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Reprinted from the Alaska Fishery Research Bulletin
Vol. 9 No. 1, Summer 2002

The Alaska Fisheries Research Bulletin can be found on the World Wide Web at URL:
http://www.state.ak.us/adfg/geninfo/pubs/afrb/afrbhome.htm

Alaska Fishery Research Bulletin 9(1):53–64. 2002.

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ABSTRACT: Chinook salmon *Oncorhynchus tshawytscha* and chum salmon *O. keta* are caught incidentally in Alaska groundfish fisheries, primarily in the walleye pollock *Theragra chalcogramma* trawl fishery. From 1990-2001, an average of 37,819 chinook salmon and 69,332 other salmon species (> 95% are chum salmon) were incidentally caught annually in the Bering Sea and Aleutian Islands groundfish trawl fisheries, and 20,799 chinook salmon and 20,496 other salmon were incidentally caught annually in the Gulf of Alaska trawl fisheries. In 1999 and 2000, chinook salmon bycatch was reduced in the Bering Sea, but increased in the Gulf of Alaska. Chum salmon bycatch has remained relatively stable in recent years. Bycatch is primarily juvenile salmon that are one or two years away from returning to the river of origin as adults. The origin of salmon taken as bycatch includes rivers in western Alaska, Southcentral and Southeast Alaska, Asia, British Columbia, and Washington. Analysis indicates that an incidental catch of 30,000 chinook salmon in Bering Sea and Aleutian Islands groundfish trawl fisheries equates to about 14,581 adult chinook salmon from western Alaska. Similarly, a bycatch of 60,000 chum salmon in Bering Sea and Aleutian Islands groundfish trawl fisheries equates to about 13,120 adult chum salmon from western Alaska. We estimated that, on average, salmon bycatch in Bering Sea and Aleutian Islands groundfish trawl fisheries reduced the western Alaska chum salmon run by less than 0.2%, and reduced the western Alaska chinook salmon run by less than 2.7%. Impacts of salmon bycatch from the Gulf of Alaska groundfish trawl fisheries cannot be estimated at this time.

INTRODUCTION

Pacific salmon, including pink salmon *Oncorhynchus gorbuscha*, sockeye salmon *O. nerka*, coho salmon *O. kisutch*, chum salmon *O. keta*, and chinook salmon *O. tshawytscha* support large commercial, recreational, and subsistence fisheries throughout Alaska. Salmon are also taken incidentally as bycatch in commercial groundfish fisheries.

Chinook salmon and chum salmon runs in western Alaska (Arctic, Yukon, Kuskokwim, and Bristol Bay drainages as shown in Figure 1), as well as sockeye salmon runs in Bristol Bay, are currently at low levels relative to run strengths observed over the last 20 years. By 2000, salmon returns throughout the Yukon and Kuskokwim River drainages and the entirety of Norton Sound were less than 50% of the 20-year average (D. Eggers, Alaska Department of Fish and Game, Juneau, personal communication). These run declines resulted in severe constraints on commercial, recreational, and subsistence harvests (ADF&G 2000). In 1998, 2000, and 2001, the Alaska governor declared that an emergency disaster existed in western Alaska as a result of collapsed salmon runs. Although these reduced salmon runs appear to be attributable, at least in part, to changes in ocean conditions (Hare and Francis 1995; Kruse 1998), the governor requested fisheries managers to reexamine any and all factors that may have contributed to the decline. One factor that may have influenced the decline is the bycatch of salmon in groundfish fisheries.

This paper reviews available information regarding salmon taken incidentally in the U.S. North Pacific groundfish fisheries of the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) areas. The groundfish fisheries are prosecuted by a fleet of approximately 250 trawl vessels, 1,000 longline vessels, 250 vessels using pot gear, and 50 vessels using jig

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Acknowledgments: We thank D. Eggers at the Alaska Department of Fish and Game for providing salmon run estimates for western Alaska, and C. Pautzke, C. Oliver, and three anonymous reviewers for their helpful comments and suggestions to improve the paper. We also thank the National Marine Fisheries Service Observer Program for collecting the salmon bycatch data, and M. Furuness of the National Marine Fisheries Service for providing annual salmon bycatch numbers.

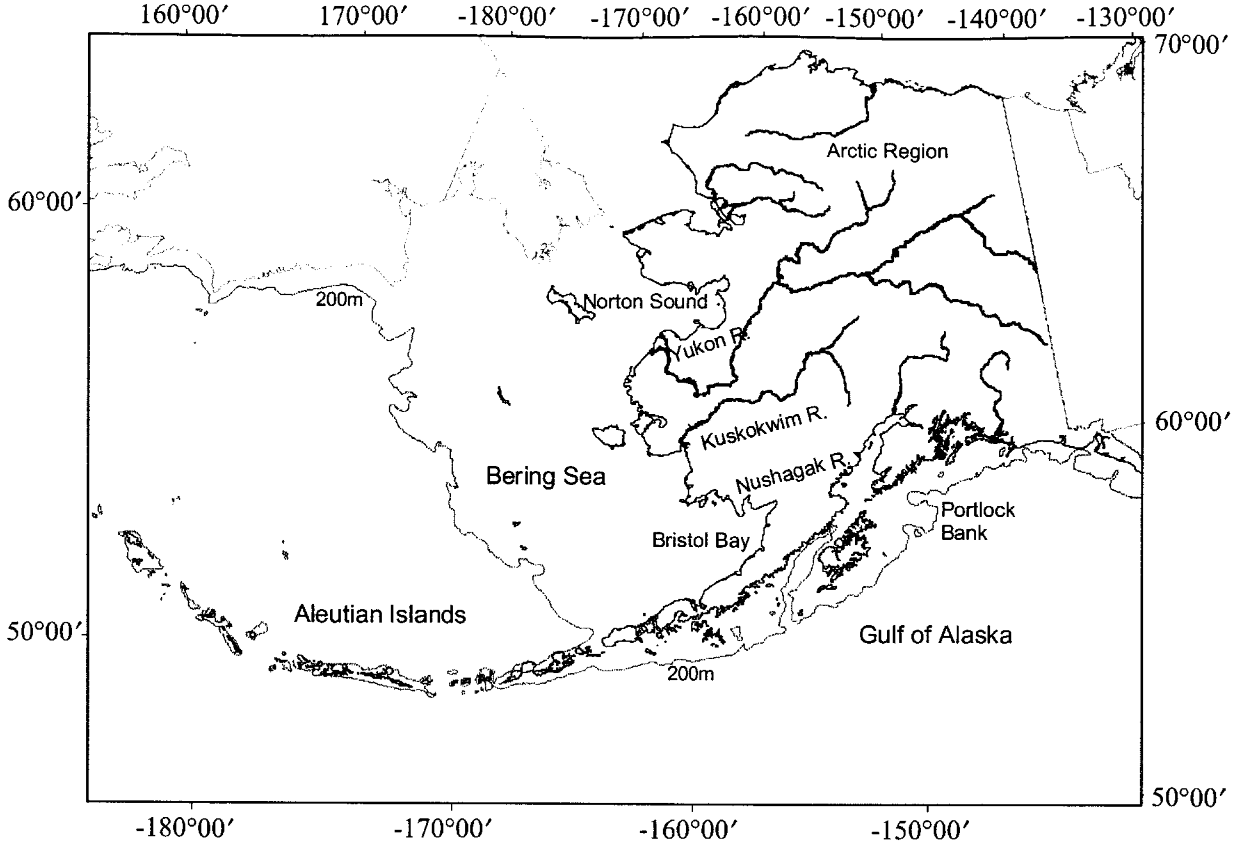


Figure 1. Map of Alaska showing locations of major river drainages in western Alaska.

