Research and Restoration Plan for Norton Sound Salmon

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Prepared by the

Scientific Technical Committee

For the

Norton Sound Steering Committee

SCIENTIFIC TECHNICAL COMMITTEE

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OEO/ADA STATEMENT

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INTRODUCTION

Declining salmon abundance and low demand for Norton Sound salmon have combined to cause severe economic hardship for the fishery-dependent communities in this region. Funding is available for research and restoration efforts that lead to better understanding of the root causes of these problems and that might bring some relief to resource-dependent people in the region. To help forge a long-term solution to these problems, the Norton Sound Steering Committee (Steering Committee), has called for production of a research and restoration plan.

In response to the request of the Steering Committee, the Norton Sound Scientific Technical Committee (STC) has designed the science plan to provide as much specific advice as possible on how to select projects needed to advise managers and residents of the region on short-term and long-term research and restoration actions needed to secure sustainable salmon resources.

The STC has worked in close cooperation with the Steering Committee to identify and prioritize the scientific and technical questions that reflect the concerns of the people of the region for the conservation and sustainable uses of salmon. A series of questions has been posed to guide the selection of projects based examining information needs for salmon life cycle stages, operation of the fishery and economy, and the Alaska Policy for the Management of Sustainable Salmon Fisheries. Answers to those questions represent the body of information necessary to advise managers and community members on how to provide for the conservation and sustainable uses of salmon, both in the immediate future, and in the long-term.

The Steering Committee has further identified the degree to which the necessary body of information is lacking for each question. These gaps in scientific knowledge regarding salmon production in Norton Sound will guide salmon research now and into the future. Gaps in necessary information point to information gathering projects that need to be conducted to answer each question, and the combination of the priority of the question, the cost of the project, and the available funding will define the recommended list of projects to be implemented.

This plan is not only to be applicable to utilizing the remaining years of grant money but also to provide a long-term perspective appropriate for pursuing additional research monies. The document includes a prioritization of research activities, or projects. Projects range from the relatively low-tech small-scale private contractor type to the high-tech large-scale agency type.

Identifying the Research Questions

Taking actions to benefit those people who depend on Norton Sound salmon for subsistence, commerce, and culture requires information on what the people of the region need and expect to achieve, as well as on the status and dynamics of the salmon resource and its environment. Before actions can be taken to meet people's needs, information on the resource and its environments should be applied to understand the chances of those actions successfully meeting those needs.

Federal and state laws provide general guidance on what people need and expect to achieve with scientific information on the status and dynamics of natural resources. Federal laws have repeatedly recognized the need to shape human actions toward those that allow animal and plant species to exist in their native habitats (i.e. Marine Mammal Protection Act, Forest Practices Act, Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, and others). Corresponding state laws of Alaska derive their foundations from the constitutional mandate to provide for the sustainable use of natural resources. For example, the Alaska Board of Fisheries has adopted into regulation (April 2000) Policy for the Management of Sustainable Salmon Fishery that identify actions for protecting the sustainable use of Alaska's native salmon populations. The five principles of sustainable salmon management are summarized as follows.

(1) Wild salmon populations and their habitats must be protected to maintain resource productivity.
(2) Fisheries must be managed to allow escapements within ranges necessary to conserve and sustain potential salmon production and maintain normal ecosystem functioning.
(3) Effective salmon management systems must be established and applied to regulate human activities that affect salmon.
(4) Public support and involvement for sustained use and protection of salmon recourses should be sought and encouraged.
(5) In the face of uncertainty, salmon stocks, fisheries, artificial propagation and essential habitats shall be managed conservatively.

Scientific information requirements of these five principles serve as a guide for this report. Additional guidance is provided by research planning efforts of the past and present. Similar general scientific questions from the Alaska Regional Marine Research Plan, The Bering Sea Ecosystem Research Plan, International GLOBEC, the Ocean Carrying Capacity Study of National Marine Fisheries Service and the Gulf of Alaska Ecosystem Monitoring and Research Program also serve as a basis for the Norton Sound Research and Restoration Plan (GEM 2001). With respect to Norton Sound salmon the historical questions may be summarized as follows:

- "What controls the abundance of salmon in Norton Sound?" and
- "What can we do about it?"

Factors such as predation and habitat conditions operate to control salmon abundance in both the freshwater and the marine environments of the salmon's ecosystem. Current understandings of the factors responsible for change in the Norton Sound salmon populations throughout the life cycles of the salmon species are discussed below in the section, Life Cycle of Norton Sound Salmon. Information is organized by stages of the life cycle for each salmon species.

NORTON SOUND SALMON AND AREA DEFINITION

Salmon included in this plan originate in the tributaries to Norton Sound from Point Romanof and Port Clarence in the northwest to the Pikmiktalik River, just east of the Yukon River delta in the south , which corresponds to the ADF&G definitions of the fishing districts of Norton Sound and Port Clarence (Figure 1). Forty-two key river systems in this area were identified by the

Norton Sound/Bering Strait Regional Planning Team (Figure 2) to have spawning salmon (Rue 1996). It is recognized that human use of salmon and spawning habitat extends outside this area to include St. Lawrence Island, Diomede Islands, and peoples serviced by Bering Straits Native Corporation. This plan does not exclude future study of salmon in this greater area.

Norton Sound chum salmon are included in one of the three distinct North America genetic clusters. Populations from Kotzebue Sound south to Bristol Bay, including the Susitna River in upper Cook Inlet, fall into the Northern cluster (Seeb and Crane 1999a, 1999b). This cluster further divides into three primary groups, of which Norton Sound salmon are represented in the coastal Western Alaska group that spawn less than 750 river kilometers from the ocean. The coastal population does not seem to subdivide based on geographic proximity except that Southern Bristol Bay collections appear to group together. (Habicht and Seeb in preparation).

PEOPLE OF NORTON SOUND

Residents of Norton Sound live in 11 villages and towns, largest of which is the City of Nome, home to 3,595 of the region's 6,936 people (Table 1). Chronologically various peoples/cultures settled the Norton Sound area (Rue 1996), American Paleo-Arctic tradition (8000 to 6000 B.C.), Northern Archaic culture (3,000 B.C.), Arctic Small-Tool tradition (1,000 B.C.), Ipiutak tradition (500 A.D.), Northern Maritime tradition (800 A.D.), Inupiat Eskimos (1200 A.D.), and Euro-Americans (1700 A.D.) Though people of a variety of origins and cultures now live in the region, 81% are of Native American heritage (Windisch-Cole 1998). People native to the region include the Inuit, Yup'ik, and Siberian Yup'ik from St. Lawrence Island.

Archeological evidence dating back 2,000 years (Bockstoce 1979) indicates that fishing has long been a part of life in Norton Sound. The largest pre-contact settlements on the Western Seward Peninsula were located where marine mammals were the primary subsistence resource. The rest of the region's population lived in small groups scattered along the coast, often moving on a seasonal basis to access fish and wildlife resources (Thomas 1982). During summer months residents would disperse, usually in groups of one or two families, and set up camps near the mouths of streams to harvest what their families and one or two dogs needed through the winter (Thomas 1982).

A large-scale fur trade was developed by the Russians in the late 1800's and continued after the American purchase (Magdanz and Punguk 1981). The activities and support for hundreds of commercial whalers and trading ships caused trading to increase in the region around 1848 (Ray 1975). Increased competition for walrus, caribou, and other species by outsiders may have increased the importance of salmon to area residents (Magdanz and Punguk 1981). In the late 1890's gold was discovered on the Seward Peninsula and thousands of new immigrants flocked to the region.

The impact of mining was significant on fish and the peoples of Norton Sound. Nearly every stream on the Seward Peninsula had some type of mining operations, ranging from gold panning or sluice boxes to hydraulic giants or bucket line dredges (Brennan et al. 2002). The population of the region also grew greatly from 1900 to 1930. Communities like Nome grew to a population of 30,000 while Council, with 10,000 people, had not previously existed. Dried salmon became a major commodity to feed the larger-sized dog teams used for winter transportation of mail and supplies by mining camps, trading posts, or stores. After the gold rush the number of people gradually declined. The advent of the mail plane and snow machine also greatly reduced the need for fish for dog teams.

The importance of salmon to the people of the region provided the impetus for this research and restoration plan. Salmon play a central role in the lives of many of the region's people; hence the political will to conserve and restore the salmon is very strong.

ECONOMICS OF NORTON SOUND

Subsistence Economy

The subsistence economy is an important part of the life of the region. People in the subsistence economy harvest a wide variety of animals and plants (Table 2). The record of species harvested by subsistence users is one way of identifying at least a portion of the species that are prominent in the ecosystems of Norton Sound. Principal fisheries related subsistence foods are salmon, halibut, saffron cod, Dolly Varden char, shellfish (primarily red king crab), clams and mussels (Rue 1996, Thomas 1982). Subsistence use of rainbow smelt, capelin, northern pike, starry flounder, yellow fin sole, arctic flounder, Alaska plaice, graying, burbot, Arctic Wolffish, and Pacific herring have also been documented although effort and catch vary in importance among localities in Norton Sound (Brennan 2002, Thomas 1982).

Cash Economy

People of Norton Sound are employed locally in the cash economy by government, non-profit corporations, and private enterprise, with about 39% being government employees and 61 % being private enterprise and non-profit corporation employees (Windisch-Cole 1998). Government employers include local, state, and federal agencies, while the leading private/non-profit corporation employers are Norton Sound Health Corporation and Kawerak, Inc. (Table 3).

Commercial salmon fisheries in Norton Sound since 1962 have provided annual landed values from $21,500 to $ 1,039,000 (Brennan et al. 2002), with the recent five-year average of $250,000 (Table 4). Other important sources of income include red king crab ($41 thousand to $1.9 million) and sac roe herring ($0.2 to $4.5 million). Of the total landed value of commercial fisheries, salmon fisheries have provided an average 29% over the past decade, however the overall trend in income from salmon fisheries is downward (Table 4). Due to low salmon returns, Norton Sound has been declared an economic disaster area by the federal government, providing the opportunity for the funding to produce this plan.

There are many challenges that must be overcome before salmon fisheries can again be a viable part of the cash economy in Norton Sound. Some of these challenges are faced by the entire state. According to Knapp (2001) the problem for the Alaska salmon industry is not just competition from farmed salmon. Salmon runs are variable and uncertain and declining in some areas, costs need to be lowered and quality improved. Markets conditions not favoring Alaska salmon include a strong U.S. dollar, slowdown of the world economy, and changes in consumer demand and the food distribution system.

In general wild chum salmon markets are depressed everywhere and the demand for salmon roe weak. In Norton Sound specifically, a number of chum stocks have been designated stocks for which there is either a "management concern" or a "yield concern" as defined in the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222). The remote location of harvest in many districts and the great distance to market translates to high cost of harvest and processing.

There are many questions related to the economics of the region's fisheries that need consideration. What changes in the fishery would result in an increase in the value of each fish landed? What changes in the fishery would result in a decrease in the cost of harvesting? What would be the effects in terms of total employment and equitable access to the fishery if such changes were made? What changes would be necessary to locally retain a larger fraction of the value added between the harvested fish and the product presented to consumers?

FISHERIES OF NORTON SOUND

Subsistence

Most area residents of Norton Sound rely heavily on the subsistence use of fish and wildlife. Subsistence fishers operate gillnets or seines in the main rivers and, to a lesser extent, in the coastal marine waters capturing primarily salmon. Saffron cod are harvested through the ice by jigging, fishing with gillnets in open water, and with dipnets. Red king crabs are captured in pots and by hand lines through the ice in the winter. Some invertebrates are harvested by hand or shovel.

Subsistence use of salmon is monitored using surveys conducted in most villages, annually since 1994 and for the earlier period 1963-1982. Permits (or earlier permit registration) have been required in the Nome Subdistrict since 1968 (Brennan 2002, Bue 2000). The subsistence harvest has ranged from 22,000 to 134,000 salmon (Table 5). Permits are also required to harvest red king crab upon which daily effort and catches are recorded. The harvest documented by permits (Brennan 2002) has ranged from 213 to 12,500 crabs (Table 5).

Commercial

A number of species have been used for commerce in Norton Sound. Most important of these have been salmon, king crab, and herring (Table 6). Minor fisheries have also been conducted for halibut and whitefish.

In 1959 and 1960, ADF&G biologists conducted resource inventories in the Norton Sound area. As a result harvestable surpluses of salmon were documented in several river systems. Various fishing regulations were liberalized and processors were encouraged to explore and develop new fishing grounds.

Most early commercial salmon fishing occurred in the Unalakleet and Shaktoolik Subdistricts. Chinook and coho salmon were flown in dressed condition to Anchorage for further processing. Pink and chum salmon were purchased from freezer and floating cannery ships operated in northern Norton Sound. Canning of salmon peaked during 1963 and thereafter markets have been sporadic. Often, some subdistricts have been unable to attract buyers for entire seasons. A joint venture between Koyuk, Elim, and Golovin Fisheries and NPL Alaska, Inc. operated from 1984 until mid-season 1988, allowing two Japanese freezer ships to buy directly from domestic fishers in this area. Currently the most consistent markets are at Unalakleet and Shaktoolik where some onshore processing occurs.

Commercial fishing is closed or extremely restricted in other subdistricts of Norton Sound. Nome Subdistrict has been closed in recent years due to extremely poor chum salmon runs to some of the rivers draining that area. Chum salmon escapement goals for rivers in the Golovin Bay and Moses Point Subdistricts have been difficult to meet or have not been met even with little or no commercial exploitation occurring as a result of closures or lack of markets.

The majority of commercial fishers and many buying station workers are resident Native Alaskans (Yup'ik, Inupiat, and Siberian Yup'ik from St. Lawrence Island). Commercial fishers operate set gillnets from outboard powered skiffs to capture salmon. All commercial salmon fishing is done in coastal marine waters and effort is generally concentrated near river mouths. Only 79 fishing permits made deliveries in 2000, the most recent year for which data are available, compared to the 1990-1999 average of 107 (Brennan et al. 2002).

Commercial salmon harvests in Norton Sound, recorded since 1961, have fluctuated between 23,051 and 1,108,184 salmon. Based on the 1991-2000 average (344,267) total harvest, pink salmon (246,991) represent the majority of salmon harvested followed by coho (54,953), chum (36,008), and chinook salmon (6,197).

Recreational

Recreational fisheries are growing in importance in the Norton Sound region. As a result of reduced subsistence opportunities and overcrowding of other areas, sport fishing is gaining popularity as a way to target a variety of salmon stocks (Bue and Menard 2000). Rural Alaskans often feel resentment toward "outsiders" who come into remote areas traditionally used by local people for subsistence hunting or fishing (DeCicco 2001). Recreational or sport fishing with rod and reel is also practiced to some extent by rural residents, but most often as an extension of subsistence activities and less for recreational purposes (DeCicco 2001).

Norton Sound is within the ADF&G Northwest Alaska sport fish management area (NWMA) and includes all waters north of the Yukon River drainage to Point Hope north of Kotzebue

Sound. Some guided and unguided sport fishing for salmon takes place throughout the management area, however the vast majority of salmon fishing occurs in the Seward Peninsula/Norton Sound sub-area with concentrations near Unalakleet and in waters accessible from the Nome area road system (DeCicco 2001).

Total fishing effort estimated for all species of fish in the NWMA has ranged from 11,000 angler-days in the late 1970's to 33,000 angler days in 1991. Effort has declined in recent years and was estimated at 22,000 angler days in 1999. Salmon harvest is estimated to have ranged from 3,800 fish in 1977 to 20,000 fish in 1982. Mean annual harvest of salmon of all species from 1989-1998 was about 11,000 fish, with 97% of the harvest reported from Seward Peninsula and Norton Sound, and only about 3.0% from Kotzebue drainages. Over the past five years (1994-1998), about 45% of the total average harvest has been coho salmon, 40% pink salmon, 7% chum salmon, and 6% chinook salmon. During years of high pink salmon abundance (even numbered years: 1992, 1994, 1996, and 1998), harvest of this species has comprised about 50% of the total annual salmon harvest. However, during years of low pink salmon abundance such as 1993, 1995, and 1997 coho salmon have accounted for about 60% of the total salmon harvest.

CURRENT RESEARCH, ASSESSMENT, AND RESTORATION

Salmon projects conducted in Norton Sound exist mainly to assess harvest removals and spawning abundance (Appendix 1). Harvest removals are censused through fish tickets for commercial fisheries or estimated for sport and subsistence fisheries and in places the age, sex, and length (ASL) composition of those salmon are estimated (Appendix 1). Escapement projects are often operated in the lower reaches of salmon producing rivers to estimate total upriver passage thought to represent spawning abundance. These projects also provide cumulative inseason abundance estimates to ADF&G staff, to be used when regulating harvest to ensure adequate escapement. ASL sampling of escapement has been sporadic and incomplete. Methods used to index, estimate, or census salmon passage include counting towers (estimate), weirs (census), aerial survey (index), and inriver test fisheries (index).

Numerous studies in which Norton Sound salmon have been tagged were conducted to identify the migratory path of salmon through Norton Sound and Norton Sound salmon through the Aleutian Island chain (Area M) and past Hooper Bay. Study objectives of these tagging projects also included estimates of the stock composition of salmon at these locations. Genetic and scale pattern analysis techniques have also been used to estimate or identify stock composition in Norton Sound or of Norton Sound salmon along their migratory pathway (Appendix 1). Sockeye smolt abundance leaving Salmon Lake has also been estimated using mark and recapture techniques.

Restoration efforts in Norton Sound have included lake fertilization, streamside incubation boxes, small temporary recirculating incubation facilities, and establishment of coho fry rearing ponds as well as culvert correction and clearance of periodic blockages. Streamside incubation boxes, primarily for chum salmon, have been employed on several rivers in the Nome area (Sandone 2001). Larger, more central recirculating incubator facilities have been proposed and a small facility was built on Hobsen Creek, a tributary of the Nome River. The focus of aquaculture efforts has been on rehabilitation of damaged or over-exploited streams. Small temporary structures were chosen rather than large aquaculture facilities (Rue 1996). Numerous rearing ponds for coho fry have been established or proposed for use. Many of these sites were used in mining operations (e.g., as settling ponds).

The success of these rehabilitation and enhancement efforts has not been rigorously evaluated, although this evaluation is thought very important (Sandone 2001). New mass marking techniques being used in other areas need to be investigated. Fry production at Hobsen Creek has been suspended until such evaluation can be conducted.

