Abstract.—Depredation of bottomfish on longline catches by killer whales, *Orcinus orca*, has been documented throughout the Bering Sea. Stations where repeated interactions with killer whales had been noted were examined during Japan-U.S. cooperative longline research surveys conducted from 1980 to 1989. During vessel surveys in 1988, killer whales were shown to depredate Greenland turbot, *Reinhardtius hippoglossoides*, sablefish, *Anoplopoma fimbria*, arrowtooth flounder, *Atheresthes stomias*, Pacific halibut, *Hippoglossus stenolepis*, and searcher, *Bathymaster signatus*, selecting the largest fish available for each species. Depredation rate, based on averages of total catch, was higher than calculated from direct counts of damaged fish. The average annual monetary loss to the survey calculated over a 4-month research season as a result of killer whale predation for the years 1982 through 1988 was estimated to range from $2,982 to $34,571 (from ¥402,500 to ¥4,667,110).

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Killer whale, *Orcinus orca*, depredation on longline catches of bottomfish in the southeastern Bering Sea and adjacent waters

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Killer whales, *Orcinus orca*, are cosmopolitan in distribution (Leatherwood and Dahlheim, 1978), and reports of their interference in fishery operations occur worldwide (Sivasubramanium, 1965; Leatherwood et al., 1990; Tasmanian Fisheries Development Authority[1]). In Alaska, killer whales depredate longline catches of bottomfish, such as sablefish (also known as blackcod), *Anoplopoma fimbria*, and Greenland turbot, *Reinhardtius hippoglossoides*, in the southeastern Bering Sea and Prince William Sound, Alaska (Dahlheim[2]). Information from sources in the U.S. domestic longline fishery in the Bering Sea suggests that killer whale depredation occurs on at least 20% of the bottom longline sets (Dahlheim[2]). In Prince William Sound, an estimated 25% of the total catch is lost to killer whales (Matkin[3]).

Annual Japan-U.S. cooperative longline research surveys for sablefish and Pacific cod, *Gadus macrocephalus*, resources have occurred in Alaskan waters since 1979. Research vessels use similar fishing gear to that used during Japanese commercial bottom longline operations. This study reports on the nature and extent of fishery interactions with killer whales on Japan-U.S. research longline operations in Alaskan waters from 1980 to 1989. The survey area included the eastern Aleutian Islands, north into the Bering Sea along the continental slope, eastward following the Alaska Peninsula to the Gulf of Alaska, and then south into Southeast Alaska (Fig. 1). Objectives of the study include 1) definition of the areas where fishery interactions occur; 2) estimation of killer whale depredation on longline-caught fish; 3) iden-

[1] Tasmanian Fisheries Development Authority. 1981. Assessment of impact of interference from *Orcinus orca* (killer whale) on Tasmanian dropline fishery. Australian National Parks and Wildlife Service, Tasmanian Fisheries Development Authority, 23 Old Wharf, Hobart, Tasmania 7000, Australia. Unpubl. manuscr., 35 p.

[2] Dahlheim, M. E. 1988. Killer whale (*Orcinus orca*) depredation on longline catches of sablefish (*Anoplopoma fimbria*) in Alaskan waters. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northwest Alaska Fish. Cent., 7600 Sand Point Way NE, BIN C15700, Seattle, WA 98115. Proc. Rep. 88-4, 31 p.

[3] Matkin, C. O. 1986. Killer whale interactions with the sablefish longline fishery in Prince William Sound, Alaska, 1985, with comments on the Bering Sea. Rep. to the National Marine Mammal Laboratory, Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115-0070. Unpubl. manuscr. contract 40-HANF-6-0068, 10 p.

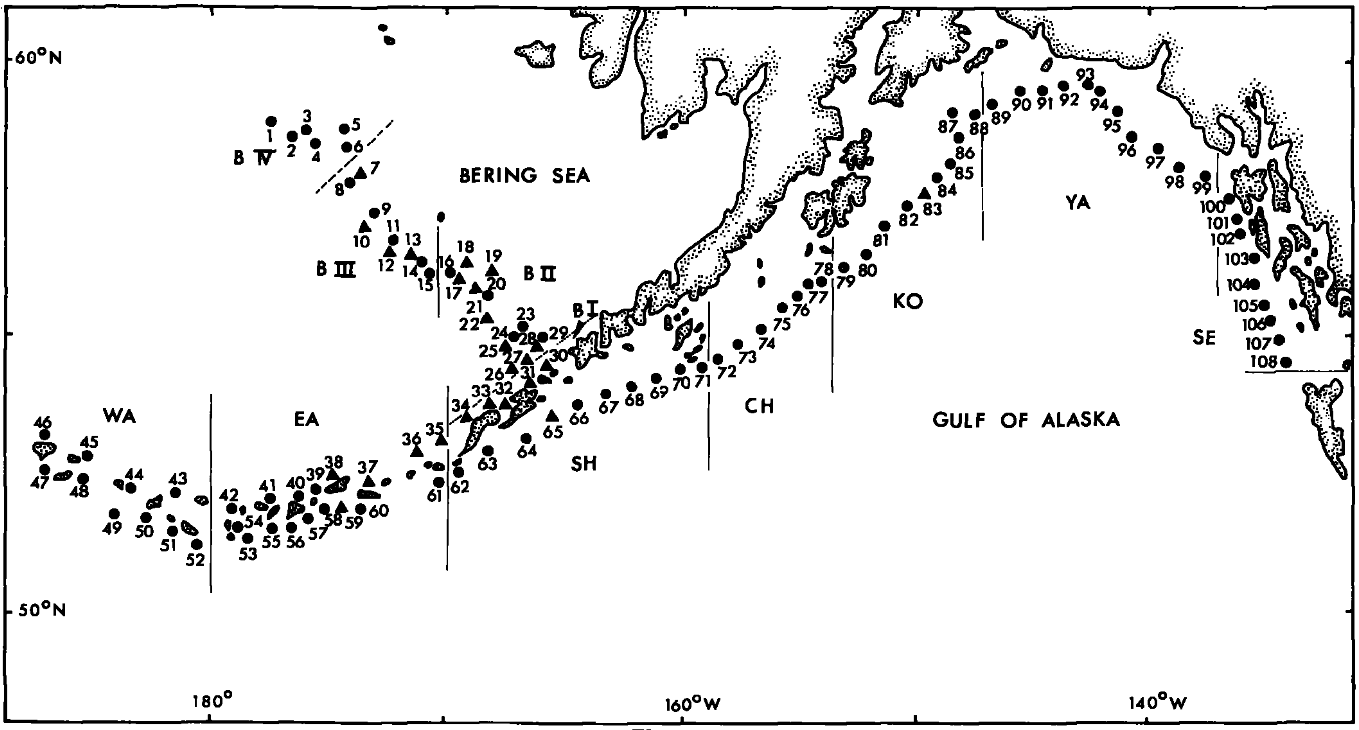

Figure 1

Survey stations of Japan-U.S. cooperative longline surveys in Alaskan waters (1980-89). Surveys were not conducted in the Bering Sea (B-II, B-III, and B-IV) during 1980 and 1981 seasons. (•) = stations where killer whales, *Orcinus orca*, were not encountered; (▲) = stations where whales were encountered (stations 10, 19, and 83 killer whales were observed but no depredation occurred). B = Bering Sea, WA = Western Aleutian Islands, EA = Eastern Aleutian Islands, SH = Shumagin Islands, CH = Chirikof Island, KO = Kodiak Island, YA = Yakutat, SE = Southeast Alaska.

tification of species and size of fish consumed by killer whales; and 4) quantification of the amounts of longline catch lost to killer whales.

Materials and methods

Stations for the Japan-U.S. longline research survey in Alaskan waters were established by the National Research Institute of Far Seas Fisheries, Fisheries Agency of Japan, and the National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center. In 1980 and 1981, 76 stations were fished, excluding areas B-II, B-III, and B-IV (29 stations) in the Bering Sea (Fig. 1). Beginning in 1982, the number of stations (which represent 11 major fishing areas) increased to 108 to include the additional Bering Sea stations (Sasaki, 1985; Fig. 1). Surveys were conducted between May and September each year (1980–89). Weather permitting, one station was fished per day.

The research vessels selected for the surveys were chartered Japanese commercial longline vessels that had been used for previous sablefish and Pacific cod fishing operations in the North Pacific Ocean. The bottom longline was 16 km long and consisted of 160 "hachis" (skates). Each hachi was 100 m long and contained 45 hooks which were spaced 2 m apart. Gangion lengths were 1.2 m. Each hook was baited with squid (total number of hooks=7,200). The hook (standard type: Tara [=cod] no. 18) was 74 mm in length and 21 mm in width. The depth at which fish were caught was estimated by measuring the depth of water under the vessel with an echo sounder at every fifth hachi. The catch was recorded by estimating the numbers of species or species groups for each hachi. The total catch of the major species was weighed to the nearest gram. Total length (TL) or fork length (FL) was measured for each species to the nearest millimeter. Details of the survey methods and longline gear are described in Yano[4,5].

