PACIFIC FISHERIES RESOURCE CONSERVATION COUNCIL
Conseil pour la conservation des ressources halieutiques du pacifique

PACIFIC SALMON IN CANADA'S ARCTIC DRAINING RIVERS, WITH EMPHASIS ON THOSE IN BRITISH COLUMBIA AND THE YUKON

MARCH 2009

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Pacific Fisheries Resource Conservation Council
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Irvine, J.R., Linn, E., Gillespie, K., McLeod, C., and J.D. Reist. 2009. Pacific Salmon in Canada's Arctic Draining Rivers, With Emphasis on Those in British Columbia and the Yukon. Vancouver, BC: Pacific Fisheries Resource Conservation Council.

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Printed and bound in Canada

ISBN 1-897110-49-9

Cover photo credit: Fred Seiler

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EXECUTIVE SUMMARY

This report is one of several published by the Pacific Fisheries Resource Conservation Council that describe the salmon resources of areas within British Columbia and the Yukon (i.e., Fisheries and Oceans Canada (DFO) Pacific Region). Our primary objective is to document what is known of Pacific salmon within DFO Pacific Region Arctic draining rivers. There appear to be only two such river systems with Pacific salmon: the Peel River that originates within the Yukon, flows past the community of Fort McPherson in the Northwest Territories before joining the lower Mackenzie, and the Liard River that also originates within the Yukon, skirts along the northern BC border and then flows northeast through the Northwest Territories before entering the Mackenzie River at Fort Simpson.

We focus on providing information on salmon from the Liard watershed, since little of this information has been published, and because there is little known of salmon in the Peel. To put this information in context, we also summarise salmon information from other rivers in the Mackenzie River watershed. We conclude by briefly speculating how salmon in Arctic draining rivers may be impacted by climate change.

All five species of Pacific salmon have been documented within the Mackenzie River watershed but there is general consensus that only chum regularly return to successfully spawn in the watershed. Chum are widely distributed in the Arctic, and have been recorded in various locations for more than 125 years. Pink salmon have been reported less frequently than chum, and in smaller numbers. Small catches of sockeye, chinook and coho salmon have all been recorded occasionally.

Chum salmon are frequently caught in the Peel River, and pink salmon, less frequently. Chum have been caught in that portion of the river within the Yukon, as well as downstream within the Northwest Territories. The Peel River flowed into the Porcupine River (tributary of the Yukon River) and vice versa during or following recent glaciations, resulting in a two way transfer of fish species between the two systems. Interestingly, Peel River chum salmon are genetically more closely associated with Alaskan and some Russian populations than with Yukon River chum.

Intensive fishery surveys in the Liard River watershed during 1978–1980 documented modest runs of chum salmon during the falls of 1979 and 1980. One chinook salmon was also caught. Adult chum salmon were captured each year from late September until early November. Radio-tagging results demonstrated that these fish ascended as far as the Grand Canyon of the Liard River ~540 km upstream of where the Liard joins with the Mackenzie, about 2000 km upstream of the mouth of the Mackenzie. Mark recapture and expanded catch per effort data generated spawning escapement estimates of several hundred fish each year, but these underestimate the actual run since chum were still entering the study area when ice conditions necessitated the termination of field studies. Efforts to capture chum in subsequent years have been largely unsuccessful, but this may be due to the major sampling challenges encountered when trying to catch salmon in a large and remote northern river.

Chum salmon captured at the two primary study sites in the Liard River ranged between 55 and 78 cm fork length and 2000 and 6200 g. Four year old fish predominated, with some three and five year old fish also caught. Sizes and ages of Liard chum were not significantly different from chum caught in the upper Yukon River.

We predict that with climate change, numbers of chum salmon in the Canadian Arctic will increase and pink salmon will eventually successfully colonise the Mackenzie watershed and regularly spawn. We do not foresee regular use of the watershed by coho, chinook or sockeye salmon, at least in the immediate future. Overwintering habitat in fresh water will continue to hamper the survival of early life history stages of these three species, although increasing groundwater input may work to their favour. However, the main limiting

factor for all species may be the winter marine environment. Regular monitoring is needed to track changes in salmon abundance and future colonization; we also recommend additional genetic analyses of tissue samples from chum and other salmon species to help understand patterns of relatedness and which species and populations may be natal to the area.

ACKNOWLEDGEMENTS

We thank B.C. Hydro and Power Authority who provided the resources to investigate the aquatic resources of the Liard River watershed, staff formerly with R. L. & L. Environmental Services Ltd. for conducting field studies, Al von Finster of DFO Whitehorse for insight into the role of groundwater in northern rivers, and Gordon Ennis, formerly with the Pacific Fisheries Resource Conservation Council, for encouraging the write up of this report.

INTRODUCTION

It is now almost universally accepted that the world's climate is changing. In general, the earth is becoming warmer, and nowhere is this more evident than near the poles; in the Arctic, average temperatures increased at almost twice the global average rate during the past century (Trenberth *et al*. 2007). This raises the question—with climate change, will Canada's northerly areas become more important for salmon?

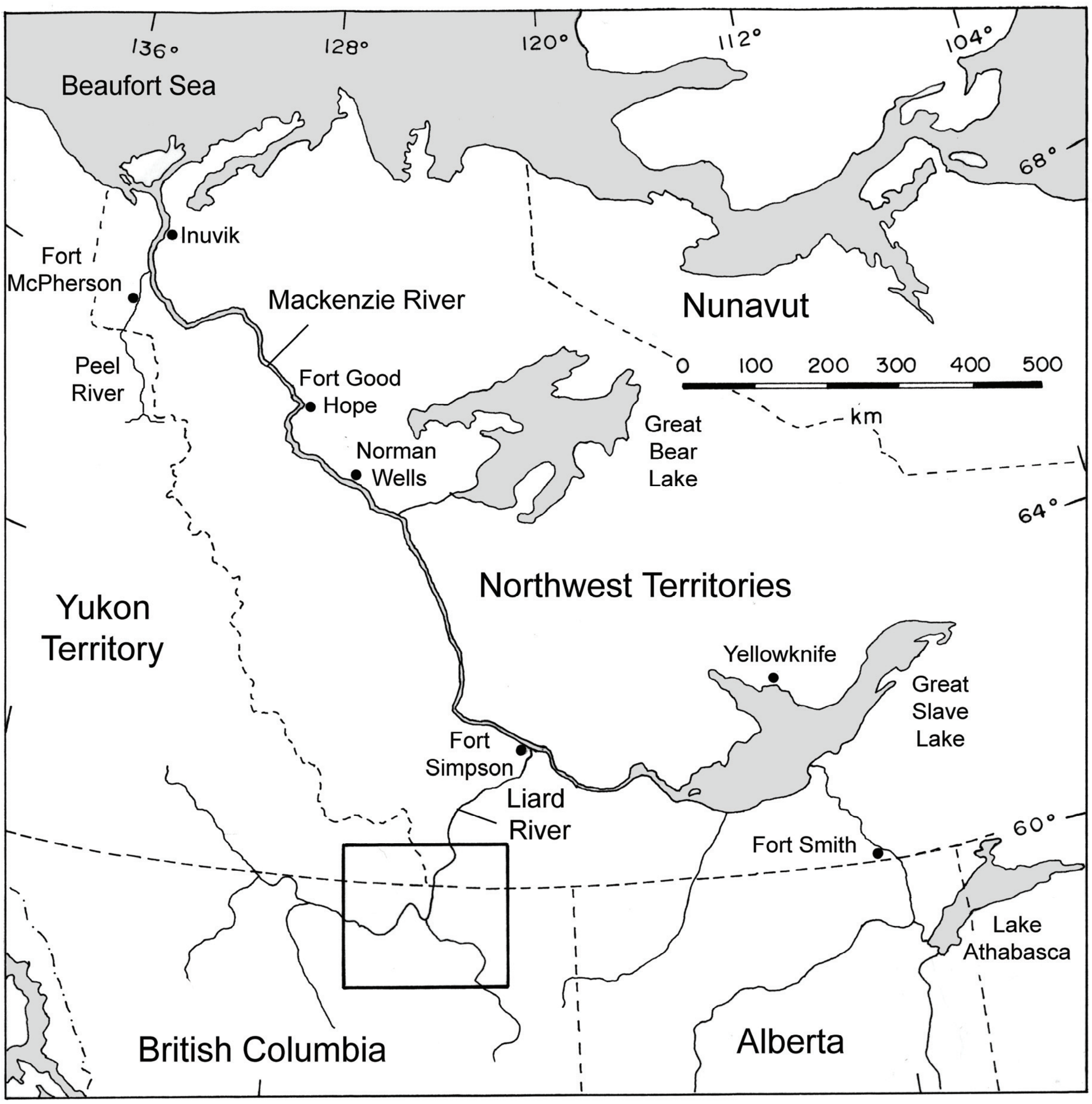
Chum (*Oncorhynchus keta*) and pink (*O. gorbuscha*) salmon have the broadest distributions in the Arctic, occasionally encountered west of the Lena River in Siberia, and east of Canada's Mackenzie River (Heard 1991; Salo 1991). Documentation from the 1881 Alaskan voyage of the Revenue-Steamer Corwin (Bean 1883), to our knowledge, provides the first published records of Pacific salmon in arctic North America. In passing, Bean notes the presence of both pink and chum salmon in the Bering Strait, chum salmon in Hotham Inlet (Kotzebue Sound), and pink salmon in the Colville River (northern Alaska). In an 1894 report Bean describes the life history of Pacific salmon and speculates that the range of pink salmon probably extends to the Mackenzie River while chum salmon can be found as far east as Point Barrow, Alaska. Early accounts of salmon in the Mackenzie River came from interviews with former Yukon fishermen in the early 1900s (Preble 1908) who were then fishing the Mackenzie. They reported catching salmon that "appear identical to the common one of the Yukon." Preble referred to these salmon as "*Oncorhynchus nerka* (?)"; we assume they were in fact chum salmon.

