POTENTIAL CAUSES OF SIZE TRENDS IN YUKON RIVER CHINOOK SALMON POPULATIONS

Prepared by

THE UNITED STATES AND CANADA
YUKON RIVER JOINT TECHNICAL COMMITTEE

SALMON SIZE SUBCOMMITTEE

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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SALMON SIZE SUBCOMMITTEE

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ABSTRACT

Concerns regarding the size and sex composition of Yukon River Chinook salmon *Oncorhynchus tshawytscha* have been expressed in public meetings for over a decade. However, reports of small size and low numbers of females have become increasingly common in recent years, and apprehension over the long-term health of the stock has grown within the drainage. In response to these reports, the Salmon Size Subcommittee of the US/Canada Yukon River Joint Technical Committee was formed and charged with advising the Committee, and thereby the US/Canada Yukon River Panel, with respect to changes in Chinook salmon age, sex, and size composition. This report, which summarizes the findings of prior investigations and the scientific literature on factors that influence salmon morphology, represents the first product of the subcommittee. Overall, evidence that the morphology of Yukon River Chinook salmon has been altered over time is limited, but suggestive. Existing analyses document a decrease in the mean weight of commercial harvests, a reduction in the prevalence of the largest fish, and the apparent near disappearance of age-8 fish. However, other important metrics, such as mean length-at-age, do not appear to have changed substantially. Whether the changes observed within Yukon River Chinook salmon have resulted from environmental or fishery-induced selective pressures, or a combination of both, is difficult to determine with certainty. In any case, the morphology of Yukon River Chinook salmon may be slowly changing. Expanded monitoring of age, sex, and size is warranted, as is directed research to identify causes and consequences.

Key words: *Oncorhynchus tshawytscha*, age, sex, length, morphology, commercial, subsistence, fishery, harvest, escapement, net selectivity, selective harvest, heritability, competition, survival, growth, adaptation, Bering Sea, Pacific Ocean.

INTRODUCTION

Yukon River Chinook salmon age, sex, and size trends have received much attention at recent fishery-related meetings. Anecdotal information and local knowledge suggests that the size of Chinook salmon has decreased and some fishers have expressed concerns over a reduction in their encounters with large fish. The subject has been discussed in U.S.-Canada Yukon River Panel (Panel) meetings, Joint Technical Committee (JTC) meetings, Alaska Board of Fisheries and Federal Subsistence Board meetings, and other forums that involve Yukon River subsistence, aboriginal, commercial, domestic and sport fishers. The Panel has directed the JTC to keep them informed of relevant information concerning salmon age, sex, and size trends. At a meeting in 2006, the JTC formed a subcommittee to undertake additional examination and analyses of age, sex, weight and length (ASL)[1] trends in Yukon River Chinook salmon. This subcommittee is referred to as the JTC Salmon Size Subcommittee. The subcommittee includes representatives of the U.S. Fish and Wildlife Service, Office of Subsistence Management, Yukon River Drainage Fisheries Association, and Bering Sea Fishermen's Association, and is co-chaired by representatives of the Alaska Department of Fish and Game (ADF&G) and the Department of Fisheries and Oceans (DFO) Canada.

The primary goal of the subcommittee is to assess and analyze ASL trends in Yukon River Chinook salmon. Specifically the subcommittee will:

(i) summarize existing literature relating to Yukon River Chinook salmon ASL composition and possible causes of size trends in salmon populations;

(ii) identify research themes and hypotheses that can be investigated with existing data;

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[1] ASL is a common fisheries acronym that normally refers to age, sex, and length, but is used more inclusively herein to also reference weight.

(iii) identify pertinent hypotheses and research themes that can not be investigated due to limitations of existing data, and make recommendations to the JTC for the collection of additional data that would support such investigations;

(iv) assess potential causes for changes in Chinook salmon ASL composition;

(v) develop timelines and determine financial and personnel requirements for completing these tasks; and

(vi) provide updates to the JTC, Panel, Federal Subsistence Board, Alaska State Board of Fisheries, ADF&G, DFO, and other interested parties.

This information summary represents the first step in compiling relevant information and literature and assessing potential causes for changes in Yukon River Chinook salmon ASL composition.

Ricker (1980) outlined several possible causes of change in salmon age and size composition, which were grouped into four general themes by Quinn (2005). The first theme describes the possibility that some of the declines in size may be due to statistical artifacts (biased data) and not to actual changes in the size of salmon. The second potential cause of change in size or age at maturity is genetic change resulting from selective reduction of stocks of large-sized fish or genetic selection against delayed maturity. The third theme involves environmental changes within ocean habitats including temperature, salinity, upwelling, and competition for food, which may influence salmon growth and size. Finally, the fourth theme addresses hatchery propagation of salmon, which may affect size and age at maturity of returning fish for reasons related to hatchery growth rates and the genetics of mating schemes, as well as increased ocean competition. Salmon populations are likely exposed to a combination of these possible causes of change in size and age of maturity (Quinn 2005).

The six sections of this information summary – history of the Alaskan Yukon River Chinook salmon harvest and fishery sampling, history of the Canadian Yukon River Chinook salmon harvest, summary of prior age, sex and size investigations, summary of Yukon River gillnet selectivity, heritability of traits and potential effects of selective fisheries, and oceanic influences on salmon size – will explore these themes in further detail. While not providing an exhaustive review of the subject, it is hoped that this summary will be useful to those interested in the ASL composition of Yukon River salmon. This summary may be used to develop hypotheses for further study that may directly answer remaining research questions of interest, or to inform discussions between fisheries resource users, management agencies, and policy makers on possible strategies for mitigating observed size and age trends.

HISTORY OF ALASKAN HARVESTS AND FISHERY SAMPLING OF YUKON RIVER CHINOOK SALMON

It is unlikely that exploitation has had no impact on Yukon River Chinook salmon stocks that have been harvested in subsistence fisheries for thousands of years and in commercial fisheries for nearly a century since humans invariably influence the characteristics of any resource they utilize. Hence it is important to consider the history of harvest of Yukon River salmon stocks to gain a better understanding of anthropogenic effects on the structure of the present population.

Rural residents in the Yukon area have depended upon fishery resources, including salmon, as a source of food for centuries. The first recorded commercial harvest of salmon in the U.S. portion of the Yukon River drainage occurred in 1903 (Pennoyer et al. 1965, Regnart 1975). However, it was not until 1918 that there was a commercial fishery for export in the lower 114 miles (182 km) of the river (Pennoyer et al. 1965, Carey 1985). Relatively large harvests of Chinook salmon (up to 105,000 fish) occurred from 1919 to 1921 using drift gillnets, set gillnets, and fish wheels. Due to concerns for the existing in-river subsistence fishery, fishing for export was prohibited inside the Yukon River in 1921, and from 1924-1931 the commercial fishery was closed in the entire Yukon Area, including coastal waters (Carey 1985). Commercial fishing was allowed again in 1931 and was managed by the federal government using various harvest quotas until statehood was granted in 1959. In 1934, the commercial harvest quota was increased to 100,000 Chinook salmon and in 1936, the quota was reduced to 50,000, of which not more than half could be harvested inside the mouth of the river. From 1954 to 1960, the subsistence fishery was closed on weekends, and a quota of 65,000 Chinook salmon was in effect for the Alaskan portion of the Yukon River (Vania et al. 2002).

In 1960, the State of Alaska assumed management of the fisheries, and ADF&G initiated regulation of the commercial and subsistence harvest of Yukon salmon stocks by imposing restrictions on gear, fishing areas, and fishing time, but did not restrict the amount available for subsistence harvest. In 1981, the Alaska Board of Fisheries implemented guideline harvest ranges for Yukon River Chinook salmon of 60,000-120,000 fish caught in Districts Y-1 and Y-2 (Vania et al. 2002). Between 1974 and 1984, the commercial fishery was managed with separate seasons for Chinook and summer chum salmon by allowing consecutive unrestricted mesh size gillnet periods early in the season followed by restricted or small-mesh gillnet (<6-inch stretch mesh) periods. Post 1984, unrestricted and restricted commercial periods were more intermittent. Concerns for possible over harvest of Chinook salmon runs resulted in some reduction in annual harvests starting in the late 1980s and continuing until the mid to late 1990s. Poor runs in the late 1990s and early 2000s resulted in a very restrictive management regime for Yukon River Chinook salmon commercial fisheries. In 2001, for the first time since 1931, commercial fishing in the Alaskan portion of the Yukon River drainage was closed completely.