gear (Hiatt et al. 2001). In general, most of the smaller vessels (<60 ft length overall) fish only in the GOA. The fleet catches about 1.8 million metric tons (mt) of groundfish per year, consisting of walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, flatfish, rockfish, sablefish *Anoplopoma fimbria*, Atka mackerel *Pleurogrammus monopterygius*, and other species (Hiatt el al. 2001). A portion of the total allowable quota for target species (10% for walleye pollock and 7.5% for other groundfish) is allocated to the Community Development Quota program to increase economic opportunities for rural western Alaska communities (National Research Council 1999). Additional details regarding the North Pacific groundfish fisheries and the environmental impacts associated with these fisheries can be found in National Marine Fisheries Service (NMFS) (2001a).

The objectives of this paper are to synthesize information on salmon bycatch (amount caught, species composition, timing and location of bycatch), to provide estimates on the impacts of bycatch on salmon stocks of western Alaska, and to review existing management measures to control salmon bycatch.

METHODS

Pacific salmon bycatch data, provided by the NMFS groundfish fishery observer program, were examined to gain insight into the amount, species composition, timing, and location of salmon caught incidentally in Alaska groundfish fisheries. Since 1990, all vessels larger than 60 ft (length overall) participating in the groundfish fisheries have been required to have observers onboard at least part of the time. Observer coverage is based on vessel length, with 30% coverage required on vessels 60 ft to 125 ft, 100% coverage on vessels larger than 125 ft, and 100% coverage at shore-based processing facilities. Observers estimate catch and bycatch by randomly selecting hauls to be sampled, and then determine species composition and weight of the catch by sampling the entire haul, a portion of the haul, or employ subsampling techniques using baskets or other means (Volstad et al. 1997). Observer data are combined with weekly production reports from processors to provide weekly total estimates of catch and bycatch. The combined data provide for accurate and relatively precise estimation of groundfish catch, particularly on fleets with high levels of observer coverage (Volstad et al. 1997). The precision of the salmon bycatch estimates depend upon the number of vessels observed and the fraction of hauls sampled within vessels (Karp and McElderry 1999). Because a high percentage of hauls are sampled in the larger fisheries (e.g., 60–70% in the BSAI walleye pollock fishery), which account for most of the salmon bycatch, fleet wide estimates of salmon bycatch are thought to be reasonably accurate for management purposes (NPFMC 1995a, 1995b, 1999).

We reviewed scientific literature on age composition, stock composition, and management of salmon caught incidentally in fisheries off Alaska, and estimated the impacts of the BSAI groundfish fisheries on salmon stocks of western Alaska. To estimate impacts of bycatch on salmon stocks, we adjusted bycatch numbers to account for mortality associated with age at incidental capture. Thus, we can express bycatch as adult equivalents that would have returned to their natal river drainages. We based our calculations of adult equivalents on an annual BSAI groundfish trawl bycatch of 30,000 juvenile chinook salmon and 60,000 juvenile chum salmon, which are the bycatch amounts projected to result from implementation of the Steller sea lion *Eumetopias jubatus* protection measures in 2002 (NMFS 2001b). To estimate the impacts of bycatch on mature chum salmon in western Alaska, we used the proportion of bycatch estimated to originate from western Alaska (27% based on Wilmot et al. 1998; Kondzela et al. 1999), and adjusted for natural mortality based on adjustments calculated for chinook salmon, as discussed below.

For chinook salmon, we first estimated the number of juvenile salmon from western Alaska taken as bycatch, based on Myers and Rogers (1988) estimate data indicating that 60% of the bycatch originated from western Alaska. Further, according to Myers and Rogers (1988), within the western Alaska component of intercepted chinook salmon, 17% were from the Yukon River and 29% were from Bristol Bay. Since the available age-at-return information is primarily from the Yukon River and Bristol Bay systems, it was assumed for purposes of this paper that all western Alaska chinook salmon were from these two systems only. Adjusting the percentages resulted in 37% of the western Alaska chinook salmon from the Yukon River and 63% from Bristol Bay.

We then adjusted the regional numbers based on age at return and natural mortality. Using fairly general assumptions based on chinook salmon return information to the Yukon River (Brannian 1990) and Bristol Bay (using the Nushagak drainage as a proxy, based on data from Minard et al. 1992), and assuming that all fish return as age 1.3 or 1.4 (years in fresh water, years in salt water), a rough approximation was made that 30% and 43% of chinook salmon return to the Yukon River and Bristol Bay, respectively, as age 1.3, and approximately 70% and 57% return at age 1.4 to the Yukon River and Bristol Bay, respectively. These proportions were used to allocate salmon bycatch to stream of origin across several years from time of incidental capture.

We adjusted for natural mortality, from the time the fish were incidentally caught to the year that the fish would have returned to their natal streams in western Alaska, using age at capture information from the BSAI groundfish fisheries provided by Myers and Rogers (1988). They estimated that 56% of the chinook salmon included in their analysis were age 1.2 fish and that 26% of the chinook salmon were age 1.3. If we assume that all bycatch is age 1.2 or 1.3, then the numbers are adjusted accordingly such that 68.3% are age 1.2 and 31.7% are age 1.3. Incorporating the above assumptions about the ages of return to western Alaska systems, the annual at-sea natural mortality rates between ages 1.2 and 1.3 were assumed to be 20%, and the natural mortality rate over the year between ages 1.3 and 1.4 was assumed to be 10% (Pacific Salmon Commission 1988). Of the 1.2 age fish, some will return the next year (with a 20% mortality) and some in 2 years with an additional 10% mortality. Some of the 1.3 age fish will return the same year and some in another year with a 10% mortality.

RESULTS

Amount of Bycatch

From 1990-2001, an average of 37,819 chinook salmon and 69,332 other salmon were incidentally caught annually in the BSAI groundfish fisheries, and 20,799 chinook salmon and 20,496 other salmon in the GOA groundfish fisheries (Table 1). Chinook salmon bycatch in the 1999 and 2000 BSAI groundfish fisheries was relatively low, but increased to 40,303 salmon in 2001. In both the BSAI and GOA groundfish fisheries, about 95% of other salmon bycatch is chum salmon (Table 1). Bycatch of coho, pink, and sockeye salmon is relatively small. Chum salmon bycatch in the BSAI has been fairly consistent over the last few years. In the GOA, chinook salmon and chum salmon bycatch has fluctuated in recent years.

Nearly all (>99%) of the salmon bycatch is attributable to trawl fisheries. Most salmon are incidentally

Table 1. Bycatch of Pacific salmon in Alaska groundfish trawl fisheries, by management area and species, 1990-2001. Bycatch includes salmon caught incidentally in the 1999-2001 Community Development Quota Program groundfish fisheries.