In 1933, Dymond and Vladykov published a report of a single ("probably") chum salmon being caught in Great Slave Lake, and subsequently Dymond (1940) detailed several verified samples of chum in the Mackenzie and Peel rivers (Fig. 1). One specimen of "dog" (chum) salmon was taken in the Peel River, 50 miles south of Aklavik, in 1937, as well as single specimens of pink salmon taken at both Kigtluidt on Richardson Island, September, 1936 and Kittigasuit, August, 1938. Wynne-Edwards (1947) indicates that "three of the five species of Pacific salmon are fairly regularly caught" in the lower Mackenzie in the fall. Chum and pink would have been two of the species, however, it is unclear what the third species was, if indeed it was a salmon. Spawning runs of pink and chum salmon were not documented in the Mackenzie until Lindsey's (1956) investigations in the 1950s. Spawning runs of pink were found only in the lower Mackenzie while chum runs were found as far south as Fort Smith on the Slave River. Scott and Crossman (1973) indicate that chum could be found as far as the Hay River and had been known to enter Great Bear Lake. Further specimens of chum salmon from Great Bear Lake, Anderson River, as well as Great Slave Lake and pink salmon samples from the Peel River in the late 1950s from domestic fisheries are reported by Hunter (1975). Unverified and admittedly "questionable" specimens of other Pacific species are noted in Hunter's report, including an account of 13 Chinook salmon (*O. tshawytscha*) caught at the mouth of the Coppermine River, Nunavut. More reliable records of several sockeye salmon caught in Bathurst Inlet and Holman Island are also provided. Hunter goes as far as to speculate that the abundance of salmon in the western and central Arctic probably lies in the range of 10 to 20 million pounds annually, but is made up exclusively of strays; however, this is likely a significant over estimation of present abundances. Stephenson (2005; 2006) provides more up-to-date reports of salmon in the Mackenzie River watershed.

This report is one of several published by the Pacific Fisheries Resource Conservation Council (PFRCC) to describe the salmon resources of areas within British Columbia (BC) and the Yukon. Our primary objective is to document what is known of Pacific salmon within DFO Pacific Region Arctic draining rivers. There appear to be only two such river systems with Pacific salmon: the Peel River that originates within the Yukon, flows past the community of Fort McPherson in the Northwest Territories before joining the lower Mackenzie, and the Liard River that also originates within the Yukon, skirts along the northern BC border and then flows northeast through the Northwest Territories before it enters the Mackenzie River at Fort Simpson (Fig. 1).

This report is shorter than earlier PFRCC salmon reviews because of limited salmon information (and salmon) in these watersheds. We focus on providing information on salmon within the Liard watershed, since little of this information has been published, and because there is little known of salmon in the Peel. To put this information in context, we also summarise published salmon information from other rivers in the Mackenzie River watershed. These are beyond the scope of the present paper and are the subject of other studies. We conclude by briefly speculating how salmon in Arctic draining rivers may be impacted by climate change.

FIGURE 1. Mackenzie River watershed.
Inset shows the location of the study area within the Liard River drainage shown in Fig. 2.



MACKENZIE RIVER WATERSHED (EXCLUDING THE LIARD AND PEEL) SALMON

The Mackenzie River watershed is the largest in Canada, and second only to the Mississippi-Missouri system in North America. From the headwaters, the river flows for 4,241 km, draining an area of 1,805,200 km^2. Since much of the information on salmon within the Mackenzie River and tributaries other than the Liard has been published elsewhere (e.g., Babaluk *et al*. 2000, Stephenson 2005, Stephenson 2006, Sawatzky *et al*. 2007), we provide only a summary here. The majority of recent records of salmon in the Mackenzie River come from salmon collection by DFO Central and Arctic Region, run by the Winnipeg, Inuvik and Hay River offices. Additional information on salmon is collected from harvest studies, and DFO science studies when salmon are captured as by-catch.

Chum salmon are believed to be the most common of the Pacific salmon found in the Mackenzie River (Salo 1991, Scott and Crossman 1973). They have been regularly harvested in small numbers since the early 1900's (Dymond 1940, Stephenson 2005, Linn, unpublished data). We agree with Stephenson (2006) that most chum salmon in the western Arctic are not strays. Traditional knowledge supports the theory that chum are natal to the Mackenzie; chum salmon have local names in both the Inuvialuktun and Dene languages, but no other salmon species are named (Coad and Reist 2004, Stephenson 2006). An absence of sub-adults in gill net catches in the Mackenzie delta region indicates that chum likely do not rear in this area.

Pink salmon have been reported less frequently than chum, and in smaller numbers, at various locations within the Mackenzie River, tributaries and along the coast (Stephenson 2006). Most pink salmon have been reported from along the coast and the Mackenzie Delta (Stephenson 2006).

Sockeye salmon (*O. nerka*) have been reported from various locations, but in much smaller numbers than chum and pink salmon. Sockeye have been turned in to the DFO collection program, reported by harvesters and by DFO biologists as well. Records exist of catches from Tsiigehtchic (formerly known as Arctic Red River, 96 km south of Inuvik), Tuktoyaktuk (150 km north of Inuvik), Norman Wells, Fort Good Hope (Stephenson 2006) and the Slave River (Little *et al*. 1998). Hunter (1975) reported an unverified identification of a sockeye salmon from Fort Providence on the Mackenzie River near the outlet of Great Slave Lake in 1908.