Commercial fishing for Chinook salmon is currently allowed along the entire 1,224 mile (1,958 km) length of the mainstem Yukon River within Alaska[2] and in the lower 225 miles (360 km) of the Tanana River. The Coastal District, other than the Black River, is open for subsistence salmon fishing only. The majority of the commercial harvest still occurs in the lower Yukon area up to river mile 301 (km 482). Commercial fishing is conducted in the lower Yukon with set gillnets and drift gillnets, while in the upper Yukon, fish wheels are used in addition to set gillnets. Subsistence fishing is primarily conducted with the same gear types and many of the subsistence fishers are also commercial fishers.

Yukon Area subsistence salmon fishery and harvest information has been collected by ADF&G since 1961 (Borba and Hamner 2001). Documentation of the subsistence harvest prior to 1961 is limited. Subsistence and personal use harvests of Chinook salmon from 1975-2005 averaged about 44,000 fish per year; harvests averaged about 43,000, 53,000, and 49,000 Chinook salmon

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[2] Within Canada there are aboriginal, commercial, domestic and sport fisheries.

per year in the 1980s, 1990s, and since 2000, respectively (Figure 1). Since 1975, Chinook salmon have comprised about 13% of the total subsistence salmon harvest in numbers of fish.

The peak decadal harvest of Chinook salmon occurred in the 1980s, when almost 130,000 fish were commercially harvested per year (Figure 1). Commercial harvests in the 1990s and since 2000 averaged about 97,000 and 27,000 Chinook salmon per year, respectively. During the past 30 years, the annual subsistence harvests have remained relatively stable while the commercial harvests peaked in the 1980s and have been significantly reduced since 1998. The ratio of the commercial to subsistence harvest of Chinook salmon in the Yukon area during the years 1975-1997 averaged about 3:1, and since 1998 the ratio is about 1:1.

Age, sex, length, and weight data were first collected on the Yukon River as early as 1919 by researchers from the U.S. Bureau of Fisheries (Gilbert and O'Malley 1921, Gilbert 1922). However, it was not until the 1960s that these data were collected regularly. ADF&G began collecting ASL data on the commercial harvest in 1961 and has sampled annually since 1964 in Districts Y-1, Y-2, Y-5, and Y-6 (Table 1). Limited commercial harvests and associated ASL sampling have occurred in Districts Y-3 and Y-4. The current sampling goal is 400 Chinook salmon for the lower river and 160 for the upper river per commercial fishing period. In addition to ASL data, bulk commercial catch weights have been recorded annually since 1964 for the lower river and since 1974 for the upper river. However, data on harvest weight by gill net mesh size and the weight of individual fish are limited.

A small percentage of the subsistence gillnet harvest was sampled sporadically in the 1970s and 1980s in District Y-1 and in the 1990s in Districts Y-4 and Y-6. Sample sizes were generally small, which is largely attributable to the difficulty and expense of obtaining these data compared to commercial fishery data which are sampled at the processing plants. Since there was no commercial fishery in 2001, ADF&G implemented a sampling goal of 400 subsistence-caught Chinook salmon per season in the lower river. This sampling plan has been in place ever since. Sampling effort has increased recently in Districts Y-4 and Y-5 with the increasing involvement of non-governmental organizations (e.g., Yukon River Drainage Fisheries Association, Tanana Chiefs Conference, and Rapids Research Center) in sampling. Approximately 10,500 subsistence ASL sample records have been documented in the ADF&G database through 2005. Despite increased sampling effort, there continue to be large ASL data gaps from the subsistence fishery, particularly from the early part of the run (pre-commercial fishery) in the lower river and from the limited coverage of District Y-4.

In 1964, ADF&G implemented a test fishery at the mouth of the Yukon to index abundance for in-season run assessment and management. The test fishing projects primarily use 25 fathom set gillnets with 8.5 inch mesh to target Chinook salmon and 5.5 inch mesh to target chum salmon. In recent years, 50 fathom drift gillnets of 8.25 inch mesh have also been used to target Chinook salmon. These projects have been operated at Flat Island, Big Eddy, and Middle Mouth. Approximately 25,300 ASL samples have been collected from the test fishery through 2005. Historically, large-mesh (>8-inch stretch mesh) test fishing samples were only collected prior to the commercial fishing season and samples of Chinook salmon caught in small-mesh gillnets (<6-inch stretch mesh) were sporadic. The current sampling goal is 30 fish per day throughout the season at both the Big Eddy and Middle Mouth test fishing sites. In 2006, ADF&G added individual weights and girths to the sampling regime.

ADF&G also conducts test fishing in conjunction with the Pilot Station and Eagle sonar projects for the purposes of species apportionment. Both of these projects fish 25 fathom drift gillnets with mesh sizes of 2.75, 4.0, 5.25, 6.5, 7.5, and 8.5 inches daily. ASL samples have been collected at Pilot Station since 1998 and at Eagle since 2005. In 2005, weight and girth measurements were also recorded as part of a separately funded project.

Few studies have evaluated the ASL data from the mainstem Yukon River fisheries for trends in Chinook salmon size (Bigler et al. 1996, U.S./Canada Yukon River Joint Technical Committee 1998). This is largely due to the difficulty of accessing historical ASL data, which were previously stored in multiple formats and locations. Prior to recent interest in this topic, there was no impetus to expend the resources necessary to convert these data into an electronic format. Mean annual commercial weights are an exception, as data have been readily available in the ADF&G Area Management Reports. Recently, in response to the increased interest in the region, resources were appropriated to compile all the available ASL data from the Arctic-Yukon-Kuskokwim (AYK) region into a Microsoft Access database. This database is projected to be available to the public in July 2007 (L. Brannian, ADF&G, personal communication). With this increase in data accessibility, it should soon be possible to examine the commercial harvest and test fishery ASL data for trends over time, not only in the Yukon River, but in other Bering Sea tributaries such as the Kuskokwim and Nushagak rivers as well.

HISTORY OF CANADIAN HARVESTS OF YUKON RIVER CHINOOK SALMON

Indigenous people who inhabited the Yukon River drainage were dependent upon wild foods for survival and relied heavily on fish (Seigel and McEwen 1984). This reliance was reflected in the aboriginal life styles and annual patterns of movement, which brought people together where fish were abundant. According to Osgood (1971), the Han Indians in the Dawson area relied so heavily on salmon that the amount of their hunting activity was inversely proportional to the amount of salmon available. Seigel and McEwen (1984) present a figure of historic aboriginal fishing sites within the Yukon Territory, which is profound in the sense that it shows widely dispersed aboriginal fishing camps which are generally associated with known Chinook salmon spawning areas.

Modern day commercial fishing within the Canadian Yukon River drainage began circa 1885, when aboriginal fishers increased their harvest for sale or trade to pioneer prospectors in the Fortymile area (Seigel and McEwen 1984). A large market for locally caught salmon developed when the population of Dawson City rapidly increased to 40,000 people in 1898 during the Klondike Gold Rush. In 1899, the Royal North West Mounted Police were assigned oversight of the fishery, followed a year later by appointment of a designated Fishery Inspector to monitor catches in the region. In 1903, the first Fishery Inspector's report was filed, however initial reports were largely qualitative and focused on the protection of non-salmon fish species (Seigel and McEwen 1984).

In the early 1900s, most commercial salmon fishing was conducted with nets in eddies or by drift nets. Regulations for the salmon fishery first appeared when fishery regulations were consolidated in 1915. Net lengths of 2000 yards (1828.8 m) of 4 inch (10.2mm) mesh size for chum salmon and 100 yards (91.4m) of 6 inch (15.2mm) mesh size for salmon generally were allowed for commercial salmon fishing in 1915. These regulations remained unchanged until

1961. Fish wheels were legalized for use in the Yukon Territory in 1917. The total landed weight (pounds) of salmon caught within the 1904-1947 period is available; however, annual reports do not distinguish between Chinook and chum salmon. The current Yukon Fishery regulations allow each commercial fisher to use: four gillnets with a maximum total length (all nets) of 98 yards (90m); or three fish wheels; or two fish wheels and two gillnets (maximum total length 49 yards (45m)); or one fish wheel and three gillnets (maximum total length 71 yards (65 m).

Chinook salmon are currently harvested in aboriginal, commercial, domestic and sport fisheries. A summary of catches for the 1961 to 2005 period (JTC 2006) is presented in Table 2. Set gillnets are the primary gear used in the aboriginal, commercial and domestic fisheries, although some aboriginal and commercial fishers also use fish wheels. Most commercial fishers currently use an 8.0 (20.3 mm) to 8.5 (21.6 mm) inch mesh size during the Chinook season. The mesh sizes used in the aboriginal fishery and domestic fisheries are generally smaller than what is used in the commercial fishery, although there has been no recent census to determine the most common mesh size used.