[4] Yano, K. 1989. Japan-U.S. joint survey for stock assessment of sablefish and Pacific cod resources in 1988. Report of the Northern Groundfish Section, Japan Scientific Council on the

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Between 1980 and 1989, stations where killer whales were present were recorded. During vessel surveys in 1988, depredation rates by killer whales were quantified. During the 1988 surveys, as the groundline was retrieved, fish that had been damaged or partially consumed by killer whales were identified by remains left on the hook (e.g. heads, lips, or gills). In addition, head length (HL) or maxillary length (ML) measurements were collected for each damaged fish. Head length (mm) was measured from the most anterior point of the snout of the upper jaw to the most distant point of the posterior margin of the operculum. Maxillary length (mm) was measured along the longest margin on the premaxillary side. Fork length (FL) for sablefish and arrowtooth flounder, *Atheresthes stomias*, and total length (TL) for Greenland turbot were also measured. Fork length and TL were measured from the tip of the snout to the central point of the caudal fin. The relationships between HL and FL or TL and between ML and FL or TL were calculated by the least-square method following the equation:

$$Y = a + bX,$$

where Y is FL or TL (mm), X is HL or ML (mm), and a and b are constants. Average lengths of damaged and undamaged fish were compared by using t-tests with a significance level of 0.05.

To obtain killer whale depredation rates for each station, direct counts were made of the remaining heads, lips, or gills that were brought aboard the research vessel. Empty hooks did not provide evidence of killer whale depredation and were not included in the analysis.

Killer whale depredation rates were calculated by two methods. RNT is the depredation rate calculated from the number of fish preyed upon as a percentage of the total number of fish landed per fishing trip. RNS is the depredation rate calculated from the number of fish preyed upon as a percentage of the number of fish landed from the time the whales were first observed to depredate them.

The two depredation rates were calculated for each station as

$$RNT\ (\%) = NP/(NT+NP) \times 100$$

and

$$RNS\ (\%) = NP/(NS+NP) \times 100,$$

where NP is the number of depredated fish, counted by the remaining heads, lips, or gills; NT is the total number of fish landed with no evidence of killer whale depredation; and NS is the number of fish landed without any physical evidence of depredation counted from the time the whales were first observed to depredate fish (determined by observing heads, lips, or gills on the groundline).

Other depredation rates (REA and REY) were obtained by averaging the catch rates (number of fish per hachi) obtained during the 1980 and 1988 surveys. REA is the depredation rate calculated from the average catch rates for all years at each station. REY is the depredation rate calculated from the average catch rates for all stations for each year. The average catch rates (REA and REY) were obtained through the following formula:

$$REA \text{ or } REY\ (\%) = 100 - (A/B \times 100),$$

where A is the average catch rate during whale depredation for all years at each station (for *REA*) or all stations for each year (for *REY*), and B is the average catch rate with no killer whale depredation for all years at each station (for *REA*) or all stations for each year (for *REY*). We tested for differences in the average catch rates for *REA* and *REY* by using the one-way analysis of variance (ANOVA). The annual survey reports of the Japan Marine Fishery Resources Research Center (JAMARC) by Inada and Sasaki,[6] Onoda and Sasaki,[7] Mizogoshi and Sasaki,[8] Funato and Sasaki,[9] Iwami and Sasaki,[10] Fukui and Sasaki,[11] Takeda and Sasaki,[12] Takeda,[13] and Yano[5] provided fish catch data for the study.

[4] *(continued)* Fisheries Resources (GSK), Tohoku National Fisheries Research Institute, Hachinohe Branch, 25-259 Shimomekurakubo, Samemachi, Hchinohe, Aomori 031, Japan, No. 22, p. 145-173. [In Japanese.]

[5] Yano, K. 1990. Report on sablefish and Pacific cod resource developmental survey, 1988. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S63/No.11, 195 p. [In Japanese.]

[6] Inada, T., and T. Sasaki. 1981. Report on sablefish and Pacific cod resource developmental survey, 1980. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S55/No.18, 156 p. [In Japanese.]

[7] Onoda, M., and T. Sasaki. 1982. Report on sablefish and Pacific cod resource developmental survey, 1981. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S56/No.15, 140 p. [In Japanese.]

[8] Mizogoshi, H., and T. Sasaki. 1984. Report on sablefish and Pacific cod resource developmental survey, 1983. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S58/No.13, 219 p. [In Japanese.]

[9] Funato, K., and T. Sasaki. 1985. Report on sablefish and Pacific cod resource developmental survey, 1982. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S57/No.13, 191 p. [In Japanese.]

[10] Iwami, T., and T. Sasaki. 1985. Report on sablefish and Pacific cod resource developmental survey, 1984. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S59/No.12, 223 p. [In Japanese.]

[11] Fukui, J., and T. Sasaki. 1988. Report on sablefish and Pacific cod resource developmental survey, 1985. Japan Marine

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Monetary losses incurred during fishing operations were calculated from data for product (kg) and from price per kilogram (yen) of sablefish, Greenland turbot, and arrowtooth flounder, contained in the annual survey reports of JAMARC by the following formula:

Monetary loss (yen and US dollar) = (Average product value) × (depredation rate [RNT, RNS, REY or REA])/100,

where average product value is the average of product values calculated by product per operation and by price per kilogram in each area and each year.

Results

Stations with killer whales

Between 1980 and 1989, killer whales were reported at 25 stations (Fig. 1). Eighteen of these stations were in the eastern Bering Sea (B), five stations were near the eastern Aleutian Islands (EA), and one station each was near the Shumagin Islands (SH) and off Kodiak Island (KO). Fishery interactions consistently occurred at several of the sampling locations (Table 1). The highest frequency of killer whale interactions was reported for two areas in the Bering Sea: B-I (stations 31, 32, and 33) and B-II (stations 22, 25, 26, and 27) (Table 1, Fig. 1). Killer whale group size ranged between 4 and 50 animals during the 1988 survey (Table 2). From the 1988 field observations and photographs of killer whales, there appears to be three killer whale groups involved in the Bering Sea fishery interactions (BS1, BS2, and BS3 in Table 2; Yano and Dahlheim[14]).

Depredation by killer whales

During the 1988 survey, when killer whales were observed around the vessel, the hooks on the retrieved groundline frequently contained only fish heads, lips, or gills (Fig. 2), providing evidence that killer whales were responsible for depredation of longline-caught fish. Occasionally, whole fish showed extensive rake marks made by killer whale teeth (Figs. 3 and 4). Whales consumed longline catches of sablefish, Greenland turbot, arrowtooth flounder, and Pacific halibut, the latter remaining whole but showing extensive rake marks. Two heads of searcher were also noted. Other species of fish caught on longlines but not eaten by killer whales included Pacific cod, grenadier, *Coryphaenoides acrolepis*, rockfish, *Sebastes* spp., walleye pollock, *Theragra chalcogramma*, and shortspine thornyhead, *Sebastolobus alascanus*.

Depredation rates

Killer whale depredation rates calculated by four different methods showed that the rates based on averages of total catch (REA and REY) were higher than the rates calculated directly from damaged fish (RNT and RNS). Based on our sampling, depredation rates for Greenland turbot were highest, followed by depredation rates for sablefish, arrowtooth flounder, and Pacific halibut (Table 3). Depredation rates of about 10% or more (based on both RNT and RNS values) were noted for stations 30, 33, 25, 22, and 20. The highest RNT and RNS values were found at station 25 for Greenland turbot and sablefish and at station 22 for arrowtooth flounder. Arrowtooth flounder typically had lower depredation rates than those calculated for Greenland turbot or sablefish. However, a large number of damaged arrowtooth flounder (15-72 specimens) were present in the catch at stations 30, 17, 20, 22, and 25.

Annual catch rates (total number of fish caught per hachi) of sablefish, Greenland turbot, and arrowtooth flounder for each station in the EA, B-I, B-II, B-III, and SH areas (Fig. 1) were used to calculate depredation rates for all years at each station (REA) and for all stations for each year (REY). Twenty-one stations had fishery interactions involving killer whales during the period 1980-88 (Table 4). Depredation rates (REA) calculated from the average fishery catch rates for years with and without killer whale predation showed that the average catch rates of sablefish and Greenland turbot were significantly lower when killer whales were present than when killer whales were absent (ANOVA, $P<0.01$). However, for arrowtooth flounder average catch rates were independent of killer whale depredation (ANOVA, $P>0.05$). In addition average catch of arrowtooth flounder was similar among years regardless of the presence or absence of whales (Table 4). Depredation rates (REA) calculated from the average

[11] *(continued)* Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S60/No.12, 197 p. [In Japanese.]

[12] Takeda, Y., and T. Sasaki. 1988. Report on sablefish and Pacific cod resource developmental survey, 1986. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S61/No.12, 179 p. [In Japanese.]

[13] Takeda, Y. 1988. Report on sablefish and Pacific cod resource developmental survey, 1987. Japan Marine Fishery Resources Research Center, 3-27 Kioi-cho, Chiyoda-ku, Tokyo 102 Japan, JAMARC Rep. S62/No.11, 191 p. [In Japanese.]

[14] Yano, K., and M. E. Dahlheim. Behavior of killer whales, *Orcinus orca*, during longline fishery interactions in the southeastern Bering Sea and adjacent waters. Fisheries Science (unpubl. manuscript).

