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Pacific Salmon in the North American Arctic

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ABSTRACT. All five North American Pacific salmon species occur in small numbers in arctic waters, but only pink and chum salmon appear to have viable populations north of Point Hope, Alaska. Pink salmon are the most common species and constitute 85% of salmon caught in biological surveys. Pink salmon apparently have small runs in eight arctic drainages, while chum salmon may have small runs in six. Arctic pink salmon are smaller in size than individuals to the south but have similar meristic characteristics. It is likely that minimal use of freshwater habitats by pink and chum salmon has allowed them to colonize characteristically cold arctic rivers.

Key words: Arctic, Beaufort Sea, Chukchi Sea, pink salmon, chum salmon

RÉSUMÉ. Les cinq espèces de saumon pacifique nord-américain nagent en nombre restreints dans les eaux arctiques mais seuls les saumons rose et kéta semblent exister en nombres viables au nord de Point Hope, en Alaska. Le saumon rose est l'espèce la plus commune, comportant 90% des saumons pris dans les recensements biologiques. Il existe apparemment de petites montaisons de saumon rose dans 8 drainages arctiques, tandis le saumon kéta est présent en petites montaisons dans 6 de ces drainages. Le saumon rose arctique est de plus petite taille que son cousin plus au sud mais possède les mêmes caractéristiques méristiques. Il est possible que l'usage peu fréquent d'habitats à eau douce par les saumons rose et kéta leur ait permi de coloniser les froides rivières arctiques.

Mots clés: Arctique, mer de Beaufort, mer Chukchi, saumon rose, saumon kéta

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INTRODUCTION

The distributions of all five North American Pacific salmon species (pink, *Oncorhynchus gorbuscha*; chum, *O. keta*; chinook, *O. tshawytscha*; sockeye, *O. nerka*; and coho, *O. kisutch*) extend into arctic waters; however, salmon numbers decrease north of the Bering Strait, and they are relatively rare in the Beaufort Sea. Spawning runs in arctic streams are minor compared to those of commercially important populations farther south, but salmon contribute a supplement to native subsistence economies at several North Slope villages (NSB, 1979). Documentation of distributions and biological characteristics of arctic salmon is scattered, often occurring as short sections in reports of limited circulation. In this paper we provide a synopsis of the available information and describe some characteristics of arctic pink and chum salmon populations.

STUDY AREA

The geographic region examined is Alaska's North Slope and the western Canadian Arctic, including rivers and coastal waters of the Beaufort and northeast Chukchi seas, with Point Hope as the southern boundary (Fig. 1). The Chukchi Sea represents a transition zone between the Pacific and Arctic oceans and their associated fish communities. The fish fauna of the northeast Chukchi Sea is basically an arctic one in that it has low species diversity and a high degree of species overlap (74%) with the Beaufort Sea fauna (Craig, 1984). Chukchi waters south of Point Hope are more directly influenced by the northward flow from the Bering Sea, and the fish fauna of the southeastern Chukchi Sea bears more resemblance to that of the Bering Sea (Wolotira *et al.*, 1979). Rivers south of Point Hope support comparatively large runs of chum and pink salmon and are basically the northern distributional limits for chinook, coho and sockeye salmon.

METHODS

In 1977 and 1978 we sampled pink salmon during a study of coastal fishes in Simpson Lagoon, located 50 km west of Prudhoe Bay. All pink salmon were captured in fyke nets set perpendicularly to the shoreline with a 67 × 1.2 m lead, 15 × 1.2 m wings and a 3.7 × 1.2 m trap. On two days directional fyke nets were used side by side to determine direction of fish movement. Fish not retained for dissection were measured (fork length), tagged with Floy anchor tags and released. Retained fish were measured and weighed, and counts were made of gill rakers, dorsal fin rays and anal fin rays. If no eggs were extruded from females during handling, a fecundity estimate was obtained by counting the number of eggs in a weighed subsample of the total egg weight. Additional details about the sampling program appear in Craig and Haldorson (1981).

Other reports of salmon captures in the study area were compiled, but it was usually not possible to assess whether these fish represented small stocks in local streams or strays from other areas. In cases where few specimens were caught during at least moderate sampling programs, we assumed them to be strays.