Chinook salmon are caught by aboriginal people throughout the Yukon and catches are annually recorded in the following communities: Old Crow; Dawson City; Mayo; Pelly Crossing; Ross River; Carmacks; Whitehorse; and Teslin. Many of the aboriginal communities are located in headwater areas. For example, Ross River and Teslin are located 1,602 (2,563 km) and 1,780 (2,848 km) miles, respectively, from the mouth of the river.

The commercial fishery occurs in two discrete areas; the lower area is located between Sheep Rock (approx. 12 miles (19 km) upstream of the U.S./Canada border) and the White River confluence, and the upper fishing area is situated on the mainstem Yukon River between the White River confluence and the Tatchun Creek confluence and includes the lower sections of the Stewart and Pelly rivers. Dawson City, where most commercial fishing occurs, is located 1,319 miles (2,110 km) from the river mouth. Within the Stewart River, commercial fishing is permitted downstream of the confluence of the Stewart and McQuesten rivers. Within the Pelly River, commercial fishing is permitted downstream of the confluence of the Pelly and Macmillan rivers.

The marketing of Yukon River Chinook salmon caught in the commercial fishery has often been hampered by inadequate long-term storage facilities. In 1980, Moosehide II River Transports, a company which operated a fish packing barge and bought salmon from fishers along the Yukon River near Dawson City was established, but the venture was unsuccessful and folded in 1982. In 1982, a fish processing plant, Han Fisheries Ltd., was established in Dawson City. The plant had the capacity to freeze 10,000 pounds of fish daily and store 100,000 pounds of fish. Han Fisheries Ltd. operated until 1995 and ventured into Chinook salmon value added products as well as chum salmon roe (caviar). The highest Chinook salmon commercial harvest occurred in 1988 when 13,217 were recorded. At the present time, most commercially caught Chinook salmon is sold locally in Dawson City as a fresh or frozen product. Two fishers process a value added product (vacuum packed smoked fish) and the recently formed Yukon Salmon Cooperative is attempting to develop a Yukon processing facility, value added products, and markets within and outside the Yukon Territory. There were 21 eligible commercial license holders in 2006.

The domestic fishery involves non-aboriginal fishers who usually reside in remote locations. There were 7 eligible domestic license holders in 2006. The number of license holders in the domestic fishery has been constant for the last five 5 years and this fishery targets Chinook salmon. The Chinook salmon sport fishery takes place throughout the Yukon; however most fish are taken on the mainstem Yukon near the Tatchun Creek confluence. Sport fish catches are reported through a mandatory Yukon Salmon Conservation Catch Card program, which was introduced in 1999.

There have been unprecedented restrictions in Canadian Upper Yukon fisheries in recent years in response to poor Chinook salmon returns. In 1998, the sport fishery was closed, fishing opportunities in the commercial and domestic fisheries were severely restricted, and aboriginal harvests were voluntarily reduced. In 2000, the commercial, domestic and sport fisheries were closed and aboriginal harvests were voluntarily reduced. The reduced harvests in recent years (Table 2) have been attributed to a number of factors. However, there may be changes in First Nation catch allocations though basic needs agreements, which are under negotiation, and the commercial fishing industry is attempting to develop additional markets and products that will ensure a more viable fishery. The Yukon Salmon Committee, which is a public advisory body set up under the Umbrella Final Agreement, a land claims agreement, has recommended increased daily catch and possession limits in the sport fishery.

DFO has been systematically collecting ASL data from the border fish wheels since 1982 and some additional ASL data are available from fish wheel tagging programs which were conducted prior to 1982. Commercial fishery ASL data are available for the 1975 to 1996 period and fishery or test fishery data is available for most years since 1997. A recent initiative to document the availability of all Canadian Chinook salmon ASL data has confirmed that there is very limited Chinook salmon ASL data available from spawning tributaries (P. Milligan, DFO, personal communication). This initiative has confirmed that there is very limited Chinook salmon ASL data available from spawning tributaries. Historic escapement sampling efforts were usually conducted opportunistically due to funding limitations; hence, where data are available, the time series is typically short. The Yukon River Restoration and Enhancement (R&E) Fund has provided an opportunity to improve the Canadian ASL database through the inclusion of mandatory ASL data collection from all applicable Yukon River R&E funded programs. The collection of ASL data, for example, is a required component at the Blind Creek weir, a tributary of the Pelly River, and carcass sampling was incorporated into the Big Salmon River sonar program in 2006.

A SUMMARY OF EXISTING AGE, SEX, AND SIZE INVESTIGATIONS FOR YUKON RIVER CHINOOK SALMON

Several studies have evaluated the available data looking for trends in the ASL composition of Yukon River Chinook Salmon. In 1997, the JTC compiled available information at the request of the treaty-negotiating delegations. The JTC examined length-at-age over time in six locations using a combination of commercial fisheries data (unrestricted mesh size), test fishing data, escapement data, and Canadian mainstem assessment data. The data sets available at the time of the analysis were: the Y-1 commercial fishery (1962, 1964-1968 and 1979-1997), Big Eddy test fishery (1979-1997), Andreafsky River escapement (1981-1997), Salcha River escapement (1982-1997), Canadian border fish wheel (1974-1996), and Canadian commercial fishery (1975-

1996). The JTC length-at-age data analysis concluded that no substantial change in Chinook salmon size had occurred over the period examined (U.S./Canada Yukon River Joint Technical Committee 1998). However, the report noted that: a) the data time series was more limited than the inter-generational knowledge that suggested size had decreased; and b) that although the length at age analysis did not indicate substantial change, a shift in the composition of catches by age and/or sex could account for perceived changes in the size of fish.

Bigler et al. (1996), as part of a study on the size trends in North Pacific salmon, analyzed the average weight data for Yukon River Chinook salmon caught in nearshore commercial fisheries. They reported a 17.5% decrease in the weight of commercially caught Yukon River Chinook salmon from 1975–1993. They also reported a 3.82% decrease in the length of four-year-old Chinook salmon, but found no change in the length of five- and six-year-old Chinook salmon caught during the same period. The study documented decreases in average body size in 45 of 47 North Pacific salmon populations, comprising five species from North America and Asia. The results suggested that there is a limitation to the salmon-sustaining resources of the ocean. The study concluded that environmental trends in the ocean environment increased salmon survivorship and coupled with the expansion of enhancement programs in the 1980s and 1990s, were probable factors in the ocean-wide reduction in the size of salmon.

To determine whether sex composition, length, age, and length-at-age of Chinook salmon in spawning escapements have experienced a basin-wide decline over time, Hyer and Schleusner (2005) examined escapement data from six long-term (9 or more years) ASL escapement data sets from the Andreafsky, Anvik, Gisasa, Salcha, Chena, and Big Salmon rivers. The data used in the analysis represents the longest time series of escapement data available within the Yukon River drainage (Figure 2).

Chinook salmon escapement samples were examined for trends in: (1) proportion of female Chinook salmon; (2) proportion of large (≥ 900 mm) Chinook salmon; (3) proportion of 6- (age-1.4) and 7-year-old (age-1.5) Chinook salmon; and (4) average length of 6- and 7-year-old Chinook salmon.

No basin-wide trends were found in the proportion of female Chinook salmon, the proportion of 6- (age-1.4) and 7-year-old (age-1.5) Chinook salmon, or the average length of 6- and 7-year-old Chinook salmon. While some changes were seen, there was no clear pattern to the direction (increase or decrease) of change. The geographic pattern of results made it difficult to conclude that there was a basin-wide trend over the study years.

Only the proportion of large (≥ 900 mm) Chinook salmon showed a basin-wide trend. Four of seven time series examined show significant decreases in the relative abundance of large Chinook salmon over time. Escapement data showed a 4% (95% CI ={2.0%-5.0%}) decrease per year in the in the proportion of large Chinook salmon in the Anvik River, a 2% (95% CI ={2.0%-3.0%}) decrease in the Chena River, a 2% (95% CI ={1.0%-2.0%}) decrease in the Salcha River, and a 7% (95% CI ={4.0%-10.0%}) decrease per year in the Big Salmon River. No significant trends were found in the data collected at the Andreafsky and Gisasa rivers weirs or during the Andreafsky River carcass surveys. Of the four data sets examined, the proportion of large Chinook salmon was the only one to show a declining trend in over half the time series.

One of the difficulties in evaluating the ASL composition of Yukon River Chinook salmon is the availability and variability of data on Yukon River salmon. The data used in all three of the studies mentioned above are both limited and are from a noncontiguous time series. While subsistence fisheries predate historical records and commercial fisheries have occurred on the Yukon River for over 100 years, most data sets reflect a relatively recent history of fisheries and their escapements. While anecdotal information exists, it is intermittent and often contradictory. Confounding these issues are changes in the environment, fisheries, gear type, and the protocols used to collect the data. The two primary explanations for the declines discussed above are selective fisheries and long-term variation in the ocean environment. Quite plausibly, the explanation for changes in the weight and/or length of Yukon River Chinook salmon represents the effect of both factors.