LIFE CYCLE OF NORTON SOUND SALMON

Introduction

The proposed strategy is to use the ADF&G AMR series, the RPT planning documents (Norton Sound/Bering Strait Regional Comprehensive Salmon Plan 1996-2010, Rue 1996), ADF&G and USFWS processed publications, the open scientific literature, traditional knowledge, and other local sources of information to fill in as many gaps in information needs posed by critical questions as possible. Gaps that are not filled from these sources are to be addressed by research projects. To avoid duplicating past or present efforts, all the citations and abstracts for salmon information for Norton Sound are organized in an electronic bibliography, using ProCite software. Some review documents, such as The Norton Sound/Bering Strait Regional Comprehensive Salmon Plan 1996-2010, contain background information that serves as a starting point for this research project.

Life Cycle of Norton Sound Chum Salmon

Introduction

Principal chum salmon stocks in the Norton Sound area are summer chum salmon, with peak escapements occurring in mid-July (Clark 2001a,b). Genetic structure of Bering Sea chum salmon stocks reveals no significant differentiation within summer chum salmon in the Norton Sound region (Wilmot et al.1994, Seeb and Crane 1999b). Some differences exist within the adjacent Yukon River drainage between seasonal races, and between upper river and lower river spawners. Overall, there appears to be a difference in timing of spawning between eastern and western Norton Sound. Norton Sound chum salmon populations originating in the Moses Point, Nome, and Golovin areas spawn in July, while those of Norton Bay, Unalakleet and Shaktoolik Rivers may spawn into August (Sandone 2001).

Many of the general aspects of chum salmon ecology and life history have not been studied for Norton Sound chum salmon populations. Most knowledge of chum salmon ecology comes from studies in Asia, the Gulf of Alaska, and the coasts of British Columbia, Southeast Alaska, and Washington State (see Salo 1991). Chum salmon populations from the Noatak and Kobuk rivers in the Kotzebue Region have received the most study of northwestern Alaskan chum salmon stocks (e.g., Bird 1982; Merritt and Raymond 1983; Salo 1991). Although the geographic regions adjoin, Kotzebue Region chum salmon tend to be fall spawners and their ecology may differ substantially from the predominantly summer spawning populations of Norton Sound. Following is an overview of documented ecology of juvenile and marine chum salmon that should serve as an introduction to the habitat requirements and life histories of Norton Sound chum salmon.

Chum salmon are a trans-Pacific species, spawning in streams along the Arctic coasts of North America and Asia, southward to Korea on the Asian continent and Monterrey on the North American continent. Of all Pacific salmon species, chum salmon and pink salmon spend the largest proportion of their life cycle in saltwater. Nearly all juvenile chum salmon migrate to saltwater within six weeks of hatching; two exceptions are Noatak and Amur River populations, which may spend a year in freshwater before migrating to saltwater. Adult chum salmon that return to freshwater to spawn usually enter the stream with advanced gonadal development and in spawning colors. Most chum salmon populations spawn relatively close to the ocean in the lower end of drainages or in intertidal zones, although some populations are capable of extensive freshwater spawning migrations (e.g., 2500 km for Yukon River populations). Because juveniles spend a large proportion of their time in saltwater, where study is difficult or impossible, they are generally less understood than are juvenile coho, chinook, and sockeye salmon, which spend greater amounts of time in freshwater.

Many river drainages contain sympatric populations of chum salmon that achieve reproductive isolation by returning to spawn at different times. Where present, these populations typically consist of earlier-returning “summer chum” populations that spawn in June and July, and later-returning “fall chum” that spawn between July and November. For management purposes, July 15 is generally the freshwater return date used to separate summer from fall chum populations in North America. The major biological differences between the two life history types are that summer chum salmon often are smaller, have lower fecundity (both absolute and relative), arrive earlier in the year in more advanced spawning coloration, and are less apt to use spawning grounds characterized by springs or groundwater upwelling (Merritt and Raymond 1983). One notable exception to these generalities is in the Yukon River, where summer chum salmon have had higher relative fecundity (eggs/ cm body length) than fall chum salmon (Anderson 1983 and Trasky 1974, reported in Salo 1991).

Once in rivers and streams, chum salmon migration rates generally decrease to an observed maximum of 40-50 km/d. Males tend to arrive at the spawning grounds earlier than females, resulting in an increase in the female-to-male ratio over the course of the spawning season. Many runs also display trends in age classes over the course of the season; these trends differ among regions, with younger fish sometimes arriving earlier and sometimes arriving later than older fish. Studies frequently report trends of size over the course of the spawning run, but such trends may be due to changing age and sex ratios over time rather than due to differences in timing of different sized fish of the same sex and age.

Egg Stage

Egg deposition and incubation habitat

Spawning habitat quality and quantity influences salmon production, therefore knowledge of habitat area and attributes is important for fisheries management. Suitable habitat for spawning and egg incubation generally consists of the correct combination of substrate, water depth, and water velocity. Depending on the area, the suitability of the habitat may also be strongly influenced by other variables such as sediment deposition and groundwater upwelling. Salo (1991) reports that chum salmon prefer to deposit eggs immediately above turbulent areas or where there is upwelling, but spawning ground attributes can vary substantially among populations. The amount (area) and condition of spawning habitats for chum salmon in Norton Sound tributaries is not known (Rue 1996), although there is some hydrographic data for the rivers of Norton Sound.

Issues and Information Needs

- Physical characteristics of spawning and egg incubation habitat.
- Amount of spawning habitat available in Norton Sound tributaries.

Fecundity, egg deposition, and production

Chum salmon fecundity – the number of eggs per female – ranges between 2000 and 4000 eggs (Salo 1991). Norton Sound female chum salmon appear to be on the lower end of this range, with fecundities of approximately 2000 to 2500 eggs (Sandone 2001). Fecundity is known to vary in proportion to the size (length or weight) of the individual, but the correlation between fecundity and body measurements in Norton Sound chum salmon has not been determined.

Average fecundity can be multiplied by chum salmon escapement to estimate total egg deposition, which is the starting point for understanding future production of adult chum salmon in Norton Sound. The total annual egg deposition places an upper limit on the number of adults that the brood year can provide in the future. The total number of fertilized eggs deposited annually by all chum salmon in Norton Sound is currently unknown because average annual fecundity is not measured.

Information Needs

- Chum salmon fecundity – absolute, and relative to size and weight.
- Total egg deposition by Norton Sound populations.
- Fertilization proportion of deposited eggs.
- Production of spring fry by fall spawners.

Egg development and physiology

In addition to fecundity, the size of the egg may be important to fry survival because egg size determines the amount of yolk available to the juvenile before it is able to begin feeding (Groot et al. 1995). The role of egg size in determining the survival of swim-up fry to the feeding stage has not been evaluated for Norton Sound chum salmon. Egg size variability among individual salmon and among years in Norton Sound is not known.

Chum salmon eggs typically require the accumulation of 400 to 600 (Celsius) thermal units to hatch (Salo 1991). Upon hatching, the alevins are photonegative and develop using the yolk sac as a food source. After the yolk is absorbed the fry become photopositive and emerge from the gravel to begin their downstream migration to the ocean. Salo (1991) reports that 700 to 1,000 thermal units are required for complete yolk absorption and Fast and Stober (1984) report chum salmon alevins being photonegative between 6 and 25 days after hatching. Chum salmon at the Sikusuilaq Springs Hatchery near Kotzebue, Alaska on average required 400 thermal units to hatch and 800 to 1,000 thermal units for complete yolk absorption (Peter Robb, ADF&G hatchery manager, retired, personal communication). The thermal unit requirements and incubation times of chum salmon eggs in Norton Sound tributaries is not known.

<u>Information Needs</u>

- Egg physical characteristics.
- Egg physiological requirements.

Egg survival

Total number of eggs deposited by the spawners is always much greater than the number of adults they eventually produce because eggs are subject to mortality from numerous sources. Factors affecting chum salmon mortality are known to include crowding (when it decreases the fraction of eggs that are deposited in a nest; Schroder 1981), predation, oxygen delivery, fungus, silt deposition, metabolic waste removal, and freezing. Freezing, low oxygen, fungus, and silt can also affect the condition of fry that survive to emergence (Salo 1991). The effects of all of these factors on Norton Sound chum salmon are unknown. In addition, the predator species composition and abundance is unknown. Effects of stream flows, water temperatures, and other physical factors are critical to understanding egg survival.

Another important mortality factor for eggs is predation, however the species of vertebrate and invertebrate predators, their population levels, and their consumption rates on eggs have not been documented for Norton Sound chum salmon. Also unknown is the degree to which Norton Sound chum salmon eggs die from mortality factors such as disease, freezing, and desiccation due to low water conditions during the fall and winter. Stream flows and water temperatures are critical to determining what fraction of the eggs survive to reach the fry stage.

Survival of eggs is also influenced by the length of incubation time, which in turn depends on water temperatures and accumulated degree-days. Chum salmon egg incubation times determine the date of emergence, which in turn allows us to know when to measure the physical (temperature etc.) and biological (food availability, predation, etc.) conditions affecting newly-emerged fry.

<u>Information Needs</u>

- Key biological and physical factors that affect egg survival.
- Egg survival rates.

Habitat status and potential restoration needs

Mining, road building, and gravel extraction in Norton Sound has directly damaged habitat and likely reduced salmon populations (Rue 1996). Another result of the human population increase associated with mining was a great increase in the harvest of salmon (primarily chum and pink salmon) to support dog teams used for transporting people and supplies. Dried salmon was even used as local currency (Selkregg 1976).

Past mining activities have caused long-term habitat changes in, or adjacent to, salmon streams in Norton Sound. Several rivers in the Nome area were heavily impacted by mining activities in the early part of the 20th century (Webb 1988; McLean 2001). Road construction and its associated gravel mining have affected streams more recently. Effective enforcement of stream protection laws was achieved only in the mid-1980s, and is still somewhat limited by lack of enforcement staff.

The Nome and Solomon Rivers have mainstem sections that have not yet stabilized following perturbations. The Snake and Fish River mainstems were also affected by mining activity, although the habitat is thought to have recovered. Tributaries of the Cripple, Snake, and Eldorado rivers were also mined, and coho salmon rearing habitat is considered degraded in some areas (Rue 1996).

<u>Information Needs</u>

- Location and rehabilitation potential of spawning habitat impacted by anthropogenic disturbance.
- Long-term changes in spawning habitat from natural processes.
- Relative effects of different disturbances on spawning habitat (e.g., road building, mining, etc).

<u>Potential Research Topics – egg stage</u>

- Identify physical characteristics of spawning and egg incubation habitat in Norton Sound tributaries – water velocity, depth, upwelling, substrate size, etc.
- Identify the location and size of spawning grounds in Norton Sound tributaries.
- Estimate fecundity of female chum salmon.
- Establish relationships between fecundity and either length or weight.
- Evaluate variability in fecundity among Norton Sound chum salmon populations.
- Estimate egg deposition per spawner and fertilization proportion to help quantify relationship between spawner abundance and fry production.
- Determine size and yolk content of eggs.
- Quantify thermal units and development times of chum salmon eggs in Norton Sound tributaries.
- Quantify the survival of eggs, both overall and in stages (deposition to alevin emergence, and alevin emergence to swim-up).
- Identify important sources of egg mortality in Norton Sound tributaries.
    - Biological – fungus, predation, displacement by sympatric spawning species, etc.
    - Physical – oxygen delivery, siltation, freezing, dewatering, etc.
- Identify stream reaches whose spawning habitat and fry production has been reduced by anthropogenic disturbance.
- Prioritize reaches with the potential for spawning habitat restoration, and identify methods to restore them.
- Estimate contribution of different anthropogenic disturbances to habitat loss, with the intent to mitigate future effects of these disturbances.

- Gather traditional ecological knowledge (TEK) to estimate “natural” historical changes in spawning habitat availability in Norton Sound tributaries – has there been a marked gain or loss over time?

Fry Stage – hatching and freshwater emigration

Emergence
Chum salmon fry typically emerge from gravel and begin their downstream migration during nighttime hours (Salo 1991). The onset, duration, and diel patterns of fry emergence in Norton Sound are unknown. Consequently, physical factors that may influence emergence patterns and survival are also unknown.

Information Needs

- Emergence timing of Norton Sound chum salmon.
- Diel patterns of chum salmon fry emergence.
- Physical factors affecting emergence patterns and survival.

Freshwater migration, feeding, and survival
Chum salmon typically begin downstream migration immediately after emerging from the gravel. Fry travel to estuarine waters and stay until they can transition to waters of higher salinity. Entry of chum salmon into seawater is commonly correlated with the warming of nearshore waters and the accompanying plankton blooms. Little is known about the timing or ecology of the freshwater migration of juvenile chum salmon in Norton Sound. Fry migration from the Yukon River (Martin et al. 1986) and Noatak River (Merritt and Raymond 1983) peaked in June and July, but freshwater emigration was detected from ice break-up until autumn. Rue (1996) estimated that Norton Sound chum salmon fry emerged from the gravel in April or May and entered Norton Sound in May and June.

Actual behavior and feeding practices of migrating fry appears varied with most research having occurred in Japan and Russia. Downstream migration of chum salmon fry probably includes different combinations of displacement and active swimming depending upon fry age and the relative strength of currents, temperature, and visual reference points (Hoar 1958). Chum salmon in long rivers, such as the Yukon River, are thought to feed as they migrate downriver (Martin et al. 1986; Loftus and Lenon 1977). Feeding activity in short streams is unknown. Norton Sound rivers generally flow less than 100 miles to Norton Sound (Rue 1996), and chum salmon fry may not feed before entering freshwater. If Norton Sound chum salmon don’t feed in freshwater, estuarine and nearshore waters have an increased importance as initial feeding grounds for fry.

Fry migrating in freshwater suffer predation from a variety of fish and birds (Groot and Margolis 1991). Coho salmon, char, and terns are present in the Norton Sound area and are presumed to prey on chum salmon fry, but predation rates have not been estimated. In general, fry survival improves with size (Groot and Margolis 1991). Coho salmon preying on chum salmon fry have been found to select smaller sized fry (Beall 1972).

Information Needs

- Downstream movement, diet, and mortality of fry.
- Sources of predation.
- Other sources of mortality on migrating fry.

Potential Research Topics – Fry stage, hatching and freshwater migration

- Estimate the start, duration, and diel patterns of fry swim-up in Norton Sound tributaries.
- Determine the rheotactic response of newly-emerged fry and determine whether downstream movements are active or passive.
- Estimate freshwater habitat use, if any, of chum salmon fry, and the variability among rivers.
- How does survival after swim-up influence brood year strength?
- What factors are important determinants of freshwater mortality – e.g., predation, fry size, food availability, and parasite presence? Determine whether downstream-migrating fry feed – if so, describe diet.
- Identify sources of mortality on downstream-migrating fry.

Fry stage - nearshore marine

Entry into marine and estuarine waters
When fry reach sea water, they respond strongly by either returning to the fresh water or swimming in the upper layer, lower salinity estuary water (Salo 1991). Chum salmon are dependant upon estuaries to transition to higher salinities and as a place of first feeding or first marine feeding. Early marine residence is considered to be a critical time in marine life history of chum salmon. Survival is likely affected by variations in entry time into estuaries and the fluctuations in weather and stream runoff patterns. Ideally, entry timing corresponds to spring plankton blooms. Movement offshore by chum salmon may correspond to decline of inshore prey resources and normally occurs at the time when the fish are larger so they can seek larger prey and avoid nearshore predators.

Information Needs

- Entry timing into saltwater.
- Behavior of fry upon entering saltwater.
- Onset of feeding for populations not feeding in freshwater.
- Role of estuaries as transition zones between fresh and salt water.
- Length of time spent in estuaries.

Diet, growth, and survival
Juvenile chum salmon diet and selectivity in Norton Sound is unknown. Elsewhere, chum juveniles are found to eat harpacticoid copepods, chironomids (Dipterans) and amphipods. Merritt and Raymond (1983) found Diptera to be the predominant prey in Kotzebue Sound. Evidence from other studies is that juveniles feed primarily on neritic invertebrates in the nearshore environment and then switch to nektonic prey as they grow and disperse (Salo 1991).

Information Needs
- Diet and growth of juvenile chum salmon in nearshore environment.
- Sources of mortality.

Distribution
Nearshore distribution of juvenile chum salmon in Norton Sound is poorly known. The most extensive attempt to capture juvenile salmon was in 1981, when the nearshore area was sampled 17 times with a seine and the offshore area was sampled 18 times with townets (Tetra Tech 1981). Although this sampling was somewhat effective at sampling pink salmon (171 juveniles collected), only two chum salmon fry were captured. Sampling was conducted in a limited spatial area (all in the Norton Sound District; Figure 1), and over a narrow time period (June 24 to July 2). However, sampling effort and gear size should have been effective for juvenile chum salmon, leading to the reasonable conclusion that chum salmon fry were not present in these waters at this time of year (or were not active during daylight sampling hours).

In Kotzebue Sound, juvenile chum salmon emigrated from the Noatak River in mid-June and remained near the mouth of the river until early July, after which they became scarce (Merritt and Raymond 1983). Nearshore abundance indices for juvenile chum salmon (catch-per-unit-effort (CPUE)) were highest in water temperatures between 9 and 12 degrees C, visible depths (i.e., turbidity) of 50-60 cm, salinities below 5 ppt, and water velocities of 6-9 cm/s. Indices were also highest in bays, where slopes were gentle (< 10 degrees), and where the substrate was predominantly coarse gravel. Chum salmon were also captured nearshore farther south of the Noatak in early August. Densities of this later sample produced estimates of 42 fish/hectare. Mean weight was 1.2 g and mean length was 55.5 mm. Kotzebue Sound chum salmon near the Noatak River mouth fed on both insects and zooplankton; chum salmon caught in August, in more saline water, fed primarily on zooplankton. Estimates of stomach fullness indicated that foraging success remained consistent throughout the sampling period (Merritt and Raymond 1983).

Migration and potential offshore movement
The length of time that Norton Sound chum salmon fry rear in estuaries is unknown, as is the size and time at which they begin moving offshore. Juvenile chum salmon are generally thought to move offshore in the second half of the calendar year of hatching, as nearshore prey concentrations decline (Salo 1991). Juvenile chum were not captured in the nearshore zone near Nome from June 24 to July 2, indicating that chum may have moved offshore before the end of June (Tetra Tech 1981). This would be slightly earlier than Kotzebue Sound juvenile chum, which appeared to move offshore in early July (Merritt and Raymond 1983). Alternatively, it may simply mean that juvenile chum had moved laterally along the coast and still remained in the nearshore zone elsewhere along the Norton Sound coast.