Table 1

Areas and stations where killer whales, *Orcinus orca*, were encountered (X) during Japan-U.S. cooperative longline surveys (1980 to 1989). B-II and B-III areas were not surveyed (—) in 1980 and 1981. Asterisks (*) indicate the stations where killer whales were encountered but no depredation occurred.

		Year										Total per
Area[1]	St. no.	1980	1981	1982	1983	1984	1985	1986	1987	1988[2]	1989	station
EA	35				X							1
EA	36					X						1
EA	37							X		X	X	3
EA	38										X	1
EA	59							X				1
B-1	30						X			X		2
B-1	31	X			X	X		X		X	X	6
B-1	32	X	X		X				X			4
B-1	33	X		X	X		X	X	X	X		7
B-1	34			X					X			2
B-II	17	—	—							X	X	2
B-II	18	—	—							X		1
B-II	19	—	—							X*		1
B-II	20	—	—			X		X		X		3
B-II	22	—	—		X				X	X		3
B-II	25	—	—	X			X	X	X	X	X	6
B-II	26	—	—	X				X	X	X	X	5
B-II	27	—	—		X			X	X			3
B-II	28	—	—		X							1
B-III	7	—	—							X		1
B-III	10	—	—							X*		1
B-III	12	—	—		X						X	2
B-III	13	—	—		X							1
SH	65									X		1
KO	83									X*		1
Total per year		3	1	4	9	3	3	8	7	15	7	60

[1] EA = Eastern Aleutian Islands; B = Bering Sea; SH = Shumagin Islands; KO = Kodiak Island, see Figure 1 for areas.
[2] Detailed observations of killer whale predation were documented.

catch rates for years with and without killer whale predation ranged from 9.2 to 92.4% for sablefish, from 2.2 to 90.4% for Greenland turbot, and from 1.4 to 80.3% for arrowtooth flounder (Table 4).

Between-year comparisons (REY) for catches of all species at the same station (except for 1982 of sablefish) indicate catches were lower in years with killer whale depredation (Table 5). The average catch rates of sablefish and Greenland turbot for stations with killer whale depredation were significantly lower than in stations without depredation (ANOVA, $P<0.05$). However, the average catch rate of arrowtooth flounder (for stations with killer whale depredation) was not significantly lower than that for stations without killer whale depredation (ANOVA, $P>0.05$). Depredation rates (REY) calculated from the average catch rates for stations with and without killer whale predation ranged from 33.4 to 84.1% for sablefish, from 53.3 to 82.6% for Greenland turbot, and from 17.0 to 70.8% for arrowtooth flounder (Table 5). REY values calculated from average catch rates for years with and without killer whale depredation were slightly lower than REA values (Table 6).

Predation rates based on the average catch landed (REA and REY values) were higher than those rates (RNT and RNS values) calculated directly from counting heads, lips, and gills of fish remains on the deck during the 1988 survey (Table 6). Depredation rate, based on the four different methods of calculations (i.e. RNT, RNS, REY, and REA), suggested that whales took 14-60% of the sablefish, 39-69% of the Greenland turbot, and 6-42% of the arrowtooth flounder.

Size of fish consumed by killer whales

The size of the fish taken by whales was determined by measurements of HL or ML. The relationships

Table 2

Stations where killer whales, *Orcinus orca*, were encountered during the 1988 Japan-U.S. longline research survey.

Area[1]	St. no.	Date	Operating depth (m)	Estimated number of whales	Arrival time of killer whales	Hachi[2] number when killer whales arrived	Fishing depth of retrieved hachi (m)	First hachi number with evidence of killer whale depredation	Fishing depth of first hachi number that received killer whale depredation (m)	Group[3] identified
EA	37	17 June	160–744	40–50	13:30	50	380	54	440	?
B-I	30	23 June	144–480	20–30	10:25	68	380	76	390	1,3
B-I	31	27 July	110–820	5–6	12:15	120	550	123	600	2
B-I	33	22 June	122–812	20–30	8:40	1	800	7	780	1,3
B-II	17	14 July	174–980	8–10	11:05	86	210	95	300	1
B-II	18	15 July	133–215	8–10	8:30	8	136	24	137	1
B-II[4]	19	17 July	150–245	4	13:16	156	238	—	—	2
B-II	20	18 July	160–820	8–10	9:30	42	160	117	440	2
B-II	22	28 June	197–680	15–30	8:45	1	680	6	670	1
B-II	25	24 June	430–613	10–20	8:30	1	610	6	610	2
B-II	26	21 July	485–720	15–20	8:10	1	485	31	509	?
B-III	7	08 July	130–155	10–15	10:50	46	145	110	150	2
B-III[4]	10	10 July	167–562	—	8:20	1	167	—	—	?
SH	65	30 July	135–765	6–8	13:08	127	455	133	660	1
KO[4]	83	18 August	360–750	7–8	11:00	65	520	—	—	?

[1] EA = Eastern Aleutian Islands; B = Bering Sea; SH = Shumagin Islands; KO = Kodiak Island, see Figure 1 for areas.
[2] A length of groundline equal to 100 m.
[3] See Yano and Dahlheim (See Footnote 14 in text).
[4] No predation observed at station.

Figure 2

Heads, lips, and gills of partially consumed sablefish, *Anoplopoma fimbria*, Greenland turbot, *Reinhardtius hippoglossoides*, and arrowtooth flounder, *Atheresthes stomias*, at station 22. Scale represents 300 mm.

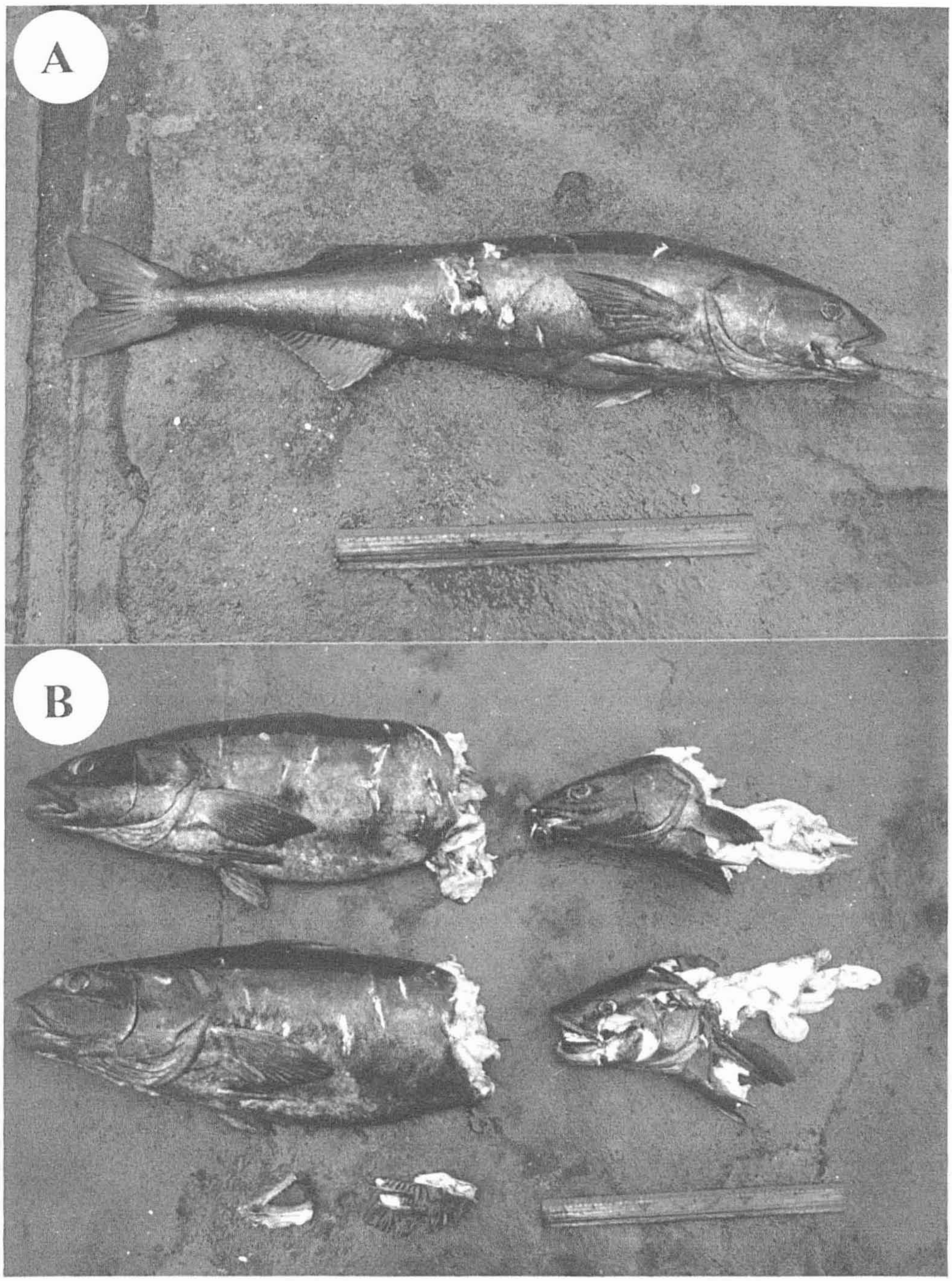

Figure 3

Depredated sablefish, *Anoplopoma fimbria*, at station 33. (**A**) Whole fish with rake marks made by killer whale teeth; (**B**) partially consumed fish showing head, lips, and gills. Scale represents 300 mm.