SUMMARY OF YUKON RIVER GILLNET SELECTIVITY

Most fisheries do not harvest fish with equal probability, but rather use fishing gear or techniques that preferentially select fish having desired characteristics, such as large size (Walters and Martell 2004). Most people would agree that large-mesh gillnets should tend to catch large fish, and this has been verified in numerous investigations. Similarly, at least one investigation suggests that fish wheels may preferentially select small Chinook salmon (Meehan 1960). Knowledge of gear selectivity can be useful in many aspects of fisheries research and management, such as in designing non-selective experimental gillnets or establishing mesh-size regulations.

Size selectivity (selectivity) investigations are usually characterized as either direct or indirect (Regier and Robson 1966). A direct investigation requires the size composition of the population to be known. Direct investigations are thereby most commonly implemented via a preliminary release of marked fish whose sizes are known (e.g., Pierce et al. 1994); the collection of all marked fish that are released then comprises the population under study. Although direct methods require very few assumptions, the requirement that the size composition of the population is known limits their utility.

Indirect investigations of selectivity are based on a comparison of catches in several varieties of gear that are fished on the same population, whose size composition is unknown. By conditioning on fish of a particular size, the relative magnitude of the catches among gears is proportional to gear selectivity. Most indirect investigations of gillnet size selectivity utilize an experimental gillnet comprised of multiple meshes (e.g., Carlson and Cortés 2003). One disadvantage of indirect estimation is that a functional form, or mathematical model, for selectivity must be assumed (Millar 1995). Millar and Fryer (1999) provide the most comprehensive modern reference for methods of estimating selectivity in indirect studies.

Although the scientific literature is replete with investigations of gear selectivity, the majority of the literature concerns species that are commercially targeted in marine waters. Comparatively few investigations of selectivity for salmon have apparently been conducted. Peterson (1954) studied the gillnet selectivity on Fraser River sockeye salmon. Several studies of the selectivity of gillnets for salmon in the North Pacific were published, primarily by members of a working group of the International North Pacific Fisheries Commission charged with developing methods to standardize catches (e.g., Manzer et al. 1965, Peterson 1966, Ishida 1967, and Tagaki 1975). The selectivity of gillnets for Skeena River sockeye and pink salmon was studied by Todd and Larkin (1971). With one exception, we are unaware of any published investigations of the selectivity of gillnets on Alaskan salmon in freshwater or nearshore marine waters. Although we have not attempted to search the gray literature, or unpublished agency reports or memoranda, we are aware of a 1981 report to the State of Alaska Board of Fisheries on the selectivity of gillnets for Cook Inlet Chinook salmon (ADF&G 1981). Appendices IX and X of that report contain limited information on gillnet selectivity for Chinook salmon from the Taku, Stikine, and Yukon rivers.

ADF&G fishes a variety of gillnets in association with the Yukon River Sonar project located near Pilot Station, Alaska. Gillnet catches are adjusted to account for fishing time and net selectivity, and the adjusted catches are used to apportion sonar estimates of abundance to species (e.g., Pfisterer 2002). A variety of net selectivity models and estimation methods have been used over the years, although the methods used were not always well documented. Maximum likelihood methods of estimating the parameters of a selectivity model are generally thought to be superior to other methods (Millar 2000), and those methods are now used for Yukon River Sonar (T. Hamazaki, ADF&G, personal communication). However, an assessment of the suitability of potential net selectivity models has only recently been completed.

Bromaghin (2004) used over 92,000 gillnet catch records obtained from 1990 to 2003 by Yukon River Sonar staff to evaluate the suitability of 38 candidate selectivity models for each of nine species groups. He found that a single selectivity model, based on a Pearson function, provided a good fit to the data for all nine species groups, and recommended its use for Yukon River Sonar. Bromaghin (2005) compared the fit of the Pearson model to that of models that have previously been employed in the literature. The Pearson model is currently used by ADF&G at Yukon River Sonar (T. Hamazaki, ADF&G, personal communication). Plots of the estimated selectivity of common mesh sizes for Chinook, summer chum, fall chum, and coho salmon are presented in Figures 3-6, respectively. In general, gillnets appear to be most selective for salmon whose length (mid-eye to fork) is nearly four times the stretch-mesh size of a net. However, it is important to note that selectivity estimates reflect tendencies only, and that nets of nearly any mesh can catch fish of nearly any size.

The estimates of net selectivity for Yukon River salmon provide valuable information for managers. At a minimum, we presume use of the new Pearson model has improved species apportionment at Yukon River Sonar. In addition, the estimates could be used to predict the length distribution of a harvest, given knowledge of the length distribution of the population being fished and an exploitation rate. Similarly, the estimates could be used to explore the effects of various maximum mesh size restrictions. While certainly informative, the results of such analyses should be used with some degree of caution. Yukon River salmon fisheries have complex temporal and spatial structures. The spawning migrations of individual populations, and age classes within a migration, have different run-timing, and fishing activity does not occur uniformly over the entire migratory period. Such temporal changes in the characteristics of fish available to a fishery and the prosecution of a fishery preclude use of selectivity estimates to make precise predictions.

While the work of Bromaghin (2005) represents the best available information on the gillnet selectivity of Yukon River salmon, additional questions merit further study. The current models of selectivity represent the relative probability of retention given contact with a net. No data to investigate the presence of species, gender, or size heterogeneity with respect to vulnerability to nets, or the ability to detect and avoid nets, currently exists. Similarly, current models assume that each mesh size is equally effective for fish of an optimum size, i.e., all selectivity models have a maximum height of 1.0. Although some direct selectivity studies of other species challenge the assumption of equal peak efficiency (e.g., Mattson 1994), peak efficiency can not be estimated with indirect methods and a more logical assumption is not apparent. Future research into these issues would require the use of direct techniques, a supremely challenging task in the Yukon River, or the application of new technologies.

HERITABILITY OF TRAITS AND POTENTIAL EFFECTS OF SELECTIVE FISHERIES

Biologists and conservationists are increasingly concerned by the phenotypic changes, such as reduced size and age, being observed in exploited fish populations worldwide. Any number of forcing factors may underlie change occurring in any particular fish population. However, a suspicion that the genetic structure of many populations is being altered by selective exploitation is now widespread, and supported by a growing body of evidence (e.g., Loder 2005). That fisheries have the potential to alter population genetics is not surprising. Most fisheries preferentially harvest larger or older individuals (Walters and Martell 2004), characteristics that can directly affect the productivity of many fish species.

Numerous investigations have documented changes in phenotypic characteristics of exploited fish populations, most frequently declines in average size, age, or age-at-maturation. Many of these investigations concern fisheries for long-lived marine species. The reduced abundance, size, and age-at-maturation of northwest Atlantic cod (*Gadus morhua*) during the latter portion of the 20th century is perhaps the most familiar example (e.g., Trippel 1995, Olsen et al. 2005). Levin et al. (2006) described shifts in the species composition of demersal fish along the Pacific coast of the United States, and found that average fish size declined by nearly 50% over two decades. Rijnsdorp et al. (2005) reported an increase in the proportion of body weight being invested in reproduction by North Sea plaice (*Pleuronectes platessa*). A review by Law (2000) lists numerous examples of both increases and decreases in size-at-age and size-at-maturation in several marine fisheries, as well as Pacific salmon. The Food and Agriculture Organization of the United Nations recently estimated that nearly 25% of the world's marine fisheries are either overexploited or depleted (FAO 2004). Given the examples listed above and the fact that most fisheries are selective, it is reasonable to presume that the phenotypic structure of many marine fish populations has been altered.

Examples of modified population structure in salmon are either less frequent or less well documented, but the number appears to be increasing in recent years. Ricker (1981) documented substantial declines in the mean weight of harvested Chinook, coho, and pink salmon from the early 1950s to the mid 1970s, though the trends did not all persist (Ricker 1995). Similarly, Bigler et al. (1996) reported declines in the weight of Pacific salmon in 45 of 47 populations examined, including Yukon River Chinook, coho, and chum salmon. Among the populations examined by Bigler et al. (1996), the mean relative reduction in weight from 1975 to 1993 was almost 15%. Hyer and Schleusner (2005) found a declining trend in the relative abundance of the largest Chinook salmon (≥ 90 cm) in the escapements to four of the seven Yukon River tributaries they examined. Changes in population characteristics other than weight have also been documented in salmon. For example, Ricker (1981) reported a reduction in the mean age of Chinook salmon. Quinn et al. (2002) described a shift in the run-timing of both Chinook and coho salmon from three hatcheries in Washington and Quinn et al. (2006) documented a long-term decline in weight, as well as a change in run-timing, of Atlantic salmon (*Salmo salar*) in Ireland.