Martin et al. (1986) found that juvenile chum salmon of the Yukon River did not utilize the nearshore habitat of the delta. Outmigrants were thought to be dispersed by the large river plume, and the smaller fry (36.8-43.8 mm) were particularly vulnerable. Offshore migration was at 60 mm fork length in Prince William Sound (Cooney et al. 1978).

Offshore distribution of juvenile chum salmon may be driven by water temperature and zooplankton distribution. For example, as coastal water temperatures increased off Hokkaido, zooplankton and juvenile chum both moved offshore (Salo 1991). If offshore movement is related to zooplankton availability, models of zooplankton abundance should provide clues to chum salmon offshore movements from Norton Sound.

Information Needs

- Timing and location of offshore movement.
- Size at which fry move offshore.
- Relationship between offshore movements, food availability, and environmental conditions.

Potential Research Topics – fry stage, nearshore marine

- Document timing and interannual variability in saltwater entry by chum salmon fry.
- Determine feeding activity, diet, and stomach fullness of chum salmon fry.
- Determine the spatial pattern of juvenile chum in estuarine versus adjacent non-estuarine nearshore habitats.
- Determine feeding activity, diet, and stomach fullness of chum salmon fry.
- Identify main predators of fry in the nearshore environment. Summarize known trends of predator abundance as a secondary indicator of fry trends.
- Estimate the daily mortality rate of fry in the nearshore environment.
- Examine correlations between mortality and environmental or biological factors such as freshwater runoff, salinity, temperature, or fish density.
- Sample nearshore and offshore waters over time to obtain time series of fry presence/absence. Measure fry length, weight, body condition, etc. to correlate with fry movement.
- Measure temperature, salinity, and plankton abundance over time to correlate trends with fry movement.
- Examine vertical distribution of fry to determine the most likely sources of predation and the level at which water currents affect the largest proportion of fry.

Marine Stage

Compared to other populations throughout North America, relatively little is known about the ecology and life history of chum salmon from Norton Sound. This lack of ecological knowledge is especially noteworthy (and problematic) given that environmental conditions are much different from better-studied areas. Unusual regimes of salinity, temperature, and light may have both direct (migration patterns, physiology) and indirect (zooplankton distribution and seasonal presence) effects on Norton Sound salmon. One of the drainages in which juvenile chum salmon remain in freshwater for a year is the Noatak River; if this life history type is a result of the river’s northern location, it may also be present in nearby drainages of the Norton Sound.

Physical and Oceanographic Environment of the Bering Sea and Norton Sound – Water Current, Plankton Production, and Salinity

Surface water currents in the Bering Sea are thought to generally circulate in a counter-clockwise direction, with relatively few large-scale changes among seasons (Mathisen and Coyle 1996). On the eastern edge of the Bering Sea, the current flows through the Aleutian passes and northward along the coast of the Bering Sea before reaching Norton Sound. Currents in the Norton Sound region continue north or northwest, depending on the season, at velocities up to 20 cm/s. Current velocity probably increases through the Bering Strait. Water currents also flow north along the western side of the Bering Strait, but velocities appear to be lower (5 to 10 cm/s instead of 20 to 50 cm/s) than on the eastern side (Figure 3).

Across the Bering Sea from Norton Sound, current direction within the Gulf of Anadyr is varied, flowing in all four compass directions at different times and locations. South of the Gulf of Anadyr, the currents along the Russian coast flow south and east at speeds of up to 50 cm/s before reaching the Aleutian Arc (Figure 3). Fish migrating along the western coast toward the Gulf of Alaska could presumably be transported at relatively high speeds.

Surface salinities in the main part of the Bering Sea increase from approximately 31 ppt along the coastlines to 33.5 ppt in the open ocean (Luchin et al. 1999). Peak river runoff in June usually results in minimum salinity in shelf waters in July. The lowest salinities are at the heads of Anadyr Bay (20 ppt) and Norton Sound (< 29 ppt; Luchin et al. 1999). There is little large-scale seasonal change in salinity throughout the Bering Sea.

Primary production in the Bering Sea begins with phytoplankton blooms in the late winter and early spring that stimulate zooplankton feeding and reproduction. Production varies substantially with season and region. Zooplankton biomass peaks between late May and early July, but individual species peak at various times throughout the year. Plankton concentrations rise from approximately 100 mg/m^3 in the winter to over 2000 mg/m^3 in the spring before declining through the summer and fall (Loughlin et al. 1999). Concentrations throughout the year are generally highest in the deep waters and off the eastern shelf, and lowest in the nearshore zones.

Spring zooplankton species are generally nektonic and dwell at depths of 10 m to 100 m below the surface. Spatial peaks of Bering Sea plankton biomass are in the Gulf of Anadyr, Norton Sound, and Bering Strait, where concentrations can reach 3,200 mg/m^3. Zones of high zooplankton biomass also include a zone from the southeastern Bering Sea north to the Chukchi Sea and another along the Kamchatka coast (Loughlin et al. 1999). These data appear to conflict with the report by Coyle et al. (1996) that 2/3 of the biomass in the upper 200 m occurs over the deep basin of the western region.

<u>Information Needs</u>

- Physical and biological characteristics that affect chum salmon in Norton Sound and the Bering Sea.

<u>Potential Future Research Topics:</u>

- Describe the surface water currents within Norton Sound, the Gulf of Anadyr, along the Bering Sea coasts, and along other potential migration routes. Describe how these currents may assist or impede migrating salmon.
- Determine the depth at which the majority of chum salmon migrate and feed.

- Describe physical features such as water current, salinity, and temperature in Norton Sound and the Bering Sea.
- Determine the location and seasonal distribution of biological factors that affect salmon in the Bering Sea – where, when, and how might prey availability and coccolithophores affect migrating salmon?
- Compare Norton Sound environmental features with potentially similar regions – can behavior and strategies of Norton Sound chum salmon be inferred from environmentally similar populations?

Marine migration

Southward Migrations to the Gulf of Alaska.

The prevailing belief is that all juvenile chum salmon from western Alaska move southward from their home rivers, pass through the Aleutian Islands, and enter the Gulf of Alaska (Figure 4; Salo 1991). Timing and route of southward migration is not known. Given their relatively late entry into saltwater, chum salmon from northern areas like Norton Sound probably do not reach the Gulf of Alaska until late in their first year. If salmon move offshore at a small size, as suggested by preliminary evidence from Norton and Kotzebue sounds (Tetra Tech 1981; Merritt and Raymond 1983; Martin et al. 1986), they may migrate through the Bering Sea to reach the Aleutian passes. If they remain in or near the nearshore zones, chum salmon would not enter the open Bering Sea, and would instead travel across Bristol Bay and westward along the north edge of the Alaskan Peninsula before reaching the passes to the Gulf of Alaska.

In the Yukon River Delta, juvenile chum salmon were markedly absent from the nearshore environment. Instead, chum salmon fry were found offshore, leading to speculation that they were displaced by the powerful plume of water discharged from the Yukon River (Martin et al. 1986). This has ramifications for chum salmon fry migrating southward from Norton Sound because the Yukon River enters the Bering Sea immediately south of Norton Sound and Norton Sound chum salmon would presumably have grown little before encountering its discharge. If the Yukon River's plume is strong enough to displace juvenile Yukon River chum salmon offshore, it should be strong enough to force juvenile Norton Sound chum salmon offshore.

Movement Within the Gulf of Alaska.

Once in the Gulf of Alaska, juvenile chum salmon are thought to mingle with other species of salmon from North America and from Asia. Most North American chum salmon are probably distributed from 45 to 54 degrees north and from 135 to 170 degrees west. These fish migrate seasonally in a counter-clockwise direction with the Alaska Gyre, south of the Alaska Peninsula. North American chum salmon probably do not re-enter the Bering Sea before returning to spawn (Salo 1991).

Aydin et al. (2000) found that chum salmon fed in the summer in two distinct latitudinal zones in the Gulf of Alaska. Cooler sea surface temperatures (SST) and high concentrations of micronektonic squid marked the southern zone, whereas warmer SST and high concentrations of zooplankton marked the northern zone. Although chum salmon fed on zooplankton in each zone, chum salmon in the northern zone were significantly heavier than cohorts from the southern zone. The interface of these zones varied from 51 to 54 degrees north from 1994 to 1998 (Aydin et al. 2000).

When compared to summer distribution, chum salmon winter distribution in the Gulf of Alaska was compressed in a narrow latitudinal range between the 4 and 8-degree isotherms (Ueno et al. 2000). Salmon may overwinter in this relatively cold zone because the cold water reduces metabolic rates, thereby reducing food requirements at a time when zooplankton numbers drop by about 90% throughout chum salmon summer range (Nagasawa 2000a).

The prevailing belief is that chum salmon from North America rarely stray west of the Gulf of Alaska because tagging studies conducted between from 1956 to 1984 rarely recovered North American chum salmon east of 180 degrees. However, the total numbers of tagged salmon recovered west of 180 degrees (approximately 13 per year) is relatively low. Scale pattern analysis and genetic stock identification (GSI) techniques may increase sample range and size, helping to verify the ranges indicated by the tagging studies.

<u>Potential Movement Northward (and then Westward) to Asian Coast, then Southward to the Gulf of Alaska.</u>

An unexplored possibility is that Norton Sound juvenile chum salmon migrate to the Asian coastline instead of south through the Aleutian Island chain and into the Gulf of Alaska. Juvenile chum salmon migrating along the western edge of the Bering Sea to the Gulf of Alaska travel with the current nearly the entire way, whereas fish traveling along the eastern edge would travel against the current. As noted above, salinity and forage base (zooplankton) in the Gulf of Anadyr are largely similar to those in Norton Sound, suggesting that biological trade-offs may be minimal. Small juveniles migrating north and west from Norton Sound would be able to reach Russia's Chukostk Peninsula while remaining in the nearshore zone nearly the whole time. Once on the Asian coastline, the fish would presumably have similar life history strategies as the Anadyr River chum salmon, which enter Anadyr Sound and are also thought to migrate to the Gulf of Alaska. Although the Asian route to the Gulf of Alaska would be longer than the southern route, if overall migration conditions were better the greater travel distance might be offset.

<u>Information Needs</u>

- Migration routes and seasonal distribution of Norton Sound salmon.
- General ecology of Norton Sound salmon in the open ocean.

<u>Potential Research Topics</u>

- Conduct fish sampling or marking programs, use tag recoveries and stock identification techniques (scales, genetics, etc.) to identify:
    - seasonal and spatial distribution patterns of Norton Sound salmon.
    - arrival of salmon into the Gulf of Alaska.
    - differences in distribution among Norton Sound populations.
    - diet of chum salmon in the Gulf of Alaska and the Bering Sea.
    - migration routes of salmon traveling from Norton Sound to the Gulf of Alaska.
- Compare known trends between Norton Sound and non-Norton Sound populations to identify parallel factors.

Diet

Invertebrate prey appears to be an important part of chum salmon diets at all ages. Euphausids (crustaceans) comprised the majority of stomach contents, by weight, of juvenile chum salmon (94 – 195 mm) in the Gulf of Alaska; vertebrate prey comprised a substantial proportion (23%) in only one (the 200 m contour line) of four ecozones (Auburn and Ignell 2000). Among four species of salmon (pink, chum, coho, and sockeye), juvenile chum salmon summer diets overlapped most with pink salmon and least with coho salmon. Juvenile chum salmon in the Gulf of Alaska had a low incidence (3%) of empty stomachs (Auburn and Ignell 2000). Chum salmon that fed on fish and squid larvae in another study did so at lower levels than conspecific pink salmon and coho salmon (Salo 1991). Although these studies indicate that invertebrates comprise the largest proportion of diet throughout the chum salmon life cycle, changes with season or geography are not well known.

<u>Information Needs</u>

- Marine diet of Norton Sound salmon.
- Likely sources of competition and diet overlap for chum salmon.

<u>Potential Research Topics</u>

- Marine diet of salmon.
- Potential for intra- and inter-specific competition.
- Effects of density on forage success.

Age and growth

Growth can affect fish by influencing forage ability, predator susceptibility, and swimming ability (stamina and speed). Growth rate and absolute size are known to correlate with salmon survival (Rogers 1987; Salo 1991), but the relative effects of growth rate on survival of Norton Sound chum salmon are not known. There do not appear to be any annual growth estimates for Norton Sound chum salmon stocks. Growth rates of chum salmon in general appear to slow in the second year and differences among cohorts that will mature at different ages become apparent (Salo 1991). Chum salmon growth (fork length) slows 50% from their first to second year, then by another 10% each year thereafter. In their year of maturity, however, chum weight increases markedly, with reported gains of 46% to 156%. Mean length at maturity has been positively correlated with sea surface temperature, mean air temperature, and mean dew point (Helle 1979). Average length and weight of fish at maturity, both within and among age classes, generally increase from northern to southern latitudes (Salo 1991).

Both genetic and environmental variables affect final age at maturity. In general, there appears to be a latitudinal trend in age composition, with northern populations dominated by four- and five-year-old fish (in their third and fourth years of growth) and more southern populations dominated by three- and four-year-old fish. Notable exceptions to this trend are the chum salmon from Kotzebue Sound, which are larger and have a greater tendency to mature at age-2 than chum salmon from more southern parts of western Alaska (Salo 1991). Environmental variables that can influence age at maturity include the presence of dominant year classes of pink salmon (Salo 1991), chum salmon growth during the second year (Helle 1979), and the abundance of the parent escapement (Beacham and Starr 1982).

Variability in growth is due to both environmental and genetic influences and thus varies among stocks and regions. In the first year, growth is generally similar within stocks, although Salo (1991) indicates that earlier-maturing fish within a stock sometimes grow faster than later maturing fish. Growth rates of first-year chum salmon are summarized by Salo (1991), who reports weight gains of 3.5% body weight/d to 6.7% body weight/d and length gains of 0.75 mm/d to 1.75 mm/d. Variation in genetics and time at sea, due to differences in origin and migration timing, causes chum salmon lengths to vary substantially at the end of their first year of growth.

Information Needs

- Size at age and at maturity for Norton Sound chum salmon.
- Effects of environment, competition, and density on growth and maturation.
- Seasonal and annual variability in instantaneous growth rates.

Potential Research Topics

- Examine links between growth and survival of chum salmon in Norton Sound and elsewhere.
- Develop estimates of Western Alaska chum salmon growth by year and compare these to environmental variables (physical and biological).

Survival

Marine survival offshore and in the open ocean may be an important determinant of year class strength, but is difficult to estimate and remains largely unknown. Survival is assumed to be related to environmental conditions, swimming strength, prey availability, and predator avoidance. Larger fish are thought to be better able to cope with all four of these factors. Large chum salmon juveniles were less vulnerable to coho salmon predation in saltwater enclosures, and survival rates of hatchery fry increased with size (Salo 1991). Coastal sea surface temperatures were negatively correlated with ocean survival of hatchery chum salmon in Japanese waters (Fukuwaka and Suzuki 2000).

Estimates of survival rates for chum salmon from egg to fry range from 1.3% to 58.9%. Estimates from fry to adult range from 0.3% to 3.2%. Estimating marine survival requires separating freshwater survival from marine survival, and is therefore more difficult than measuring overall survival from egg to returning adult. Several studies have estimated substantial daily mortality rates 31% to 46% for fry emigrating offshore, suggesting that most mortality over their life cycle occurs in the first few months of life at sea (Salo 1991). Growth rate and absolute size appear to influence chum marine survival, along with pink salmon abundance, sea temperature, cloud cover, and water salinity (Salo 1991). Elsewhere in the Bering Sea, marine survival of sockeye salmon has been correlated with fish size and mean sea surface temperature (Rogers 1987).

Information Needs

- Marine survival of Norton Sound chum salmon and variability at different ages.

Potential Research Topics

- Develop time series of annual estimates of marine survival.

- Correlation between survival and factors such as environmental condition (temperature, etc.) predation, size, body condition, etc
- Identify sources of predation on Norton Sound chum salmon migrating through the Bering Sea and within the Gulf of Alaska.
- Determine the relative importance of survival by age and life stage. For example, does survival in the second year influence Norton Sound returns more than survival in the third?
- Do Norton Sound populations share enough similarities of environment or biology (e.g., similar latitude or oceanographic conditions) with any other stock to place special emphasis on examining that stock?

Immigrant (Adult) Stage

Chum salmon spawn in most river drainages within Norton Sound (Rue 1996). With the exception of a few streams with tower or weir operations, escapements are poorly known. Recently, more tower and test net projects have been added (Bue and Menard 2000). Aerial counts have been taken annually, although there are numerous missing values. Productivity of these stocks is poorly known (Sandone 2001). A recent attempt at generating escapement estimates for the purpose of estimating escapement goals for Norton Sound chum salmon rivers (Clark 2001a,b) frequently required estimating escapements in one stream based on observed escapements in another stream – in the Nome fishing subdistrict, over 90% of the estimates were made this way.

Physical and Oceanographic Environment Encountered by Fish
The general physical conditions encountered by mature chum salmon returning through the Bering Sea are summarized in the discussion of immature and maturing salmon, above. The main difference in oceanographic conditions is that mature chum salmon migrating through the Bering Sea presumably move with the current, instead of against it, as they migrate north to Norton Sound.

Distribution
Little is known about the migration of Norton Sound chum salmon through the Bering Sea. Regardless of whether adult chum salmon migrate close to the eastern coast or in the open ocean, strong ocean currents moving north from the Pacific Ocean to the Chukchi Sea assist their northward migration. Most knowledge of adult chum salmon distribution comes from tagging studies (e.g., Myers et al. 1996). Unfortunately, chum salmon disperse widely after tagging, making it difficult recapture enough fish to determine migration routes through the Bering Sea.

Migration times of chum salmon traveling through the Bering Sea to Norton Sound have been estimated from ten chum salmon tagged on the southern side of the Alaska Peninsula in 1987 and recaptured in Norton Sound commercial fisheries (Eggers et al. 1989). Chum salmon tagged between June 13 and July 1 averaged 25.8 d, with an SD of 5.4 d, before recapture in Norton Sound. The average recovery date in Norton Sound was July 16. These fish appear to have been part of the late-arriving component of the run, given that 1987 was a normal escapement year and that 90% of the chum salmon escapement to the Kwiniuk River was already complete

(Kohler and Knuepfer 2001). There are no data to estimate the travel times for different segments of the run (e.g., early, mid, and late), or of the interannual variation in travel times through the Bering Sea.