According to Stephenson (2006), verified records of Chinook are rare in the Canadian Arctic. Within the Mackenzie River, Chinook have been captured at Norman Wells and Aklavik (58 km west of Inuvik) (Stephenson 2006) and also in the Tsiigehtchic area (Dymond 1940). Reports of chinook along the coast of the Beaufort Sea area from subsistence fishing camps, such as Shingle Point in the Yukon, also exist (Stephenson 2005).

Coho salmon (*O. kisutch)* are the least frequently reported and captured species of Pacific salmon in the Canadian western Arctic. A single coho salmon in Great Bear Lake was captured in September of 1987 (Babaluk *et al*. 2000). Stephenson (2005) reports the only other confirmed capture (hook and line through the ice) and identification of a coho in the Mackenzie Delta near Inuvik in October of 1998.

PEEL RIVER WATERSHED SALMON

The Peel River is a large lower river tributary of the Mackenzie River. Originating in the Yukon, it flows through the Northwest Territories and into the Mackenzie River near Fort McPherson (Fig. 1). The Peel River is 441 km long with drainage of 110,150 km^2 (Dryden *et al*. 1973). Within the Northwest Territories, the Peel has steep muddy riverbanks and erosion is evident as trees cling to the edge with roots exposed. The turbid water carries a high silt load (Toyne and Tallman 2000). The lower portion of the river is primarily bedrock while upstream areas contain extensive gravel beds (Dryden *et al*. 1973). Large fluctuations in water level and velocity throughout the year are due to rain and snow runoff from the mountains (Dryden *et al*. 1973). Spring floods cause water to rise several meters; the fall brings a seasonal drop in water levels, exposing mud and gravel bars (Toyne and Tallman 2000).

Most of the Peel River watershed has been glaciated. Land forms and stream channel morphology are similar to alpine areas of the glaciated section of the Yukon River Basin. The Peel drainage is further north, and is therefore more subject to permafrost. Flows reversed directions various times during the last glacial period. The upper Peel drained into the Porcupine basin (Yukon River drainage) when the lower Peel was blocked by ice, and the upper Porcupine entered the Peel basin when the lower Porcupine was similarly blocked at the Canyon Creek/Eagle River pass. This glacial history enabled a two way transfer of fish species between the Peel and Porcupine drainages, resulting in six fish species in the Peel that are genetically different from the same species in the Mackenzie (Bodaly and Lindsey 1977). Interestingly, Peel River chum salmon are not closely related to Yukon River chum (Beacham *et al*. 2009), and if fact are more closely associated with Alaskan and some Russian populations.

Most salmon captured in the Peel River have been chum (Dymond 1940, Stephenson 2006). Hunter (1975) reports several years when pink salmon were also been captured, including 1945, 1947 and 1957. Chinook salmon were reported caught on the Peel in 1914 (Dymond 1940). No coho have been recorded for the Peel River.

There have not been any recent salmon studies within the Northwest Territories portions of the Peel River. Any recent reports of salmon in the Peel have come from the DFO reward program to obtain salmon from subsistence domestic, and commercial fisheries in the Arctic. Harvest studies and fish studies, such as the Peel River Fish Study, from the Gwich'in Renewable Resource Board (GRRB) and DFO make up the remainder of studies providing incidental catch information of salmon in the Peel River.

The Peel River Fish study was conducted by the GRRB and DFO from 1998 to 2002, provides the most recent and useful netting study on the Peel where salmon were captured and positively identified. In 1998, the program caught 40 chum salmon, but no salmon of any species were captured in 1999 (Toyne and Tallman 2000), or from 2000 to 2002 (Walker-Larsen 2001; VanGerwen-Toyne 2002, 2003).

DFO's Central and Arctic Region have been conducting an active salmon sampling program since 2000 in an attempt to document the occurrence of Pacific salmon in the Canadian Arctic. Prior to 2000, DFO sampled salmon opportunistically. The salmon collection program offers a monetary reward for the delivery of salmon carcasses and basic catch information (date and location). Commercial and subsistence harvesters from Fort McPherson, fishing on the Peel River have turned in or reported their salmon to DFO. Chum salmon are the dominant species turned into the program for the Peel River in recent years (Linn, unpublished data).

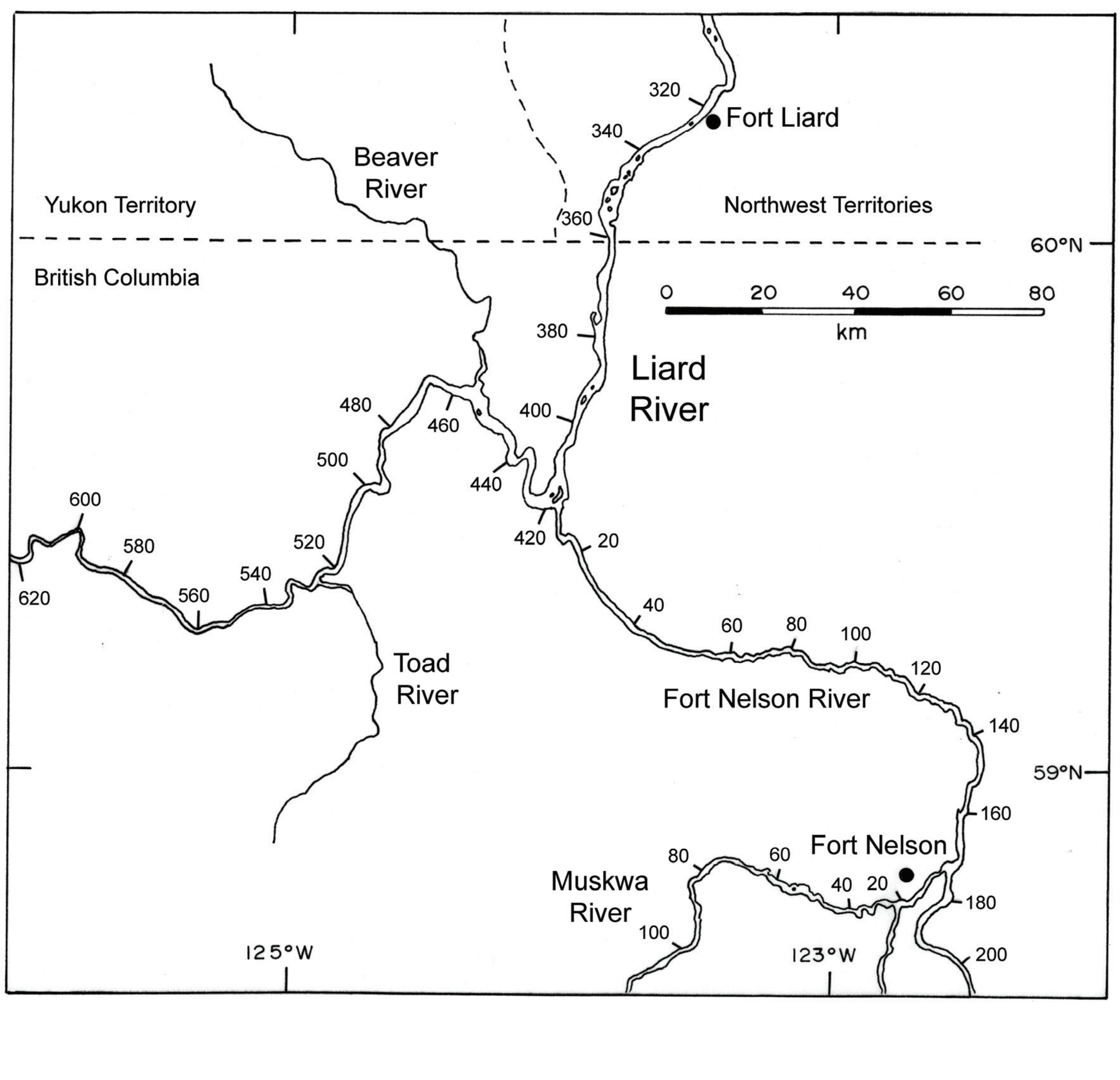
LIARD RIVER WATERSHED SALMON

The Liard River and tributaries were the site of intensive fishery investigations during the late 1970's as part of studies evaluating potential impacts of proposed hydroelectric development. Much of the results in this report have been adapted from unpublished reports and data gathered during these studies. We present these results in considerable detail in order to permit comparisons with chum population data from other systems.

