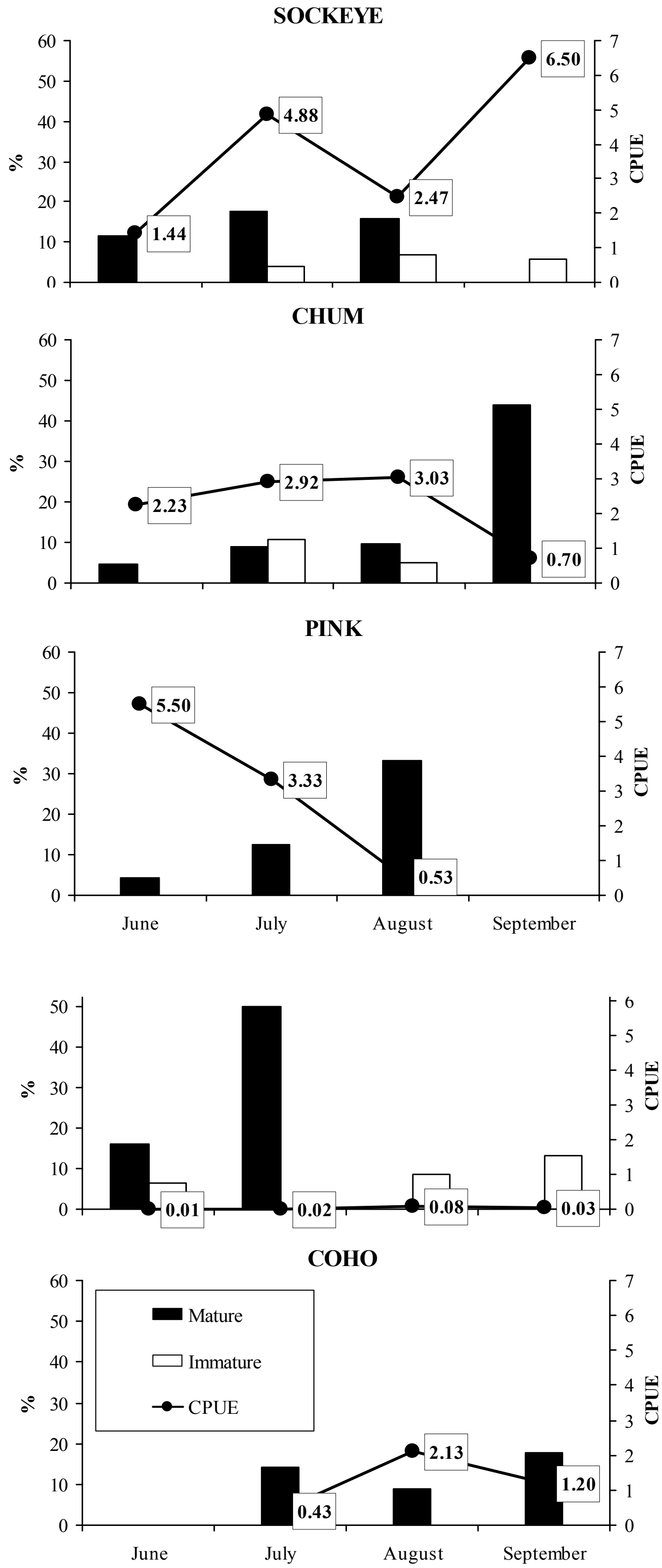

Fig. 3. Temporal (monthly) dynamics of the relative abundance of Pacific salmon (catch per unit effort (CPUE, fish/net) and percentages of mature and immature salmon with wounds caused by piscivorous fishes and seals in the northwest North Pacific Ocean in June-September 2004.

of data from this region allows us to gain insight into the temporal (monthly) dynamics of wounded salmon in gillnet catches (Fig. 3).