While a conclusion that fundamental characteristics of many exploited fish populations have changed, and are changing, seems unavoidable, attribution of cause is much more difficult. For salmon, deleterious effects of fishing on life history have been suspected for a long time, even before a genetic basis for any of these traits was demonstrated. Rutter (1904) argued that harvest of Sacramento River Chinook salmon enhanced reproductive success of smaller, younger males and would lead to a reduction in adult size. Smith (1920) expressed concern that removal of immature salmon in ocean harvests would reduce future yields, presumably through earlier maturity. Whether such scenarios would materialize depends on both the degree of genetic influence on these traits of interest and on the intensity of selection imposed by fishing.

A relatively small number of experiments have documented substantial genetic influence on variation in numerous characteristics of salmon populations. Several investigators have demonstrated a link between the age of breeding adults and the maturation age of the progeny. For example, Iwamoto et al. (1984) found that coho salmon jacks (precocious males) produced 4.6 times as many jacks as did older males. Similarly, Hankin et al. (1993) conducted breeding experiments with Chinook salmon and found that the heritability of maturation age was relatively high and differed by gender. Interestingly, they also found that the maturation age of females was independent of the age of the male parent. Withler and Beacham (1994) provided estimates of the heritability of both body weight and flesh color in coho salmon. Funk et al. (2005) found that several morphological traits, including length, were heritable in pink salmon. Hard et al. (1999) found that both body size and shape of Chinook salmon are under partial genetic control. In addition, there is mounting evidence that selective exploitation may affect more complex characteristics of salmon populations than simply age or size. For example, Jonasson et al. (1997) found that the return rate of sea-ranched Atlantic salmon, as well as body weight, is heritable. McIsaac and Quinn (1988) and Hard and Heard (1999) provide evidence that there is a genetic component to a salmon's ability to home, i.e., return to its natal stream. An individual's ability to resist disease also appears to have a measure of genetic control (Hard et al. 2000, Hard et al. in press). Such experiments document the heritability of traits inherently linked to survival and reproduction, revealing a mechanism by which selective exploitation could alter population genetics and lead to the type of phenotypic changes being observed in fish populations worldwide.

An increasing number of investigators implicate over-exploitation and selective exploitation as factors altering the structure of fish populations. This appears to be especially common in the case of marine fisheries (e.g., Rijnsdorp et al. 2005, Levin et al. 2006). With respect to salmon, the attribution of cause is somewhat more varied. For example, Ricker (1981) concluded the declining trend in salmon size was mainly a result of selection by troll and gillnet fisheries against large size and rapid growth. However, subsequent analyses of size trends through the late 1980s indicated that some declining trends in size had reversed since the mid 1970s (Ricker 1995). An intriguing aspect of these patterns is that the period from the late 1970s to the early 1990s may have been less favorable for growth in eastern Pacific populations than during the previous quarter century (e.g., Hare et al. 1999). Quinn et al. (2002) concluded that fishery-induced selectivity (selection of brood stock) was stronger than opposing natural selective pressures in determining the spawning timing of Chinook and coho salmon. Hamon et al. (2000) concluded that selectivity in gillnet fisheries can be a strong selective force. Law (2000) opined that the primary question is not whether fishery-induced evolution is occurring, but rather how quickly. However, other explanations remain plausible. Healey (1986) concluded that observed declines in the size of Pacific salmon previously attributed to selective fisheries are at least partially driven by climatic conditions, noting that fishery mortality accounts for only a fraction of total mortality, as does Riddell (1986). Similarly, Bigler et al. (1996) largely attributed the decline in weight of Pacific salmon to ocean conditions and density-dependent effects, perhaps caused by large-scale hatchery production. Ricker (1995) concluded that the effects of selective fishing may be ameliorated by variation in the marine environment or by reduced abundance of competitors.

Although no consensus has emerged on whether the observed declines in size and age-at-maturation in specific populations can be attributed to the effects of selective fishing, that possibility certainly exists. That the size of individual salmon is correlated with reproductive success is a reasonable hypothesis. For example, large females are more fecund (Healey and Heard 1984) and construct deeper redds, which may increase the survivorship of progeny (Steen and Quinn 1999). Size is thought to be an important factor in mate choice and breeding behavior of salmon (Foote 1989, Quinn and Foote 1994, Esteve 2005). However, conclusively demonstrating that selective harvests of wild, free-ranging populations causes evolutionary change is a difficult challenge. Measuring traits such as size and correlating them with hypothesized drivers establishes association rather than cause. Similarly, evidence that traits are heritable suggests that fisheries have the potential to alter population genetics, but does not prove that it has occurred.

Further experimentation on the effects of selective exploitation may prove valuable. For example, Conover and Munch (2002) conducted tank experiments in which selective harvests of large Atlantic silverside (*Menidia menidia*) led to substantial reductions in both fish size and fishery yield in as little as three generations. Unfortunately, such experimentation with salmon would be difficult, especially under approximately natural conditions. Computer simulation may provide insights into mechanisms, interaction of competing pressures, and time scales over which change might be expected. For example, Hankin and Healey (1986) found that selective fisheries can decrease the mean age of Chinook salmon populations and increase the probability of significant population decline. Kaitala and Getz (1995) conclude that biologists must consider genetics in management if mate-pairing has a genetic basis. In addition, they found that selective exploitation can lead to evolution in life-history traits. The results of an age-structured simulation conducted by Hard (2004) suggest that the selective exploitation of large Chinook salmon could lead to modest reductions in size-at-age within approximately five generations. However, while experimentation and computer simulation may provide valuable insights, they are unlikely to be definitive. For example, Riddell (1986) cautioned that the realized magnitude of fishery-induced evolution will be less than predicted by simple models of single-trait selection.

In summary, it is clear that selective exploitation has the potential to alter both genetic and phenotypic characteristics of fish populations. However, it is exceedingly difficult to establish that changes observed in any particular fish population are being driven by fishery-induced evolution. While controlled experimentation is invaluable for exploring the potential effects of selective exploitation, unraveling the relative importance of all selective forces operating simultaneously on naturally reproducing populations is much more difficult. Given these difficulties, even if fishery-induced selection is leading to evolutionary change, the relationship may never be proven. However, continued scientific exploration and investigation, improved monitoring of exploited populations, and potentially long-term management experiments may eventually result in sufficient evidence to lead managers, biologists, fishers, and others to a reasoned consensus.

OCEANIC INFLUENCES ON SALMON SIZE

Salmon originating in the Yukon River drainage spend up to 6 years growing and maturing in marine environments. Survival during their first year at sea is thought to largely regulate the abundance of maturing fish and salmon gain more than 95% of their mature body mass while at sea (Quinn 2005). While it is generally thought that Yukon River Chinook salmon remain in the Bering Sea, there are unconfirmed reports of Whitehorse hatchery tags recovered from the eastern Pacific for the first time in 2006 (P. Milligan, DFO, personal communication). Other species such as chum and sockeye salmon apparently do enter the North Pacific (e.g., Seeb and Crane 1999) making Yukon River salmon, as a whole, subject to conditions across a broad expanse of marine habitat.

Specific effects of the ocean environment on salmon size and age composition are difficult to identify or quantify because the ocean component of salmon life history is not well understood, largely due to the expense and difficulty of conducting research at sea. However, observations of similar patterns across a broad geography (e.g., Bigler et al. 1996) strongly suggest that ocean conditions are important drivers. Potential influences of the ocean environment on salmon size can be broken into broad categories: international, federal, and state fishery management (e.g., groundfish fisheries and incidental harvest), chemical and physical oceanography (e.g., nutrients and temperature), and inter- and intra-species interactions (e.g., hatcheries and food).

The incidental harvest of salmon in Bering Sea groundfish fisheries is unlikely to directly alter the composition of individual salmon populations, given the small harvests relative to the total abundance of salmon in marine waters. However, incidental harvest can not be completely eliminated as a contributing factor. For example, the age composition of Chinook salmon caught incidentally in the Bering Sea - Aleutian Islands (BSAI) walleye pollock fishery has shifted from younger (age 1.2 and 1.3) to older (age 1.4) aged fish, coinciding with a gradual northward shift in fish location and a southeastern shift in location of harvesters (Myers 2003). It is more likely that the annual removal of substantial groundfish biomass may alter ecosystem function or community structure (e.g., Levin et al. 2006) in ways that influence the growth or survival of immature salmon.