The Liard is a large pristine tributary of the Mackenzie River draining 275,000 km^2. Flows are lowest during late winter, increase in late April and May to a peak usually in June. This is followed by a gradual decline to winter low flow. The average annual discharge at the mouth of the Liard River is 2440 m^3 s^{-1} (Burn *et al.* 2004).

The area investigated during 1978–80 included the mainstem Liard River and tributaries downstream from where the Liard enters British Columbia at the Yukon border, to the confluence of the Liard River and Mackenzie River at Fort Simpson, Northwest Territories (Fig. 1). Here we focus on results from the area below the Grand Canyon of the Liard where anadromous fish were caught (Fig. 2, primarily downstream of Km 540).

FIGURE 2. Liard River and tributaries.
Distance markers are kilometres upstream from major tributary confluences.



METHODS

Two main study sites for field work were established—a lower site near Km 330 at Fort Liard in the Northwest Territories, and an upper site near a possible dam location at Km 477 (Fig. 2). Additional sampling occurred outside these areas as needed to provide specific information on species range and distribution. Fish were sampled over three years, July–October 1978, July–November 1979, and February–October 1980. Here we summarise relevant results from work investigating migratory fish populations, specifically *Oncorhynchus*.

FISH CAPTURE

Various capture methods included gill nets, electrofishing, hoop traps, set traps, beach seines, and fry traps. Monofilament gill nets were the only method that caught adult salmon. These nets, 2.4 m deep and 15.2 m long were set in deep backeddies and side channels and checked 1–4 times daily. Various mesh sizes were experimented with (1.9, 3.8, 6.4, 8.9, and 10.2 cm). Catch per unit effort (CUE) was calculated as catch per 24 hours in 100 m^2 of each mesh.

Fish lengths were measured using measuring boards and weights using a Chatillon Model 1038B spring scale or Hanson Dietary Scale. Sex and maturity were determined through observation of external characteristics, dissection, and/or release of sexual products. In some cases the ovaries were removed to estimate fecundity by weighing a known number of eggs and then estimating total egg numbers from the ovary weight. Salmon were aged by examining scales collected from the area immediately below the anterior insertion of the dorsal fin on the left side of the fish. Most salmon were released alive after the attachment of Floy FD67 Anchor Tags into the dorsal musculature immediately below the insertion of the dorsal fin. Fish kept for further study were preserved in 10 percent formalin and later transferred to 37 percent isopropyl alcohol.

Various sampling techniques were tested in an attempt to capture salmon smolts and other juvenile fish during 3 to 26 May 1980. An inclined plane trap proved too unwieldy because of high water velocities and debris. A 2-m-long, tapered net towed from a small boat successfully captured larval fish, but since no salmon were caught, these results are not discussed further.

RADIO TELEMETRY

In 1979 and 1980, movements of selected fish species including chum salmon were monitored with two radio-tracking systems. The system from Smith-Root Incorporated, Vancouver, Washington, U.S.A. and a prototype system from Sensory Systems Laboratories Ltd., Edmonton, Alberta, Canada differed in functional characteristics (frequency, signal identification, transmitter size, and antennae).

Radio transmitters were attached by either stomach insertion or surgical implantation into the body cavity. The larger Smith-Root transmitters were inserted through the mouth into the stomach; some of the smaller Sensory Systems units were also inserted this way while others were surgically implanted. Most fish were held for 12–24 h after tagging to monitor fish condition and check for tag regurgitation. Fish were individually checked with a hand-held antenna to ensure correct functioning of the transmitter before being released.

Tracking was conducted periodically using a fixed-wing aircraft (Cessna 185) supplemented by short helicopter surveys (Bell 206B). Code identification of Sensory Systems transmitters required a variable number of low altitude passes at 30 to 100 m above river elevation after tagged fish were located. Fish were radio-tagged at both field sites (i.e., near Fort Liard and further upstream near km 477) in 1979 and 1980 (Fig. 2). However, most fish were radio-tagged at the upstream site.

POPULATION ESTIMATION

Estimating the size of migratory populations in a large remote river is extremely challenging. Two approaches were used to determine the approximate number of chum salmon in the Liard River, mark recapture (1979 only; stratified Schaefer and pooled Peterson estimates (Ricker 1975)), and expansion of capture efficiency data (1979 and 1980).

To estimate population sizes by mark recapture, fish captured at Fort Liard in 1979 were tagged with Floy Tags and the ratio of tagged to untagged fish was determined at Km 477. Sampling was assumed to be random, and tag loss to be negligible.

Capture efficiency data were expanded to estimate population size (N) according to:

$N = CUE \bullet Ef \bullet P \bullet T$

where CUE = average number of fish/day/capture unit over the migration period, Ef = estimated gill net capture efficiency, P = proportion of available channel width available for migration sampled, and T = total upstream migration period (days).

We are well aware of the limitations of these approaches to estimate population sizes. While accuracy and precision are unknown, our estimates should nevertheless provide some indication of the approximate magnitude of the runs.

RESULTS

CHUM SALMON

A total of 165 adult chum salmon were captured in the Liard River by gill nets set during 1979 and 1980, plus 81 in the domestic fishery at Ft. Liard (Table 1). No salmon were caught during somewhat less intensive sampling during 1978. All salmon caught were in good physical condition, with few frayed fins or wounds, suggesting relatively easy passage conditions, and few predators.

Size, Age, and Sex Composition

Chum salmon captured at the two study locations ranged between 55 and 78 cm fork length (Fig. 3) and 2000 and 6200 g (Fig. 4). Four year old fish predominated, with some three and five year olds also caught (Fig. 5). Approximately 61% of the catch was males, and 39% females (Fig. 6).

In 1979, the spawning run was made up of age 3 (1976 brood year) and age 4 (1975 brood year) fish (Table 2). Of the total aged sample (n = 71), 28% were age 3 and 72% were age 4. In the smaller 1980 sample (n = 14), 79% were age 4 (1976 brood year) and 21% were age 5 (1975 brood year). These results confirm that successful spawning occurred during two consecutive years, 1975 and 1976.

Age 4 fish captured in 1979 were the only age group with an adequate sample size to test for differences between sizes of males and females. Males ($\bar{x}$ = 68.3 cm; S.D. = 3.46; n = 29) were significantly longer (Student's t-test; $P<0.05$) than females ($\bar{x}$ = 65.6 cm; S.D. = 3.53; n = 19). Similarly, males ($\bar{x}$ = 4127 g; S.D. = 475.4; n = 22) were heavier than females ($\bar{x}$ = 3596 g; S.D. = 592.2; n = 18). The maximum fork length of 78 cm was for a male captured at Km 477 in 1980, while the maximum weight of 6250 g (13.8 lb) was for a male collected at this site in 1979.

Length and weight frequencies by age and sex (Table 3, Figs. 7–8) confirm the tendency of older fish to be largest, while differences between males and females were not consistent. The median fork length for all salmon caught was 66.7 cm. The median fork length for males was 68.5 cm (age 3 = 63.5 cm; age 4 = 68.7). Female median fork length was 66.1 cm (age 3 = 64.8 cm; age 4 = 66.4 cm). The median weight for all chum salmon was 3820 g. Median weights for all males, age 3 males, and age 4 males were 3975 g, 3550 g, and 3968 g, respectively. Median weights for all females, age 3 females, and age 4 females were 3700 g, 3662 g, and 3750 g, respectively.