RESULTS

All five species have been caught in arctic waters north of Point Hope, but only pink salmon, and to a lesser degree chum salmon, occur with any regularity and presumably maintain small populations in several of these northern drainages. Most of these populations occur in streams west of Barrow (Fig. 1, Table 1). Salmon abundance in the study area is low, especially when compared to numbers of each species in southern waters. The only escapement estimates available are for the Kukpuk River, the southernmost stream in the study area. Smith *et al.* (1966) observed 2600-5000 pink salmon in this stream in 1959

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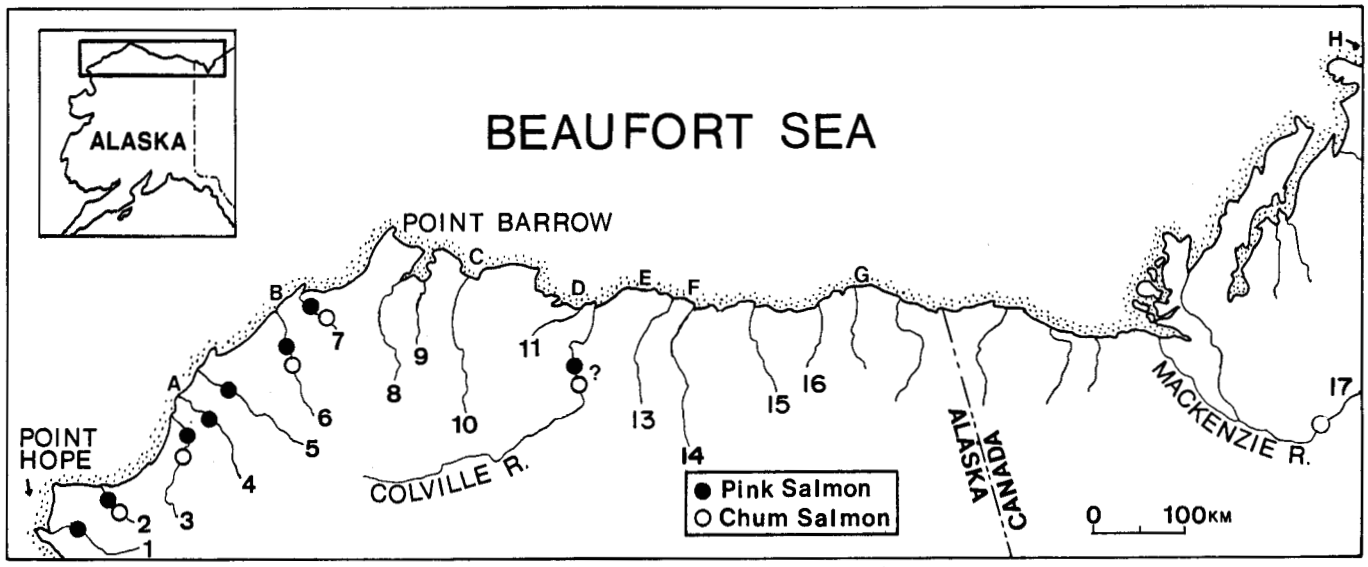

FIG. 1. Streams in the study area that apparently support small populations of pink and chum salmon. Location numbers and letters refer to Table 1.

TABLE 1. Occurrence of Pacific salmon in arctic waters north of Point Hope, Alaska (location numbers and letters refer to Figure 1)