Sockeye Salmon: In June–September sockeye salmon were the most abundant species in gillnet catches in the northwest North Pacific Ocean (1.44–6.50 fish/net). The total percentage of mature sockeye salmon with wounds averaged 11.3% (range 11.6–17.6%). The highest numbers of fish with wounds were observed in July and August. Most wounds were identified as Type II (seals); average 7.7%; range 7.4–12.7%). The maximum number of both types of wounds occurred in July. The next most frequent wounds were Type I–a (longnose lancetfish or North Pacific daggertooth; average 3.4%; range 3.2–5.3%; peak in August). The percentage of sockeye salmon with wounds caused by lampreys (Type I–b) was low (average 0.1%). Only one wound identified as a salmon shark bite was recorded in June (Type I–c). The total percentage of wounding in immature sockeye salmon was lower than that of mature fish (average of 4.2%; range 0–6.8%; peak in July). Wounds caused by seals were the most frequent (average 2.2%, range 0–4.0%), followed by longnose lancetfish and North Pacific daggertooth wounds (average 1.3%; range 0–2.7%). The percentage of immature fish with lamprey wounds was somewhat higher than that of mature fish (average 0.7%; range 0–1.4%).

Chum Salmon: Chum salmon were also relatively abundant in the catches in this area (0.70–3.03 fish/net). Wounding of mature chum salmon in this area was extremely variable (average 16.6%; range 4.8–43.8%; peak in September). The most frequent wounds were caused by longnose lancetfish and North Pacific daggertooth (average 7.7%; range 1.2–25.0%; peak in September). The percentage of chum salmon with wounds caused by seals averaged 5.3% (3.6–6.5%), and there was no clear temporal trend in incidence. The percentage of chum salmon with lamprey wounds was relatively high compared to other salmon species (average 3.8%; range 0–12.5%; peak in August). The total percentage of wounding in immature chum salmon was lower than in mature fish (average 3.9%; range 0–10.6%). The wounds were mostly caused by pinnipeds (average 2.1%; range 0–8.5%) and longnose lancetfish and North Pacific daggertooth (average 1.8%; range 0–5.0%). No other types of wounds were observed.

Pink Salmon: Pink salmon catches in this area varied between 0.53–5.50 fish/net. All pink salmon in the gillnet catches were mature. The percentage of pink salmon with wounds in June–August averaged 16.6% (range 4.2–33.3%). The peak was recorded in August, i.e., at the very end of the prespawning run. The highest percent of wounds were caused by seals (average 10.6%; range 2.5–20.0%). The percentage of salmon with wounds caused by piscivorous fishes was somewhat lower than those caused by seals (longnose lancetfish and North Pacific daggertooth: average 4.2%, range 1.7–10.0%; lamprey: average 1.9%; range 0–3.3%).