Since the slopes and intercepts of length weight regressions did not differ between years or locations, we pooled these data. The length-weight relationship for chum salmon (n = 90) captured in the Liard River in 1979 and 1980 was $W = (9.84 \bullet 10^{-7}) \bullet L^{3.39}$ ($r^2 = 0.93$).

.Age-length data for chum salmon captured at Km 477 during 1979 and 1980 and at Fort Liard in 1979 are presented in Table 3. In order to enable comparisons of growth rates of Liard chum salmon with chum from other locations, average lengths at age were computed for salmon captured at Km 477, assuming scale growth was proportional to fish growth (Table 4).

Fecundities were determined for eight female chum salmon captured from the Liard River in 1979. Egg counts ranged from 1961 to 3911, the mean fecundity of the samples was 2986 (S.D. = 609).

Adult Migration

In 1979, the first chum salmon was captured at Fort Liard (Km 330) on 24 September (Table 5). Chum salmon were not encountered at Km 477 until 9 October. In 1980 they appeared at Km 477, 10 days earlier than in 1979, on 29 September. Higher flows during the fall of 1980 compared to 1979 may have resulted in the earlier timing in 1980. Since there was no reduction in CUE in early November when ice conditions forced the end of sampling, we assume chum continued to enter the study area after sampling was finished.

A total of 35 chum salmon were marked with miniature radio transmitters and subsequently monitored by aircraft. Radio-tagged chum salmon ascended an additional 129 km above Km 477 near the upper limit of the Grand Canyon of the Liard River (Table 6). This appears to be the limit of all upstream fish movement in the Grand Canyon. Radio tracking surveys above this point, extending an additional 102 km upstream to the Fireside River, failed to record any tagged chum salmon. A ground inspection of the rapids and constricted channel section in the canyon area was conducted on 21 October 1979. The combination of high velocities and severe turbulence at approximately Km 610 appeared to present an impassable barrier to upstream fish movements. Radio-tagged chum salmon (or their carcasses or tags) were still detected below this point near Km 606 on surveys flown 27 November 1979 and 13 February 1980.

Due to the limited radio-tracking program conducted in 1980, chum salmon movements were not monitored as extensively as in 1979; however, sampling at Km 606 in late October 1980 indicated that chum salmon had again ascended to this point. Approximately 55% of the radio-tagged chum salmon were located during 1979 surveys (Table 6). Of these, one-half moved downstream, probably due to stress associated with the holding and radio-tagging procedures. Most of the salmon ultimately exhibiting upstream movement appeared to require several days to reorientate and continue their migration; during this orientation period they apparently drifted with the current or remained in a protected location.

Handling and tagging apparently affected some individuals more than others. For example, one radio-tagged individual released at Fort Liard travelled 330 km downstream to the Mackenzie River; it then migrated upstream in the Mackenzie River and was eventually captured at Fort Providence (below Great Slave Lake, Fig. 1).

Another individual, marked at Km 477 with a conventional Floy Tag, exhibited a similar movement pattern and was captured in the Mackenzie River by a native fisherman near Jean-Marie River (62 km above Fort Simpson). A third chum salmon was located, by radio-tracking, in a tributary to the Fort Nelson River. After being released at Km 477, this fish had moved downstream to the Fort Nelson River, then 245 km up the Fort Nelson and the Muskwa rivers (Fig. 2).

Based on mark-recapture data from the Fort Liard tagging and recoveries chiefly at Km 477, and radio-tracking data from individual fish, information was obtained on upstream movement rates of chum salmon (Table 7). Chum salmon exhibited a maximum upstream migration rate of 30.5 km/d from Fort Liard to Km 477. Measured movement rates may underestimate the movement of unstressed fish. The exact length of delay experienced by these fish is unknown; however, 19 chum tagged and released at Km 477 were subsequently recaptured at the same location (range 0.5–8.0 days). Between Km 477 and the Grand Canyon of the Liard River, measured movement rates were slower than they were downstream; however, sample size was low (n=2). The mean movement rate of the two radio-tagged fish was 8.9 km/d. Rapids within the lower Grand Canyon were apparently navigated without major difficulty, but higher water velocities upstream appeared to slow, and eventually stop, upstream migrations. In comparison, the mean migration rate for chum salmon in the upper Yukon was much greater, the mean migration speed was 37.9 km/day (Milligan *et al*. 1986) but these fish were initially radio-tagged much further from their spawning grounds than the chum in the Liard

Abundance

A total of 93 chum salmon were captured at Km 477 in the fall of 1979 (Table 1). During the same period 96 were captured at Fort Liard; 46 of these were taken in a small domestic net fishery. Capture data indicated, a smaller escapement in 1980, but sampling efficiency was considerably lower because of very high water levels and debris. A total of 22 chum were collected at Km 477 from late September to November 1980. Sampling was not conducted at Fort Liard in 1980; however, 35 chum were captured in two domestic gill nets maintained from September to early November.

A helicopter reconnaissance of the mainstem Liard River above the Fort Nelson River was conducted on 21 October 1979 in an attempt to locate and possibly enumerate spawning salmon. Visual reconnaissance by fixed-wing aircraft was also conducted on several occasions during camp servicing and radio-tracking flights. Attempts at visually locating salmon were unsuccessful due to high turbidity and the partially-frozen state of backwaters and nearshore areas; however, because of the large expanse of the study area and aircraft time limitations, these surveys were not exhaustive.

Mark-recapture estimates of the number of chum passing Fort Liard in 1979 were 245 (Schaefer) and 525 (Petersen). Assuming no loss of tags between Fort Liard and Km 477 (i.e., no spawning in this stretch of river or tributaries), these estimates also apply to Km 477. Catch/unit effort estimates made at two netting locations at Site 477 resulted in estimates of 400 and 390 chum salmon.

Based on the two approaches used to estimate population sizes, we estimate that ~400 chum passed Fort Liard prior to early November in 1979. The gill net catch in 1980 was approximately 30% of the 1979 catch; however, poor gillnetting conditions in the Liard River for most of October reduced capture success. Consequently we suggest that the 1980 escapement may have been as high as 50% of the 1979 total, or ~200 fish. Our estimates for 1979 and 1980 probably significantly underestimate the total population size since fish were still entering the study area at the end of sampling (Table 5).

FIGURE 3. Length frequency distribution of chum salmon (ages combined) from the Liard River, 1979–1980.

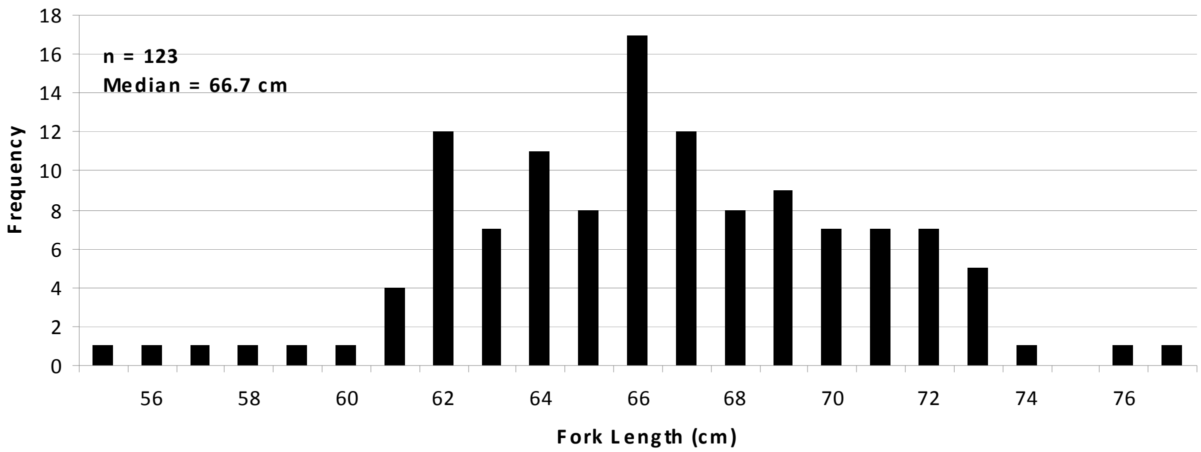


FIGURE 4. Weight frequency distribution of chum salmon from the Liard River, 1979–1980.