	Drainage or coastal area	Species occurrence[a]					References[b]
		Pink	Chum	Chinook	Sockeye	Coho	
POINT HOPE							
1	Kukpuk River	×	*			*	1,2
2	Pitmigea River	×	×				1,3
	Kuchiak Creek		*			*	1
3	Kukpowruk River	×	×				1,3,4
A	Kasegaluk Lagoon	×	*				5-8
4	Kokolik River	×	*				1,3,4,7,8
5	Utukok River	×	*				1,3,4,7
6	Kuk River	×	×	*			7
B	Wainwright Coast	×	*	*			5
7	Kugrua River	×	×				1,3,7,9
POINT BARROW							
	Inaru River		*				7
	Elson Lagoon	×					10-12
8	Meade River	*	*				1,3,5,7
9	Chipp River	*					1,3,7,9,37
10	Ikpikpuk River	*					1
C	Smith Bay	×					11
D	Harrison Bay	×					11
11	Fish River	*	*				1
12	Colville River	×?	×?	*	*		1,3,4,12-17
E	Simpson Lagoon	×	*		*		14,18,19
13	Kuparuk River	*					20
F	Prudhoe Bay	*	*	*		*	24,36
14	Sagavanirktok R.	*	*				1,3,21,22
15	Canning River	*	*		*		1,23
16	Sadlerochit River	*					1,23
G	Barter Island Area	*					14
CANADA							
17	Mackenzie River	*	×	*	*		16,25-33
	Anderson River		?				16,26,28,29,34
H	Franklin/Darnley Bay		*				35
	Coppermine River			*			26,31
	Bathurst Inlet				*		26,28

[a] × = probably a small run or stock; * = probably strays, often only a single specimen caught.

[b] Source: 1 ADF&G, 1985; 2 Smith *et al.*, 1966; 3 Bendock and Burr, 1985a; 4 Bendock, 1979b; 5 Craig and Schmidt, 1982; 6 Fechhelm *et al.*, 1984; 7 Hablett, 1979; 8 Craig and Schmidt, 1985; 9 Netsch *et al.*, 1977; 10 Murdoch, 1884; 11 Schmidt *et al.*, 1983; 12 Walters, 1955; 13 Bean, 1887; 14 Craig and Haldorson, 1981; 15 McElderry and Craig, 1981; 16 McPhail and Lindsey, 1970; 17 Roguski and Winslow, 1970; 18 Dew, 1983; 19 Moulton and Fawcett, 1984; 20 Moulton, 1980; 21 Griffiths *et al.*, 1983; 22 Yoshihara, 1973; 23 Smith and Glesne, 1982; 24 Griffiths and Gallaway, 1982; 25 Dymond, 1940; 26 Hart, 1973; 27 Hatfield *et al.*, 1972; 28 Hunter, 1969; 29 Morrow, 1980; 30 O'Neill *et al.*, 1982; 31 Scott and Crossman, 1973; 32 Stein *et al.*, 1973; 33 Wynne-Edwards, 1952; 34 Hunter, 1975; 35 Hunter, 1979; 36 Moulton *et al.*, 1985; 37 Bendock and Burr, 1985b.

and 1960. Escapements in other arctic Alaskan streams are probably much smaller.

The relative abundance of salmon is also low compared to that of other fishes in northern coastal waters. While the catch rate of subsistence fishermen using large mesh gill nets is unknown, salmon caught in scientific studies using variable-mesh gill nets usually range from 0-4% of the total sample. From 1970 to 1984, scientific research teams in the study area have apparently caught only 788 salmon in total, almost all of which have been pink salmon: 85% pink, 13% chum, 0.6% sockeye, 0.6% chinook and 0.4% coho (Netsch *et al.*, 1977; Bendock, 1979a, b; Hablett, 1979; Moulton, 1980; Craig and Haldorson, 1981; McElderry and Craig, 1981; Smith and Glesne, 1982; Craig and Schmidt, 1982, 1985; Dew, 1983; Schmidt *et al.*, 1983; Griffiths and Gallaway, 1982; Griffiths *et al.*, 1983; Fechhelm *et al.*, 1984; Moulton and Fawcett, 1984; Moulton *et al.*, 1985). We examined an additional 16 studies conducted since 1970 in which no salmon were caught.

Pink Salmon

Pink salmon are a widely distributed species with a distinctive two-year life cycle. They inhabit the Pacific rim from Korea to California, with most spawning stocks occurring 48-64° N latitude in North America (southern British Columbia to northern Bering Sea) (Heard, 1986). An early report of this species in the Arctic related the purchase of two barrels of pink salmon at the Colville River mouth in 1875 (Bean, 1887). Additional early records have been sporadic (summarized by McPhail and Lindsey, 1970; Scott and Crossman, 1973; Morrow, 1980). Recent studies indicate that small runs of pink salmon may occur in eight drainages north of Point Hope, and probable strays have been encountered in nine additional drainages east of Barrow (Table 1). The status of pink salmon in the Colville River is not clear. Very few have been caught in this drainage — the largest number (n = 64) was caught by Bendock (1979b), who noted that they were spawning near Umiat and the Itkillik River 11-19 August 1978. However, Bendock and Burr (1984) later suggest that "none of the salmon species have established sustained populations in Alaskan waters east of Point Barrow." Pink salmon have not been found east of Barter Island since Dymond (1940) reported them in the lower Mackenzie River.