Information Needs

- Migration routes, timing, and travel times of chum salmon returning to Norton Sound.

Potential Research Topics

- Identify migratory paths and behavior using state-of-the-art tagging equipment.
- Combine ocean sampling programs with stock identification techniques to identify spatial and temporal distribution of Norton Sound chum salmon in the Bering Sea and Gulf of Alaska.
- Determine the direction(s) from which adult chum salmon enter Norton Sound
- Document the dispersal of adult chum salmon within Norton Sound.

Potential Interception Fisheries.
Because little is known about the migration of Norton Sound adult chum salmon, there is speculation that fish may be harvested in "interception" fisheries before returning to Norton Sound. The South Peninsula June Fishery (also known as the False Pass fishery) has received the most attention as a potential interception fishery. In 1987, over 6,300 chum salmon were tagged to estimate the origin of stocks captured in the South (Alaska) Peninsula fishery in June (Eggers et al. 1988). Based on subsequent recoveries in Norton Sound, Eggers at al. (1988) estimated that Norton Sound chum salmon comprised a maximum of 1.6 % of the South Peninsula harvest. Multiplying this by the 443, 019 chum salmon harvested in the 1987 South Peninsula fishery (Eggers et al. 1988) yields a maximum harvest estimate of 7,088 Norton Sound chum salmon. This estimate represents 6.9% of the 1987 Norton Sound chum salmon harvest of 102, 457 fish (Brennan et al. 1999). This estimate, however, is almost certainly high because the estimated proportion of Norton Sound chum salmon in the South Peninsula fishery (1.6%) did not include Asian stocks. High seas driftnetting was also listed as a potential interception fishery, but has largely been eliminated in recent years. Until the full distribution of adult and maturing chum salmon is known, it is also conceivable that other fisheries in the North Pacific may intercept Norton Sound chum salmon.

Gaudet and Schaefer (1982) marked and recaptured adult chum salmon in Norton Sound to estimate interception in the subdistrict fisheries. In this study, 1,693 chum salmon were tagged in Norton Sound and 274 were eventually recovered in the fisheries or on the spawning grounds. Important trends indicated by this study were:

1. Chum salmon appear to enter Norton Sound from the west, in the north central portion of the sound. The majority of the fish then move clockwise towards the Yukon River, while the minority migrate counterclockwise, towards the Nome subdistrict.
2. Fisheries in the northern subdistricts (Nome, Golovin Bay, Moses Point, and Norton Bay) do not appear to be interception fisheries; fisheries in the southern subdistricts (Shaktoolik, Unalakleet) are interception fisheries. An estimated 29% of the Unalakleet chum salmon were recaptured in the Yukon River.
3. Populations from the different subdistricts were not separated by time.

Information Needs

- Locations and relative effects of interception fisheries affecting Norton Sound chum salmon populations.

Potential Research Topics

- Identify locations of potential interception fisheries, ways in which to sample the fisheries, and ways to identify salmon from Norton Sound.

Return Migration and Spawning Ground Access
Norton Sound area chum salmon are primarily summer-run fish, with peak escapement counts on the spawning grounds occurring in mid-July (Clark 2001a,b). Chum salmon return to streams throughout the region; the largest escapements are typically to the Kwiniuk, Shaktoolik, Tubutulik, Fish, Unalakleet, and Eldorado rivers. Little is known about the travel and straying rates of Norton Sound chum salmon. In general, adult chum salmon appear to have strong homing abilities and migration timing, as indicated by straying rates, which helps explain the proliferation of reproductively separated sympatric populations. Average migration rates for chum populations approaching their terminal streams is thought to range from 15 km/d to 80 km/d (Salo 1991). Once at their streams, chum salmon typically mill for several days and undergo physiological changes necessary for entering freshwater. Increases in stream runoff stimulate entry. Individuals returning late in the run mill for less time and are more likely to enter the stream with less hydrological stimulus.

Information Needs

- Distribution of adult chum salmon within Norton Sound.
- Dispersal of adult chum salmon to spawning grounds.
- Key spawning ground locations.

Potential Research Topics

- Once in Norton Sound, how long do chum salmon mill and what is the estimated change in milling time throughout the season.
- Identify key spawning reaches in the major chum salmon rivers – is it possible to reliably locate the majority of useable and unusable areas on any river?
- Describe important spawning ground attributes.
- Quantify the overall amount of spawning habitat in at least one river system or stream.

Life Cycle of Norton Sound Coho Salmon

Introduction

Coho salmon spawn in streams on both sides of the Pacific Ocean, from California north to Point Hope on the eastern side, south to North Korea on the western side. Coho salmon typically rear in a stream for one or two years before migrating to sea then spend one winter at sea before returning to spawn in natal streams. Most coho salmon spawners are in their second or third year post-hatching. With the exception of pink salmon, coho salmon have the shortest life cycle and fastest growth rates of the North American species of Pacific salmon (Sandercock 1991).

Coho salmon typically spawn in small coastal streams and tributaries of larger rivers, and usually do so later in the year than other salmon species. Coho fecundity increases with latitude from California to south central Alaska, with population means ranging from approximately 2,000 eggs/fish to 5,000 eggs/fish. Fecundity has been positively correlated with fish length and with latitude (Sandercock 1991).

Coho salmon are less abundant than most sympatric salmon, and return later in the year when weather is often harsh. As a result, they are often studied less than other salmon species in remote regions like Norton Sound, where coho salmon return timing and lower abundance makes assessment difficult. Tower and weir escapement estimation projects generally operate during the chinook salmon and chum salmon runs, and are inactive in August when the bulk of later-arriving coho salmon are entering spawning streams (Sandone 2001). Aerial escapement counts in August are frequently limited because of poor weather and a shortage of staff time and suitable aircraft (Bue and Menard 2000).

Although much is known about coho salmon from some regions of the North Pacific (e.g., Sandercock 1991), it is not well known how the unusual environmental conditions of Norton Sound (e.g., temperature and light) may affect coho salmon life histories.

Egg Stage

Egg deposition and incubation habitat
Norton Sound coho salmon generally spawn from late August to early September, but spawning commonly continues into October. Nest sites (redds) are usually located in small flowing streams, often at the head of riffle areas. Females may deposit eggs in multiple redds. A spawning pair uses about 12 square meters of space. Coho salmon are known to re-use redds ("redd superimposition") spawned in by other coho salmon (Sandercock 1991). The physical attributes of coho salmon spawning grounds (e.g., water depth, water velocity, substrate composition) in Norton Sound have not been studied. In general, coho salmon are thought to have relatively flexible spawning habitat requirements (Sandercock 1991)

Fecundity, egg deposition, and production
Coho salmon can produce 2000 to 5000 eggs per female (Sandercock 1991), but Norton Sound coho salmon fecundities are unknown. Norton Sound salmon average about 3.3 kg (7.3 lbs; Brennan et al. 1999), which is on the lower end of mature coho salmon weights (Sandercock 1991). The correlation between coho salmon size and fecundity (Sandercock 1991) suggests that Norton Sound salmon would thus be on the lower end of the fecundity range; however, fecundity is known to increase with latitude and to be higher in North America than in Asia (Sandercock 1991), suggesting that Norton Sound coho salmon may have higher fecundities than would be indicated by size alone. Kamchatkan coho salmon averaged 3.0 – 3.5 kg (6.6 – 7.7 lbs) and had average fecundities of 4880 eggs (range = 2880 to 5970; Gribanov (1948), reported in Sandercock 1991). Average size of Norton Sound coho salmon was 3.3 kg (7.3 lbs) from 1967

to 1998 (Brennan et al. 1999), which is comparable to the weights reported in Gribanov's assessment of Kamchatka River fecundity.

Because estimates of coho salmon escapement to Norton Sound tributaries are uncertain, estimates of potential egg deposition are even less reliable than for chum salmon. The relationship between escapement level, egg deposition, and fry production in Norton Sound is also unknown. Total amount of coho salmon spawning habitat used or potentially useable in Norton Sound streams is unknown.

Egg development and physiology

Sandercock (1991) reports that most coho salmon eggs require from 300 to 427 thermal units, the sum of the average daily temperatures of the stream water (in °C). Another 40 to 80 thermal units are then required during the period from egg hatching to alevin emergence. However, Sandercock also references a study by Fraser et al. (1983) in which coho salmon eggs required over 1,000 thermal units from deposition to alevin emergence. The thermal unit requirement of coho salmon eggs in Norton Sound tributaries is unknown.

Egg survival

As a species, survival to emergence of coho salmon is affected by floods and associated siltation, freezing, low flows, egg predators, and fungus, all of which cause survival rates to emergence to be highly variable from year to year (Holtby and Healy 1986). Survival to emergence in Norton Sound coho salmon is not likely to be affected by floods because winter floods do not usually occur in Norton Sound streams (Sandone 2001). However, flooding may be a mortality factor for other life cycle stages of coho salmon in Norton Sound; spring floods and summer floods do not appear to deposit much sediment, but summer floods are marked by high tannic content (Sandone 2001).

Habitat status and potential restoration needs

As with chum salmon habitat, it is thought that some coho salmon habitat in Norton Sound is damaged from mining, road building, and gravel extraction. Several potential restoration areas were identified by Rue (1996). Causes and location of the degraded habitat are detailed in the chum salmon section, above.

Coho salmon may be susceptible to degraded stream habitat than chum salmon because of differences in life history. Coho salmon fry typically have much longer stream residence times than chum salmon, making the fry more susceptible to habitat degradation in suitable nursery streams. Coho salmon also typically spawn father upstream than chum salmon, making them more susceptible to disturbances in headwater areas. At the same time, these greater susceptibilities may also make them more responsive to habitat restoration in these same locations. Although many potentially degraded stream locations have been identified (Rue 1996), restoration priority and potential for coho salmon production increases have not yet been fully evaluated.

Information Needs

- Issues and information needs for coho salmon during the egg life cycle are essentially the same as those described for chum salmon, above.

Potential Research Topics

- Potential research topics for coho salmon during the egg life cycle are also similar to those described for chum salmon, above.

Juvenile Stage – hatching, freshwater residence, and freshwater emigration

Emergence
Coho salmon fry emerge from redds over a wide time ranges that may be 10 to 47 days after the first fry emerge. Emergent fry are generally less than 40 mm in total length, and have absorbed nearly all of their yolk sac (Sandercock 1991). Emergence timing in Norton Sound tributaries is unknown, but could be estimated from spawning times if thermal unit requirements were known.

Freshwater residence – behavior, diet, and mortality
Juvenile coho salmon typically rear from 15 months to 4 years in freshwater before migrating seaward (Groot and Margolis 1991). Studies to estimate the age composition of emigrating smolts have not been conducted in Norton Sound. Scales collected from adults returning to Norton Sound rivers indicate that a significant portion reared in fresh water for two years (age 2.1).

Newly emerged coho salmon fry typically inhabit calmer stream habitats with substantial cover and distribute to areas of higher velocity as they age. Coho fry are generally territorial, and size is thought to be a major factor in competition and survival (Sandercock 1991). As fry age, or grow, they are thought to require progressively larger territories. Streams with greater habitat complexity, such as those containing woody debris and boulders, are thought to have higher carrying capacity for coho salmon fry. Coho salmon typically inhabit the slower moving sections of streams, and their tendency to rear in small streams is thought to be due to the high proportion of slack water in small streams (Sandercock 1991). Streams with pool to riffle ratios of 1:1 are thought to provide optimal coho salmon fry rearing habitat. Coho salmon fry may also occupy lakes.

Coho salmon fry in their first year (age-0) are known to feed on both terrestrial and aquatic invertebrates while in streams. Age-1 coho salmon fry are often predatory and are known to feed on pink, chum, chinook and other coho salmon fry, in addition to sticklebacks (Sandercock 1991). Coho salmon fry diets in Norton Sound streams have not been evaluated.

Coho salmon fry are susceptible to a greater number of mortality sources than chum salmon because coho salmon fry remain instream for a year or two. Physical factors that could affect coho salmon survival include seasonal stream dewatering and flooding, entrainment in structures and diversions, and extreme temperatures. Coho salmon fry are also susceptible to predation from birds and fish.

Freshwater emigration
Coho salmon smolts have demonstrated strong diel migration patterns, with notable peaks during nighttime hours. Smolts typically migrate in schools, which is a substantial change from their

normal instream territoriality. Sandercock (1991) reports that coho salmon smolt size is consistent over the range of the species, with most smolts measuring approximately 10 cm total length. Migration timing, size, and diel patterns for Norton Sound smolts have not been determined.

Information Needs

- Issues and information needs for coho salmon fry in freshwater include those described for chum salmon, above, in addition to the following:
  - Freshwater residence time of coho salmon fry.
  - Seasonal habitat use and diet.

Potential Research Topics

- Potential research topics for coho salmon fry in freshwater also include those described for chum salmon, above, in addition to the following:
  - Evaluate coho salmon residence time, including variability within and among populations.
  - Estimate habitat use and diet, including changes among seasons and between age-0 and age-1 coho salmon.

Smolt Stage – nearshore marine

Entry into marine waters

Rue (1996) noted that coho salmon smolts typically migrated to saltwater in June and July at sizes exceeding 10 cm total length and suggested that Norton Sound coho salmon smolts probably followed a similar pattern. Coho smolt migrations occur later in the year as latitude increases (Drucker 1972) and typically occur in Alaska when water temperatures are 5° to 13.3° C. Alaska coho salmon smolts are thought to be larger in size than coho salmon smolts from elsewhere.

Diet, growth, and survival

Coho salmon eat mostly marine invertebrates when they first enter the estuary, but fish become a larger part of their diet as they grow. Slaney et al. (1985) showed coho salmon to be important predators on pink and chum salmon fry. Feeding habits are unknown for Norton Sound, but would most likely include both forage fish and marine invertebrates. Groot et al. (1995) summarized published studies and found the following food items in order of importance to estuary smolts: Gammaridea, Decopoda, Calanoida, Pisces, and Hyperiidae. In contrast, Pisces were found to be the most important food item in marine adult coho salmon diets (Groot et al. 1995). Growth rates appear to increase rapidly soon after coho salmon smolts enter marine waters.

Migration and potential offshore movement

Coho smolts are thought to stay in the nearshore area for several months before migrating further offshore. Nearshore distributions and offshore movement by juvenile coho salmon in Norton Sound are not known. Juvenile coho salmon were not captured during test netting in the Nome Subdistrict in 1981 (Tetra Tech 1981).

<u>Information Needs</u>

- Issues and information needs for coho salmon fry during the nearshore marine stage are essentially the same as those described for chum salmon, above.

<u>Potential Research Topics</u>

- Potential research topics for coho salmon fry during the nearshore marine stage are also similar to those described for chum salmon, above.

Marine Stage

Physical and Oceanographic Environment of the Bering Sea and Norton Sound – Water Current, Plankton Production, and Salinity

Coho salmon migrating through the Bering Sea should encounter the same general oceanographic conditions as chum salmon. Surface water currents in the Bering Sea are thought to generally circulate in a counter-clockwise direction, with relatively few large-scale changes among seasons (Mathisen and Coyle 1996). Differences in chum and coho salmon migration timing, as well as the different effects of the Bering Sea environment on each species, are not known. Coho salmon are thought to be more sensitive to cold water than chum salmon are (Sandercock 1991).

Distribution of Coho Salmon

<u>In nearshore Norton Sound</u>

Nearshore distribution of juvenile coho salmon in Norton Sound has not been studied. Juveniles were not captured during seining that captured pink and chum salmon in 1981 (Tetratech 1981). Though limited in area, the effort and gear size should have been effective for juvenile coho salmon, leading to the reasonable conclusion that coho salmon juveniles were not present in these waters at this time of year (or were not active during daylight sampling hours). To the south of Norton Sound, only one juvenile coho salmon was captured during extensive sampling of juvenile salmon in the Yukon River Delta in the summer of 1985 (Martin et al. 1986). To the north, Merritt and Raymond (193) reported no juvenile coho salmon captures during their chum salmon sampling in Kotzebue Sound in 1981.

<u>Fish moving offshore – timing, location, and depth.</u>

Timing of offshore movements of Norton Sound coho salmon appears to be entirely unstudied. Juvenile coho salmon have not been captured frequently enough in the nearshore zone to describe offshore movements.

<u>Southward migrations to the Gulf of Alaska</u>

The prevailing belief is that all juvenile coho salmon from western Alaska move southwards from their home rivers, pass through the Aleutian Island Chain passes, and enter the Gulf of Alaska (Sandercock 1991). Timing and route of these migrations is not known. As with chum, coho salmon from northern areas like Norton Sound probably do not reach the Gulf of Alaska until late in their first marine year.

Movement within the Gulf of Alaska

Once in the Gulf of Alaska, juvenile coho salmon are thought to mingle with other species of salmon from North America and from Asia. Coho salmon from western Alaska are known to range south of 46° N, and between 175° E and 175° W (Sandercock 1991). Coho salmon appear to prefer warmer water than other species, and are typically not found in marine waters colder than 7° C. Coho salmon from the Kamchatkan Peninsula are known to migrate as far south as 40° N as water temperatures decline (Sandercock 1991). Most other movements of coho salmon within the Gulf of Alaska are thought to be similar to those of chum salmon.

Potential movement northward (and then westward) to Asian coast, then southward to the Gulf of Alaska

As with chum salmon, it seems plausible that Norton Sound juvenile coho salmon could migrate to the Asian coastline instead of south through the Aleutian chain and into the Gulf of Alaska. Juvenile coho salmon migrating along the western edge of the Bering Sea to the Gulf of Alaska would travel with the current nearly the entire way, whereas fish traveling along the eastern edge would travel against the current. As noted above, salinity and forage base (zooplankton) in the Gulf of Anadyr are largely similar to those in Norton Sound, and biological conditions may thus be suitable for Norton Sound salmon. Small juveniles migrating north and west from Norton Sound would be able to reach Russia's Chukostk Peninsula while remaining in the nearshore zone nearly the whole time. Although the Asian route to the Gulf of Alaska would be longer than the southern route, if overall migration conditions were better the greater travel distance might be offset.