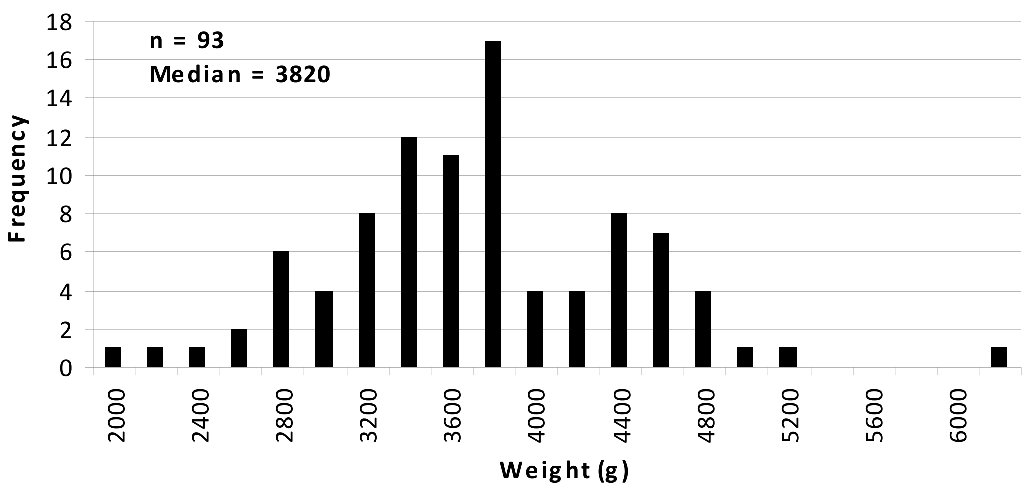


FIGURE 5. Percent age composition of chum salmon from the Liard River, 1979–1980.

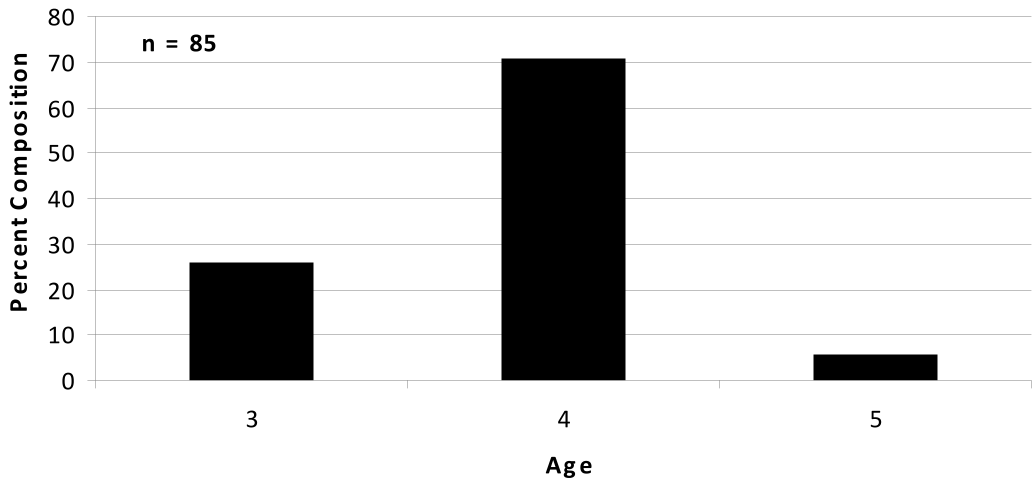


FIGURE 6. Percent sex composition of chum salmon from the Liard River, 1979–1980.

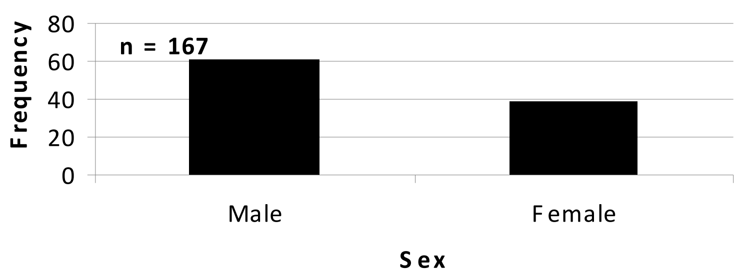


FIGURE 7. Length frequency distriution of male and female chum salmon from the Liard River, 179–1980.

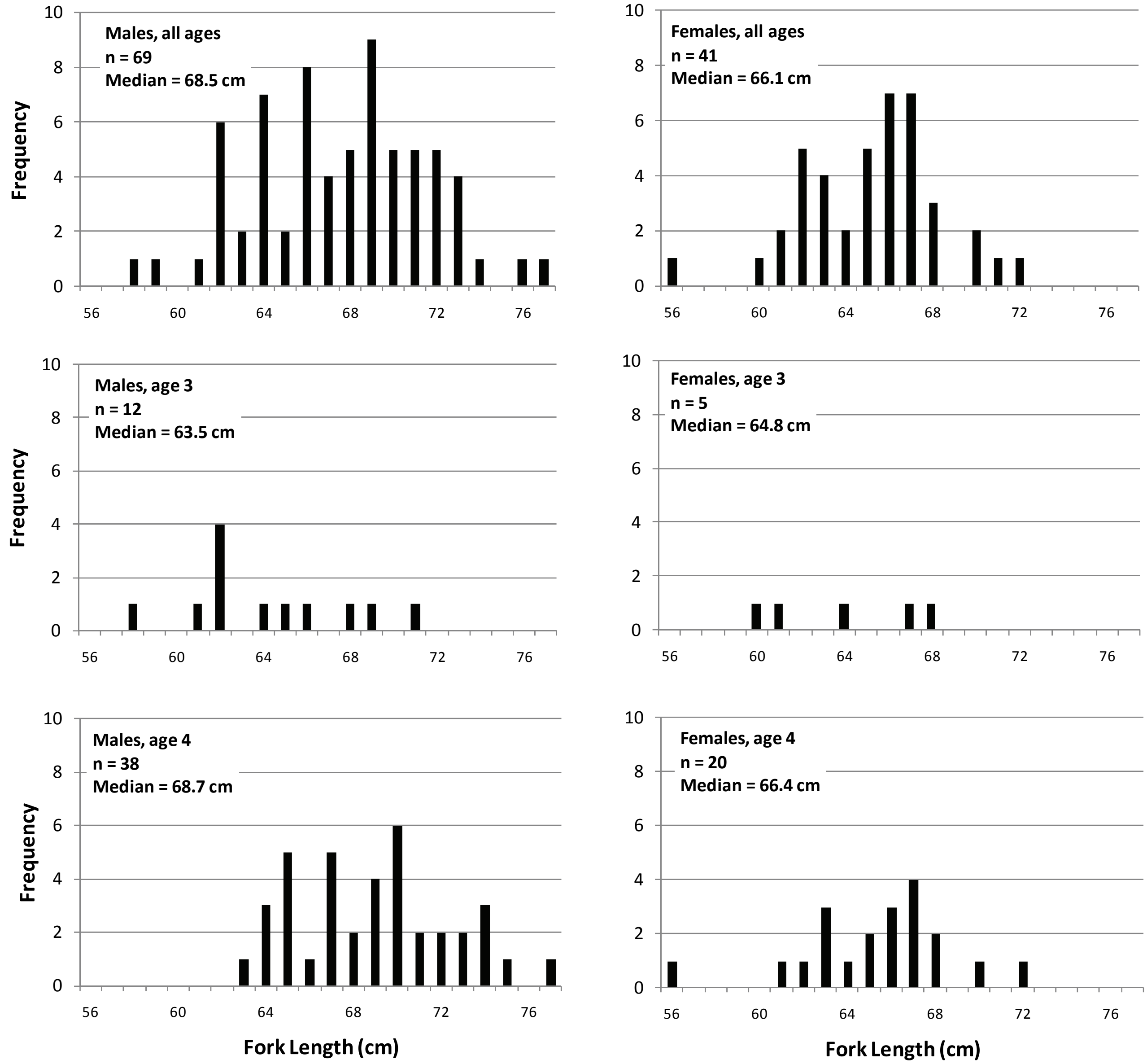


FIGURE 8. Weight frequency distribution of male and female chum salmon from the Liard River, 1979–1980.