Run Timing and Migration. No pink salmon were caught in Simpson Lagoon in 1977, but 118 were caught the following summer. The run began on 2 August, peaked 6-8 August and ended 15 August 1978. When directional nets were fished, over 95% (n = 56) of the pink salmon were moving eastward. Eighty-seven pink salmon were tagged, and one was recovered in a subsistence fishery at Barter Island, 230 km east of the tagging site. Run timings in other years and locations were generally similar to that in Simpson Lagoon: Prudhoe Bay, 31 July-25 August 1982 (Griffiths *et al.*, 1983); Simpson Lagoon, 28 July-30 August 1982 (Dew, 1983); Kasegaluk Lagoon, 31 July-8 August 1983 (Craig and Schmidt, 1985). However, in 1978 Bendock (1979b) reported that pink salmon were already in three rivers between Point Hope and Point Barrow (Utukok, Kokolik and Kukpowruk rivers) by 20 July, although these fish had not yet begun to spawn.

Available data suggest that pink salmon are more abundant in even-numbered years than in odd-numbered years, as is the general pattern for this species in western Alaska (Heard, 1986). In coastal waters between the Colville River and Prudhoe Bay, pink salmon were relatively abundant in 1978 and 1982 (i.e., about 50-150 were caught each summer in several scientific studies — Craig and Haldorson, 1981; Dew, 1983; Griffiths *et al.*, 1983; Schmidt *et al.*, 1983) and were virtually absent in odd-numbered years from 1975 to 1983 (i.e., about 0-10 were caught each summer — Bendock, 1979a; Moulton *et al.*, 1980; Craig and Haldorson, 1981; Griffiths and Gallaway, 1982; Woodward-Clyde Consultants, 1983; Moulton and Fawcett, 1984). However, low catches also occurred in even-numbered years of 1976 (Bendock, 1979a) and 1984 (Moulton *et al.*, 1985).

Length and Weight. The mean fork length of the 1978 sample in Simpson Lagoon (451 mm) was similar to mean lengths of the 1982 Prudhoe bay sample (452 mm), the 1982 west Beaufort Sea sample (451 mm) and the 1983 Kasegaluk Lagoon sample (462 mm) (Table 2). Length-weight regressions for males ($\ln W = -10.2 + 2.80 \ln L$, n = 14) and females ($\ln W = -22.1 + 4.75 \ln L$, n = 16) indicate that the 1978 mean length corresponds to weights of 1004 g and 1022 g for the two sexes respectively. These low values are consistent with the observation that pink salmon are smallest at the northern end of their range (1.3 kg in the Arctic compared to 2.8 kg in California — Takagi *et al.*, 1981).

Meristics. A sample of 31 fish from Simpson Lagoon was analyzed for meristic characters. Counts of gill rakers on the first arch (range 28-35, mode 30, mean 30.2), dorsal fin rays (range 11-14, mode 13, mean 12.6) and anal fin rays (range 14-17, mode 16, mean 15.7) all fall within the ranges reported for this species (Hart, 1973).

Fecundity. The fecundity of pink salmon in Simpson Lagoon was slightly lower than the range generally recorded for this species (1200-1900 eggs; Heard, 1986). The mean fecundity of six females was 1159, with a range of 854-1549 eggs (fork lengths 432-465 mm). A regression of fecundity on length ($\ln F = -24.9 + 5.25 \ln L$, r = 0.59) estimates the fecundity of a 451 mm female as 1320 eggs. Craig and Schmidt (1985) report the average egg size of 25 females in Kasegaluk Lagoon as 5.2 mm (range 4.7-5.7 mm, not water-hardened).