Year	Chinook	Chum	Coho	Sockeye	Pink	Year	Chinook	Chum	Coho	Sockeye	Pink
			Number of Fish								
Bering Sea and Aleutian Islands Area						**Gulf of Alaska Area**					
1990	14,085	16,202	153	30	31	1990	16,913	2,541	1,482	85	64
1991	48,873	29,706	396	79	79	1991	38,894	13,713	1,129	51	57
1992	41,955	40,090	1,266	14	80	1992	20,462	17,727	86	33	0
1993	45,964	242,895	321	22	8	1993	24,465	55,268	306	15	799
1994	44,380	95,978	231	20	202	1994	13,973	40,033	46	103	331
1995	23,079	20,901	858	0	21	1995	14,647	64,067	668	41	16
1996	63,205	77,771	218	5	1	1996	15,761	3,969	194	2	11
1997	50,218	67,349	114	3	69	1997	15,119	3,349	41	7	23
1998	58,966	69,237[a]				1998	16,941	13,539[a]			
1999	14,586	47,204[a]				1999	30,600	7,529[a]			
2000	8,219	59,306[a]				2000	26,706	10,996[a]			
2001	40,303	60,460[a]				2001	14,946	5,995[a]			
Average	37,819	69,332[b]				Average	20,799	20,496[b]			

[a] Coho, sockeye, and pink salmon are combined with chum salmon.
[b] Average chum salmon bycatch includes chum, coho, sockeye, and pink salmon.

caught in the walleye pollock trawl fishery and, to a lesser extent, in trawl fisheries for Pacific cod and other target species (Table 2). In the 1993 BSAI trawl fisheries, the average size of salmon taken as bycatch was 2.1 kg (56 cm fork length) for chum salmon and 2.9 kg (58 cm fork length) for chinook salmon (NPFMC 1995a, 1995b). The chinook salmon are generally one to two years away from returning to their streams of origin to spawn (Myers and Rogers 1988).

Table 2. Bycatch of Pacific salmon in Alaska groundfish trawl fisheries, by area and target fishery, 2000 and 2001. Bycatch does not include salmon taken incidentally in Community Development Quota fisheries.

	Number of Chinook Salmon		Number of Other Salmon	
Fishery	2000	2001	2000	2001
Bering Sea and Aleutian Islands Area				
Walleye pollock	3,968	30,130	56,715	52,690
Pacific cod	2,688	3,529	128	1,835
Flatfish	536	2,702	297	1,044
Other targets[a]	278	1,381	460	1,600
Total BSAI	7,470	37,742	57,600	57,169
Gulf of Alaska Area				
Walleye pollock	18,413	9,421	7,450	2,741
Pacific cod	2,747	2,796	0	677
Flatfish	4,386	2,295	2,979	1,857
Other targets[a]	1,160	434	567	720
Total GOA	26,706	14,946	10,996	5,995

[a]Other targets include rockfish, sablefish, and Atka mackerel.

Location and Timing of Bycatch

Chinook salmon are caught incidentally in trawl fisheries in areas with bottom depths of 100 m to 200 m. In the Bering Sea, chinook salmon are taken throughout the area, whereas in the GOA, bycatch appears to occur in more discrete locations (Figures 2 and 3). The lower observer coverage in the GOA trawl fisheries limits the amount of data available for interpretation (a greater number of small vessels fish in the GOA relative to the BSAI). However, it appears that the highest bycatch in the GOA occurs along the outer margins of Portlock Bank. In the eastern Bering Sea, areas of high bycatch rates, or hot spots, can occur in any location, not just within the eastern section of the Chinook Salmon Savings Areas. The Chinook Salmon Savings Areas are closed to trawling when annual chinook salmon bycatch limits are reached by trawl fisheries (Witherell and Pautzke 1997). No chinook salmon were caught incidentally in the western section of the Chinook Salmon Savings Areas in 2000 and 2001 due to the closure of the Aleutian Islands walleye pollock fishery during those years.

The locations of chum salmon bycatch closely mirror bycatch locations for chinook salmon (Figures 4 and 5), although there is little temporal overlap between the two, as discussed below. This is not surprising since both chum salmon and chinook salmon are caught incidentally by fisheries in similar proportions, with the exception of the Pacific cod fishery that incurs some incidental catch of chinook salmon but almost no chum

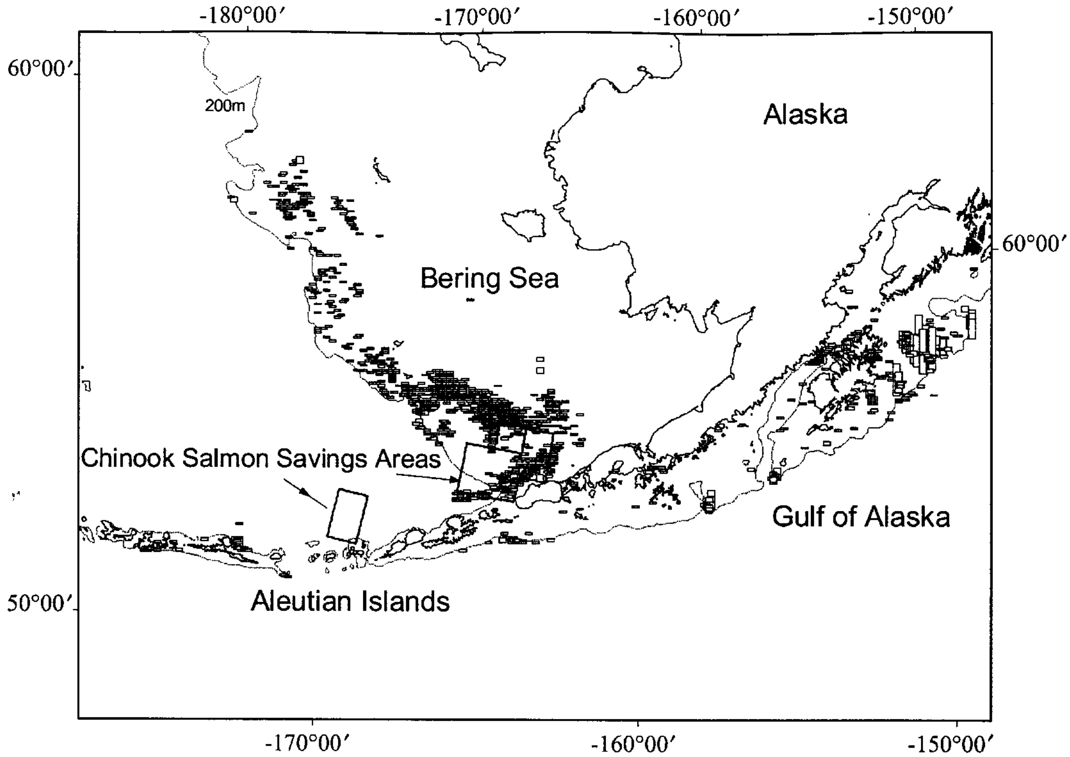
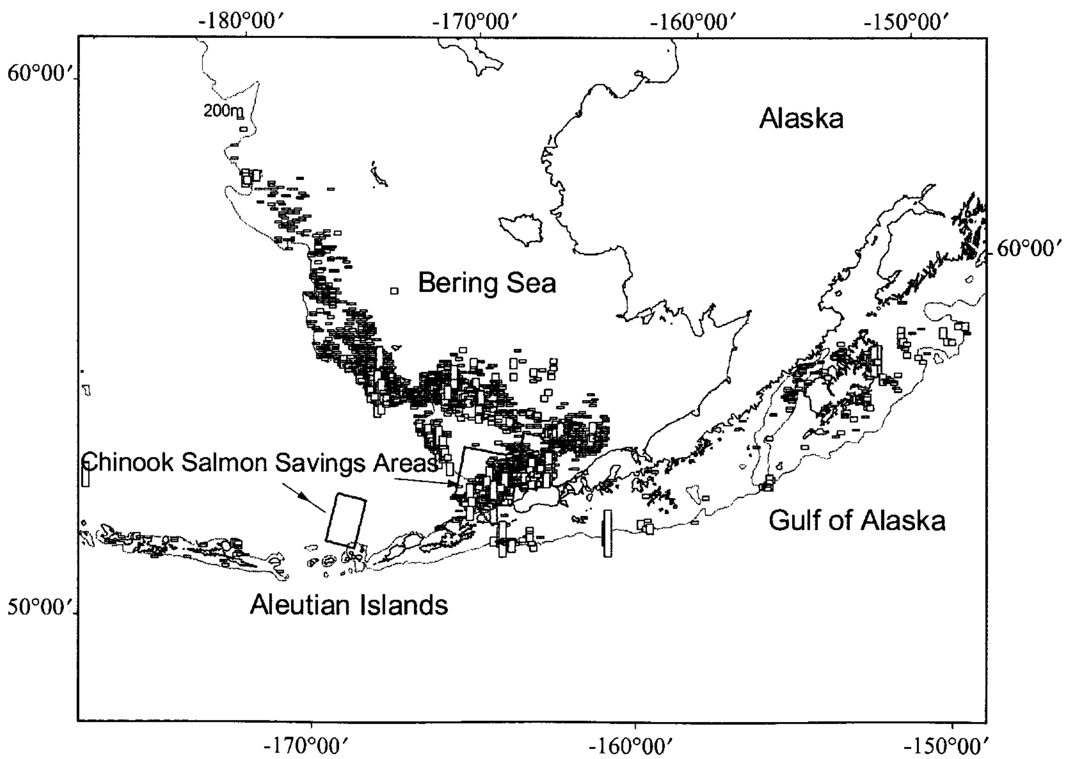