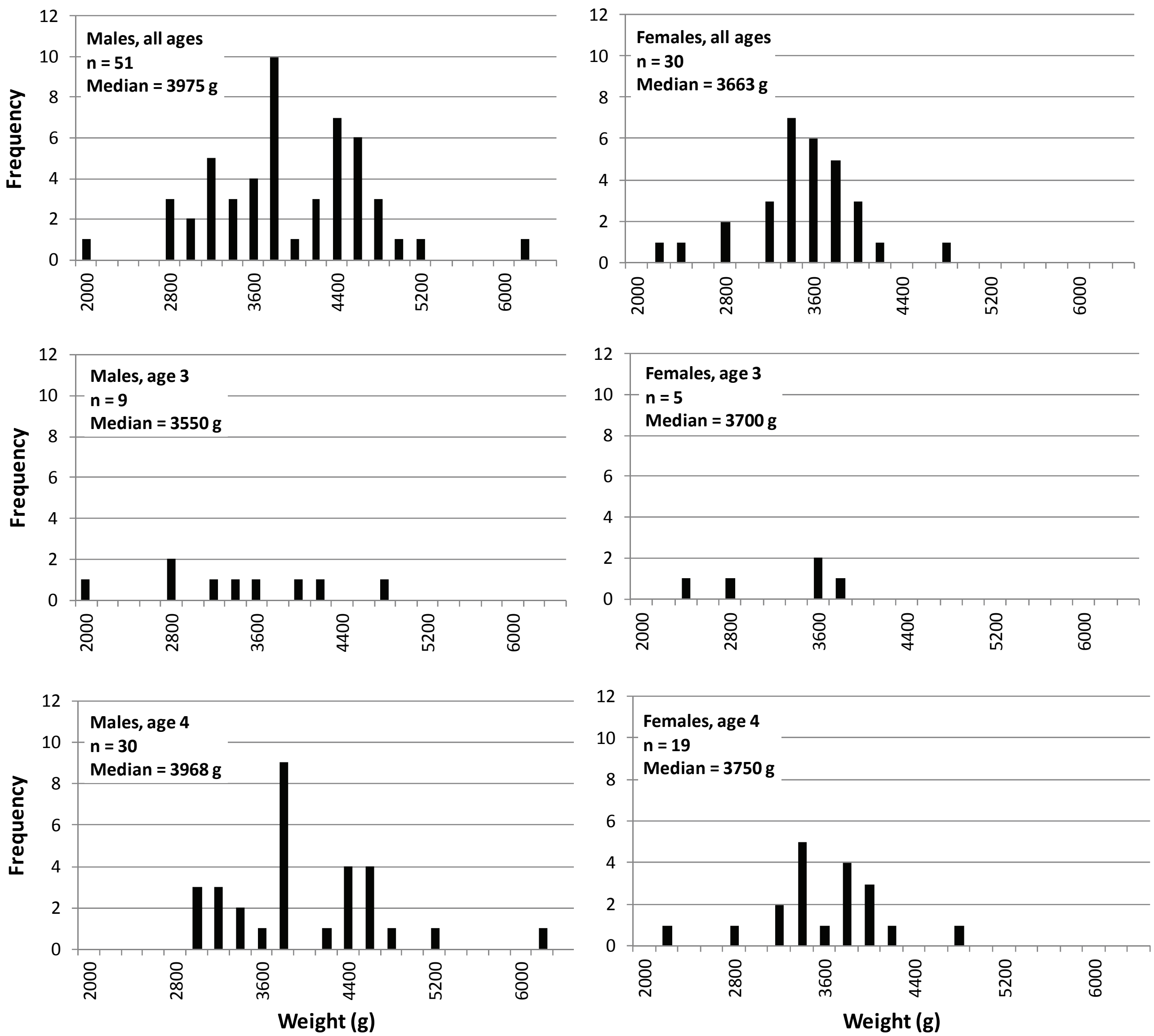


TABLE 1. Summary of adult chum captures in the Liard River in 1979 and 1980.

	Method	1979	1980	Total
Fort Liard	Experimental Gillnet	50		50
Fort Liard	Domestic Fishery	46	35	81
Km 477	Experimental Gillnet	93	22	115
Total		189	57	246

TABLE 2. Age composition of chum salmon captured in the Liard River by brood year.

	Returns at age 3		Returns at age 4		Returns at age 5	
Brood Year	Capture Year	Number	Capture Year	Number	Capture Year	Number
1975			1979	51	1980	3
1976	1979	20	1980	11		

TABLE 3. Age-length relationships (by sex) for chum salmon from the Liard River, 1979 and 1980.
FL=mean fork length (cm); POH = mean post-orbital hypural length (cm).

		Fort Liard 1979			Km 477 1979			Km 477 1980		
Age	Sex	n	FL	POH	n	FL	POH	n	FL	POH
3	male	6	64.6	52.1	6	65.2	52.4			
	female	3	64.5	53.5	3	66.4	54.7			
4	male	8	68.1	55	16	68.6	55.9	4	67.6	56.5
	female	8	67.5	55.7	10	65	.	2	67.7	55.6
5	male							2	70.1	56.9

TABLE 4. Mean back-calculated fork length of each age class for chum from Km 480, 1979.

Age at Capture	N	Measured Length (mm)	Back-calculated length (mm) Age 1	Age 2	Age 3
3	19	648	306	523	
4	47	671	278	478	612
Age classes combined	66		286	491	612

TABLE 5. Gill net CUE (chum catch/24 h/100 m²).

			Net Days	Net Area m^2	CUE
Fort Liard	1979	10-17 Aug	2.7	144	0
		17-24 Aug	3.6	144	0
		24-31 Aug	7.4	144	0
		31 Aug-7 Sept	10.7	144	0
		7-14 Sept	7	144	0
		14-21 Sept	11	144	0
		21-28 Sept	15.6	144	<0.1
		28 Sept-5 Oct	13.2	144	0
		5-12 Oct	17	144	0.3
		12-19 Oct	13.9	144	1.1
		19-26 Oct	8.8	144	1.5
Km 477	1979	27 Jul-3 Aug	4.1	144	0
		3-10 Aug	3.6	144	0
		17-24 Aug	1	144	0
		24-31 Aug	11.4	144	0
		31 Aug-7 Sept	11.3	144	0
		7-14 Sept	11.3	144	0
		14-21 Sept	9.8	144	0
		21-28 Sept	11.2	144	0
		28 Sept-5 Oct	15.6	144	0
		5-12 Oct	13.5	144	1.1
		12-19 Oct	18	144	1.2
		19-26 Oct	15.5	144	0.9
		26 Oct-2 Nov	13.1	144	1.2
Km 477	1980	30 Apr-4 May	4	72	0
		4-11 May	4.1	144	0
		11-18 May	7.9	144	0
		18-25 May	3.9	72	0
		25-31 May	6.3	108	0
		28 Sept-5 Oct	9.8	180	0.1
		5-12 Oct	6.3	180	0.1
		12-19 Oct	9.3	180	0.4
		19-26 Oct	12.1	180	0.3
		16 Oct-2 Nov	14.3	180	0.2
		2-5 Nov	7	180	0.1

TABLE 6. Movements of radio tagged chum salmon, Liard River, 1979 and 1980.