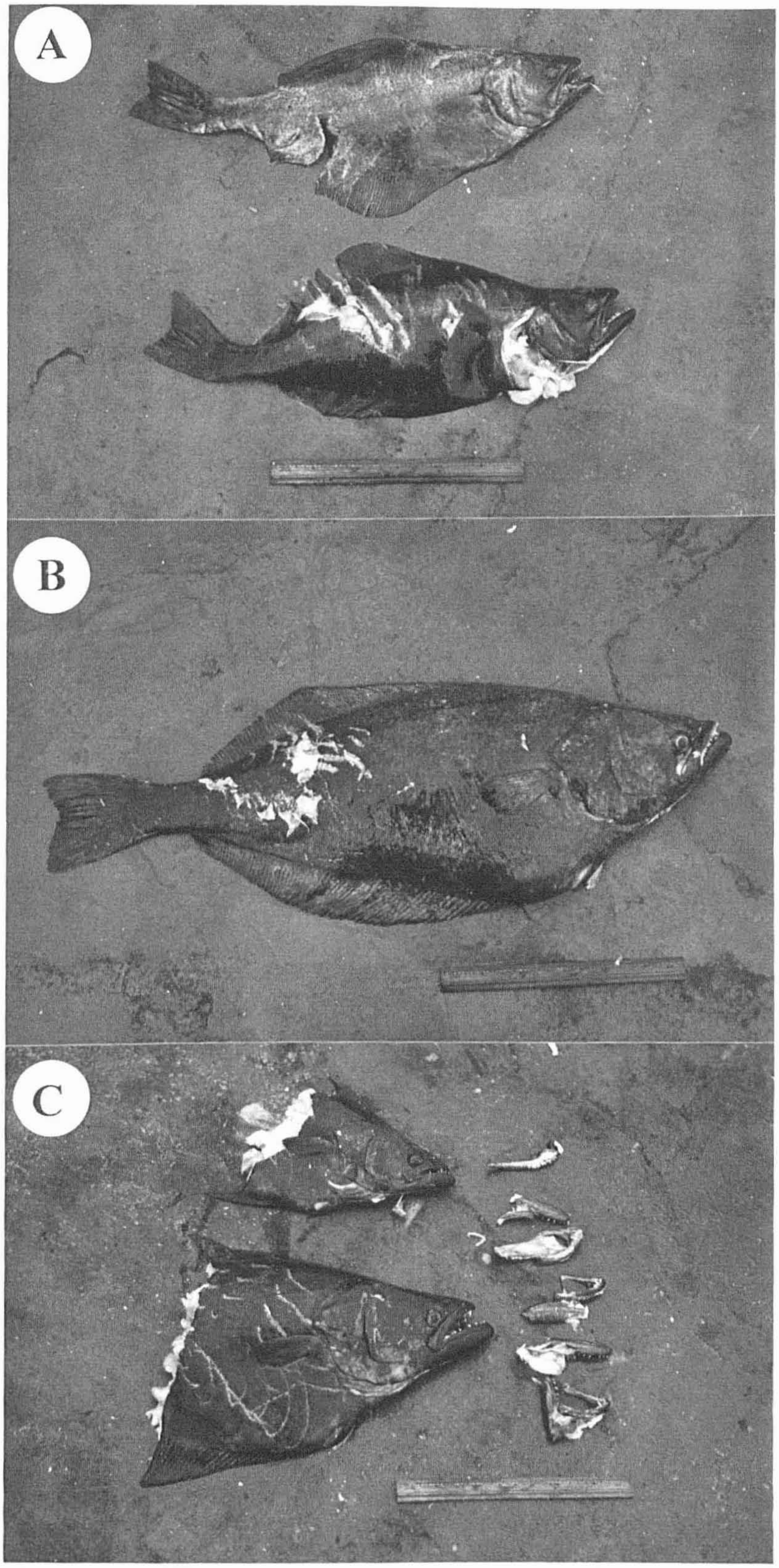

Figure 4

Partially consumed Greenland turbot, *Reinhardtius hippoglossoides*, and arrowtooth flounder, *Atheresthes stomias*. Scales represent 300 mm. (**A**) Arrowtooth flounder with rake marks made by killer whale teeth at station 22; (**B**) damaged Greenland turbot at station 17; (**C**) head and lips of partially consumed Greenland turbot at station 22.

Table 3

Killer whale, *Orcinus orca*, predation rates for 1988 on sablefish, *Anoplopoma fimbria*, Greenland turbot, *Reinhardtius hippoglossoides*, arrowtooth flounder, *Atheresthes stomias*, and Pacific halibut, *Hippoglossus stenolepis*. NPF: number of damaged fish; RNT (%) = (number of partially consumed fish, *NP*)/(number of total catch fish) × 100; RNS (%) = (NP)/(number of fish (remaining heads, lips, or gills seen) counted from the start of depredation by killer whales) × 100.

		Sablefish			Greenland turbot			Arrowtooth flounder			Pacific halibut		
Area[1]	St. no.	NPF	RNT	RNS	NPF	RNT	RNS	NPF	RNT	RNS	NPF	RNT	RNS
EA	37	69	14.11	14.53	33	30.00	30.00	1	2.04	5.88	0	0.00	0.00
B-I	30	13	38.24	43.33	3	60.00	60.00	19	14.29	61.29	0	0.00	0.00
B-I	31	7	2.57	17.07	6	14.63	54.55	0	0.00	0.00	0	0.00	—
B-I	33	27	9.68	9.93	3	9.09	10.34	0	0.00	0.00	0	0.00	0.00
B-II	17	9	7.38	9.47	7	16.28	17.07	15	3.50	17.65	0	0.00	0.00
B-II	18	1	0.26	0.26	0	—	—	3	0.59	0.59	1	0.72	0.72
B-II	20	25	26.04	71.43	27	71.05	77.14	27	7.42	26.21	0	0.00	0.00
B-II	22	8	5.76	6.20	9	37.50	37.50	72	19.46	19.62	0	0.00	0.00
B-II	25	32	62.75	62.75	21	95.45	95.45	15	12.20	12.20	1	8.33	8.33
B-II	26	3	0.64	0.89	11	20.75	23.91	1	8.33	8.33	0	—	—
B-III	7	0	0.00	—	0	—	—	1	0.77	1.64	4	0.57	4.04
SH	65	5	0.28	2.69	0	—	—	0	0.00	0.00	0	0.00	—
Average			13.98	21.69		39.42	45.11		5.72	12.78		0.87	1.46

[1] EA = Eastern Aleutian Islands; B = Bering Sea; SH = Shumagin Islands, see Figure 1 for areas.

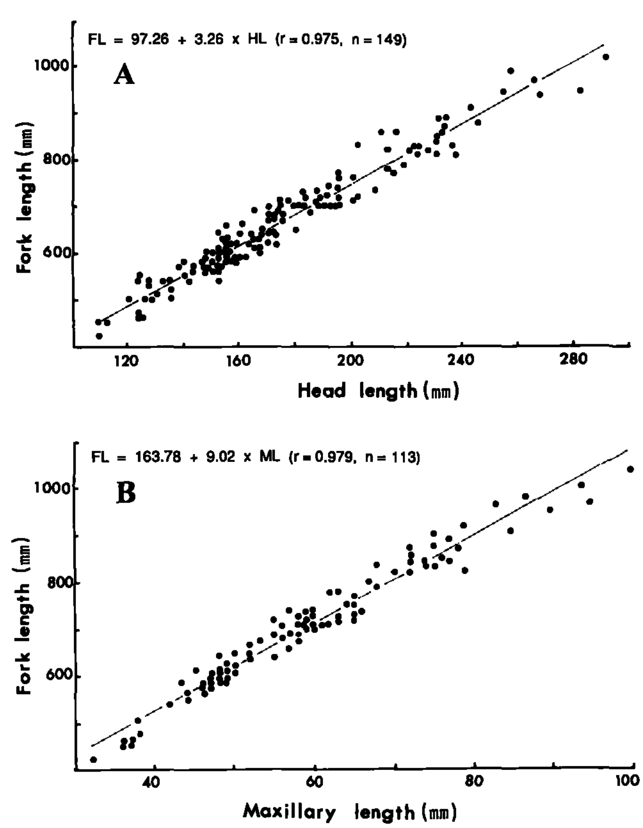

Figure 5

Size of partially consumed sablefish, *Anoplopoma fimbria*. (**A**) The relationship between head length (HL) and fork length (FL); (**B**) the relationship between maxillary length (ML) and fork length (FL).

Table 4

Average catch rates (number of fish per hachi) for years with and without killer whale, *Orcinus orca*, predation (1980–88), and calculated REA [REA = 100 – C (%)]. A = predation occurred; B = no predation occurred; C = A/B × 100 (%); AO = average when C>100% are omitted, and when REA≤0 are omitted.