Figure 2. Locations of chinook salmon bycatch in the 2000 trawl fisheries. Bar height indicates relative number observed with hauls summed over a 25 km^2 area. The 200 m depth contour and the Chinook Salmon Savings Areas are also shown.



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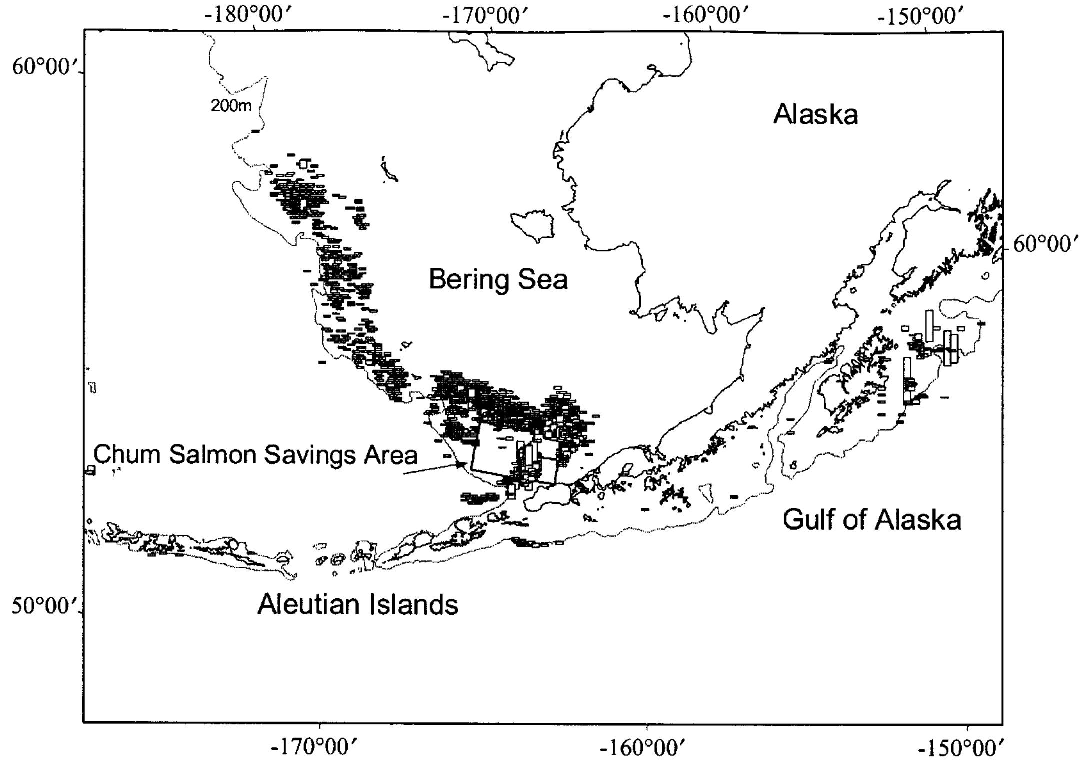

Figure 4. Locations of chum salmon bycatch in the 2000 trawl fisheries. Bar height indicates relative number observed with hauls summed over a 25 km² area. The 200 m depth contour and the Chum Salmon Savings Area are also shown.