Diet

Diet in the Nearshore Environment

Lack of juvenile coho salmon catches in Norton Sound has precluded any study of diet by juvenile coho salmon. In general, juvenile coho salmon are thought to prey on invertebrates upon arrival in saltwater, then become piscivorous early in their marine life. As summarized by Sandercock (1991), herring, sand lance, and juvenile pink and chum salmon are known to be important components of coho salmon diets. Diet can vary substantially among populations, however; Sandercock (1991) reports that coho salmon populations on the east side of Vancouver Island are known to be primarily insectivorous, whereas populations on the western side of the island are primarily piscivorous. Fish prey comprised 93%, by weight, of coho salmon stomach contents from nearshore waters of Southeast Alaska, and 52% of the stomach contents of coho salmon from Prince William Sound nearshore waters (Auburn and Ignell 2000).

Diet as fish move offshore and towards overwintering grounds

Fish appear to be an important part of coho salmon diets in several habitat types. Fish were the major component of coho salmon stomachs from the shelf and from the 200 m depth contour of both Southeast Alaska and Prince William Sound. Offshore (60-120 nm) from Southeast Alaska, invertebrates were the largest component of coho salmon stomachs (Auburn and Ignell 2000). Among four species of salmon (pink, chum, coho, and sockeye), juvenile coho salmon summer diets overlapped more with pink salmon and sockeye salmon than it did with chum salmon. Among the same four species, coho salmon also had the greatest dietary consistency among habitat types (Auburn and Ignell 2000).

Age and growth
There do not appear to be any estimates of marine growth of Norton Sound coho salmon. In a summary of marine growth rates, Sandercock (1991) reports rates of between 1.1 mm/d and 1.5 mm/d and approximately 2% by weight/day for coho salmon in their first marine year. Coho growth rates appear to slow to an estimated 0.22 kg/month, 0.45 kg/month in their second marine year.

Survival
Coho salmon often have high survival rates relative to other salmon. In a summary of coho salmon survival rates, Sandercock (1991) cites wild coho salmon marine survival rates of 0.98% to 7.72%, with an average of 4.95%. This study also includes a reference to Bilton et al. (1982), who reported marine survival rates over 40% when optimizing coho salmon release time and size. As with other salmon species, the majority of coho salmon marine mortality is thought to occur in the first year at sea.

Information Needs

- Issues and information needs for coho salmon during the marine stage are essentially the same as those described for chum salmon, above.

Potential Research Topics

- Potential research topics for coho salmon during the marine stage are also similar to those described for chum salmon, above.

Immigrant (Adult) Stage

Physical and Oceanographic Environment Encountered by Fish
General physical conditions encountered by mature coho salmon returning through the Bering Sea have been summarized above. Although some coho salmon populations are known to remain near their natal streams for their entire marine life (Sandercock 1991), the intolerance of coho salmon to cold water means that Norton Sound coho salmon should overwinter far from their natal streams. Because of this, returning Norton Sound coho salmon are likely subject to similar conditions as chum salmon in the Bering Sea.

Distribution
Little is known about the distribution of Norton Sound coho salmon adults as they migrate northward from the Gulf of Alaska. Coho salmon migrating northward through the Bering Sea would presumably be moving with the prevailing currents, but their distribution within the Bering Sea (nearshore or offshore) is unknown. Similarly, coho salmon entry into, and distribution within, Norton Sound is largely unknown.

Potential Interception Fisheries
How much concern is there about coho salmon interception fisheries away from Norton Sound? Does their later arrival mean that they are more or less likely to be intercepted away from their terminal fisheries?

If coho salmon follow a pattern similar to chum salmon, the study by Gaudet and Schaefer (1982) may allow some inference of coho salmon interception fisheries within the Norton Sound fishing district. Important trends indicated by this study were:

1. Chum salmon appear to enter Norton Sound from the west, in the north central portion of the sound. The majority of the fish then move clockwise, towards the Yukon River. A minority of the fish migrates counterclockwise, towards the Nome Subdistrict.
2. Fisheries in the northern subdistricts (Nome, Golovin Bay, Moses Point, and Norton Bay) do not appear to be interception fisheries; fisheries the southern subdistricts (Shaktoolik, Unalakleet) are interception fisheries. An estimated 29% of the Unalakleet chum salmon were recaptured in the Yukon River.
3. Populations from the different subdistricts were not separated by time.

Return Migration and Spawning Ground Access

Norton Sound coho salmon return to most of the chum salmon streams in Norton Sound, with the Shaktoolik and Unalakleet rivers being the primary producers (Bue and Menard 2000). Little is known about the travel and straying rates of Norton Sound coho salmon. In other populations of coho salmon, straying has been positively correlated with smolt production and negatively correlated with smolt size (Sandercock 1991). Migration rates of coho salmon approaching Norton Sound are unknown, as are milling times at the river mouths. Coho salmon appear to have relatively elastic milling time and stream lives, perhaps because of their need to access small or headwater streams for spawning. Coho salmon returning to Alaska Peninsula streams in an unusually dry year milled for 60 days in pools 3 km upstream from the ocean before completing their migrations to spawning grounds. This extended milling time represented a five-fold increase over the stream life during the prior, wetter, year (Hetrick and Nemeth 2002). Reiser and Bjornn (1979) reported that coho salmon normally migrate when water velocities drop below 2.44 m/s and when depths exceed 18 cm.

<u>Information Needs</u>

- Issues and information needs for coho salmon during the adult immigrant stage are essentially the same as those described for chum salmon, above.

<u>Potential Research Topics</u>

- Potential research topics for coho salmon during the adult immigrant stage are also similar to those described for chum salmon, above.

Life Cycle of Norton Sound Sockeye Salmon

Introduction

Sockeye salmon (*Oncorhynchus nerka*) are distinct from other Pacific salmon species in that sockeye typically have the strongest association with freshwater lakes. Despite this generalization, sockeye populations also display highly variable life histories. Across their range, sockeye populations may spawn and rear in either lakes or rivers, mature in fresh or salt water, and return to spawn across a wide range of ages. In keeping with this variability, sockeye salmon have a relatively high degree of localized or racial adaptation for spawning, migrating, or rearing (Burgner 1991).

In regions with a large amount of accessible lake habitat, such as Bristol Bay and the Fraser River watershed, sockeye salmon are often the most abundant salmon species. This abundance coupled with the edibility of sockeye salmon means that the species has traditionally supported major commercial and subsistence salmon fisheries. Abundance and importance of sockeye salmon has resulted in extensive study over the past 100 years; as a consequence, their life histories are relatively well known, both at species and population levels.

Norton Sound is near the northern edge of sockeye salmon range in North America and populations are not as large or widespread as populations further south. Sockeye salmon are present in only a few Norton Sound drainages and there are presently no directed fisheries (Brennan et al. 1999). Sockeye salmon are most abundant in the Pilgrim/Grand Central, Sinuk, and Unalakleet drainages, and are present at low levels in several others. Norton Sound sockeye salmon are typically captured in fisheries targeting chum, chinook, or pink salmon, and the ten-year average of total sockeye salmon harvest in the region is less than 1,200 fish (Brennan et al. 1999). Consequently, relatively little is known about the populations, and the potential for unusual biological or life history requirements has not been assessed. Until Norton Sound sockeye salmon are studied directly, their biology and life history must be inferred from populations in other regions.

Although sockeye salmon currently play have only a small role in the region's fishery, there is evidence that historical populations were a significant source of food for indigenous people and miners. Photographs of train cars loaded with sockeye salmon date from the late 1800's and early 1900's, when sockeye salmon were transported from local rivers to Nome to feed the town's rapidly growing human population. This potential production has led, in part, to recent attempts to study and enhance sockeye salmon production in two river systems in the Nome subdistrict. Limnological studies and sockeye salmon fry population assessments have been conducted on Salmon Lake, in the Pilgrim River drainage, and Glacial Lake, in the Sinuk River drainage, since the mid to late 1990s (Rue 1996). Both lakes have also been fertilized sporadically as part of these studies. Although there are no historical escapement records for sockeye salmon, historical production is thought to have been higher than present production. Norton Sound river systems may be capable of producing 200,000 adult sockeye salmon annually (Rue 1996). Recent research and management activities on these two lakes have yielded most of what is known of the biology of sockeye salmon in the entire region.

Much of the information on sockeye salmon life history and ecology comes from other Alaskan populations. In general, these populations rear in freshwater lakes for one to three years before migrating to sea, making sockeye salmon the most dependent on freshwater of the five Alaskan species of Pacific salmon. Adult sockeye salmon return to spawn after spending from one to four winters at sea, and may migrate anywhere from 10 to 2,500 km inland to spawn. Although sockeye salmon are typically anadromous, some, known as kokanee, spend their entire life cycle in freshwater. The variability in freshwater rearing, ocean maturity, migration, and freshwater habitat use has resulted in a high frequency of local or racial adaptations (Burgner 1991). Adaptations can vary substantially both within and among regions and can persist for generations after sockeye salmon have been transplanted to new environments (Burger et al. 2000). The potential for these local adaptations has important ramifications for population conservation and management, and underscores the need to research sockeye salmon biology and life history at the regional and local levels.

Egg Stage

Egg deposition and incubation habitat
Spawning habitat quality and quantity influences salmon production. Knowledge of habitat area and attributes is therefore important for fisheries management. Sockeye salmon are capable of spawning in either lakes or streams (Burgner 1991); such spawning sites are examples of local adaptations by sockeye salmon populations (Burger et al. 2000). Suitable habitat for sockeye salmon spawning and egg incubation generally consists of the correct combination of substrate, water depth, and water velocity. Median particle size used by sockeye salmon spawners ranged from 14.5 mm to 48.0 mm in seven studies reported by Kondolf and Wolman (1993). DeVries (1997) reports riverine egg burial depths ranging from 15 to 30 mm for Alaskan populations of sockeye salmon. Norton Sound sockeye salmon are thought to spawn in both lakes (Salmon Lake, Glacial Lake) and in rivers (various). River spawning may be influenced by groundwater upwelling, which can favorably influence water temperature and percolation through the redd gravel. Substrate sizes and burial depths are not known for Norton Sound sockeye salmon populations. Amount (area) and condition of spawning habitats for sockeye salmon in Norton Sound tributaries is not known (Rue 1996), although there is some hydrographic data on Norton Sound rivers.

Information needs
- Physical characteristics of useable spawning and egg incubation habitat.
- Distribution and amount of spawning habitat available in Norton Sound tributaries.

Fecundity, embryo development, and production
Sockeye salmon fecundity – number of eggs per female – ranges between 2,000 and 5,000 eggs, and may be influenced by fish size and time at sea (Burgner 1991). Sockeye salmon fecundity is positively correlated with female size and the number of years spent in the ocean but does not appear correlated with the number of years spent as juveniles in fresh water (Burgner 1991). In drainages where sockeye salmon return over an extended period of time each year, fecundity often varies over the course of the run. Such variation appears to be due more to changes in fish size during the run than to timing (Burgner 1991). Although fecundity increases with size, it does so at a slower rate in sockeye salmon than it does in other salmon species (Healy 1987). Sockeye salmon fecundity and the correlation between fecundity and body size are not known for Norton Sound populations.

Total fertilized egg deposition is an important component of production because it places an upper limit on the number of adults that the brood year can provide in the future. Fertilized egg deposition can only be determined if average fecundity, sex ratio, fertilization rate, and escapement are known. Sockeye salmon production in Norton Sound is unknown because many of these data are incomplete or missing. In particular, average fecundity, sex ratio, and fertilization rates are not known.

Information needs

- Sockeye salmon fecundity – absolute, and relative to size and weight.
- Total egg deposition by Norton Sound populations.
- Fertilization proportion of deposited eggs.
- Production of spring fry by fall spawners.

Egg development and physiology

Egg size may be important to fry survival because egg size determines the amount of yolk available to the juvenile before it is able to begin feeding (Groot et al. 1995). The role of egg size in determining the survival of swim-up fry to the feeding stage has not been evaluated for Norton Sound sockeye salmon. Egg size variability among individual salmon and among years in Norton Sound is not known.

Sockeye salmon eggs in Norton Sound are typically deposited in June or July and are thought to emerge from the gravel as alevins in March or April (Lean 2002). Sockeye salmon embryonic rates have a curvilinear relationship with temperature, with fewer temperature units being required at lower temperatures (Brannon 1987). Embryonic development rates for Norton Sound sockeye salmon populations have not been evaluated. Of the studies reported in Burgner's (1991) overview of sockeye salmon egg development, the temperatures from the Gulkana River may be the most similar to that in Norton Sound. At a mean temperature of 3.2° C, Gulkana River sockeye salmon eggs reached peak emergence after accumulating 723 degree-days, or TUs (Roberson and Holder 1987). Temperatures of sockeye salmon redds in Norton Sound have not been measured, but are presumed to be near the low end of embryo studies reported in the literature. Sockeye salmon eggs typically have slower development rates than other salmon (Burgner 1991).

Information Needs

- Egg physical characteristics.
- Egg physiological requirements.

Egg survival

The total number of eggs deposited by the spawners is always much greater than the number of fry they eventually produce because eggs are subject to mortality from numerous sources. Factors affecting salmon egg mortality are known to include crowding (when it decreases the fraction of eggs that are deposited in a nest; Schroder 1981), predation, oxygen delivery, fungus, silt deposition, metabolic waste removal, and freezing. Freezing, low oxygen, fungus, and silt can also affect the condition of chum fry that survive to emergence (Salo 1991), and would also presumably affect sockeye salmon fry. The effects of all of these factors on Norton Sound sockeye salmon are unknown. In addition, the predator species composition and abundance is unknown. The effects of stream flows, water temperatures, and other physical factors are critical to understanding egg survival.

Survival of salmon eggs is also influenced by the length of incubation time. Egg incubation times dictate the date of emergence; knowledge of incubation time allows researchers to know when to measure the physical (temperature, etc.) and biological (food availability, predation, etc.) conditions affecting newly-emerged fry.

Information Needs
- Key biological and physical factors that affect egg survival.
- Egg survival rates.

Habitat status and potential restoration needs
Mining, road building, and gravel extraction in Norton Sound has directly damaged habitat and likely reduced salmon populations (Rue 1996). In particular, past mining activities have caused long-term habitat changes in or adjacent to salmon streams in Norton Sound, especially in the Nome area (Webb 1988; McLean 2001). Road construction and its associated gravel mining have affected streams more recently. Effective enforcement of stream protection laws was achieved only in the mid-1980s, and is still somewhat limited by lack of enforcement staff. Most of these perturbations were in rivers such as the Nome River and Solomon River, which do not have large lakes, and thus affected sockeye salmon less than other salmon species. If stream-rearing sockeye salmon existed before these perturbations, the populations were apparently extirpated before being documented.

The largest historical populations of sockeye salmon were probably in Glacial and Salmon lakes and were probably affected more by human exploitation during the gold rush era at the turn of the 20th century than by habitat degradation. Human population growth in this era caused substantial increases in salmon harvests, to support both humans and dog teams. Dried salmon was even used as local currency (Selkregg 1976). The Sinuk and Pilgrim rivers are typically shallow and clear, making the sockeye salmon populations easy to target and over-harvest. General consensus is that most salmon-producing streams in the area were over-exploited when the Nome population increased sharply and it is reasonable to assume that the salmon populations in Glacial and Salmon lakes were fished to low levels.

Information Needs
- Location and rehabilitation potential of spawning habitat impacted by anthropogenic disturbance.
- Long-term changes in spawning habitat from natural processes such as erosion.
- Relative effects of different disturbances on spawning habitat quality and quantity (e.g., road building, mining, etc).
- Population effects, including abundance bottlenecks, of harvest and over-exploitation by humans in the early 20th century.

Potential Research Topics – egg stage
- Determine prevalence of lotic and lentic sockeye salmon spawning in Norton Sound watersheds.
- Identify physical characteristics of spawning and egg incubation habitat in Norton Sound tributaries – water velocity, depth, upwelling, substrate size, etc.
- Identify the location and size of spawning grounds in Norton Sound tributaries.

- Estimate fecundity of female sockeye salmon.
- Establish relationships between fecundity and either length or weight.
- Evaluate variability in fecundity among Norton Sound populations.
- Estimate egg deposition per spawner and fertilization proportion to help quantify relationship between spawner abundance and fry production.
- Determine size and yolk content of eggs.
- Quantify thermal units and development times of sockeye salmon eggs in Norton Sound tributaries.
- Quantify the survival of eggs, both overall and in stages (deposition to alevin emergence, and alevin emergence to swim-up).
- Identify important sources of egg mortality in Norton Sound tributaries
    - Biological – fungus, predation, displacement by sympatric spawning species, etc.
    - Physical – oxygen delivery, siltation, freezing, dewatering, etc.
- Identify stream reaches whose spawning habitat and fry production has been reduced by anthropogenic disturbance.
- Prioritize reaches with the potential for spawning habitat restoration, and identify methods to restore them.
- Estimate contribution of different anthropogenic disturbances to habitat loss, with the intent to mitigate future effects of these disturbances.
- Gather TEK to estimate “natural” historical changes in spawning habitat availability in Norton Sound tributaries – has there been a marked gain or loss over time?

Juvenile Stage – hatching, freshwater residence, and freshwater emigration

Emergence

Fry emergence from the gravel into the stream is a critical stage for juvenile salmon and can have strong consequences for fry survival and population recruitment. Fry with relatively inflexible behavior may flourish in optimal conditions but be poorly suited to survive when physical conditions are altered or when transplanted to a new environment (Krueger et al. 1981). Sockeye salmon fry are known to have highly specific innate emergence behavior and the conditions they experience thus have strong ramifications for their overall ecology in freshwater.

Sockeye salmon alevins and fry emerge from the gravel when light is weak or absent (Burgner 1991). Prior to emergence, the fry are markedly photonegative, and will accumulate below the gravel surface until the inhibitory effect of daylight is removed (Burgner 1991). Once they have emerged from the gravel into the stream, fry may disperse upstream, downstream, or laterally, depending on a combination of environmental and genetic influences (Brannon 1967; Burgner 1991). Some sockeye salmon fry populations have demonstrated a rheotactic response – the innate response to water current – that directs them towards their ultimate rearing area. Populations hatching downstream of the intended nursery lake have exhibited stronger upstream responses to water current than have populations hatching upstream. Such rheotactic response is thought to be critical for juvenile survival; fry that access their ultimate feeding grounds fastest should expend less energy and be less susceptible to predators than fry that move randomly or in the wrong direction (Nemeth et al. 2003). The failure to match rheotactic response with environmental conditions is thought to have compromised the success of some past transplanting and restoration programs (Raleigh 1971).