		Sablefish				Greenland turbot				Arrowtooth flounder				Frequency[2]	
Area[1]	St. no.	A	B	C	REA	A	B	C	REA	A	B	C	REA	D	ND
EA	35	0.20	2.02	9.90	90.10	0.02	0.15	13.33	86.67	0.37	0.24	154.17	–54.17	1	8
EA	36	0.17	0.35	48.57	51.43	0.01	0.04	25.00	75.00	0.31	0.14	221.43	–121.43	1	8
EA	37	5.41	7.65	70.72	29.28	0.72	1.92	37.35	62.65	0.30	0.36	83.33	16.67	2	7
EA	59	1.90	3.66	51.91	48.09	0.01	0.01	100.00	0.00	0.06	0.20	30.00	70.00	1	8
B–I	30	4.22	6.18	68.28	31.72	0.25	1.32	18.94	81.06	0.73	0.74	98.65	1.35	2	7
B–I	31	3.02	6.63	45.55	54.45	0.46	3.26	14.11	85.89	0.37	0.32	115.63	–15.63	5	4
B–I	32	1.34	6.35	21.10	78.90	0.23	0.37	62.16	37.84	0.20	0.49	40.82	59.18	4	5
B–I	33	2.50	5.45	45.87	54.13	0.19	1.88	10.11	89.89	0.20	0.17	117.65	–17.65	7	2
B–I	34	2.89	8.81	32.80	67.20	0.37	2.09	17.70	82.30	0.81	0.40	202.50	–102.50	2	7
B–II	17	0.76	5.66	13.43	86.57	0.28	0.86	32.56	67.44	2.68	0.75	357.33	–257.37	6	1
B–II	18	2.54	2.80	90.71	9.21	—	—	—	—	3.18	0.64	496.88	–396.88	1	5
B–II	20	2.94	3.58	82.12	17.88	0.32	1.79	17.88	82.12	1.06	1.26	84.13	15.87	3	4
B–II	22	0.53	6.94	7.64	92.36	0.13	1.05	12.38	87.62	1.69	1.09	155.05	–55.05	3	4
B–II	25	1.38	6.34	21.77	78.23	0.08	0.83	9.64	90.36	0.34	0.95	35.79	64.21	4	3
B–II	26	2.25	6.87	32.75	67.25	0.45	0.46	97.83	2.17	0.09	0.06	150.00	–50.00	4	3
B–II	27	4.80	11.09	43.28	56.72	0.68	0.78	87.18	12.82	0.75	0.07	70.09	29.91	4	3
B–II	28	1.91	6.73	28.38	71.62	0.39	0.12	325.00	–225.00	0.39	1.98	19.70	80.30	1	6
B–III	7	—	0.02	—	—	—	—	—	—	0.81	0.14	578.57	–478.57	1	6
B–III	12	1.03	4.21	24.47	75.53	0.34	2.33	14.59	85.41	0.75	1.42	52.82	47.18	1	6
B–III	13	1.65	6.06	27.23	72.77	0.23	0.86	26.74	73.26	0.58	0.93	62.37	37.63	1	6
SH	65	11.36	10.86	104.60	–4.60	—	—	—	—	1.23	0.15	820.00	–720.00	1	8
Average		2.64	5.63	43.55	56.45	0.29	1.12	51.25	48.75	0.80	0.64	187.95	–87.95	2.6	5.3
(AO)				(40.34)	(59.66)			(31.09)	(68.91)			(57.77)	(42.23)		

[1] EA = Eastern Aleutian Islands; B = Bering Sea; SH = Shumagin Islands, see Figure 1 for areas.
[2] Frequency of sampling. D = depredation; ND = no depredation.

between HL and FL and between ML and FL for sablefish, Greenland turbot, and arrowtooth flounder are shown in Figures 5–7.

Length-frequency distributions from the 1988 survey data for sablefish, arrowtooth flounder, and Greenland turbot are shown in Figures 8-10. Each figure depicts three different length-frequency distributions for each species: 1) those for all areas fished (EA, B-I, B-II, B-III, and SH) including stations that had reports of killer whale interference with longline operations without estimated length specimens (all areas; Figs. 8A, 9A, and 10A); 2) size distributions of undamaged fish for all stations (station numbers are presented in Table 3) that reported killer whale depredation (all stations; 8B, 9B, and 10B); and 3) size distribution of partially consumed fish and whose estimated length was based on the calculations made through the above formula of HL and ML (partially consumed fish; Figs. 8C, 9C, and 10C).

Average length of sablefish was 635.7 mm FL for all areas fished, 607.5 mm FL for undamaged fish at stations where killer whale depredation was evident, and 633.1 mm FL for the partially consumed fish (Fig. 8, A, B, and C). Significant differences were found between average lengths of damaged fish and undamaged fish for all stations where killer whale predation was evident (t=19.65, P<0.05). However, no significant differences were found between average lengths of damaged fish and undamaged fish for all areas fished (t=0.43, P>0.05). The average length of damaged fish was significantly larger than that of undamaged fish at stations where killer whale depredation was evident (t=19.65, P<0.05), but the total average length was about equal to that for all areas fished.

Average length of arrowtooth flounder was 528.3 mm FL for all areas fished, 506.5 mm FL for stations fished where killer whale depredation was evident, and 575.2 mm FL for fish that were preyed upon. Significant differences were found between average lengths of damaged fish and undamaged fish (t=7.71 and t=10.99, P<0.05). The average size of

Table 5

Average catch rates (number of fish per hachi) for stations with and without killer whale, *Orcinus orca*, depredation (stations indicated in Table 4), and calculated REY [REY=100–C(%)]. A = depredation occurred; B = no depredation occurred; C = A/B × 100(%); AO = average when C≥100% are omitted, and when REY<0 are omitted.

	Sablefish				Greenland turbot				Arrowtooth flounder				Frequency[1]	
Year	A	B	C	REY	A	B	C	REY	A	B	C	REY	D	ND
1980	1.11	2.53	43.87	56.13	0.13	0.60	21.67	78.33	0.19	0.25	76.00	24.00	3	7
1981	0.51	3.20	15.94	84.06	0.48	1.24	38.71	61.29	0.19	0.26	73.08	26.92	1	9
1982	5.03	4.50	11.78	–11.78	0.30	1.18	25.42	74.58	0.14	0.48	29.17	70.83	4	17
1983	2.09	4.56	45.83	54.17	0.38	0.92	41.30	58.70	0.39	0.47	82.98	17.02	9	12
1984	2.04	9.49	21.50	78.50	0.12	0.69	17.39	82.61	0.23	0.31	74.19	25.81	3	18
1985	5.16	7.75	66.58	33.42	0.27	0.72	37.50	62.50	0.33	0.60	55.00	45.00	3	18
1986	3.52	6.69	52.62	47.38	0.36	0.77	46.75	53.25	0.47	0.67	70.15	29.85	8	13
1987	1.42	3.75	37.87	62.13	0.40	1.12	35.71	64.29	0.70	1.31	53.44	46.56	7	14
1988	2.18	4.55	47.91	52.09	0.19	0.48	39.58	60.42	1.33	1.18	112.71	–12.71	12	9
Average	2.56	5.22	49.32	50.68	0.29	0.86	33.78	66.22	0.44	0.61	69.63	30.37	5.56	13.00
AO			41.51	58.49			33.78	66.22			64.25	35.75		

[1] Frequency of sampling. D = depredation; ND = no depredation.

partially consumed fish (Fig. 9C) was significantly larger than that reported from all areas fished (Fig. 9A; t=7.71, P<0.05) and for the stations fished where killer whales were present (Fig. 9B; t=10.99, P<0.05).

There was a bimodal length-frequency distribution for Greenland turbot (Fig. 10, A–C). Average length of Greenland turbot was 744.3 mm TL for all areas fished, 730.8 mm TL for the stations fished where depredation occurred, and 756.1 mm TL for the partially consumed fish. Significant differences were found between average lengths of damaged fish and undamaged fish for all stations with killer whale depredation (t=2.03, P<0.05). However, no significant differences were found between average lengths of damaged fish and undamaged fish for all areas fished (t=1.08, P>0.05). The average length of damaged fish was significantly larger than that of undamaged fish at stations with killer whale depredation (t=2.03, P<0.05) but the total average length was about equal to that for all areas fished.

Monetary loss

For the years 1982–88, data were collected on the product yield of each area and operation, unit price per kilogram (commercial price when landed), and product price per operation for sablefish, Greenland turbot, and arrowtooth flounder (Table 7). The average monetary loss in the total catch per operation (using 160 hachi per operation) was estimated to range from ¥96,853.7 ($717.40 [U.S. dollars] @¥135 calculated from RNT) to ¥790,934.2 ($5,858.80 calculated from REA)(Table 8). The average overall loss incurred for all years at all stations (Table 9) as a result of killer whale depredation ranged from ¥402,499.6 to ¥4,667,109.6 (from $29,181.50 to $34,571.20). The total product value of the 4-month survey for each year (D in Table 9) ranged from ¥98,812,086.0 to ¥283,932,240.0 (from $731,941.40 to $2,103,201.80) and the product values per operation (yearly total product value/number of stations per each survey, F in Table 9) ranged from ¥950,116.2 to ¥2,629.002.2 (from $7,037.90 to $19,474.10; Table 9). The yearly loss was 0.21 to 2.96% (G in Table 9) of the total product value in survey and 3.80 to 34.22% (H in Table 9) of the product value per station (per operation). These values suggest that the rate of yearly overall loss is not large (less than 3%) in total product (survey area is extensive, ranging from the Aleutian Islands to Southeast Alaska in Figure 1),

Table 6

Estimated depredation rate (%) calculated by remaining heads, lips, or gills (RNT and RNS) and by averaging the catch rates (REY and REA).