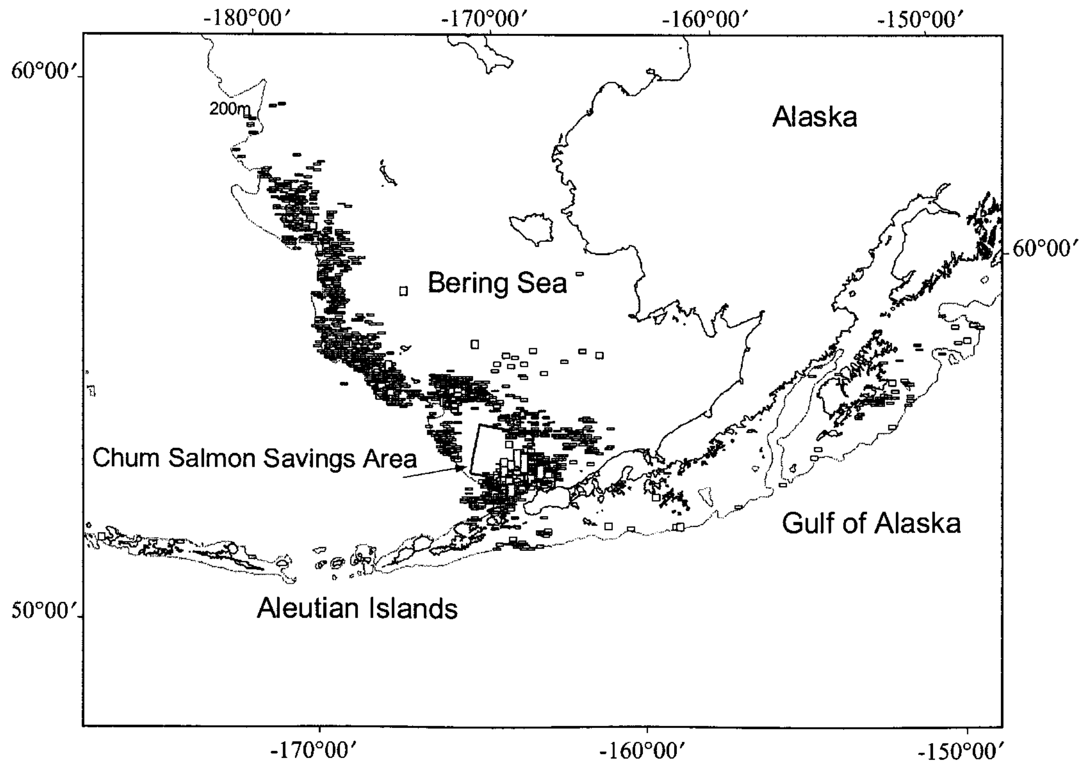

Figure 5. Locations of chum salmon bycatch in the 2001 trawl fisheries. Bar height indicates relative number observed with hauls summed over a 25 km² area. The 200 m depth contour and the Chum Salmon Savings Area are also shown.

salmon (Table 2). By design, the Chum Salmon Savings Area encompasses nearly all the hot spot locations of chum salmon bycatch in the Bering Sea. The Chum Salmon Savings Area, located in the eastern Bering Sea, is closed to trawl fishing during the month of August, and remains closed through October 14 if annual chum salmon bycatch limits are reached by trawl fisheries (Witherell and Pautzke 1997). Bycatch locations of chum salmon in the GOA are similar to chinook salmon bycatch locations, except that almost no chum salmon are taken in Shelikof Strait.

The timing of salmon bycatch in the Bering Sea follows a predictable pattern (Figures 6 and 7). For 2000 and 2001, chinook salmon bycatch occurred during October and November, and January through April (weeks 1-16, 38-44). Chum salmon bycatch was taken during the months of July through October (weeks 26-44). Our results are consistent with previous temporal analyses of BSAI salmon bycatch taken in the mid-1990s (NPFMC 1995a, 1995b, 1999).

In the GOA groundfish fisheries, salmon bycatch does not appear to occur in discrete time periods. In 2000 and 2001, both chinook and chum salmon were taken in every week the GOA groundfish fishery was prosecuted (Figures 8 and 9). Bycatch of chinook salmon was generally higher in the winter, and bycatch of chum salmon was higher in the summer. The spike of salmon bycatch observed in weeks 32 and 33 of the 2000 fishery was due to increased bycatch in the walleye pollock fishery when the fleet was forced to fish outside of Steller sea lion critical habitat, per order of the U.S. District Court.

Stock Composition of Bycatch

Information on the origins of chinook salmon caught incidentally in the BSAI groundfish fisheries comes from scale pattern analysis. Scale pattern analysis of chinook salmon bycatch in the 1979–1982 foreign and joint venture trawl fisheries indicated that about 60% of the chinook salmon bycatch originated from western Alaska, 17% from Southcentral Alaska, 14% from Asia, and 9% from Southeast Alaska and Canada (Myers and Rogers 1988). These results should be interpreted with some caution, however, as the information comes from fisheries that were prosecuted over 20 years ago; many changes in groundfish fisheries and salmon stocks have since occurred.

Future studies of chinook salmon bycatch will likely utilize allozyme methodology because the allozyme baseline is complete enough to discriminate chinook salmon stocks in Bering Sea stock mixtures (Teel et al. 1999). Allozymes have been successfully applied to chinook salmon mixtures from confiscated high seas chinook salmon catches (R. Wilmot, National Marine Fisheries Service, Juneau, personal communication). Attempts are underway to obtain further tissue collections from Russian stocks that would improve the accuracy of allozyme methods for delineating stock origins. However, funds to collect and analyze chinook salmon samples from trawl bycatch are limited. Additional research on stock discrimination is being conducted using microsatellite DNA, but the microsatellite DNA baseline is not complete enough at present to be used for analysis of chinook salmon mixtures that po-

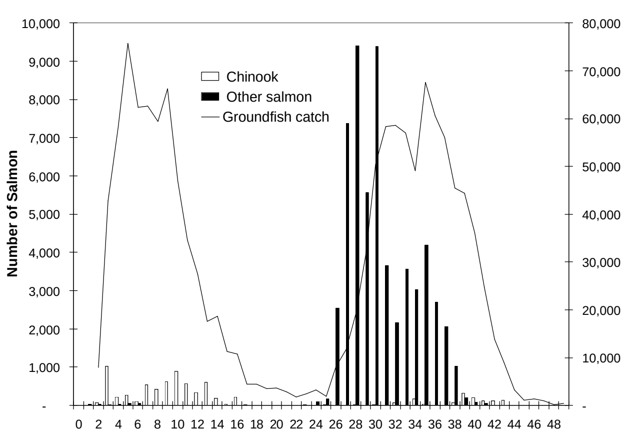

Figure 6. Bycatch of chinook salmon, other salmon (primarily chum salmon), and groundfish catch in the BSAI trawl fisheries, by week, 2000.

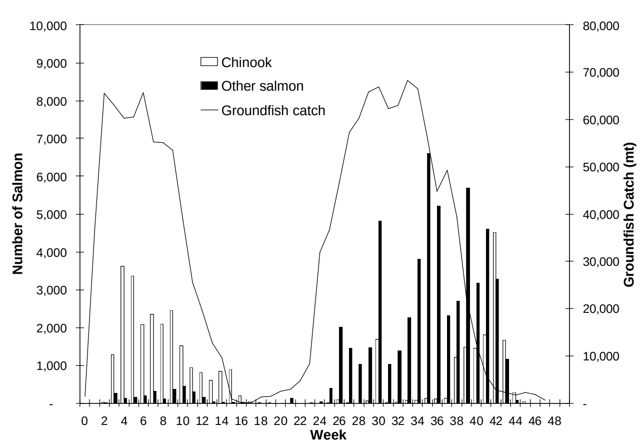

Figure 7. Bycatch of chinook salmon, other salmon (primarily chum salmon), and groundfish catch in the BSAI trawl fisheries, by week, 2001.