			Survey Date and Movement Upstream (+) or Downstream (-) from Release Site															
	Release		October 1979							November 1979					Feb. 1980	Oct. 1980		
Fish (Tag Code)	Location (km)	Date	11	14	17	20	24	29	30	1	2	3	27	28	13	28	30	Other
1979																		
6	483	13 Oct					-83											
10	483	13 Oct						+123	+123				+123		+123			
18	483	13 Oct						+123					+123		+123			
20	483	13 Oct											(301)[a]					
21	336	16 Oct								+93								
23	336	16 Oct						+143	+147									
24	336	18 Oct							+227									
30	336	16 Oct						+251	+261		+270		+270		+270			
34	332	25 Oct								-11								
37	336	16 Oct																(585)[b]
45	336	18 Oct								-143								
46	483	13 Oct				(-2)[c]							-430		-430			
4-57	483	13 Oct						+57	+69		+30							
8-124(1)	483	13 Oct						-5										
8-124(2)	332	25 Oct								+26								
9-57	347	9 Oct								-232								
1980																		
7	478	27 Oct														0	0	
17	478	27 Oct															-32	
Total chum salmon radio tagged - 35					Tracked or Recovered - 18					No Record - 17								

[a]Located at km 63, Muskwa River. Total Distance from release site 301 km.
[b]Recovered from the Mackenzie River at Fort Providence; Oct 19 1980 (249 km above Liard/Mackenzie confluence).
[c]Recaptured in net, released

TABLE 7. Upstream movement speeds of chum salmon recorded in selected reaches of the Liard River, October 1979[a].

			Speed (km/d)			
From	To	Distance (km)	n	Min	Mean	Max
Fort Liard	Km 477	147	5	9	24.9	30.5
Km 477	565	88	2	4	8.9	13.7
Km 565	Km 606	41	1		13	

[a]both radio tags and conventional Floy tags

CHINOOK SALMON

One male chinook salmon was captured at Fort Liard on 12 October 1979. This individual was 67 cm in length and 2910 g in weight. The age was determined at 4_2, which means that this individual spent one full year in fresh water after emergence, and two winters in the ocean. This was the first confirmed record for a chinook salmon within the Mackenzie River watershed (McLeod and O'Neil 1983).

DISCUSSION

We agree with Stephenson (2006) that chum salmon are the only salmon species natal to the Mackenzie River watershed. Additional genetic analysis of chum and other salmon species captured in the Mackenzie and nearby areas would assist in determining patterns of relatedness and which species and populations may be natal to the area. The locations of chum salmon spawning sites within this vast watershed are poorly understood. The Peel River likely is one system habitually used by spawning chum salmon, but it is impossible to know for sure about the Liard. Chum catches in 1979 and 1980 and subsequent age analysis determined that these chum were the progeny of fish that spawned in 1975 and 1976. Population estimates for 1979 and 1980 (400 and 200 respectively) underestimated the true run size since chum were entering the system when sampling was terminated. Chum were not caught during intensive sampling in 1978, or during less intensive sampling in 1977. Similarly, attempts to capture salmon in the Liard in 2000 and 2001 were also unsuccessful, although one specimen was turned in at Fort Liard in 2003 (Dave Hamilton, pers. com.). However, the difficulty in capturing relatively uncommon fish migrating through a large turbid and remote river in fall and early winter cannot be over emphasised. The effort expended sampling the Liard River in the late 1970`s was huge, much greater than has been expended since.

Chum salmon tend to show an age gradient in relation to latitude. Southern populations are predominated by three and four year olds while four and five year olds are proportionally greater in northern regions (Salo 1991). Interestingly, while three year olds are common when one looks at Alaska chum in general (Table 7 in Salo 1991), chum salmon sampled in the Canadian portion of the upper Yukon River basin were predominantly four years old (up to 95% in some sample locations) (Milligan *et al.* 1986).

We compared the sizes of chum salmon from the Liard with chum from the Yukon River watershed as documented by Boyce (2001, 2002) and Boyce and Vust (2002), and Boyce and Wilson (2001). In the Porcupine River, tributary of the Yukon, for the four years we considered (1995–1998), returning chum ranged from three to six years with the majority being age three to five; age four fish were most common in all years. Liard chum were three to five years of age with four year olds being most abundant. Male and female chum caught in weirs in the Yukon did not differ in abundance, while in the Liard, males were caught most frequently, perhaps a result of sex-biased sampling by gill nets. When we compared the sizes of male and female chum of each age caught in the Liard with those in the Yukon, we did not find significant size differences, although in some cases, Liard sample sizes were small.

Chum found in northerly latitudes are a departure from their southern kin in that the distance they travel to reach spawning grounds can be far greater. Chum salmon found in the upper Mackenzie and Yukon watersheds migrate approximately 2000 km from the ocean. The added body mass that comes with an extra year of ocean growth may assist with long upstream migrations.

Groundwater is important to chum salmon in the upper Yukon River watershed, and probably also for chum in the Mackenzie. Spawning is often in groundwater discharge sites associated with alluvial fans (A. von Finster, pers. comm.). In the Klondike River, the highest densities of emergent fry are seen in mid May, and some fry are found near the spawning grounds until mid June or later. Chum downstream migration is essentially over by the first week in July (Bradford *et al.* 2008).

What is the likely impact of climate change on salmon in Canada's arctic rivers? While it is tempting to predict large increases in salmon abundance, there is little evidence this will be the case, at least in the short term. Before range extensions can be successful, habitats, food supplies, predators, and pathogens must be acceptable and dispersal routes must exist (Reist *et al.* 2006). Reist *et al.* speculate that while additional Pacific salmon may eventually colonise arctic areas, salmon (and other species) initially will probably exhibit increased variability in abundance associated with increased variability in the environment.

Sockeye, coho, and chinook salmon, because they generally spend at least one year in fresh water, will continue to have difficulty establishing themselves in the Arctic. Exceptions may occur in watersheds with significant groundwater input. Climate warming has increased the groundwater contribution to winter stream flow in the Yukon as a result of permafrost melting (Walvoord and Striegl 2007) and this is presumably occurring within the Mackenzie watershed as well. This potential benefit to salmon will be counteracted to some extent by additional sedimentation rates resulting from increased channel instability and landslides. The fact that kokanee (i.e., non-anadromous sockeye) have colonized regions of the upper Mackenzie (i.e., headwaters of the Peace River) (McPhail and Lindsay 1970) and are reported in Great Slave Lake (Babaluk *et al.* 2000) but have not established anadromous populations suggests to us that limiting factors may be present in the marine environment.

We predict that with climate change, numbers of chum salmon will increase and that pink salmon will eventually successfully colonise the Mackenzie watershed and regularly spawn. We do not foresee regular use of the watershed by coho, chinook or sockeye salmon, at least in the immediate future. Freshwater overwintering habitat will continue to hamper the survival of early life history stages of these three species, although increasing groundwater input may work to their favour. The main limiting factor for all species may be the winter marine environment. Conditions in the Beaufort and Chukchi seas are generally unsuitable for overwintering salmonids and while suitable conditions exist in the Bering Sea, this is a long distance from the Mackenzie watershed for salmon to migrate. Regular monitoring is needed to track changes in salmon abundance and future colonization; we also recommend additional genetic analyses of tissue from chum and other salmon species to help understand patterns of relatedness and which species and populations may be natal to the area.

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