Feeding. Most pink salmon caught in Simpson Lagoon had not recently fed (88% empty stomachs, n = 17) The only available information on marine feeding is from Kasegaluk Lagoon, where stomachs of 17 adult pink salmon caught by gill net contained mostly fish (84% by wet weight), with some amphipods (11%) and mysids (5%) (Craig and Schmidt, 1985). In that study the single most important prey species was arctic cod (*Boreogadus saida*).

Chum Salmon

Chum salmon are as widely distributed in arctic waters as pink salmon (Table 1) but are less common. Because few chum salmon have been caught east of Point Barrow, we suspect most of their occurrences in that region consist of strays or very small stocks. Average weights of arctic chum salmon are 3.1-3.9 kg (Table 2). Spawning occurs in the lower Colville River from mid-August to mid-September (Bendock, 1979b), although Bendock and Burr (1984) suggest that streams in this region do not support sustained populations of salmon. Only 35 chum salmon were caught in the Colville River by Bendock (1977b).

In the Canadian Arctic, chum salmon occur in the Mackenzie River and possibly the Anderson River (Table 1). Their long migration up the Mackenzie (about 2000 km) is nearly as impressive as that of chum salmon in the Yukon River (3200 km; Hart, 1973). They have been recorded at several locations

TABLE 2. Lengths and weights of pink and chum salmon at various arctic locations (lengths are fork lengths — snout tip to tail fork — unless indicated otherwise)

Location	Year	n	Length (mm) Mean	Length (mm) Range	Weight (kg) Mean	Weight (kg) Range	Source
PINK SALMON							
Simpson Lagoon	1978	118	451	340-570	1.0[d]	0.5-2.0	Craig and Haldorson, 1981
	1982	151	466	355-549			Dew, 1983
Colville River	1978	64	408[b]	371-460[b]	1.1	0.8-1.5	Bendock, 1979b
Prudhoe Bay	1982	30	452	410-530			Griffiths and Gallaway, 1982
Chukchi-Beaufort[a]	1977-78	79	502[c]	464-590[c]	1.5	0.9-2.1	Hablett, 1979
	1982	50	451	380-510			Schmidt *et al.*, 1983
Kasegaluk Lagoon	1983	41	462	388-540	1.1	0.7-2.0	Craig and Schmidt, 1985
CHUM SALMON							
Colville River	1978	35	602[b]	548-648[b]	3.9	2.6-5.4	Bendock, 1979b
Chukchi-Beaufort[a]	1977-78	25	650[c]	430-743[c]	3.1	2.3-4.1	Hablett, 1979

[a] Varied rivers combined.
[b] Mid-eye to tail fork.
[c] Total length.
[d] n = 30.

within the Mackenzie drainage, including the Great Bear, Slave, and Liard rivers (Scott and Crossman, 1973; O'Neil *et al.*, 1982). A 1979 escapement estimate (based on mark-recapture methods) in the Liard River was about 400 chum salmon, which first appeared on their spawning grounds on 9 October in 1979 and 29 September in 1980 and were present through early November when sampling efforts terminated (O'Neil *et al.*, 1982). Although the total size of the Mackenzie chum salmon population appears small, it seems surprising that they have not been reported from the Mackenzie delta or adjacent coastal waters of the Beaufort Sea during numerous scientific surveys conducted there over the past decade.

Chinook, Sockeye and Coho Salmon

There are no known stocks of chinook (king), sockeye (red), or coho (silver) salmon in arctic waters north of Point Hope. Collection records of these species (Table 1) usually consist of single specimens.

DISCUSSION

Of the five Pacific salmon species, pink salmon are by far the most abundant in arctic waters north of Point Hope. We suspect that they spawn successfully and maintain small but viable populations in at least some arctic drainages. Straying of pink salmon from southern streams into the study area probably occurs but seems an improbable source of all the pink salmon observed in arctic rivers between Point Hope and Barter Island, a distance of about 1000 km. It does seem unusual, however, that no salmon fry of any species have been collected in the study area, even near the Mackenzie River, which is known to support stocks of chum salmon. It may be that the absence of fry is due to the small population sizes of arctic salmon, the timing and location of sampling efforts or the gear used.