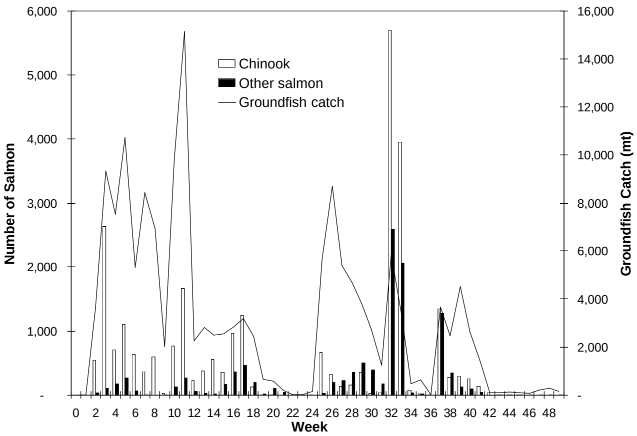

Figure 8. Bycatch of chinook salmon, other salmon (primarily chum salmon), and groundfish catch in the GOA trawl fisheries, by week, 2000.

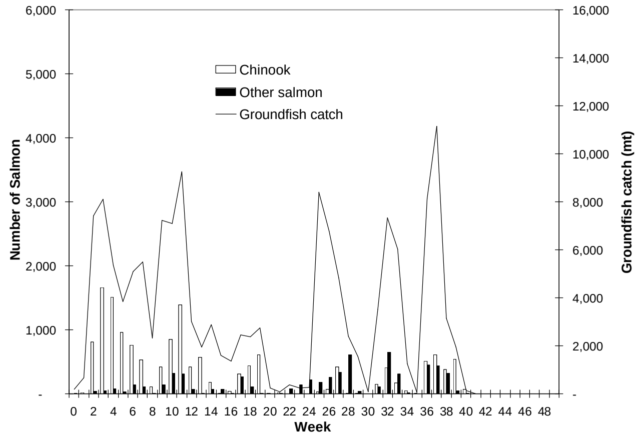

Figure 9. Bycatch of chinook salmon, other salmon (primarily chum salmon), and groundfish catch in the GOA trawl fisheries, by week, 2001.

tentially include chinook salmon throughout the Pacific Rim (A. Gharrett, University of Alaska Fairbanks, Juneau, personal communication).

More recent studies have examined the stock composition of chum salmon taken as bycatch in Bering Sea fisheries. Scale pattern analysis of 1994 bycatch data resulted in a regional composition as follows: 18.6% from western and central Alaska, 49.7% from Asia, 28.6% from Southeast Alaska and Canada, and 3.1% from Washington (Patton et al. 1998). Wilmot et al. (1998) and Kondzela et al. (1999) examined allozyme allele frequencies of chum salmon taken in the 1994, 1995, and 1996 Bering Sea trawl fisheries. They found that, on average, about 27% of the chum salmon bycatch originated from western Alaska, 5% from Southcentral Alaska, 38% from Asia, 12% from Southeast Alaska, and 18% from Canada and Washington.

No studies have examined the stock composition of salmon bycatch from GOA trawl fisheries. However, the allozyme methodology has been applied to chum salmon samples collected by research gillnets in the high seas (Urawa et al. 2000). Results indicate that Alaska stocks were common in the eastern and central GOA (15% western Alaska, 25% Alaska Peninsula and Kodiak, 28% Southeast Alaska, and 18% from Canada), and Asian chum salmon were predominant in the western GOA (25% Japan, 53% Russia, 13% western Alaska, 10% elsewhere).

Impacts of Bycatch to Western Alaska Salmon

Western Alaska chinook and chum salmon runs have declined over the last 20 years, with runs in the two most recent years being the lowest in the time series (Table 3). Because escapement estimates are not available for all populations, total run estimates are incomplete (D. Eggers, Alaska Department of Fish and Game, Juneau, personal communication). The total salmon run estimates do not include populations of chum salmon in

Table 3. Total minimum run estimates (numbers of fish) of chum salmon and chinook salmon in western Alaska, 1980-2000. Run estimates include commercial, subsistence, sport, and personal use catch plus escapement estimates if available[a].

Year	Chum	Chinook
1980	9,508,189	[b]
1981	9,846,452	[b]
1982	5,831,092	828,827
1983	6,613,306	859,578
1984	9,045,035	620,088
1985	7,736,404	650,884
1986	7,446,330	476,393
1987	7,192,637	574,037
1988	9,706,599	498,619
1989	7,494,325	511,362
1990	5,185,707	536,699
1991	6,810,977	522,983
1992	5,331,200	556,947
1993	3,869,983	601,789
1994	6,231,791	704,798
1995	8,323,800	674,555
1996	6,809,532	501,758
1997	3,639,176	611,377
1998	3,713,143	531,029
1999	[b]	391,533
2000	[b]	282,309

[a] Data provided by D. Eggers, Alaska Department of Fish and Game, Juneau.
[b] Data not available.

Subdistricts 2, 4, 5, and 6 of the Norton Sound area, the Yukon River summer run chum salmon above the Anvik River, several important spawning populations of Yukon River chinook salmon in the lower and middle river tributaries, or any spawning population estimate for chum salmon or chinook salmon in the Kuskokwim Area (i.e., the Kuskokwim River, Kanectoc River drainage, and the Goodnews River). Therefore, the actual run sizes of chum salmon and chinook salmon to western Alaska are likely to be substantially higher than reported in Table 3.

Based on Myers and Rogers (1988) estimate that 60% of the chinook salmon bycatch originated in western Alaskan systems, a BSAI trawl bycatch of 30,000 juvenile chinook salmon would be comprised of about 18,000 fish from western Alaska. When adjusted for natural mortality, we have calculated that 14,581 chinook would have been removed as adult equivalents (Table 4). Details of the calculation are provided in Table 4. For comparison, an adult equivalent bycatch of 14,581 adult chinook salmon equates to about 2.7% of a 540,000 fish minimum run size estimate for western Alaska (1990-2000 rounded average).

Age-specific information for chum salmon was not available for this paper, however, the impacts of bycatch appear to be smaller on chum salmon runs due to the larger population size and lower bycatch composition from western Alaska. As previously mentioned, about 27% of the chum salmon bycatch in the BSAI trawl fisheries are from stocks that originate from western Alaskan systems. Applying this percentage, an average BSAI trawl bycatch of 60,000 juvenile chum salmon results in a total of about 16,200 fish from western Alaska. If we assume the same mortality as calculated for chinook salmon, this would equate to about 13,120 mature chum salmon from western Alaska. An adult equivalent bycatch of 13,120 adult chum salmon equates to about 0.24% of the minimum run size estimate of 5.5 million chum salmon for western Alaska (1990-1998 rounded average).

It is not known at this time what proportion, if any, of the chinook salmon or chum salmon caught incidentally in GOA groundfish fisheries originate from western Alaska. Hence, we are unable to estimate the impacts of GOA groundfish fisheries on western Alaska salmon stocks or other stocks of Pacific salmon.

Bycatch Control Measures

The North Pacific Fishery Management Council has adopted measures over the years to control the bycatch of salmon in trawl fisheries (Witherell and Pautzke 1997). Salmon are listed as a prohibited species in the groundfish fishery management plans, meaning that they cannot be retained and sold. However, regulations implemented in 1994 prohibit the discard of salmon

Table 4. Adult equivalent bycatch of chinook salmon from western Alaska stocks taken incidentally in the BSAI trawl fisheries, based on a bycatch of 30,000 salmon, adjusted for proportion from western Alaska, age composition by region, and natural mortality.