Chinook Salmon: The relative abundance of chinook

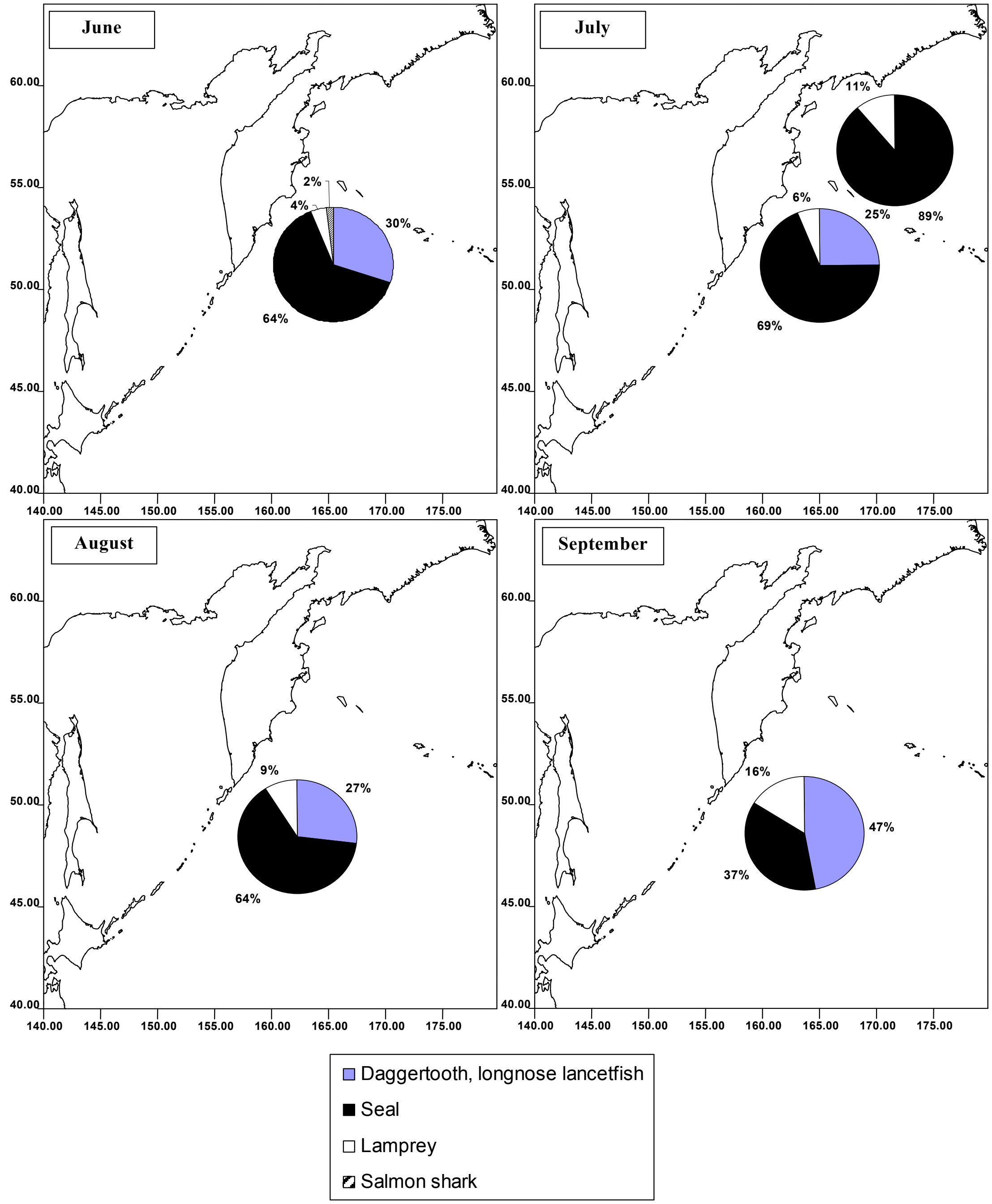

Fig. 4. Distribution (%) of wounds caused by four types of predators on all species of mature and immature Pacific salmon caught by drift gillnets in June-September 2004 in the northwest North Pacific Ocean and southwest Bering Sea.

salmon was low throughout the period of observation (range 0.01–0.08 fish/net). The percentage of mature chinook salmon with wounds in the northwest North Pacific Ocean in June–July averaged 16.5% (range 16.0–50.0%). The wounds were mostly Type II (seals; average 15.5%; range 12.0–50.0%). Longnose lancetfish and North Pacific daggertooth attacked mature chinook salmon less frequently than the other salmon species (average 1.0%; range 0–4.0%). The total percentage of wounding of immature chinook salmon was lower than that in mature chinook (average 7.1%; range 0–13.3%). The percent of immature chinook salmon with wounds caused by seals (average 3.4%; range 0–8.7%) and fishes (average 2.4% by longnose lancetfish and North Pacific daggertooth, and 1.6% by lampreys) were similar.

Coho salmon: Over the entire period of observations, the CPUE of coho salmon varied from 0.43 to 2.13 fish/net.

All coho salmon in the gillnet catches were mature. The percent of coho salmon with wounds averaged 13.6% (8.8–17.8%). The percent of coho salmon with wounds caused by seals averaged 9.2% (7.5–10.7%). The percent of coho salmon with wounds caused by longnose lancetfish and North Pacific daggertooth averaged 4.4% (range 1.3–7.1%).

Southwestern Bering Sea

Because observations in the southwestern Bering Sea were limited to early July, we do not have information on monthly variation in the incidence of salmon wounded by predators in this region. Nevertheless, the data for the major species of Pacific salmon caught by gillnets in early July are informative (see Tables 2 and 3).

Sockeye Salmon: The incidence of predation on mature sockeye salmon in this area was higher than that of other Pacific salmon species. Approximately 10.0% of the sockeye salmon had wounds, and all the wounds were identified as seal bites. Immature sockeye salmon were not observed during this period.