The extension of pink and chum salmon into the Arctic is probably due to their relative tolerance of cold water temperatures and their predominantly marine life cycle (Salonius, 1973). Tolerance of cold temperatures is particularly required during the freshwater phase of a salmon life cycle. The rate of embryonic development of salmon eggs in freshwater is directly related to water temperature. Approximately 900-1000 temperature units (centigrade degree days) are required for pink salmon to reach the stage when fry emerge from spawning gravel (Heard, 1986). These values approach the total number of temperature units occurring annually in some arctic rivers — estimated at 1050-1150 temperature units for the lower Kokolik, Sagavanirktok and Canning rivers (estimated from the data of Craig and McCart, 1975; Griffiths and Gallaway, 1982; Craig and Schmidt, 1985). Therefore, it seems probable that arctic salmon populations have physiologically adapted to lower temperatures and, in addition, they probably select spawning sites where water temperatures are highest. Stream temperatures in winter are typically 0-0.5°C but may reach 2-4°C or higher in areas influenced by groundwater upwelling. Such upwelling areas are probably essential for egg and alevin development. For example, initial water temperatures above 4.5°C are required for normal development of pink salmon eggs in northern regions (Bailey and Evans, 1971; Persov *et al.*, 1983).

Chum salmon in Alaska require about 700-900 temperature units to complete incubation and emergence (Raymond, 1981). In the Noatak River, an arctic drainage just south of Point Hope, chum salmon spawn in areas where intragravel temperatures are 3-5°C higher than in the mainstem (Merritt and Raymond, 1983). These warmer spawning habitats provide about 1130 temperature units between spawning and emergence, compared to only 215 temperature units available elsewhere in the drainage during the same period.

Relative independence from fresh water may also be an important adaptive feature for colonization of arctic streams by salmon. Brett (1952) found that young salmon (two months after hatching) were very sensitive to low temperatures. Sockeye and coho salmon in particular were unable to withstand an exposure to 0°C for four days. This would certainly limit their extension into the Arctic, where streams are characterized by low temperatures during all but a few summer months. Pink and chum salmon juveniles, in contrast to other salmon species, migrate to sea soon after their spring emergence, thereby minimizing their

habitation in streams and avoiding possible competition with other fish species for limited overwintering habitat in arctic rivers (e.g., Smith and Glesne, 1982; Bendock, 1983; Craig, 1986).

Once in coastal waters, pink and chum salmon juveniles probably migrate southward toward the Bering Sea, thereby avoiding the cold waters (about –2°C) of the arctic marine environment in winter. There is apparently evidence from a few tag recoveries that chum salmon from arctic rivers may migrate as far south as the Gulf of Alaska (Neave, 1964).

The above characteristics of pink salmon apparently override another aspect of their life cycle that would seem to put them at a distinct disadvantage in the arctic environment. Unlike other anadromous fish species in the Arctic, the pink salmon is a short-lived species that places all its reproductive effort into a single spawning event, and then it dies. With its rigid two-year life cycle, there is virtually no reproductive overlap between generations, and so every spawning event must be successful for the continued survival of the stock. Given the vagaries of arctic conditions, this seems a vulnerable requirement and one that has caused difficulties in man's attempts to establish new runs of pink salmon in northern Russian rivers (Persov *et al.*, 1983). Presumably for this very reason, other arctic anadromous fishes tend to be long-lived and capable of repeated spawnings over several years and consequently can withstand the occasional loss of a year-class. Along this line of thinking, we might predict that (1) pink salmon populations in arctic rivers undergo relatively frequent cycles of colonization-extinction compared to other anadromous species, and (2) straying of pink salmon to non-natal streams would be particularly advantageous to the species in order to repopulate marginal sites (Quinn, 1984).

In summary, the expansion of Pacific salmon into the Arctic appears restricted by cold water temperatures, particularly in freshwater environments. Salmon species differ in their tolerance of cold temperatures and in the length of time that their eggs and young are exposed to such temperatures in fresh water. Pink and chum salmon are probably able to maintain small stocks north of Point Hope by virtue of their relative cold tolerance and predominantly marine life cycle. These features apparently enable them to briefly inhabit and reproduce in arctic rivers, and their ability to complete long oceanic migrations probably allows them to overwinter in more hospitable marine waters to the south.

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