Region and Age at Capture	Percent	Survival Rate (%)	Number of Fish
BSAI trawl bycatch:			30,000
Western Alaska component of intercepted chinook	60.0		18,000
Arctic/Yukon/Kuskokwim component	37.0		6,652
Age 1.2	68.3		4,543
Age 1.3	31.7		2,109
Age 1.2 returning next year as 1.3	30.0	80.0	1,090
Age 1.2 returning 2 years later as 1.4	70.0	90.0	2,290
Age 1.3 returning same year	30.0	100.0	633
Age 1.3 returning next year as 1.4	70.0	90.0	1,329
Total contribution to Arctic/Yukon/Kuskokwim region			5,342
Bristol Bay component	63.0		11,348
Age 1.2	68.3		7,750
Age 1.3	31.7		3,598
Age 1.2 returning next year as 1.3	43.0	80.0	2,666
Age 1.2 returning 2 years later as 1.4	57.0	90.0	3,180
Age 1.3 returning same year	43.0	100.0	1,547
Age 1.3 returning next year as 1.4	57.0	90.0	1,846
Total contribution to Bristol Bay region			9,239
Total annual contribution to western Alaska from intercepted chinook salmon			14,581

taken as bycatch in the BSAI groundfish trawl fisheries until the number of salmon has been determined by a NMFS certified observer. Subsequent regulations have allowed for voluntary retention and processing of salmon bycatch for donation to foodbanks.

Several bycatch hot spot areas have been closed to trawl fishing (salmon savings areas) if too many salmon are encountered. Beginning in 1994, the Chum Salmon Savings Area has been closed to all trawling from August 1 through August 31. Additionally, the area remains closed through October 14 if a bycatch limit of 42,000 chum salmon is caught incidentally in the southeastern part of the Bering Sea. Although more than 42,000 chum salmon were caught incidentally over the course of a year from 1995 through 2001, additional closures were not triggered because the bycatch limit was not attained within the designated area during the accounting period (August 15 to October 14). From 1996 through 1999, regulations were in place to prohibit trawling in the Chinook Salmon Savings Areas through April 15 if and when a bycatch limit of 48,000 chinook salmon was attained in the BSAI trawl fisheries. More than 48,000 chinook salmon were taken as bycatch annually from 1996 through 1998, but closures were not triggered because bycatch limits were not exceeded before April 15.

In 2000, new regulations to reduce chinook salmon bycatch in BSAI trawl fisheries were implemented (NPFMC 1999). The regulations incrementally reduced the chinook salmon bycatch limit from 48,000 to 29,000 chinook salmon over a 4-year period, implemented year-round accounting of chinook salmon bycatch in the walleye pollock fishery, revised the boundaries of the Chinook Salmon Savings Areas, and set more restrictive closure dates. In the event the limit is triggered before April 15, the Chinook Salmon Savings Area closes immediately. The closure would be removed on April 16, but would be reinitiated September 1 and continue through the end of the year. If the limit were reached after April 15, but before September 1, then the areas would close on September 1. If the limit were reached after September 1, the areas would close immediately through the end of the year. The bycatch limit for 2002 BSAI walleye pollock fisheries was 33,000 chinook salmon.

Regulations have not yet been implemented to control salmon bycatch in the GOA groundfish fisheries for several reasons. First, salmon bycatch has historically been much lower in GOA groundfish trawl fisheries, and thus has been of lower concern to managers. In recent years, chinook salmon bycatch is about 50% less in GOA groundfish trawl fisheries as compared to BSAI groundfish trawl fisheries, and chum salmon bycatch in GOA groundfish trawl fisheries is about one tenth of the BSAI groundfish trawl fisheries. Second, fewer hauls are observed in the GOA trawl fisheries, so a majority of the salmon bycatch is not observed and enumerated until it is delivered to a shoreline processor. This would make it more difficult for the GOA trawl fleet to monitor bycatch hot spots as is done for the BSAI trawl fleet. Lastly, there have not been any studies to date on the origins of salmon taken as bycatch in GOA groundfish fisheries, and thus the impact on Alaska salmon stocks and other salmon stocks remains unknown. Nevertheless, in February 2002, the Council initiated a process to implement salmon bycatch control measures for GOA groundfish trawl fisheries. These measures may include bycatch limits that, when attained, would trigger closures in areas with the historically highest bycatch rates.

DISCUSSION

Our analysis suggests that chum salmon bycatch in the BSAI groundfish fisheries has negligible impacts on western Alaska salmon runs. This was also the conclusion of Patton et al. (1998), who examined the high chum salmon bycatch levels of 1993 and 1994, and determined that bycatch was in no way responsible for the simultaneous drop in salmon catches. Based on our findings, the impacts of incidental catch in the BSAI groundfish fisheries would be small (<0.4%), even at the lowest minimum run size estimated for chum salmon in western Alaska (3.6 million in 1997). Although additional information on age at incidental capture, age at return, natural mortality, and total run size for chum salmon would improve the precision of our estimates, we believe that salmon bycatch in BSAI groundfish fisheries is not a conservation issue for western Alaska chum salmon stocks.

Our results indicate that the BSAI groundfish fisheries have larger impacts on chinook salmon stocks. Although we estimated that bycatch reduced western Alaska chinook salmon runs by 2.7%, actual impacts are likely much lower for two reasons. First, escapements are unknown for many populations of chinook salmon from western Alaska, so total run size has been underestimated. Second, the stock composition study of chinook salmon bycatch (Myers and Rogers 1988) was based on data collected over 20 years ago during foreign and joint venture fisheries, at a time when western Alaska chinook salmon were much more abundant. Application of those stock composition estimates would likely overestimate the contribution of western Alaska chinook salmon. Although bycatch does not appear to be responsible for the decline in western Alaska chinook salmon stocks, fishery managers should remain concerned about the possibility that bycatch could have disproportional impacts on small chinook salmon populations in western Alaska and elsewhere.

Bycatch of salmon in the BSAI trawl fisheries has fluctuated over the years. Changes in annual bycatch amounts are attributable to changes in salmon abundance, establishment of salmon bycatch limits and other regulatory changes (particularly those associated with Steller sea lion protection measures), bycatch avoidance measures by the fleet, and changes in fishery operations due to the formation of cooperatives allowed under the American Fisheries Act of 1998. For example, the amount of chinook salmon taken in the 2000 BSAI walleye pollock fishery was unusually low, primarily due to a U.S. District Court order which closed all Steller sea lion critical habitat (including the offshore foraging areas) to trawling from August 8 through December 14, 2000. This injunction prevented the walleye pollock fishery from being prosecuted in the Bering Sea Steller sea lion foraging area, which historically had the highest chinook salmon bycatch rates.