The emergence behaviors of fry that hatch in lakes and of fry that rear exclusively instream are not well understood. Burgner (1991) relates evidence that lake-hatching fry may move inshore upon emergence, and that stream-rearing fry in systems devoid of lakes may delay downstream migration by holding in cover immediately after emergence.

Studies that document strong photonegative behavior by sockeye salmon fry have typically done so for populations south of Norton Sound in systems that receive more hours of darkness in the spring and summer when the fry hatch. It is assumed that Norton Sound sockeye salmon fry are similarly photonegative, but it is not known whether they cope with the decreased amount of darkness by compressing their emergence times, or by possessing more tolerance for light. In addition, the directional behavior of newly hatched Norton Sound fry is unknown for populations that hatch in either lakes or streams.

Information Needs

- Emergence timing of Norton Sound sockeye salmon.
- Diel patterns of sockeye salmon fry emergence.
- Physical factors affecting emergence patterns and survival.
- Rheotactic response of sockeye salmon, and the differences among Norton Sound populations.

Freshwater residence, behavior, feeding, and survival

Once sockeye salmon fry have emerged from the gravel, peak movement typically coincides with the darkest hours and movement slows or ceases altogether in daylight. Fry behavior may change markedly after emergence. Whereas newly emerged fry disperse individually and almost exclusively at night, older fry typically migrate in schools and may do so during daylight hours (Burgner 1991). Sockeye salmon fry display a wide range of migratory behavior and tactics, many of which may be adaptations to the local hydrography. Photoperiod, odor, stream chemistry, flow, and elapsed time may all affect sockeye salmon fry migration (Raleigh 1971; Brannon 1972).

Fry entering lakes typically do so at lengths of approximately 30 mm and weights of less than 2 g. In general, young fry inhabit the littoral zone of lakes, then move offshore as they grow. Pelagic fry often show diel vertical migrations, with the fry rising in the water column at night and then moving deeper during daylight. Fry diet varies with food availability, but is comprised mainly of dipteran insects inshore and pelagic zooplankton offshore. Fry locate their prey visually, and diel patterns are thus an important part of their feeding ecology (Burgner 1991). Once in lakes or open water, sockeye salmon fry “navigate” by celestial and magnetic orientation (Burgner 1991).

Seaward migration by sockeye salmon smolts appears to be controlled by endogenous factors that affect sockeye salmon when the fish reach a certain minimum size. These endogenous factors are triggered by photoperiod. Temperature also indirectly influences seaward migration by affecting growth and by regulating the smolting process (Burgner 1991). In general, migration usually occurs after water temperature reaches 3° C and finishes before water temperature reaches 10° C. Northern populations of sockeye salmon, such as those in interior Alaska, typically have peak seaward migrations in June or early July. Emigrating smolt travel in schools and the run is typically compressed into a relatively narrow range of days, especially in single-lake systems. Emigration follows a diel pattern in some populations and typically peaks during dark hours.

There is a small but increasing amount of information on juvenile salmon in the Norton Sound region. In 1995 and 1996, salmon smolts emigrating from Salmon and Glacial lakes were captured in June using fyke nets and incline plane traps. Peak smolt emigration from Glacial Lake in 1996 was on June 19 and 98% of the emigrating smolt were captured by June 23 (Todd and Kyle 1997). Sockeye salmon smolts exiting Salmon Lake began migrating in the early evening, under full daylight conditions, and stopped by 12 AM when daylight was still full (G. Todd, pers. comm.). Smolts emigrating from the two lakes appeared to have spent from 0 to 3 winters in freshwater before migrating, but the majority of smolts were age-1 or age-2 and the actual age structure varied between the systems. From Glacial Lake in 1995, 44 % of the smolts were age-1, 49 % were age-2, and 7 % were age-3. Salmon Lake emigrants were 4% age-0, 77 % age-1, and 19% age-2 (Todd and Kyle 1997). Smolts were captured again in 1996, but age categories were unreliable due to trap avoidance (G. Todd, personal comm.).

Sockeye salmon fry were also captured with townets in Salmon Lake in September of 1996. Of the 108 fry captured, 97 (90%) were age-0 and 11 (10%) were age-1. By comparing townet catch proportions with hydroacoustic surveys, the total sockeye salmon fry population was estimated at 1.32 million fish (Todd and Kyle 1997).

Growth in freshwater is influenced by a complex set of interactions that includes size and species composition, temperature, photoperiod, turbidity, competition, feeding behavior, and migration behavior (Burgner 1991). The efficiency with which sockeye salmon convert food to growth is temperature-dependent, and appears to vary at temperatures from 5° to 17° C (Burgner 1991). Growth is rapid in the first spring and summer after hatching, slows in autumn and winter, then increases again the next spring. Growth appears to influence length of stay in freshwater, with larger fish leaving a year earlier, or earlier within the same year, than smaller fish (Burgner 1991).

Captures of sockeye salmon fry in Salmon Lake and smolts from Salmon and Glacial lakes have provided preliminary information on juvenile sockeye salmon sizes in Norton Sound. Of the fry captured during September townetting, age-0 fry had mean (SD) lengths of 52.5 (3.7) mm and weights of 1.3 (0.30) g; age-1 fry had mean (SD) lengths of 79.7 (5.02) mm and weights of 4.8 (0.99) g. Sockeye salmon smolts varied in size between systems, and between years in Glacial Lake. In 1995, age-1 smolts emigrating from Salmon Lake had mean lengths of 76 mm and weights of 3.5 g; age-2 smolts averaged 92 mm and 5.6 g (Todd and Kyle 1997). Lengths and weights were nearly identical for each age class in Salmon Lake the next year, 1996. Smolts from Glacial Lake were larger than smolts from Salmon Lake, and sizes varied among years. In 1995, age-1 smolts had mean (SD) lengths of 89 (0.3) mm and 5.7 (0.1) g; age-2 smolts had mean (SD) lengths of 97 (2.0) mm and 7.1 (0.1) g. In 1996, age-1 smolts from Glacial Lake were larger, with age-1 smolts averaging 94 (2.0) mm and 6.5 (0.4) g (Todd and Kyle 1997).

Lean (2002) also speculated that juvenile sockeye salmon from river systems without lakes might rear in brackish water estuaries. In 2002, a few (5 to 10) sockeye salmon smolts were collected from Safety Sound, east of Nome, in water that ranged from 50% to 90% of the current ocean salinity. Because Safety Sound receives water from rivers with and without lakes (the Eldorado, Flambeau, Bonanza, and Solomon rivers), it is not known whether these smolts emigrated from a lake system or river system. If they emigrated from a system without lakes, they may be using Safety Sound as a substitute for lake rearing. Stomach contents of preserved specimens will be analyzed in the fall of 2002 and further analysis is pending.

Predation is probably the major source of mortality for juvenile sockeye salmon fry in freshwater. Fry are particularly vulnerable to predation and emergence during lakeward migrations. Known predators that are prevalent in Norton Sound drainages include coho salmon, chinook salmon, Dolly Varden char (*Salvelinus malma*), northern pike (*Esox lucius*), sculpins (*Cottus* spp.), and seabird species. Predation rates vary widely in the literature, and have been reported from 13% and 91% for lakeward migrations alone (Burgner 1991). Juvenile salmon that rear in lakes are thought to be less susceptible to predation because the fry have less exposure to predators when occupying the pelagic zone. At the onset of smolting, however, the salmon again become vulnerable to high predation rates as they migrate downstream past various species of predators. Both avian and fish predators may migrate to the stream reach specifically to feed on smolts emigrating from the lake. The susceptibility of emigrating smolts to predation may be one reason why smolts tend to emigrate in large number over short time spans instead in smaller densities over a more protracted time period (Burgner 1991).

Information Needs

- Movement, diet, and mortality of fry.
- Factors (e.g., innate, environmental) controlling the dispersal and migration of fry.
- Increased information on freshwater age structure of juveniles and the variation among years and systems.
- Increased information on size and growth, and the variation among years and systems.
- Location of rearing habitat and the potential for stream or estuarine rearing.
- Sources of predation.
- Other sources of mortality on sockeye salmon fry in freshwater.

Potential Research Topics – Fry stage, hatching and freshwater migration

- Determine the age and age variability at which juvenile sockeye salmon migrate to sea.
- Determine whether some populations are able to use streams or estuaries for the entirety of their freshwater rearing.
- Document seasonal migration patterns of smolt migrations in major salmon streams.
- Document freshwater size and growth of fry.
- Document freshwater age structure among years and systems.
- Determine diet and forage quantity in freshwater.
- Identify important sources of freshwater mortality (e.g., predation, fry size, food availability, and presence of parasites).

Smolt stage - nearshore marine

Sockeye, coho, and chinook salmon have distinct fry and smolt stages that can result in different behaviors and requirements as juveniles age. These species have a low tolerance for saltwater while fry, and must undergo a series of physiological and osmoregulatory changes, typically referred to as "smolting" before entering saltwater (Groot et al. 1995). The life history strategy and requirements of the fish can be substantially different from those needed previously, during extended rearing in lakes and streams. Behavior and appearance of smolting juveniles can change at this time and must be considered when evaluating juvenile life histories of these species. Pink and chum salmon, conversely, head downstream soon after hatching and do not display a distinct smolting process (Groot et al. 1995).

Entry into marine and estuarine waters

Downstream migration of sockeye salmon is thought to happen quickly, and is often completed within a few days for populations that are relatively close to the ocean. For Norton Sound, this would mean that peak entry into saltwater is probably in mid-June for salmon from Glacial and Salmon lakes. A few sockeye salmon were captured in Safety Sound in early July 2002 (Nemeth personal communication, unpublished data), but further sampling is needed to estimate how long the fish had been in saltwater.

Juvenile sockeye salmon entering salt water may linger in estuarine or nearshore areas, or may move offshore immediately. In either case, juveniles are thought to have moved offshore by the first autumn of sea life. As in freshwater, migration and behavior varies among populations and are thought to have high potential for innate control or local adaptation (Burgner 1991). This time of early marine residence is thought to be a critical time for growth and survival of sockeye salmon. In Bristol Bay, juveniles appear to gradually migrate along a salinity gradient, and may take up to six weeks before entering the high-salinity outer bay. Timing and patterns of offshore movement by sockeye salmon from Norton Sound have not been studied.

Information Needs

- Entry timing into saltwater.
- Behavior of fry upon entering saltwater.
- Role of estuaries as transition zones between fresh and salt water.
- Length of time spent in estuaries.

Diet, growth, and survival

Juvenile sockeye salmon have a diverse diet upon entering salt water, and may eat zooplankton, insects, amphipods, euphausids, and fish larvae. Growth varies with forage, but is typically about 0.6 mm/d. In Bristol Bay, sockeye salmon acclimatizing slowly to salinity are relegated to less productive foraging waters and thus exhibit slower growth than stocks which are able to move out into more productive outer waters (Burgner 1991). Diets of sockeye salmon from Norton Sound have not been studied, but the few sockeye salmon smolts captured in Safety Sound in 2002 (M. Nemeth, personal communication, unpublished data) will be analyzed for stomach contents and age in the autumn of 2002.

Predators of juvenile sockeye salmon in the nearshore area can include diving birds, marine mammals, chinook salmon, and coho salmon (Burgner 1991). Beluga whales are thought to be a major predator of sockeye salmon in parts of Bristol Bay and consumed an estimated 5% of the sockeye salmon smolts produced from the Kvichak River in 1985 (Lowry et al. 1985). Three belugas captured in Norton Sound, near Elim, on June 12 1977 had many fish in their stomachs, but no sockeye salmon (Lowry et al. 1985).

Information Needs

- Diet and growth of juvenile sockeye salmon in nearshore environments.
- Sources of mortality.

Distribution

Nearshore distribution of juvenile sockeye salmon in Norton Sound is poorly known. The most extensive attempt to capture juvenile salmon was in 1981, when seines and townets were used to sample both nearshore and offshore waters near Nome. The sampling was conducted in a limited spatial area (all in the Norton Sound District; Figure 1) and over a narrow time period (June 24 to July 2). No juvenile sockeye salmon were captured during this effort (Tetra Tech 1981).

Migration and potential offshore movement

Sockeye salmon move offshore sometime in the autumn of their first year of sea life. Salmon from Bristol Bay move through the Aleutian Island passes sometime during the autumn or winter presumably in response to temperature and food needs. The offshore distribution of Norton Sound juvenile sockeye salmon is not known. If the sockeye salmon travel down the west coast of Alaska, they may follow a migration route through Bristol Bay that is similar to the routes and methods used by Bristol Bay populations. The use of nearshore vs. offshore zones for these migrations is not known. The influence of current direction and strength on Norton Sound sockeye salmon is also unknown.

Juvenile sockeye salmon may require minimum temperatures before being able to migrate offshore. Juvenile sockeye salmon on the north side of the Alaska Peninsula were absent from colder (<6 C) offshore water in July, despite the greater abundance of prey offshore (Farley et al. 2000). Juvenile sockeye salmon were present in the offshore waters in September, when these waters had warmed above 8.5 C (Farley et al. 2000). Although Farley et al. (2000) speculated that the observed distribution and timing indicated an avoidance of colder water. It is also possible that developmental timing influenced the distribution.

Information Needs

- Timing and location of offshore movement.
- Size at which juvenile fry move offshore.
- Relationship between offshore movements, food availability, and environmental conditions.

Potential Research Topics – juvenile stage, nearshore marine

- Document timing and interannual variability in saltwater entry by sockeye salmon smolts.
- Determine feeding activity, diet, and stomach fullness of sockeye salmon smolts.

- Determine the spatial pattern of juvenile sockeye salmon in estuarine versus adjacent non-estuarine nearshore habitats.
- Identify main predators of fry in the nearshore environment. Summarize known trends of predator abundance as a secondary indicator of smolt trends.
- Estimate the daily mortality rate of fry in the nearshore environment.
- Examine correlations between mortality and environmental or biological factors such as freshwater runoff, salinity, temperature, or fish density.
- Sample nearshore and offshore waters over time to obtain time series of presence/absence. Measure juveniles to obtain biostatistics (e.g., length, weight, body condition).
- Measure temperature, salinity, and plankton abundance over time to correlate trends with fry movement.
- Examine vertical distribution of juveniles to determine the most likely sources of predation, and the level at which water currents affect the largest proportion of the population.

Marine Stage

The abundance and economic/subsistence importance of sockeye salmon has made them one of the more studied species of Pacific salmon, and has yielded a relatively large amount of information on their marine life history. Compared to other North American sockeye salmon populations, however, relatively little is known about the marine stage of sockeye salmon from Norton Sound. Overall, it is generally assumed that Norton Sound sockeye salmon migrate south through the Bering Sea, pass through the Aleutian Islands, and reach maturity after spending one or more years in the Gulf of Alaska. Once in the southern Bering Sea and in the Gulf of Alaska, Norton Sound stocks would presumably mingle with other stocks. Norton Sound sockeye salmon are not marked, making it impossible to use recaptures to determine their distribution and migration paths. Even if they were marked, Norton Sound sockeye salmon are probably so low in abundance that a relatively large recapture effort would be needed to recapture a meaningful number.

WHAT ABOUT GENETIC MARKERS? For example: Although tagging or mass marking studies (e.g., otolith marking) studies have not been conducted, genetic studies of Norton Sound sockeye salmon have been conducted. Based on xxxx (allozyme) studies, Norton Sound sockeye salmon could be identified from tissue samples taken from mixed stock captures. However, no such captures have been reported by investigators who have conducted relevant stock ID studies (e.g.,). Until Norton Sound sockeye salmon can be tagged or tracked, most knowledge of their marine ecology must be inferred from knowledge of sockeye salmon from adjacent regions such as Bristol Bay or Asia.

The exact migration routes of juvenile salmon are particularly difficult to determine because of the lack of marked fish and the added difficulty of catching and identifying small fish. Sockeye salmon that migrate south from Norton Sound are presumed to travel along the western Alaskan coast and pass through the Aleutian Islands to enter the Gulf of Alaska. An alternative, however, is that sockeye salmon could migrate west from Norton Sound to the Asian coastline, south along the Asian coastline, and then eastward to enter the Gulf of Alaska. This "Asian route" would be longer than the route down the western Alaskan coast, but would expose migrating sockeye salmon to different conditions of water chemistry, forage, and circulation regimes. If these conditions are more favorable to the salmon, the advantages of the longer Asian route may outweigh the disadvantage of longer distance. Differences in these routes will be described in greater detail, below.

Physical and Oceanographic Environment of the Bering Sea and Norton Sound – Water Current, Plankton Production, and Salinity

Surface water currents in the Bering Sea are thought to generally circulate in a counter-clockwise direction, with relatively few large-scale changes among seasons (Mathisen and Coyle 1996). On the eastern edge of the Bering Sea the current flows through the Aleutian passes, and northward along the coast of the Bering Sea before reaching Norton Sound. Currents in the Norton Sound region continue north or northwest, depending on the season, at velocities up to 20 cm/s. Current velocity probably increases through the Bering Strait. Water currents also flow north along the western side of the Bering Strait, but velocities appear to be lower (5 to 10 cm/s instead of 20 to 50 cm/s) than on the eastern side (Figure 3).

Across the Bering Sea from Norton Sound, current direction within the Gulf of Anadyr is varied, flowing in all four compass directions at different times and locations. South of the Gulf of Anadyr, the currents along the Russian coast flow south and east at speeds of up to 50 cm/s before reaching the Aleutian Arc (Figure 3). Fish migrating along the western coast towards the Gulf of Alaska could presumably be transported at relatively high speeds.

Surface salinities in the main part of the Bering Sea increase from approximately 31 ppt along the coastlines to 33.5 ppt in the open ocean (Luchin et al. 1999). Peak river runoff in June usually results in minimum salinity in shelf waters in July. The lowest salinities are at the heads of Anadyr Bay (20 ppt) and Norton Sound (< 29 ppt; Luchin et al. 1999). There is little large-scale seasonal change in salinity throughout the Bering Sea.