Depredation rate	Sablefish	Greenland turbot	Arrowtooth flounder	$\bar{x}$
RNT	13.98	39.42	5.72	19.71
RNS	21.69	45.11	12.78	26.53
REY	58.49	66.22	35.75	53.49
REA	59.66	68.91	42.23	56.93

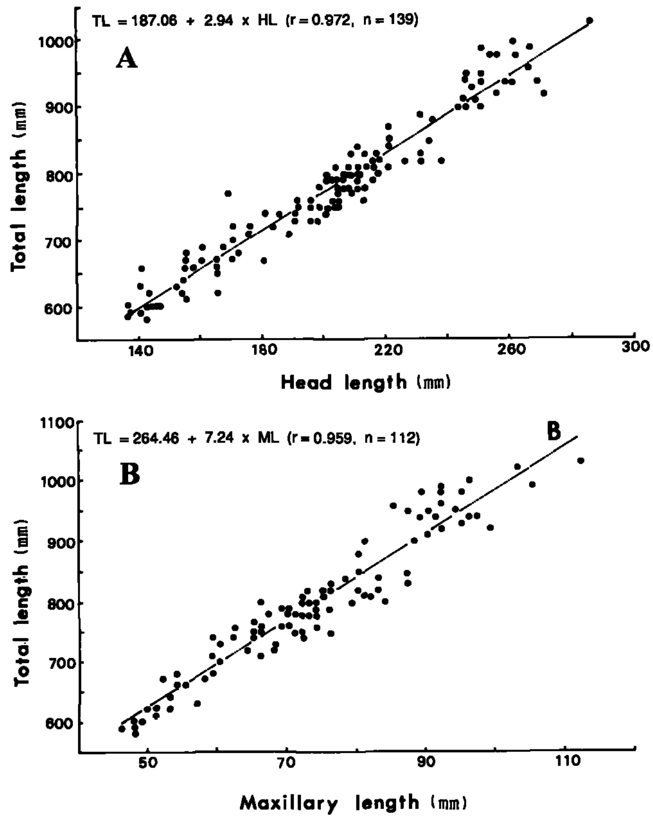

Figure 6

Size of partially consumed Greenland turbot, *Reinhardtius hippoglossoides*. (**A**) The relationship between head length (HL) and total length (TL); (**B**) the relationship between maxillary length (ML) and total length (TL).

but the rate of yearly loss per station (per operation) is relatively large in product per station.

Discussion

Although killer whales range throughout Alaskan waters (Braham and Dahlheim, 1982), fishery interactions are restricted to the Bering Sea and Prince William Sound (Dahlheim[2]). In the Bering Sea, two areas, B-I and B-II, were repeatedly noted for predation by killer whales on longline-caught fish. Despite considerable fishing effort in areas outside the Bering Sea, killer-whale-longline interactions have not been reported for most of the western Aleutian Island chain, Alaska Peninsula, Gulf of Alaska, or Southeast Alaska. However, in September 1991 in Glacier Bay National Park, fishermen reported that a small number of halibut showed evidence of tooth rake marks made by killer whales and consequently were unmarketable fish (Matkin[15]). In Canadian waters, 85% of the commercial harvest of sablefish is taken by pot gear. There have been no reports of killer whales interfering with this pot fishery. There are, however, two isolated accounts of killer whales raiding Pacific halibut longline operations in Hecate Strait, British Columbia (Ellis[16]). Sablefish longlining operations also range from Washington State to central California. Records of killer whale interference with this fishery have not been found (Parks[17]).

The only other area within Alaska where killer whales have been reported raiding longline gear is Prince William Sound. Interactions in this area are well documented (Dahlheim[2]; Matkin[3]). At least 19

[15] Matkin, D. R. Box Gustavus, AK. Pers. commun., October 1991.

[16] Ellis, G. Box 215, Station A, Nanaimo, B.C., Canada V9R 5K9. Pers. commun., March 1990.

[17] Parks, N. Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Pers. commun., May 1990.

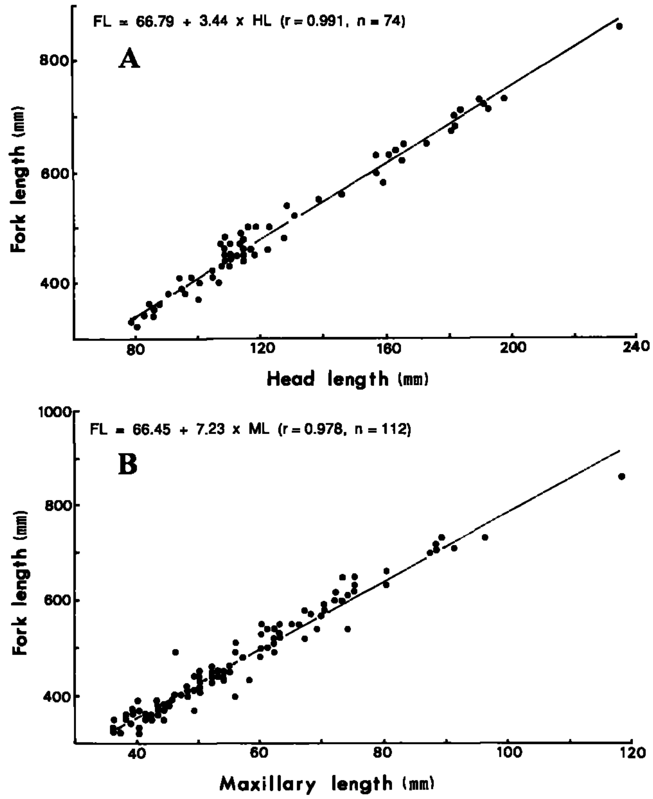

Figure 7

Size of partially consumed arrowtooth flounder, *Atheresthes stomias*. (**A**) The relationship between head length (HL) and fork length (FL); (**B**) the relationship between maxillary length (ML) and fork length (FL).

killer whale pods are known to exist within the area but only two pods have been involved in fishery interactions. Although killer whales may frequently travel between Prince William Sound and offshore waters of the Gulf of Alaska, fishery interactions have not been reported in the waters adjacent to Prince William Sound. One encounter with killer whales was reported off Kodiak Island during this study but no depredation occurred. Whales probably learned to depredate longline-caught fish by long-term exposure to fishing activities. Accounts of killer whales feeding off the discard of fish-processing vessels for a period of over 30 days has been noted in the Bering Sea (Dahlheim, unpubl. data). Active depredation may begin once the whales learn to associate fishing operations with a feeding opportunity.

An examination of the yearly catch data suggested that killer whales depredate 39–69% of the Greenland turbot, 14–60% of the sablefish, and 6–42% of the arrowtooth flounder. Whales took the largest fish for each species consumed. Although available, fish species not eaten by killer whales included Pacific cod, grenadier, rockfish, walleye pollock, and shortspine thornyhead. Little is known of the food habits of Bering Sea killer whales. The fish species consumed by the whales during this study have not been previously reported in the diet of North Pacific killer whales (Rice, 1968), perhaps because few stomachs were examined.

Within- and between-year comparisons of catch rates of sablefish, Greenland turbot, and arrowtooth flounder showed that fewer fish were landed when killer whales were present. Although annual changes in fish biomass and composition by region have been reported (Yano[4,5]; Sasaki and Yano[18]), catch rates (for

[18] Sasaki, T., and K. Yano. 1990. Report on Japan-U.S. joint longline survey by *Tomi Maru No. 88* in the eastern Bering Sea, Aleutian Region, and Gulf of Alaska, 1988. National Research Institute of Far Seas Fisheries, 5-7-1 Orido, Shimizu, Shizuoka 424 Japan, 163 p.