Climate clearly plays a major role in determining nutrient flow pathways, production levels, and ultimately growth and survival of fishes in the North Pacific Ocean and Bering Sea (Hunt and Stabeno 2002). The Pacific Decadal Oscillation (PDO) index reflects the state of North Pacific circulation and tends to alternate on a decadal scale between positive and negative regimes (Mantua et al. 1997). The most recent regime shifts occurred in 1925 (negative to positive), 1947, and 1977. Positive regimes are associated with generally high productivity in the Alaskan Gyre and generally low productivity along the western U.S. coast south of British Columbia, Canada; negative regimes have the opposite effect. In the Bering Sea during a negative regime, pelagic production (i.e. walleye pollock and salmon) decreases while benthic production (i.e. crab and shrimp) increases. While observations of a potential shift to a negative PDO phase were observed in the late 1990s, the PDO is thought to currently persist in a positive phase (Litzow 2006). However, the PDO index may no longer be a good indicator of productivity due to the unprecedented amount of heat carried north via the Alaska Coastal Current, the Alaskan

Gyre, and the deep ocean currents entering the Bering Sea (P. Stabeno, Pacific Marine Environmental Laboratory, personal communication, and N. Mantua, University of Washington, personal communication). Warmer water temperatures increase metabolic rates, and therefore the food required to maintain body function of fish and invertebrates.

The location of the Aleutian Low during winter is a major physical forcing mechanism in the Bering Sea and is driven by high altitude wind patterns (Beamish and Bouillon 1993, Finney et al. 2000, Finney et al. 2002). When the Aleutian Low produces many winter storms in the Bering Sea, deep, nutrient-rich waters are mixed with nutrient-poor surface waters, setting the stage for increased production the following spring. Timing of the retreat of winter sea ice determines the timing of the spring phytoplankton bloom, which in turn influences the path of nutrients through pelagic zooplankton and fish or to the benthic community (Hunt and Stabeno 2002). The coupling of the phytoplankton and zooplankton blooms to salmon out-migration is thought to be a major factor in early salmon survival at sea (Cooney et al. 1995).

The world's oceans, including the Bering Sea, have exhibited increased temperatures (Grebmeier et al. 2006, Hansen et al. 2006). Warmer surface waters decrease the winter ice extent, which in turn reduces the cold pool used as refugia by pelagic invertebrates from benthic predators and deepens the thermocline, thereby increasing the wind energy required to mix nutrient rich deep water (P. Stabeno, Pacific Marine Environmental Laboratory, personal communication). These synergistic effects appear to be moving northward, and their ultimate effects on the Bering Sea are unknown. Increased water temperatures, in combination with reduced transport of deep-water nutrients to the surface, are thought to be important factors in the unprecedented coccolithophorid phytoplankton blooms that first appeared in 1996 (Iida et al. 2002, Merico et al. 2004), decreased zooplankton biomass (Hunt and Stabeno 2002), and the reduced abundance of western Alaska salmon in the late 1990's (Kruse 1998). Coccolithophorids are single-celled marine plants that in large numbers deposit volumes of tiny white calcite plates, completely changing the hue and visibility of the surrounding waters. The coccolithophorid bloom's presence in the Bering Sea coincides with lower salmon counts, a redistribution of microscopic crustaceans such as copepods and euphausids in the surrounding ocean, and deaths of surface-feeding seabirds ((Baduini et al. 2001). Collectively, these observations may be indicative of a future in which warmer, nutrient-poor waters change the nutrient flow patterns to the detriment of salmon and their prey (Hunt and Stabeno 2002).

A number of environmental factors, perhaps associated with global climate change, have been suggested as contributing to trends in age and size at maturity of Pacific salmon (chum salmon: Ishida et al. 1993, Ishida et al. 1995, Morita et al. 2001; sockeye salmon: Hinch et al. 1995, Cox and Hinch 1997, Pyper and Peterman 1999). Ishida et al. (1993, 1995) found that increases in abundance and decreases in sea surface temperatures (SST) were significantly associated with reduced body length for North Pacific chum salmon. In addition, Morita et al. (2001) found that a decrease in sea surface salinity, which is probably related to global warming, was significantly associated with the reduced growth rate of chum salmon in the Sub-Arctic Domain of the Western North Pacific. Pyper and Peterman (1999) found that increases in abundance and SST were significantly associated with reduced body length for British Columbia and Alaska sockeye salmon.

Bering-Aleutian Salmon International Surveys (BASIS) over the past 5 years have provided a wealth of data on juvenile and immature life history stages for salmon occupying the eastern Bering Sea shelf during late summer and early fall (Farley et al. 2005). BASIS information indicates that cold spring temperatures likely delay out-migration from freshwater systems and slow growth of juvenile salmon during their first year at sea. The size of juvenile salmon at, during, and after the first year at sea is important to their survival (Quinn 2005). Sea surface temperatures during the first year juvenile salmon occupy the shelf have been positively correlated with Western Alaska salmon survival (Mueter et al. 2002). There is likely a link between SST and offshore distribution of salmon, where offshore distribution appears to be related to years with warm SST, higher growth rates, and higher survival of western Alaska salmon (Hare et al. 1999).

Several investigators have implicated competition as a factor likely contributing to reduced growth rates and increased age at maturation. The size of salmon decreased throughout the North Pacific during the last quarter of the 20th century (Bigler et al. 1996), and the age at maturation increased during the same period. These trends are particularly pronounced in chum salmon throughout their range, including North America (Helle and Hoffman 1995), Russia (Kaev 2000), and Japan (Kaeriyama 1998). For example, the average age at maturity of chum salmon returning to Hokkaido, Japan, increased from 3.7 years before 1972 to over 4.0 years after 1980, but the average size at maturity at age 4 years decreased by approximately 7% from 68.7 cm in the 1970s to 63.8 cm in the 1980s (Kaeriyama 1998). The trends in size and age of Japanese populations are positively correlated with smolt releases and adult returns. This suggests that reduced growth and increased age at maturity may be due to density dependent competition (Kaeriyama 1998). Similarly, Levin and Schiewe (2001) demonstrated a strong negative relationship between the survival of wild Idaho Chinook salmon and the number of hatchery fish released, particularly during years of poor ocean survival. Other fish species, such as the currently abundant walleye pollock and Pacific herring, also compete with juvenile salmon for food resources (e.g., Willette et al. 2001).

Salmon spend a substantial portion of their life cycle in marine habitats, and ocean conditions are important forcing factors driving population dynamics. Unfortunately, how the multiple facets associated with climate, community structure, and ecosystem function interact to influence salmon production and size are poorly understood. Recently initiated research through BASIS and the North Pacific Research Board, as well as numerous investigations into the ramifications of global climate change in northern latitudes, may significantly contribute to our knowledge base.

SUMMARY

The Yukon River Chinook salmon fishery in Alaska has a long history, dating back to the early portion of the 20th century. The in-river fishery was largely developed by the 1960s, and total annual harvests of approximately 150,000 or more were sustained over a period of nearly 4 decades from the 1960s to the late 1990s. However, historical harvest patterns and sustainability are not always an indication of what may occur in the future. The sharply reduced returns of Yukon River Chinook salmon that began in the late 1990s were unexpected. Because of the decline in salmon abundance throughout interior and western Alaska at that time, many attributed the run failures to reduced marine survival (Kruse 1998). The environment inhabited by salmon is dynamic and the ocean does not have an unlimited capacity to grow salmon. If current climate models are correct, increased global warming and changing climate patterns will almost certainly continue to impact salmon productivity through mechanisms such as changing availability of prey, levels of competition, in-stream flow patterns, water temperatures and emerging diseases (Hinzman et al. 2005, Hansen et al. 2006, Kocan et al. 2004).

Evidence that Yukon River Chinook salmon have undergone phenotypic alteration over time is limited, but suggestive. Existing analyses document a decrease in the weight of commercial harvests (Bigler et al. 1996), a reduction in the prevalence of the largest fish (Hyer and Schleusner 2005), and the apparent near disappearance of age-8 fish (JTC 2006). These types of changes have been observed in many other fisheries (Law 2000). Whether the changes observed within Yukon River Chinook salmon have resulted from environmental or fishery induced selective pressures, or a combination of both, is difficult to determine with certainty. It is equally difficult to discern whether or not the trends observed to date may foreshadow future impairment to the diversity and productivity of Yukon River Chinook salmon.