Primary production in the Bering Sea begins with phytoplankton blooms in the late winter and early spring that stimulate zooplankton feeding and reproduction. Production varies substantially with season and region. Zooplankton biomass peaks between late May and early July, but individual species peak at various times throughout the year. Plankton concentrations rise from approximately 100 mg/m^3 in the winter to over 2,000 mg/m^3 in the spring before declining through the summer and fall (Laughlin et al. 1999). Concentrations throughout the year are generally highest in the deep waters and off the eastern shelf, and lowest in the nearshore zones.

Spring zooplankton species are generally nektonic and dwell at depths of 10m to 100m below the surface. Spatial peaks of Bering Sea plankton biomass are in the Gulf of Anadyr, Norton Sound, and Bering Strait, where concentrations can reach 3,200 mg/m^3. Zones of high zooplankton biomass also include a zone from the southeastern Bering Sea north to the Chukchi, and another along the Kamchatkan Coast (Laughlin et al. 1999). These data appear to conflict with the report by Coyle et al. (1996) that 2/3 of the biomass in the upper 200m occurs over the deep basin of the western region.

Information Needs

- Physical and biological characteristics that could potentially affect sockeye salmon distribution and migration through Norton Sound and the Bering Sea.

Potential Future Research Topics:

- Describe the surface water currents within Norton Sound, the Gulf of Anadyr, along the Bering Sea coasts, and along other potential migration routes. Describe how these currents may assist or impede migrating salmon.
- Determine the depth at which the majority of sockeye salmon migrate and feed.
- Describe physical features such as water current, salinity, and temperature in Norton Sound and the Bering Sea.
- Determine the location and seasonal distribution of biological factors that affect salmon in the Bering Sea – where, when, and how might prey availability and coccolithophores affect migrating salmon?
- Compare Norton Sound environmental features with potentially similar regions – can we infer behavior and strategies of Norton Sound sockeye salmon from environmentally similar populations?

Marine migration routes

Southward Migrations to the Gulf of Alaska

The prevailing belief is that juvenile sockeye salmon from western Alaska move southward from their home rivers, pass through the Aleutian Islands and enter the Gulf of Alaska (Figure xx; Burgner 1991). Sockeye salmon from Bristol Bay are thought to enter the Gulf of Alaska in the autumn; sockeye salmon from Norton Sound probably do not reach the Gulf of Alaska until late in the calendar year because of the increased travel distance. If sockeye salmon migrate offshore, they may migrate through the Bering Sea to reach the Aleutian Island passes. If they remain in or near the nearshore zones, sockeye salmon would not enter the open Bering Sea, but would instead travel across Bristol Bay and westward along the north edge of the Alaskan Peninsula before reaching the passes to the Gulf of Alaska.

Juvenile sockeye salmon were not captured during extensive sampling of the Yukon River mouth, leading Martin et al. (1986) to conclude that juvenile salmon were displaced offshore by the Yukon River water plume. The absence of juvenile sockeye salmon from the catch indicates that they may migrate offshore for at least a portion of their southward migration.

Movement Within the Gulf of Alaska

Once in the Gulf of Alaska, sockeye salmon are thought to migrate in seasonal gyres, moving counterclockwise from the southeast to the northwest of their distribution. In general, western Alaskan sockeye salmon stocks have a fairly large east-west range while in the Gulf of Alaska, with seasonal ranges between 43 ° and 55 ° N and 140 ° W and 167 ° E (Burgner 1991). Maturing sockeye salmon preparing to re-enter the Bering Sea en route to natal spawning sites probably break off from the migratory gyre when migrating alongside the Aleutian Islands or Alaska Peninsula in the late spring or early summer. Sockeye salmon that remain at sea for additional seasons are presumed to repeat the annual migratory gyre until the year in which they will spawn (Burgner 1991). Stocks from western Alaska have distributions that overlap spatially with Asian and other North American stocks, but appear to separate themselves temporally.

Immature and maturing sockeye salmon are also thought to separate by the winter of their second year at sea. The migratory paths and distribution of sockeye salmon in the Gulf of Alaska are probably influenced by a combination of forage resources, genetic behavior, and oceanographic patterns or regimes. Although water current, temperature, and salinity are thought to be the major influences on the oceanic distribution of Pacific salmon, the influence is thought to be less for sockeye salmon distribution than for other salmon species (Burgner 1991).

Sockeye salmon in the Gulf of Alaska appeared to feed in two distinct latitudinal zones, based on data collected from 1994 to 1998 (Aydin et al. 2000). Cooler sea surface temperatures (SST) and high concentrations of micronektonic squid marked the southern zone, whereas warmer SST and high concentrations of zooplankton marked the northern zone. Sockeye salmon were larger in the southern (squid-feeding) zone than in the northern (zooplankton-feeding) zone, but the differences were not significant until sockeye salmon matured at age .2 or .3. The interface of the two zones varied from 51 to 54 degrees north from 1994 to 1998 (Aydin et al. 2000).

In winter, sockeye salmon distributions in the Gulf of Alaska appear to be compressed into a narrow – relative to summer distributions – latitudinal range between the 4 and 8-degree isotherms (Ueno et al. 1999). Sockeye salmon may overwinter in this relatively cold zone because the cold water reduces metabolic rates, thereby reducing food requirements at a time when zooplankton numbers drop by about 90% throughout sockeye salmon summer range (Nagasawa 2000b).

<u>Potential Movement Northward (and then Westward) to Asian Coast, then Southward to the Gulf of Alaska</u>

Although the Asian route would cause Norton Sound sockeye salmon to travel farther to reach the Gulf of Alaska than the southern route would, the greater travel distance could be more advantageous if overall migration conditions are better. Juvenile sockeye salmon would migrate counter-clockwise through the Bering Sea, migrating west to the Asian coastline, then south along the western edge of the Bering Sea, and then east to the Gulf of Alaska. Fish migrating along this counterclockwise route would appear to spend more time migrating with the prevailing currents than would fish migrating clockwise, along the eastern edge of the Bering Sea. As noted above, salinity and forage base (zooplankton) in the Gulf of Anadyr, along the Asian coastline, are largely similar to those in Norton Sound, suggesting that biological trade-offs may be minimal. Juvenile salmon would need to travel only a short distance from Norton Sound to reach the Asian coastline; sockeye salmon that remained in freshwater for a year may enter the sea at a size large enough (approximately 100 mm, 7.5 g; Todd and Kyle 1997) to cross the northern Bering Sea, and would be able to reach Russia's Chukostk Peninsula while remaining in the nearshore zone nearly the whole time.

Once on the Asian coastline, any salmon from Norton Sound would presumably have similar life history strategies as the Anadyr River sockeye salmon, which enter Anadyr Sound and are also thought to migrate to the Gulf of Alaska. If Norton Sound stocks were to migrate with Asian stocks from the western Bering Sea for their entire lives, their distribution would be considerably different than for stocks that migrate down the eastern edge of the Bering Sea (i.e., Bristol Bay). Asian sockeye salmon stocks migrate in the area between 60 and 48 degrees north, and between

170 degrees west and 160 degrees east (Burgner 1991, Figure 40), which is west and north of the major area used by western Alaskan stocks in the Gulf of Alaska.

<u>Information Needs</u>

- Migration routes and seasonal distribution of Norton Sound sockeye salmon.
- General ecology of Norton Sound sockeye salmon in the open ocean.

<u>Potential Research Topics</u>

- Conduct fish sampling or marking programs, use tag recoveries and stock identification techniques (scales, genetics, etc.) to identify:
  - seasonal and spatial distribution patterns of Norton Sound sockeye salmon.
  - arrival of sockeye salmon into the Gulf of Alaska.
  - differences in distribution among Norton Sound populations.
  - diet of sockeye salmon in the Gulf of Alaska and the Bering Sea.
  - migration routes of sockeye salmon traveling from Norton Sound to the Gulf of Alaska.
- Compare known trends between Norton Sound and non-Norton Sound populations.

Diet

Sockeye salmon appear to consume a wide variety of prey, including both zooplankton and small fish, and food availability appears to be the driving factor behind this diet (Burgner 1991). Sockeye salmon diets may vary with season, location, and diel time (Burgner 1991; Davis et al. 2000). Sockeye salmon in the central Bering Sea fed primarily on fish during the day and on euphausids and copepods during the night. Feeding activity also appeared to increase after sunset (Davis et al. 2000). In a recent study of juvenile sockeye salmon diets from the Alaska Peninsula, Auburn and Ignell (2000) reported that decapod larvae was the most substantial prey species, by weight, found in stomachs of juveniles (fork length mean = 185 mm, range = 147-229). Unidentified fish were also an important food item, accounting for 22% of the stomach content by weight in shelf waters and 31% of the content by weight in nearshore waters. Sockeye salmon tended to have a wide range of prey items, giving them consistent but average overlap with the diets of pink, chum, and coho salmon sampled in the study (Auburn and Ignell 2000). Dietary changes with season or geography were not addressed by the study, but are known to be substantial and varied from prior studies (Burgner 1991).

<u>Information Needs</u>

- Marine diet of Norton Sound sockeye salmon.
- Likely sources of competition and diet overlap for sockeye salmon.

<u>Potential Research Topics</u>

- Marine diet of salmon.
- Potential for intra- and inter-specific competition.
- Effects of density on forage success.

Age and growth

Growth can affect fish by influencing forage ability, predator susceptibility, and swimming ability (stamina and speed). Growth rate and absolute size are known to correlate with salmon survival (Rogers 1987; Salo 1991), but the relative effects of growth rate on survival of Norton Sound sockeye salmon is not known. Sockeye salmon growth rates vary by stock, maturity stage, and size at maturity. In general, maturing fish are larger than immature cohorts, length increase (growth) is greatest in the first marine year, and weight increase (growth) is greatest in the second marine year (Burgner 1991). Among juveniles with an equal number of years at sea, juveniles with a greater number of freshwater years are generally larger because of an earlier entry into marine water. It also appears that sockeye salmon growth continues throughout the year. There do not appear to be any annual growth estimates of Norton Sound sockeye salmon stocks.

Information Needs

- Size at age and at maturity for Norton Sound salmon.
- Effects of environment, competition, and density on growth and maturation.
- Seasonal and annual variability in instantaneous growth rates.

Potential Research Topics

- Examine links between growth and survival of sockeye salmon in Norton Sound and elsewhere.
- Develop estimates of Norton Sound sockeye salmon growth by year and compare these to environmental variables (physical and biological).

Survival

Marine survival is generally thought to be influenced by biological features such as size and development, but is also probably related to environmental factors that are independent of these features. Pyper et al. (1999) examined covariation of survival with length and mean age at maturity and concluded that environmental processes had effects on survival beyond the intermediary effect on size and development. Temperature, for example, may affect survival by altering distribution and therefore changing susceptibility to predators (Burgner 1991). Sockeye salmon survival studies are complicated by the species' complex life history, and there do not seem to be any trends that hold true across regions or major stock differences. Burgner (1991) summarized survival studies and reported that, with some exceptions, larger smolts tended to have higher marine survival rates. This may be due to the ability to better avoid predators, but may also be due simply to the tendency for larger fish to spend fewer years at sea, thereby decreasing their chances for annual mortality. Although patterns have been detected for many stocks, the reasons for the observed mortality patterns are mostly still unknown.

Estimates of sockeye salmon marine survival, from smolt to returning adult, have been from 5% to about 30% (Burgner 1991). Annual mortality at sea probably rages from 0 to 95% (Burgner 1991). Estimates of marine mortality would require a marking program not currently implemented for Norton Sound sockeye salmon.

Information Needs

- Marine survival of Norton Sound sockeye salmon.
- Effects of age and size on marine survival.
- Causes of mortality.

<u>Potential Research Topics</u>

- Develop time series of annual estimates of marine survival.
- Correlation between survival and factors such as environmental processes (temperature, salinity, etc.), biological factors (lengths, weight, age), and distribution.
- Identify sources of predation on Norton Sound sockeye salmon migrating through the Bering Sea and within the Gulf of Alaska.
- Determine the relative importance of survival by age and life stage. For example, does survival in the second year influence Norton Sound returns more than survival in the third year?
- Do Norton Sound populations share enough similarities of environment or biology (e.g., similar latitude or oceanographic conditions) with any other stock to place special emphasis on examining that stock?

Immigrant (Adult) Stage

Physical and Oceanographic Environment Encountered by Fish
The general physical conditions encountered by mature sockeye salmon returning through the Bering Sea are summarized in the discussion of immature and maturing salmon, above. The main difference in oceanographic conditions is that mature sockeye salmon migrating through the Bering Sea presumably move with the current, instead of against it, as they migrate north to Norton Sound.

Distribution
Little is known about the migration of Norton Sound sockeye salmon through the Bering Sea. Regardless of whether adult sockeye salmon migrate close to the eastern coast or in the open ocean, strong ocean currents moving north from the Pacific Ocean to the Chukchi Sea probably assist their northward migration. Most knowledge of adult sockeye salmon distribution comes from tagging studies (e.g., Myers et al. 1996). Unfortunately, the wide dispersal of sockeye salmon after tagging in the North Pacific makes it difficult to recapture enough fish to determine migration routes through the Bering Sea.

<u>Information Needs</u>

- Migration routes, timing, and travel times of sockeye salmon returning to Norton Sound.

<u>Potential Research Topics</u>

- Use newly-developed tagging equipment to identify migratory paths and behavior.
- Combine ocean sampling programs with stock identification techniques to identify spatial and temporal distribution of Norton Sound sockeye salmon in the Bering Sea and Gulf of Alaska.
- Determine the direction(s) from which adult sockeye salmon enter Norton Sound.
- Document the dispersal of adult sockeye salmon within Norton Sound.

Potential Interception Fisheries.
Because little is known about the migration of Norton Sound adult sockeye salmon, there is speculation that fish may be harvested in “interception” fisheries before returning to Norton

Sound. The South Peninsula June Fishery (also known as the False Pass fishery) has received the most attention as a potential interception fishery. High seas driftnetting was also listed as a potential interception fishery, but has largely been eliminated in recent years. Until the full distribution of adult and maturing sockeye salmon is known, it is also conceivable that other fisheries in the North Pacific may intercept Norton Sound sockeye salmon.

Information Needs

- Locations and relative effects of interception fisheries affecting Norton Sound sockeye salmon populations.

Potential Research Topics

- Identify locations of potential interception fisheries, ways in which to sample the fisheries, and ways to identify salmon from Norton Sound.

Return Migration and Spawning Ground Access
Sockeye salmon are the least abundant salmon spawners in Norton Sound, spawning at relatively low levels in a few drainages. Sockeye salmon are only harvested incidentally in commercial and subsistence fisheries that target other species. Approximately 1,160 sockeye salmon were harvested per year over the five-year period from 1994 to 1998, with subsistence catches accounting for approximately 90% of the catch (Brennan et al. 1999). Escapements indices are reported only for the Pilgrim and Sinuk river drainages, with aerial surveys being conducted annually on Salmon Lake, its outlet (the Grand Central River), and Glacial Lake (Todd and Kyle 1997).

Most biological data of adult sockeye salmon in the region come from fish captured in the Pilgrim and Sinuk river drainages. Over 95% of the sockeye salmon returning to Salmon Lake in 1996 had spent three winters at sea, with age 2.3 sockeye salmon accounting for most of the run. Historical Glacial Lake data from 1977 and 1979 show that three-ocean-year fish accounted for 81% of the returning sockeye salmon, with the run also being dominated by the 2.3 age class (Todd and Kyle 1997). Adult sockeye salmon return to Norton Sound in from late June to mid-August, with the peak part of the run being from mid-July to early-August.

Little is known about the travel and straying rates of Norton Sound sockeye salmon. As noted above, sockeye salmon in the Pilgrim River drainage are known to spawn in Salmon Lake, and also appear to spawn in the inlet stream, the Grand Central River. Adult sockeye salmon typically have strong homing abilities and migration timing, as indicated by low straying rates, which helps explain the proliferation of reproductively separated sympatric populations. The degree to which this has occurred in the Pilgrim River drainage is not known. Migration rates, routes, and detailed biological characteristics of Norton Sound sockeye salmon have not been examined.

Information Needs

- Distribution of adult sockeye salmon within Norton Sound.
- Nearshore and freshwater dispersal of adult sockeye salmon to spawning grounds.
- Key spawning ground locations.

Potential Research Topics

- Once in Norton Sound, how long do sockeye salmon mill and what is the estimated change in milling time throughout the season (e.g., summer vs. fall sockeye salmon)?
- Identify key spawning reaches in the major sockeye salmon rivers – can we reliably locate the majority of useable and unusable areas on any river?
- Describe important spawning ground attributes.
- Quantify the overall amount of spawning habitat in ANY river system or stream.

Life Cycle of Norton Sound Pink Salmon

Introduction

Pink salmon (*Oncorhynchus gorbuscha*) differ markedly from other species of Pacific salmon in several aspects of their ecology and life history, and generally have the greatest dependence on the marine environment. Pink salmon have the ability to spawn intertidally, move to saltwater immediately after hatching (for freshwater hatching populations), have a smaller body size than other Pacific salmon, and have a fixed, two-year life cycle (Heard 1991). Pink salmon productivity can also be unusually high, with millions of adults returning to individual watersheds. Pink salmon usually spawn in the lower reaches or tributaries of a drainage, presumably because they are relatively weak swimmers and are stopped by barriers that other salmon species are able to navigate (Heard 1991). Pink salmon spawners often reach high densities in these reaches, and their greatest interspecific competition for space is usually with chum salmon. Pink salmon are exploited by commercial and subsistence fishers, but are not considered to have as high of edibility as coho, chinook, or sockeye salmon. Commercial pink salmon fisheries are often supplemented by hatchery production, such as in Prince William Sound and southeast Alaska.

Pink salmon spawning habitats are relatively easy to discern because adults return in the summer or early fall and spawn at high abundances low in the watershed. In watersheds in which they flourish, pink salmon have the potential to deliver a substantial proportion of the marine derived nutrients to the watershed. Consequently, pink salmon have the potential for value to the ecosystem that is independent of their commercial or subsistence value.