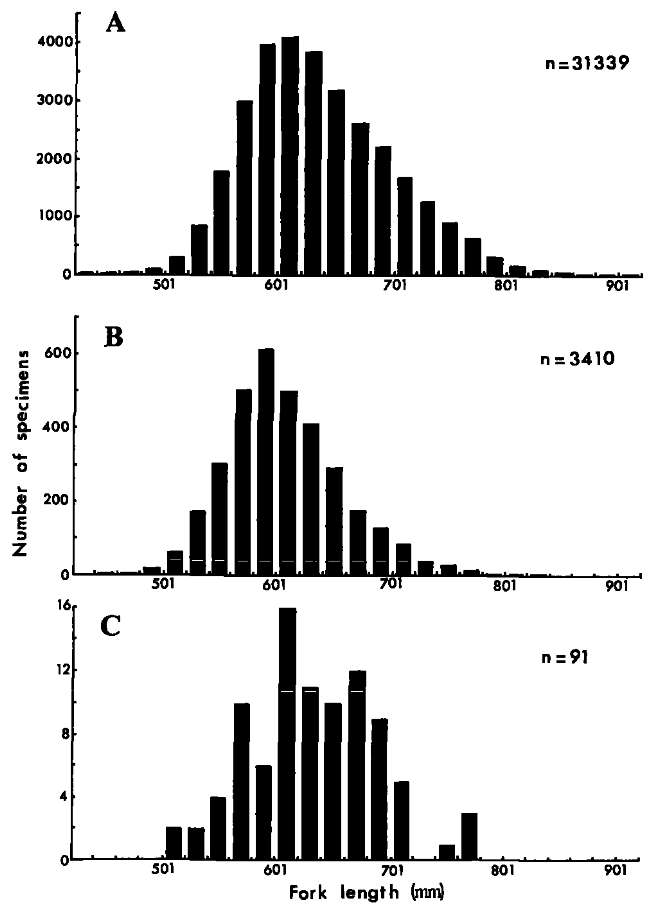

Figure 8

Length-frequency distribution of sablefish, *Anoplopoma fimbria*. (**A**) All areas (see Fig. 1); (**B**) all stations fished where depredation occurred; (**C**) calculated length (head length and maxillary length) of partially consumed fish.

the 10-year period) were typically lower when killer whales were reported as present.

Depredation rates based on average catch rates (REY and REA values) were higher than those calculated from direct counts of damaged fish (RNT and RNS values). Calculated values of RNT and RNS did not consider empty hooks. It is possible that parts of the fish that were preyed upon were pulled off or dropped off the line as it was being retrieved. Thus the rate of predation based on a direct-count method may underestimate the overall rate of depredation. However, RNT and RNS values were used as direct evidence of depredation by killer whales. RNS values indicated that killer whales actively depredate at least 22% of the sablefish, 45% of Greenland turbot, and 13% of the arrowtooth flounder. Large numbers of arrowtooth flounder are found in shallower depths where killer whales do not actively prey on fish, but sablefish and Greenland turbot are found in deeper depths where active depredation has been observed (Yano[4]). However, a greater number of damaged arrowtooth flounder prevailed in the catch (higher RNS values). Depredation rates by killer whales on the U.S. domestic Bering Sea fishery could easily be higher because some vessels (due to overall size and limited range) are forced to fish repeatedly in the same area. If a particular area is in a region of high killer whale density, the vessel may experience continual problems. Reports of killer whales following vessels over short distances from one fishing area to another have been documented (Onodera[19]).

[19] Onodera, S. Fishing master of *Tomi Maru No. 88*, 6-3-25 Irifune, Kushiro, Hokkaido 085 Japan. Personal commun., October 1988.

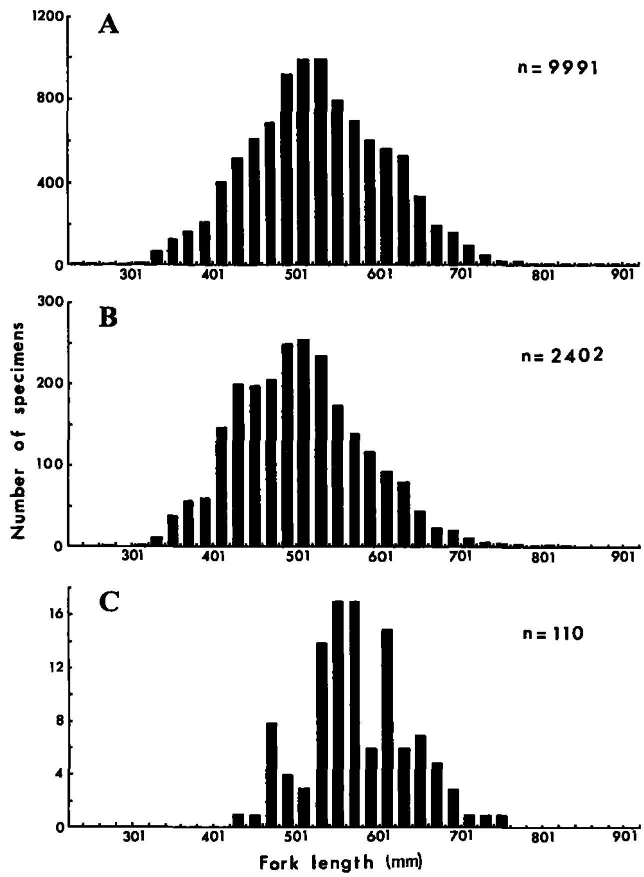

Figure 9

Length-frequency distribution of arrowtooth flounder, *Atheresthes stomias*. (**A**) All areas (see Fig. 1); (**B**) all stations fished where depredation occurred; (**C**) calculated length (head length and maxillary length) of partially consumed fish.

Dahlheim[2] estimated that the U.S. domestic longline fishery in the Bering Sea incurred an average loss of $2,300 per day during the winter of 1988, similar to the values ($928.90 in RNT and $3,373.50 in REA per operation [per day]) reported for this study. However, losses reported for this study may be underestimated. For example, monetary losses would be greater if the time spent by fishermen traveling from one area to another to escape whales was considered. Also the price per kilogram of sablefish is greater than that for larger fish. Since whales were shown to prefer larger fish, the actual monetary losses per operation may be greater than those reported (values based on an average cost/kg). Matkin et al.[20] estimated sablefish losses of $34,300 to $55,500 over the entire season for the 1986 Prince William Sound sablefish longline industry. During the 4-month research survey, a minimum value (calculated from RNT) of $2,982.00 and a maximum value (calculated from REA) of $34,571.00 was estimated.

Acknowledgments

We express our sincere appreciation to T. Sasaki (National Research Institute of Far Seas Fisheries) and M. Kuroiwa (Japan Marine Fishery Resources Re-

[20] Matkin, C. O., G. Ellis, O. von Ziegesar, and R. Steiner. 1987. Killer whales and longline fisheries in Prince William Sound, Alaska 1986. Alaska Fisheries Science Center, National Marine Mammal Laboratory, Seattle, Washington.

[20] (continued) Marine Mammal Laboratory, Seattle, Washington, National Marine Mammal Laboratory, 7600 Sand Point Way N.E., Seattle, WA 98115-0070. Unpubl. manuscr., contract 40ABNF6 2262, 18 p.

Table 7

Product of each area, product per operation, price per kilogram, and product price per operation for sablefish, *Anoplopoma fimbria*, Greenland turbot, *Reinhardtius hippoglossoides*, and arrowtooth flounder, *Atheresthes stomias*. B = product, C = product per operation (C = B/A), D = price per kilogram, and E = product value per operation (E=C × D)