The persistence of a fishery through time is strong evidence that the fishery is sustainable. The management policies and regulatory system in place for Alaskan salmon may be adequate to sustain its salmon fisheries, including Yukon River fisheries, into the future (Clark et al. 2006). Adkison and Finney (2003) concluded that, barring habitat degradation or global climate change, Alaska's salmon populations are sustainable for the foreseeable future. However, others question the maximum sustained yield concept used by the State of Alaska (Larkin 1977) as well as the general sustainability of fisheries (Longhurst 2006). A growing number of investigators argue that knowledge of fishery induced selective pressures should be incorporated into fisheries management practices. For example, Law and Grey (1989) suggest the need for an "evolutionary stable optimal harvesting strategy", while Heino (1998) urges managers to design management regimes that take advantage of fishery induced evolutionary change. It is difficult to determine which viewpoint is the most appropriate, or which course of action will provide the greatest benefit for both fish and fishers in the future. In any case, it seems likely that management practices will need to evolve and develop increased precision and flexibility to effectively respond to potential change and increased inter-annual variation in salmon abundance and the composition of salmon runs.

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TABLES

Table 1.–Age, sex, and length data sampled in the commercial, subsistence, and lower river test fishery.

Fishery	Location	Years
Commercial fishery	Y-1	1960, 1964, 1966-2000, 2002-2006
	Y-2	1961, 1973, 1982-2000, 2002-2006
	Y-3	1964, 1968, 1970-1971, 1973, 1984-1985
	Y-4	1973-1974, 1976-1978, 1980-1999, 2003
	Y-5	1965-1967, 1969-1976, 1979-2000, 2002-2006
	Y-6	1964-1965, 1968-1971, 1973-1975, 1977-1981, 1984-1987, 1989, 1992-2000, 2002-2006
Subsistence	Y-1	1978-1979, 1986-1987, 2001-2003, 2005-2006
	Y-2	
	Y-3	2003-2004
	Y-4	1975-1979, 1986-1989, 1991-1992, 1994-1995, 1998-2006
	Y-5	1977,1984, 1987, 1999, 2001-2002, 2004
	Y-6	1976, 1979, 1982-1983, 1986, 1988, 1992-1994, 1999, 2001
Lower river test fishery	Flat Island	1964-1968, 1970-1971, 1976-1977
	Big Eddy	1979-2006
	Middle Mouth	1982-2006

Table 2.–A summary of the Upper Yukon and Porcupine Chinook salmon catches in the aboriginal, commercial, domestic and sport fisheries from 1961 to 2005.

Period	Aboriginal Upper Yukon	Aboriginal Porcupine	Commercial Upper Yukon	Domestic Upper Yukon	Sport Upper Yukon
1961-1969	4,735	164	2,580	NA*	NA
1970-1979	2,616	36	3,194	576	NA
1980-1989	6,934	433	10,689	666	335
1999-1999	7,489	297	8,566	233	489
2000-2005	6,267	245	2,516	83	228

Note: * NA designates Not Available.

FIGURES

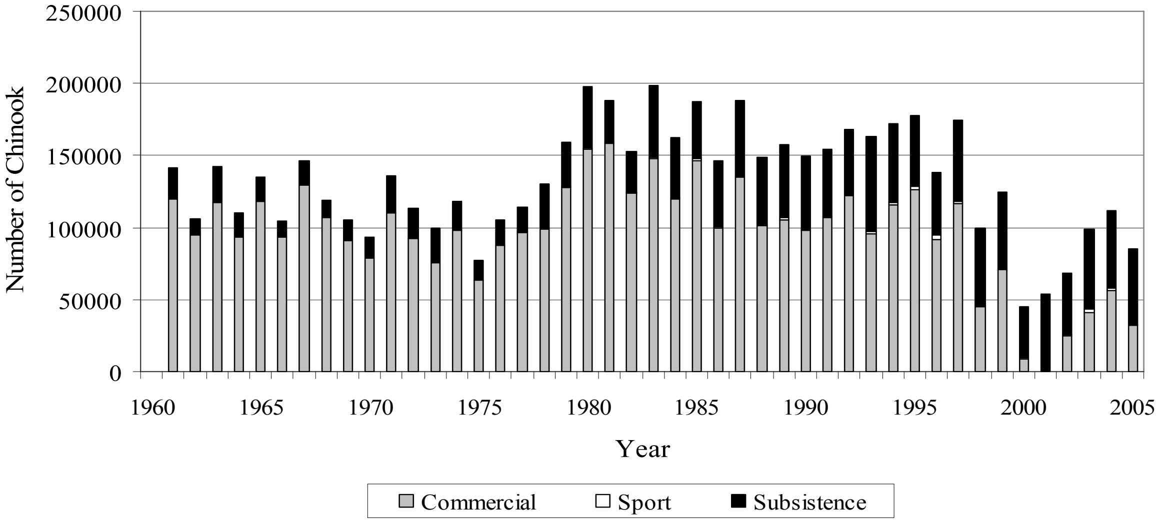

Figure 1.–Alaskan harvest of Chinook salmon, Yukon River, 1961-2005. In 2001, the commercial fishery was closed.

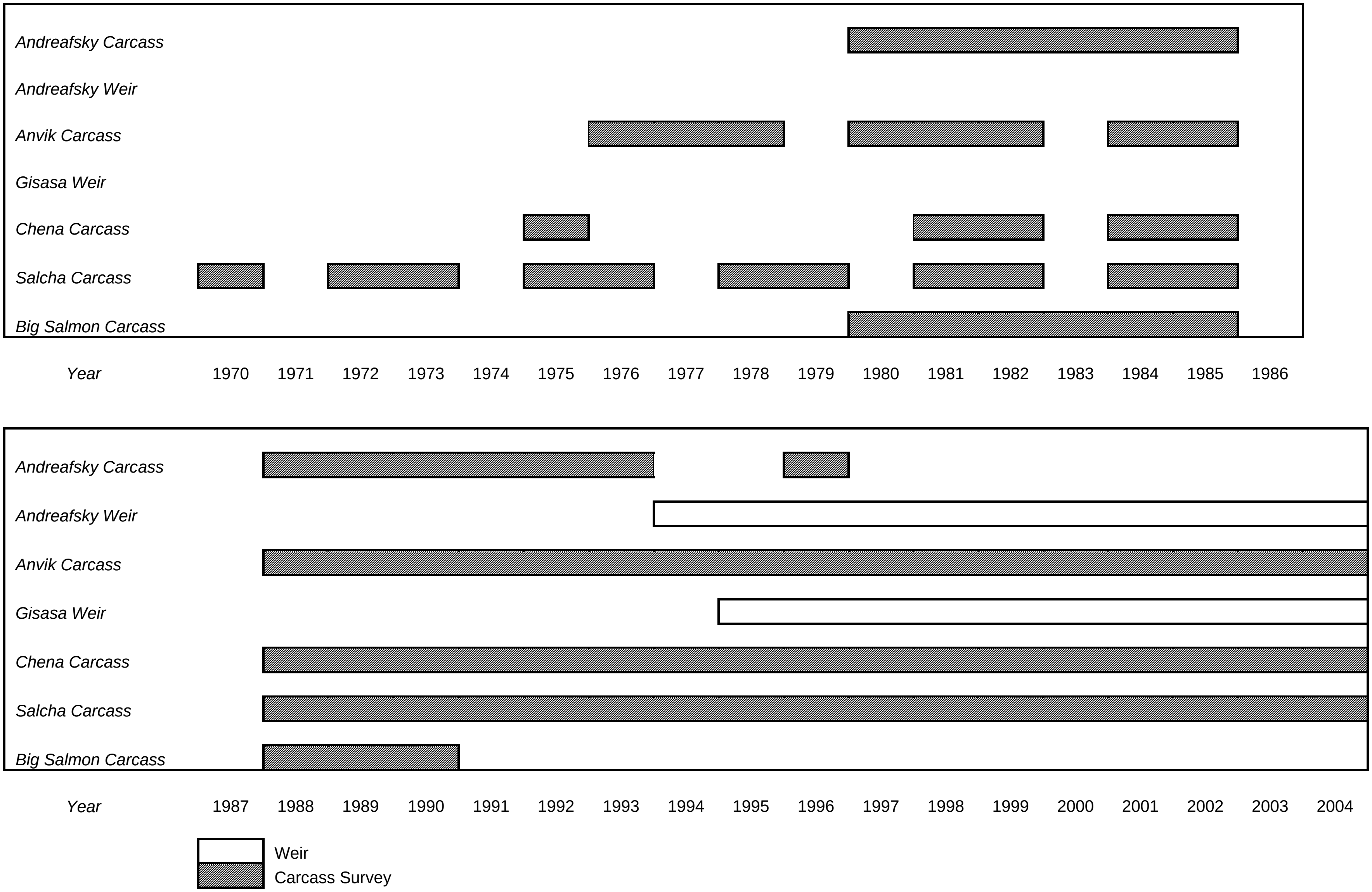

Figure 2.–Primary sampling methods and years of collection for ASL data from six Yukon River tributaries 1970-2004.