The impacts of groundfish fisheries on western Alaska chum salmon appear to be consistent with the bycatch levels established for other prohibited species. For example, the prohibited species catch limits for 1998 equated to 0.1% of the red king crab *Paralithodes camtschaticus* population, 0.1% of the snow crab *Chionoecetes opilio* population, 1.8% of the Tanner crab *C. bairdi* population, 1.0% of the Pacific herring *Clupea pallasi* biomass, and 1.3% of the Pacific halibut *Hippoglossus stenolepis* biomass (Witherell et al. 2000). Our results suggest that the impacts of bycatch on western Alaska chinook salmon may higher than the other prohibited species, and managers should continue to explore ways to reduce the impacts of the BSAI trawl fisheries on these chinook salmon stocks.

Measures to control salmon bycatch were developed primarily to address allocation concerns from competing users of the salmon resources, and to a lesser extent to address conservation concerns for western Alaska salmon stocks. Managers have attempted to create a balance by developing regulations that allow maximum groundfish catches with a minimum of bycatch. The BSAI groundfish trawl fisheries generate about $300 million exvessel value annually (Hiatt et al. 2001). In contrast, the BSAI trawl bycatch of chinook salmon originating in western Alaska (14,581 adult equivalents with average fish weight of 7.3 kg, worth $3.30/kg; ADF&G data) and similar bycatch of chum salmon (approximately 13,120 adult equivalents with average fish weight of 3.6 kg, worth $0.66/kg; ADF&G data) would have a total exvessel value of only about $382,000. The relative economic impacts of salmon bycatch to subsistence and recreational users have not been estimated, nor have the impacts of relatively small removals on populations considered to be at critically low stock sizes been assessed. The trawl fisheries also generate millions of dollars in State of Alaska fish taxes, and provide direct and indirect employment to thousands of people (NMFS 2001a). The economic impact of closing the BSAI groundfish trawl fisheries to eliminate salmon bycatch would result in significant costs at the national, state, and community level.

This paper highlights the need for additional research on salmon bycatch. We currently have no information on the stock composition of salmon taken as bycatch in the GOA trawl fisheries. Additionally, the stock composition estimates from chinook salmon caught incidentally in the BSAI trawl fisheries are over 20 years old. Given the importance of salmon to all of the user groups in Alaska, together with international mixing of salmon stocks in the North Pacific, stock composition studies should be a high priority area of research.

LITERATURE CITED

ADF&G (Alaska Department of Fish and Game). 2000. Bristol Bay and Kuskokwim Bay season summary. Currents: Alaska Department of Fish and Game, Sport Fish Division Newsletter, Winter 99–00.

Brannian, L. K. 1990. Estimates of total abundance, exploitation rate, and migration timing of chinook salmon runs in the Yukon River, 1982–1986. Fishery Research Bulletin No. 90–03, Alaska Department of Fish and Game, Juneau.

Hare, S. R., and R. C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean. Pages 357–372 *in* R. J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

Hiatt, T., R. Felthoven, and J. Terry. 2001. Economic status of the groundfish fisheries off Alaska, 2000. National Oceanic and Atomospheric Administration, National Marine Fisheries Service, Seattle, Washington.

Karp, W. A., and H. McElderry. 1999. Catch monitoring by fisheries observers in the United States and Canada. Pages 261–284 *in* C. P. Nolan, editor. Proceedings of the international conference on integrated fisheries monitoring. Food and Agriculture Organization, Rome.

Kondzela, C., C. Guthrie, M. Masuda, and R. Wilmot. 1999. Origin of chum salmon caught incidentally in the Bering Sea trawl fishery, 1994-96. Extended Abstract. Pages 6–7 *in* Proceeding of the 19th Northeast Pacific Pink and Chum Salmon Workshop. National Marine Fisheries Service, Juneau, Alaska.

Kruse, G. H. 1998. Salmon run failures in 1997–1998: A link to anomalous ocean conditions? Alaska Fishery Research Bulletin 5(1):55–63.

Minard, M. J., J. Skrade, T. Brookover, D. Dunaway, B. Cross, and J. Schichnes. 1992. Escapement requirements and fishery descriptions for Nushagak Drainage chinook salmon. A report to the Alaska Board of Fisheries, Regional Information Report No. 1D91-09, Alaska Department of Fish and Game, Dillingham.

Myers, K. W., and D. E. Rogers. 1988. Stock origins of Chinook salmon in incidental catches by groundfish fisheries in the eastern Bering Sea. North American Journal of Fisheries Management 8:162–171.

National Research Council. 1999. The community development quota program in Alaska. National Academy Press, Washington, D.C.

NMFS (National Marine Fisheries Service). 2001a. Alaska groundfish fisheries draft programmatic supplemental environmental impact statement. National Marine Fisheries Service, Juneau.

NMFS (National Marine Fisheries Service). 2001b. Steller sea lion protection measures final supplemental environmental impact statement. National Marine Fisheries Service, Juneau.

NPFMC (North Pacific Fishery Management Council). 1995a. Environmental assessment/regulatory impact review for amendment 21b to the fishery management plan for the groundfish fishery of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, Anchorage.

NPFMC (North Pacific Fishery Management Council). 1995b. Environmental assessment/regulatory impact review for amendment 35 to the fishery management plan for the groundfish fishery of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, Anchorage.

NPFMC (North Pacific Fishery Management Council). 1999. Environmental assessment/regulatory impact review for amendment 58: An amendment to further reduce chinook salmon bycatch in groundfish trawl fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, Anchorage.

Pacific Salmon Commission. 1988. Joint Chinook Technical Committee, 1987 Annual Report. Report (88)-2.

Patton, W. S., K. W. Myers, and R. V. Walker. 1998. Origins of chum salmon caught incidentally in the eastern Bering Sea walleye pollock trawl fishery as estimated from scale pattern analysis. North American Journal of Fisheries Management 18:704–712.

Teel, D. J., P. A. Crane, C. M. I. Guthrie, A. R. Marshall, D. M. Van Doornik, W. D. Templin, N. V. Varnavskaya, and L. W. Seeb. 1999. Comprehensive allozyme database discriminates chinook salmon around the Pacific Rim (NPAFC document 440). Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.

Urawa, S., M. Kawana, G. Anma, Y. Kamaei, T. Shoji, M. Fukuwaka, K. M. Munk, K. W. Myers, and E. V. Farley, Jr. 2000. Geographic origin of high-seas chum salmon determined by genetic and thermal otolith markers. North Pacific Anadromous Fish Commission Bulletin 2:283–290.

Volstad, J. H., W. Richkus, S. Gaurin, and R. Easton. 1997. Analytical and statistical review of procedures for collection and analysis of commercial fishery data used for management and assessment of groundfish stocks in the U.S. exclusive economic zone off Alaska. Versar, Inc., Columbia, Maryland.

Wilmot, R. L., C. M. Kondzela, C. M. Guthrie, and M. M. Masuda. 1998. Genetic stock identification of chum salmon harvested incidentally in the 1994 and 1995 Bering Sea trawl fishery. North Pacific Anadromous Fish Commission Bulletin 1:285–299.

Witherell, D., and C. Pautzke. 1997. A brief history of bycatch management measures for eastern Bering Sea groundfish fisheries. Marine Fisheries Review 59(4):15–22.

Witherell, D., C. Pautzke, and D. Fluharty. 2000. An ecosystem-based approach for Alaska groundfish fisheries. International Council for the Exploration of the Sea Journal of Marine Science 57:771–777.