			Sablefish				Greenland turbot				Arrowtooth flounder			
Year	Area[1]	No. of operation (A)	B (kg)	C (kg)	D (yen)	E (yen)	B (kg)	C (kg)	D (yen)	E (yen)	B (kg)	C (kg)	D (yen)	E (yen)
1982	EA	17	5,300.0	311.8	722	225,094.1	1,306.4	76.8	383	29,432.4	652.3	38.4	158	6,062.6
	B-I	5	5,100.0	1,020.0	722	736,440.0	2,101.6	420.3	383	160,982.6	296.5	59.3	158	9,369.4
	B-II	14	5,700.0	407.1	722	293,957.1	4,203.2	300.2	383	114,987.5	1,008.1	72.0	158	11,377.1
	B-III	9	2,700.0	300.0	722	216,600.0	4,430.4	492.3	383	188,538.1	474.4	52.7	158	8,328.4
	$\bar{x}$			509.7	722	368,003.4		322.4	383	123,479.2		55.6	158	8,784.8
1983	EA	15	10,172.2	678.1	506	343,142.2	2,369.3	158.0	277	43,753.1	483.9	32.3	155	5,000.6
	B-I	5	6,883.0	1,376.6	506	696,559.6	3,145.9	629.2	277	174,281.8	234.4	46.9	155	7,267.3
	B-II	14	13,388.5	956.3	506	483,898.6	2,418.4	172.7	277	47,849.4	957.5	68.4	155	10,600.6
	B-III	8	3,356.8	419.6	506	212,317.6	2,829.5	353.7	277	97,972.5	564.8	70.6	155	10,943.4
	$\bar{x}$			857.7	506	433,996.2		328.4	277	90,966.8		54.5	155	8,447.5
1984	EA	17	11,303.0	664.9	865	575,123.2	1,665.8	98.0	417	40,860.4	323.9	19.1	154	2,933.9
	B-I	5	7,378.3	1,475.7	865	1,276,445.9	2,068.1	413.6	417	172,482.9	253.0	50.6	154	7,793.0
	B-II	14	11,813.2	843.8	865	729,887.0	1,038.5	74.2	417	30,933.7	693.0	49.5	154	7,622.6
	B-III	9	5,526.4	614.0	865	531,148.4	2,673.8	297.1	417	123,887.0	541.9	60.2	154	9,271.8
	$\bar{x}$			899.6	865	778,154.0		220.7	417	92,031.9		44.8	154	6,899.2
1985	EA	17	18,592.8	1,093.7	978	1,069,632.8	1,399.2	82.3	305	25,103.3	405.6	23.9	170	4,063.0
	B-I	5	10,614.0	2,122.8	978	2,076,098.4	2,130.6	426.1	305	129,966.6	338.0	67.6	170	11,492.0
	B-II	14	13,249.2	946.4	978	925,551.3	1,478.7	105.6	305	32,214.5	1233.7	88.1	170	14,980.6
	B-III	9	7,960.5	884.5	978	865,041.0	3,021.0	335.7	305	102,378.3	794.3	88.3	170	15,003.4
	$\bar{x}$			1,261.8	978	1,234,040.4		237.4	305	72,407.0		67.0	170	11,390.0
1986	EA	16	14,219.0	888.7	737	654,962.7	874.0	54.6	436	23,816.5	266.0	16.6	152	2,527.0
	B-I	5	7,759.0	1,551.8	737	1,143,676.6	1,646.0	329.2	436	143,531.2	407.0	81.4	152	12,372.8
	B-II	14	9,864.0	704.6	737	519,269.1	1,361.0	97.2	436	42,385.4	1,239.0	88.5	152	13,452.0
	B-III	9	10,486.0	1,165.1	737	858,686.9	2,201.0	244.6	436	106,626.2	531.0	59.0	152	8,968.0
	$\bar{x}$			1,077.5	737	794,117.5		181.4	436	79,090.4		61.4	152	9,332.8
1987	EA	16	13,832.0	864.5	894	772,863.0	1,767.0	110.4	347	38,321.8	990.5	61.9	105	6,500.2
	B-I	5	2,223.0	444.6	894	397,472.4	3,021.0	604.2	347	209,657.4	990.5	198.1	105	20,800.5
	B-II	14	3,629.0	259.2	894	231,737.6	2,394.0	171.0	347	59,337.0	3,366.0	240.4	105	25,245.0
	B-III	9	3,534.0	392.7	894	351,044.0	2,394.0	266.0	347	92,302.0	1,603.8	178.2	105	18,711.0
	$\bar{x}$			490.2	894	438,238.8		287.9	347	99,901.3		169.7	105	17,818.5
1988	EA	17	13,851.0	814.8	831	677,069.5	2,008.8	118.2	193	22,805.8	1,107.8	65.2	50	3,258.2
	B-I	5	4,807.0	961.4	831	798,923.4	744.0	148.8	193	28,718.4	592.1	118.4	50	5,921.0
	B-II	14	6,004.0	428.9	831	356,380.3	558.0	39.9	193	7,692.4	6,242.9	445.9	50	22,296.1
	B-III	9	6,745.0	749.4	831	622,788.3	2,176.2	241.8	193	46,667.4	2,005.5	222.8	50	11,141.7
	$\bar{x}$			738.6	831	613,776.6		137.2	193	26,479.6		213.1	50	10,655.0
Minimum			2,223.0	259.2	506	212,317.6	558.0	39.9	193	7,692.4	234.4	16.6	50	2,527.0
Maximum			18,592.8	2,122.8	978	2,076,098.4	4,430.4	629.2	436	209,657.4	6,242.9	445.9	170	25,245.0
Average			8,428.2	833.6	790.4	658,877.4	2,122.3	245.1	336.9	82,574.2	1,021.3	95.3	134.9	12,856.0

[1] EA = Eastern Aleutian Islands; B = Bering Sea, see Figure 1 for areas.

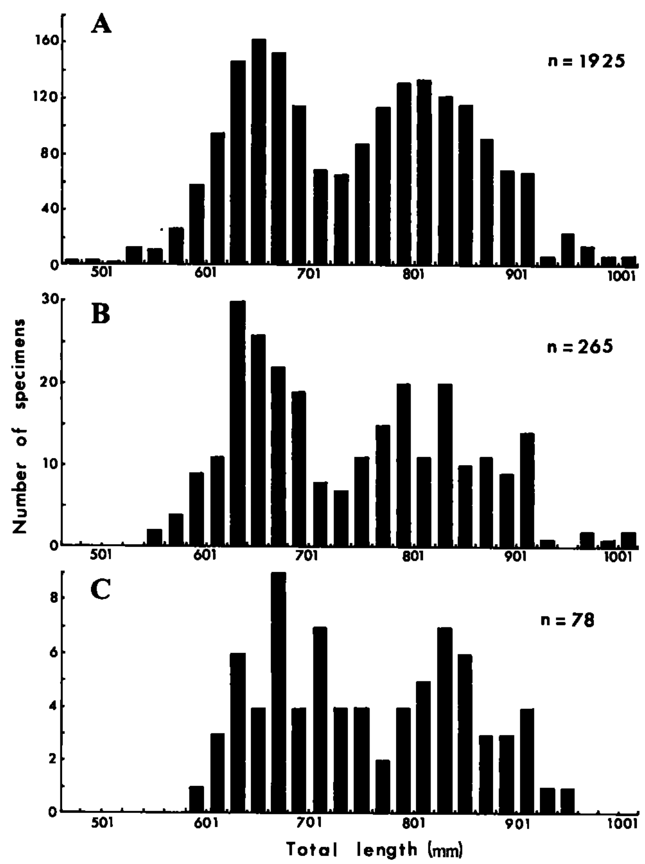

Figure 10

Length-frequency distribution of Greenland turbot, *Reinhardtius hippoglossoides*. (**A**) All areas (see Fig. 1); (**B**) all stations fished where depredation occurred; (**C**) calculated length (head length and maxillary length) of partially consumed fish.

Table 8

Average monetary loss per station (1982–88) estimated by depredation rates (RNT, RNS, REY, and REA) for sablefish, *Anoplopoma fimbria*, Greenland turbot, *Reinhardtius hippoglossoides*, and arrowtooth flounder, *Atheresthes stomias*. Total given for all three species.

	Sablefish		Greenland turbot		Arrowtooth flounder		Total	
Depredation rate	Yen	U.S. $	Yen	U.S. $	Yen	U.S. $	Yen	U.S. $
RNT	92,111.1	682.30	32,550.7	241.10	735.4	5.40	125,397.2	928.90
RNS	142,910.5	1,058.60	37,249.2	275.90	1,643.0	12.20	181,802.7	1,346.70
REY	385,377.4	2,854.60	54,680.6	405.00	4,596.0	34.00	444,654.0	3,293.60
REA	393,086.3	2,911.80	56,901.9	421.50	5,429.1	40.20	455,417.3	3,373.50

Table 9

Yearly monetary loss per station and overall loss estimated by depredation rate of RNT (minimum value) and RNA (maximum value), and yearly total product value per survey and product values per station calculated from total product value.

Year		Yearly monetary loss per station (A)		No. of depredated stations (B)	Overall monetary loss (C=A×B)		Yearly total product value in Yen (U.S. $)	No. of stations per survey (E)	Product value/station (F=D/E) in Yen (U.S. $)	Rate of loss per yearly product (G=C/D×100) (%)	Rate of loss per station product (H=A/F×100) (%)
		Yen	U.S. $		Yen	U.S. $					
1982	max.	100,624.9	745.40	4	402,499.6	2,981.50	121,346,699	108	1,123,580.5	0.33	8.96
	min.	308,350.2	2,284.10		1,233,400.8	9,136.30	(898,864.40)		(8,322.80)	1.02	27.44
1983	max.	97,015.0	718.60	9	873,135.0	6,467.70	98,812,086	104	950,116.2	0.88	10.21
	min.	325,174.7	2,408.70		2,926,572.3	21,678.30	(731,941.40)		(7,037.90)	2.96	34.22
1984	max.	145,459.5	1,077.50	3	436,378.5	3,232.40	176,102,713	108	1,630,580.7	0.25	8.29
	min.	530,579.4	3,930.20		1,591,738.2	11,790.70	(1,304,464.50)		(12,078.40)	0.90	32.54
1985	max.	201,713.2	1,494.20	3	605,139.6	4,482.50	283,932,240	108	2,629,002.2	0.21	7.67
	min.	790,934.2	5,858.80		2,372,802.6	17,576.30	(2,103,201.80)		(19,474.10)	0.84	30.08
1986	max.	142,728.9	1,057.30	8	1,141,831.2	8,458.00	238,057,678	107	2,224,838.1	0.48	6.42
	min.	532,212.9	3,942.30		4,257,703.2	31,538.50	(1,763,390.20)		(16,480.30)	1.79	23.92
1987	max.	101,666.1	753.10	7	711,662.7	5,271.60	271,467,224	107	2,537,076.9	0.26	4.01
	min.	337,820.0	2,502.40		2,364,740.0	17,516.60	(2,010,868.30)		(18,793.20)	0.87	13.32
1988	max.	96,853.7	717.40	12[1]	1,162,244.4	8,609.20	275,277,684	108	2,548,867.4	0.42	3.80
	min.	388,925.8	2,880.90		4,667,109.6	34,571.20	(2,039,094.00)		(18,880.50)	1.70	15.26
Overall	max.	96,853.7	717.40		402,499.6	2,981.50				0.21	3.80
		790,934.2	5,858.80		4,667,109.6	34,571.20				2.96	34.22

[1] Three stations where no depredation was evident.

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