Chum Salmon: A total of 5.6% mature chum salmon in the southwestern Bering Sea had wounds (3.7% caused by seals, and 1.9% by lampreys). There were no wounds observed on immature chum salmon.

Pink Salmon: Pink salmon were the most abundant species of salmon in the southwestern Bering Sea in early July, and as a result the sample size of pink salmon is the most representative. A total of 5.7% of the pink salmon had wounds (4.5% caused by pinnipeds, and 0.5% by lampreys).

General Trends in the Incidence of Predation in Gillnet Catches

We pooled our data on predator marks over all mature and immature Pacific salmon species to illustrate some general trends the distribution of wounds by four types of predators in the northwest North Pacific Ocean and southwestern Bering Sea in the summer–autumn period (Fig. 4). The results clearly show that in June–August, i.e., the principal period of prespawning salmon migrations, most wounds were caused by seals (64–69% of wounds observed on salmon in North Pacific waters adjacent to Kamchatka; 89% in the southwestern Bering Sea). In September in catches from the southeast coast of Kamchatka and northern Kuril Islands, the percentage of seal wounds decreased to 37%. Wounds caused by longnose lancetfish and North Pacific daggertooth were observed only in the northwest North Pacific Ocean. However, our observation period in the southwest Bering Sea was not long enough to make any firm conclusions about regional differences in wounds caused by longnose lancetfish and North Pacific daggertooth. During summer, 25–37% of wounds were caused by longnose lancetfish and North Pacific daggertooth, and the highest percentage (47%) of wounds by these species was observed in September. Lamprey wounds demonstrated the most spatial and temporal variability (4–16% of wounds in the northwest North Pacific Ocean; up to 11% in the southwestern Bering Sea). The percentage of wounds caused by salmon sharks was very low in our study, which is probably because most salmon die from shark attacks. The only case of a salmon shark bite was recorded in June in the North Pacific waters adjacent to Kamchatka.

Three general trends in our results can be suggested. These mostly concern mature salmon, because our study exactly overlapped the period of their prespawning migrations. First, the incidence of wounds does not depend on the body size of salmon. For example pink salmon, which is the smallest Pacific salmon species, had an incidence of wounds similar to that of chinook salmon, which is the largest Pacific salmon species. We also did not find any intraspecific size-dependent effects. Second, most wounding of salmon in gillnet catches is caused by seals, longnose lancetfish, and North Pacific daggertooth. There was no prey-selectivity preference observed among predators. We cannot exclude the possibility that the observed incidence of wounds is overestimated, because salmon in gillnets are readily available prey. This especially concerns the incidence of wounds by seals. Third, the percentage of regenerated wounds (scars) in mature salmon increased at the end of the prespawning run. Although timing varied by species, the percent of salmon with visable scars increased during the migration (below 10–20% in early and mid periods, and up to 40–50% in the late period). This trend may be directly related to salmon physiology, i.e., the energy expended to regenerate injured tissues may delay maturation.

CONCLUSION

The data presented here include our observations of wounds among Pacific salmon during a gillnet survey in the Exclusive Economic Zone of the Russian Federation in summer–autumn 2004. We present a method to classify field observations of wounds into the types caused most frequently by different predators during prespawning migrations of salmon in the open ocean. The incidence of wounds was assessed by species of predator. Some general trends typical for all Pacific salmon species were revealed. First, the incidence of wounds does not depend on salmon body size at either the intra- or inter-specific level. Second, wounds on salmon in gillnet catches were caused most frequently by seals (37–69% of wounds on salmon in North Pacific waters adjacent to Kamchatka; 89% of wounds in the southwest Bering Sea) and two piscivorous species of fish, longnose lancetfish and North Pacific daggertooth (25–47% of wounds in North Pacific waters adjacent to Kamchatka). The percentage of lamprey wounds was lower (4–16% of wounds in North Pacific waters adjacent to Kamchatka; 11% in the southwest Bering Sea). Third, the percentage of regenerated wounds (scars) in mature salmon increased at the end of the prespawning migration. We plan to continue to classify wounds on salmon by predator type during future gillnet surveys in the Russian Economic Zone.

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