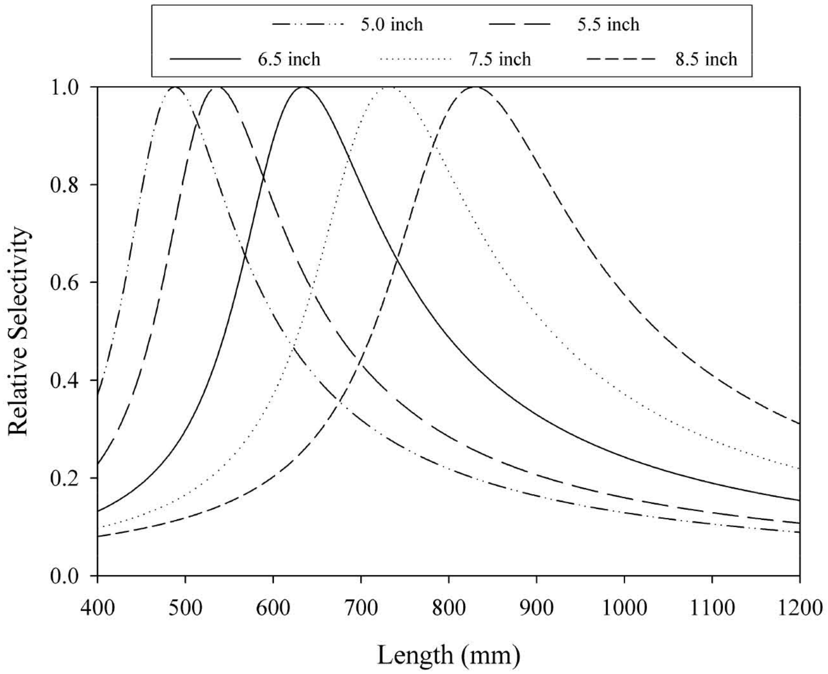

Figure 3.–Estimated selectivity of Chinook salmon in selected mesh sizes at the Yukon River Sonar project site, based on gillnet catch data records collected from 1990 to 2003.

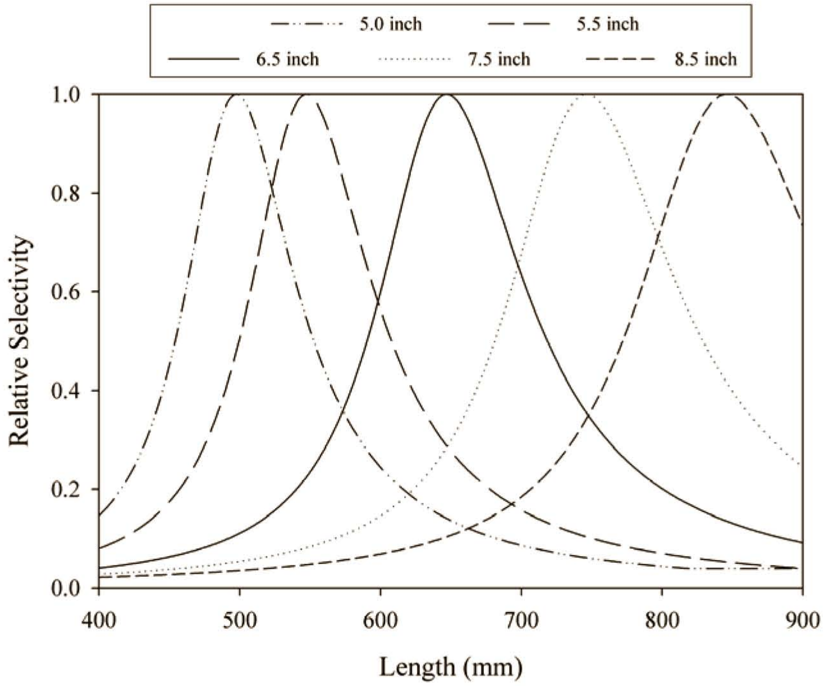

Figure 4.–Estimated selectivity of summer chum salmon in selected mesh sizes at the Yukon River Sonar project site, based on gillnet catch data records collected from 1990 to 2003.

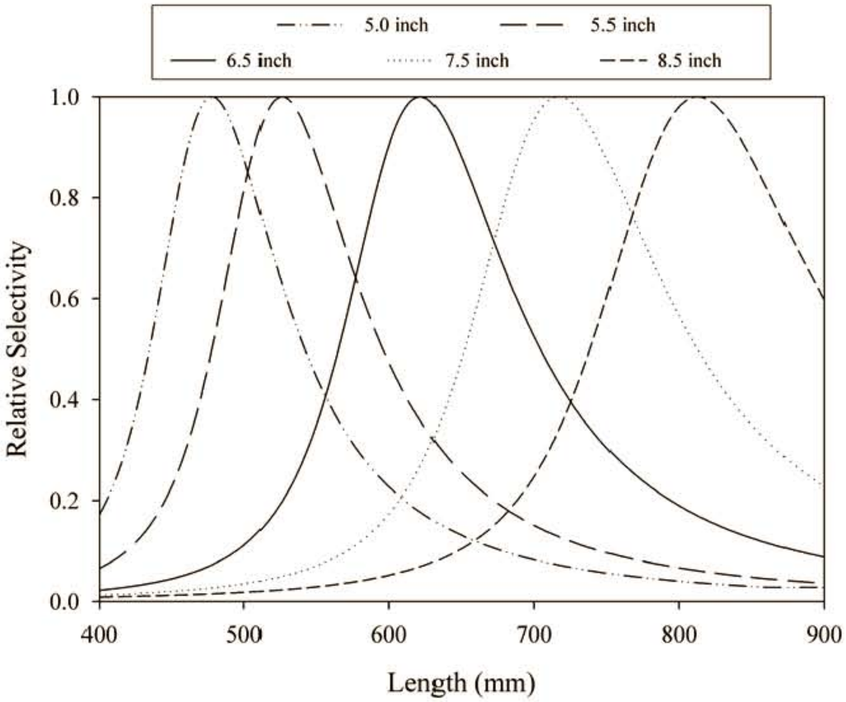

Figure 5.–Estimated selectivity of fall chum salmon in selected mesh sizes at the Yukon River Sonar project site, based on gillnet catch data records collected from 1990 to 2003.

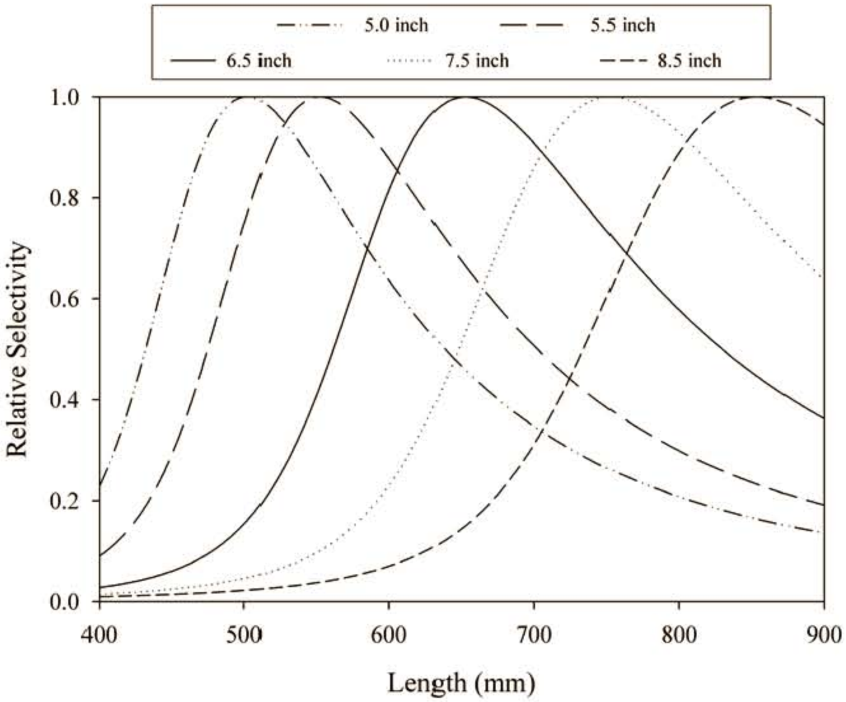

Figure 6.–Estimated selectivity of coho salmon in selected mesh sizes at the Yukon River Sonar project site, based on gillnet catch data records collected from 1990 to 2003.