Norton Sound is near the northern edge of pink salmon range in North America, and marks the northernmost boundary of commercially important populations (Heard 1991; Brennan et al. 1999). Important pink salmon-producing rivers within the Norton Sound region include the Nome, Sinuk, Eldorado, Fish, Niukluk, Kwiniuk, Tubutulik, Shaktoolik, and Unalakleet rivers. Norton Sound pink salmon follow an odd/even year cycle, with even-year abundance (e.g., 1998, 2000, 2002) typically larger than odd-year abundance (Menard 2001). Runs in the 1990's allowed for commercial harvests in even years (average harvest of 556,000 pink salmon in years 1994, 1996, 1998, and 2000; data from Menard 2001), but odd-year returns to were too low to support a commercial fishery. The forecasted run in 2002 was too low to support a commercial fishery (ADF&G 2002), making it the first even-year since 1992 in which there was no directed commercial fishery for pink salmon. Pink salmon are caught in subsistence fisheries in all six Norton Sound subdistricts. The average subsistence catch for the five years from 1994 to 1998 was 40,000 pink salmon, with harvests approximately twice as high in even years (62,500) as in odd (33,000; Brennan et al. 1999).

Although pink salmon are important for commercial and subsistence fisheries, there is little life history information specific to Norton Sound populations. Consequently, their biology and life history must be inferred from populations outside the region, and the prevalence of unusual biological or life history requirements within Norton Sound has not been assessed.

As noted earlier, the pink salmon life cycle relies more heavily on marine waters than any of the other salmon species native to Alaska. Adult pink salmon usually spawn in the lower portions of a drainage, with a large proportion of their production typically within a few kilometers of the ocean. Spawning usually occurs between July and November, and alevins emerge from the gravel between February and August. After emergence, pink salmon fry migrate downstream to oceans or estuaries, and typically enter salt water before feeding. Juvenile pink salmon are thought to spend at least some time in the nearshore coastal area, and then move offshore for feeding and migration. Timing and consistency of such movements probably varies substantially among populations. By late autumn or early winter of their first year, most populations appear to have reached the southern part of their ocean distribution. Maturing pink salmon move northward as the water warms after their first winter in the ocean, then begin migrating towards their spawning grounds. By summer, at approximately 18 months after hatching, most pink salmon are preparing to spawn in their natal streams.

Norton Sound pink salmon spawn primarily in July and August, and juveniles are thought to typically hatch and migrate seaward in May and June (C. Lean 2002, personal communication). Little is known of the marine ecology of pink salmon from Norton Sound. Adult sockeye salmon and chum salmon have been recaptured in Norton Sound after having been tagged elsewhere (Kerkvliet 1986; Eggers et al. 1989), but there is no such information for adult pink salmon from Norton Sound. The prevailing assumption is that Norton Sound pink salmon migrate southward to the Gulf of Alaska, where they overwinter before returning through the Bering Sea to Norton Sound.

Egg Stage

Egg deposition and incubation habitat

Pink salmon typically spawn anywhere from the intertidal zone upstream into the lower reaches of a watershed. Although much production is close to the ocean, pink salmon in some Alaskan systems may migrate as far as 200 km upriver to spawn if the system has no substantial velocity or gradient barriers. The extent of freshwater migration may also be influenced by population size, with pink salmon traveling further upstream in years of high abundance.

Pink salmon spawning grounds tend to be fairly uniform areas in which clean gravel underlies moderate to fast currents. Water depth and current velocity appear to be the most important spawning habitat characteristics, with pinks favoring moderately deep, fast-moving water over slow or deep areas. Typically, preferred depths range from 30-100 cm and preferred velocities range from 30 to 100 cm/s (Heard 1991). Median particle size used by pink salmon spawners ranged from 6.5 mm to 11.0 mm in seven southeast Alaska streams (Helle 1970, reported by Kondolf and Wolman 1993); these sizes are notably smaller than those reported for chinook, coho, sockeye, and chum salmon (Kondolf and Wolman 1993). DeVries (1997) reports mean egg burial depths ranging from 15 cm to 30 cm for three Asian populations of pink salmon; these depths are relatively similar to those reported for chinook, coho, sockeye, and chum salmon.

Although spawning habitats of pink and chum salmon often overlap, pink salmon appear to rely more on gradient to supply intragravel flow whereas chum salmon rely more on groundwater. Consequently, pink salmon are more likely to spawn in areas marked by a gradient increase, such as in riffles. Adult pink salmon can spawn across a wide range of temperatures, but activity typically is highest between 5 and 17 degrees. Within a system, as many as 74% of the redds may be in reaches that are tidally influenced (Heard 1991).

Oxygen supply, freezing, and substrate stability appear to be the primary factors affecting incubating eggs. Temperature and dissolved oxygen can have different effects at different stages of egg development; depending on time-specific conditions, oxygen and temperature can affect egg development rates, survival, and alevin size. Heard (1991) summarized numerous reports of temperature and dissolved oxygen levels and noted consistent problems with eggs exposed to temperatures below 5 degrees before gastrulation and dissolved oxygen levels below 5 mg/l.

Information needs

- Distribution and amount of spawning habitat available in Norton Sound tributaries.
- Physical characteristics of useable spawning and egg incubation habitat.

Fecundity, embryo development, and production

Total fertilized egg deposition is an important component of production because it places an upper limit on the brood year's future production of adult fish. Fertilized egg deposition can only be determined if escapement, sex ratio, average fecundity, egg retention, and fertilization rate are known. Pink salmon production in Norton Sound is unknown because, in part, many of these data are incomplete or missing. In particular, fecundity, sex ratio, egg retention, and fertilization rates have not been estimated for any Norton Sound populations, and must therefore be estimated from information from outside the region.

Pink salmon fecundity ranges from about 1,200 to 1,900 in the literature, making pink salmon the least fecund of the five species of salmon native to Alaska. Fecundity appears positively correlated with both length and weight in many populations (Heard 1991), and may also be correlated with return timing (Grachev 1971). Pink salmon fecundity and the correlation between fecundity and other traits are not known for Norton Sound populations.

Egg retention by spawning pink salmon can be as high as 40% (Helle et al. 1964) and appears to correlate with the abundance of returning spawners. Heard (1991) noted that egg retention is usually small compared to the number of eggs lost during spawning, and thus considered egg retention to be biologically unimportant.

Information needs

- Pink salmon fecundity – absolute, and relative to size and run timing.

- Total egg deposition by Norton Sound populations.
- Retention of eggs by spawning pink salmon.
- Fertilization proportion of deposited eggs.

Egg development and physiology

Egg size may be important to fry survival because egg size determines the amount of yolk available to the juvenile before it is able to begin feeding (Groot et al. 1995). Egg size has not been estimated for Norton Sound pink salmon, and its importance for the survival of swim-up fry to the feeding stage is thus unknown.

Development times for pink salmon embryos are typically measured in accumulated temperature units (ATUs), in which one ATU is a full day at which the egg incubates at one degree C above 0. As with other salmon, the total number of ATUs needed to hatch varies among populations and with temperature. Pink salmon embryo development has been found to be inversely proportional to water temperature, with faster development rates at low temperature (Heard 1991). This relationship is similar to that seen in other salmon, such as the curvilinear relationship between temperature and sockeye salmon embryonic development (Brannon 1987). In the curvilinear relationship, the number of ATUs required to hatch increases with increasing temperature. The result is that egg hatching dates are somewhat buffered from unusually low or high overwinter incubation temperatures. Heard (1991) reported literature ranges of 450 to 1150 degree days needed for 50% emergence of pink salmon eggs. Much of the variation in development time may be due to temperature regimes; Beacham and Murray (1986) were able to substantially alter development times of pink salmon eggs, and noted that egg development time was more sensitive to temperatures early rather than later in the development. Embryonic development rates for Norton Sound pink salmon populations have not been evaluated.

Information Needs

- Egg physical characteristics.
- Egg physiological requirements.

Egg survival

Egg survival can vary markedly among populations, and is usually attributed to any of a number of factors that can include crowding (when it decreases the fraction of eggs that are deposited in a nest; Schroder 1981), predation, oxygen delivery, fungus, silt deposition, metabolic waste removal, freezing, and incubation time. Egg incubation times dictate the date of emergence, which can be optimal in some years and sub-optimal in others, depending on flooding, temperatures, food availability, and so forth. Overwinter freezing, dissolved oxygen levels, fungus, and silt deposition can affect egg survival, and may also affect the condition of fry that survive to emergence (Salo 1991). Heard (1991) considered stream flow fluctuations to be the most important abiotic variable affecting egg survival. The high spawning densities of pink salmon also expose their eggs to mortality from intra-specific disturbance, as later-arriving spawners excavate the eggs deposited by earlier spawners (Heard 1991). The effect and extent of all these factors are critical to understanding the link between fall spawning and spring production, but are unknown for Norton Sound pink salmon. In addition, the sources and extent of predation on pink salmon eggs in Norton Sound is unknown.

Information Needs

- Pink salmon egg survival rates.
- Key biological and physical factors that affect pink salmon egg survival.

Habitat status and potential restoration needs
Mining, road building, and gravel extraction in Norton Sound has directly damaged habitat and likely reduced salmon populations (Rue 1996; Webb 1988). Mining activities between approximately 1900 and 1930 probably most damaged pink salmon habitat on the Solomon River, Osborne Creek (a tributary to the Nome River), and the Snake River (C. Lean 2002, personal communication). More recently, road construction and its associated gravel mining have affected streams such as the Nome River (C. Lean 2002, personal communication). Effective enforcement of stream protection laws was achieved only in the mid-1980s, and is still somewhat limited by lack of enforcement staff.

Historical populations of pink salmon were probably also affected as much by human exploitation during the gold rush era at the turn of the 20th century as by habitat degradation. Human population growth in this era caused substantial increases in salmon harvests, to support both humans and dog teams, and dried salmon was even used as local currency (Selkregg 1976). Area streams are typically shallow and clear, making salmon populations easy to target and over-harvest. General consensus is that most salmon-producing streams in the area were over-exploited when the Nome population increased sharply, and it is reasonable to assume that populations of all salmon local rivers were fished to low levels.

Information Needs

- Location and rehabilitation potential of spawning habitat impacted by anthropogenic disturbance.
- Long-term changes in spawning habitat from natural processes such as erosion.
- Relative effects of different disturbances on spawning habitat quality and quantity (e.g., road building, mining, etc).
- Population effects, including abundance bottlenecks, of harvest and over-exploitation by humans in the early 20th century.

Potential Research Topics – egg stage

- Determine prevalence of riverine and intertidal pink salmon spawning in Norton Sound watersheds.
- Identify physical characteristics of spawning and egg incubation habitat in Norton Sound tributaries – water velocity, depth, upwelling, substrate size, etc.
- Identify the location and size of pink salmon spawning grounds in Norton Sound tributaries.
- Estimate fecundity of female pink salmon.
- Establish relationships between fecundity and body size (length or weight).
- Evaluate variability in fecundity in Norton Sound pink salmon populations.
- Estimate egg deposition per spawner and fertilization proportion to help quantify relationship between spawner abundance and fry production.
- Determine size and yolk content of eggs.

- Quantify thermal units and development times of pink salmon eggs in Norton Sound tributaries.
- Quantify the survival of eggs, both overall and in stages (deposition to alevin emergence, and alevin emergence to swim-up).
- Identify important sources of egg mortality in Norton Sound tributaries
    - Biological – fungus, predation, displacement by sympatric spawning species, etc.
    - Physical – oxygen delivery, siltation, freezing, dewatering, etc.
- Identify stream reaches whose spawning habitat and fry production has been reduced by anthropogenic disturbance.
- Prioritize reaches with the potential for spawning habitat restoration, and identify methods to restore them.
- Estimate contribution of different anthropogenic disturbances to habitat loss, with the intent to mitigate future effects of these disturbances.
- Gather TEK to estimate "natural" historical changes in spawning habitat availability in Norton Sound tributaries – has there been a marked gain or loss over time?

Juvenile Stage – hatching and freshwater emigration

Emergence
Pink salmon alevins and fry emerge from the gravel predominantly at night, and are thought to be guided by geotactic and rheotactic responses (Heard 1991). After achieving neutral buoyancy by filling their swim bladder, newly-emerged pink salmon fry migrate downstream, either dispersing throughout the water column or occupying one specific vertical stratum of the column.

Information Needs

- Emergence timing of Norton Sound pink salmon.
- Diel patterns of chum salmon fry emergence.
- Physical factors affecting emergence patterns and survival.

Freshwater migration, feeding, and survival
Downstream migration of pink salmon is thought to happen quickly, and is often completed within a few nights for populations that are relatively close to the ocean. Fry are typically from 28 to 35 mm in length (fork length) at the point at which they begin downstream migration. Pink salmon fry appear to have stronger schooling instinct than fry of other salmon species; this schooling instinct may help reduce susceptibility to predation, but only if the fry reach the ocean quickly (Heard 1991). Migrating fry are usually photonegative, slowing or even halting movements at daybreak or in bright moonlight, but may migrate in light in longer river systems in which they must migrate further to reach the ocean. Pink salmon fry typically do not feed in freshwater, but may do so where their freshwater migration takes place over many days. Where fry do feed in freshwater, their most common prey is the larval or pupal stage of dipteran insects.

Pink salmon fry are susceptible to predation from numerous sources while migrating in freshwater. Heard (1991) summarizes several studies of freshwater predation of migrating juvenile pink salmon, listing birds, mammals, and other fish as potentially important predators.

Among fish predators, char (e.g., Dolly Varden, Arctic, Siberian) and coho salmon frequently are the leading freshwater predators of pink salmon fry.

Effects of predation on a pink salmon cohort appear to vary widely, however, ranging from negligible to over 95%. In general, the proportion of fry eaten by predators is directly proportional to migration distance and inversely proportional to fry population size (Heard 1991).

Studies that document the relationship between fry migration and light regime have typically done so for populations south of Norton Sound, in systems which receive more hours of darkness in the spring and summer when the fry hatch. It is not known how the unusual light regime in Norton Sound affects pink salmon behavior at emergence and freshwater migration. Pink salmon fry migrated throughout the day under arctic daylight conditions on the Kola Peninsula (Heard 1991) and sub-arctic daylight conditions on the Kenai River (King et al. 1990).

Information Needs

- Downstream movement, diet, and mortality of fry.
- Sources of predation.
- Other sources of mortality on migrating fry.

Potential Research Topics – Fry stage, hatching and freshwater migration

- Document seasonal timing and migration patterns of juvenile pink salmon emigration in major salmon streams.
- Determine whether fry feed in freshwater before emigrating to saltwater.
- Identify important sources of freshwater mortality – e.g., predation, fry size, food availability, and presence of parasites.

Juvenile stage - nearshore marine

Entry into marine and estuarine waters

Juvenile pink salmon entering salt water may linger near the mouths of their natal streams or move quickly into adjacent shoreline or nearshore feeding areas. Pink salmon fry can move substantial distances offshore and along shore in short periods of time, and may disperse based on a combination of habitat, food availability, temperature, and genetic adaptations. Heard (1991) reports several cases of fry moving offshore within the first week of their marine arrival and several more cases of fry remaining nearshore for weeks or months. Where fry remain in nearshore zones, they aggregate in large schools and may co-mingle with juvenile chum salmon. Pink salmon are typically thought to migrate quickly along straight smooth beaches, then mill about and feed along more protected, nursery-type beaches (Heard et al. 2000). Until fry move offshore, they are thought to remain either in the littoral zone within 150 m of shore, or slightly offshore in the open parts of bays or inlets (Heard 1991).

Juvenile pink salmon are thought to move offshore by the first autumn of sea life. Fry size probably influences timing of offshore movement, and is known to range from 45 to 70 mm at the time of first offshore movement. The largest fry captured 75 m offshore of Norton Sound in

1981 was 72 mm (Tetra Tech 1981). Fry migrate offshore in schools, but these schools are thought to be much smaller than those in the nearshore zone. Timing and patterns of offshore movement by pink salmon from Norton Sound was studied briefly in 1981 (Tetra Tech 1981).

<u>Information Needs</u>

- Entry timing into saltwater.
- Behavior of fry upon entering saltwater.
- Role of estuaries as transition zones between fresh and salt water.
- Length of time spent in estuaries and in nearshore coastal zone.
- Timing of movement offshore.

Diet, growth, and survival

Juvenile pink salmon have a varied diet upon entering salt water and may eat zooplankton, insects, amphipods, euphausids, and fish larvae. In Prince William Sound, the most important food source for juvenile pink salmon is large copepod species (Thorne and Thomas 2001). In southeast Alaska, adult pink salmon survival was correlated with early marine growth rate of juvenile pink salmon (Mortensen et al. 2000). Diets of pink salmon from Norton Sound have not been studied.

Juvenile pink salmon appear to grow between 0.8 and 1.0 mm/d during their first few weeks of ocean life. These daily growth rates typically correspond to a body weight increase of 3.5 % to 7.6% per day (Heard 1991).

Predators of juvenile pink salmon in the nearshore area can include other fish, diving birds, and marine mammals (Heard 1991; Willette et al. 2001). In Prince William Sound, the most substantial predators of juvenile pink salmon were herring and walleye pollock, followed by a group of fishes that included Pacific cod, Pacific tomcod, and Dolly Varden char. Predation on juvenile pink salmon was inversely proportional to copepod density, suggesting that predators may switch from zooplankton to juvenile pink salmon when zooplankton abundance declines, or that juvenile pink salmon may increase their foraging area when zooplankton abundance drops, thereby increasing their exposure to predators (Willette et al. 2001).

Beluga whales are thought to be a major predator of sockeye salmon in parts of Bristol Bay, but pink salmon were not detected in the stomachs of belugas captured between 1977 and 1981. Three beluga whales that were captured in Norton Sound, near Elim, on June 12, 1977 had many fish in their stomachs, but no pink salmon (Lowry et al. 1985).

<u>Information Needs</u>

- Diet and growth of juvenile pink salmon in nearshore environments.
- Sources of pink salmon mortality.

Distribution

A small amount of information on juvenile pink salmon distribution in Norton Sound was obtained in 1981, when 17 juvenile pink salmon were captured with beach seines near shore and 154 juvenile pink salmon were captured with tow nets (75 m offshore, 0-3 m below surface; Tetra Tech 1981). Sampling was conducted in a limited spatial area (all in the Norton Sound

District; Figure 1), over a narrow time period (June 24 to July 2), and relatively few juvenile pink salmon (171) were captured (Tetra Tech 1981). Despite the limited spatial and temporal sampling, the authors found preliminary evidence that juvenile pink salmon were moving offshore throughout the sampling period, and that pink salmon juveniles were more abundant to the west than the east of the Snake River mouth. Mean size of pink salmon ranged from 32 mm to 72 mm in total length (Tetra Tech 1981).

Migration and potential offshore movement
Most juvenile salmon from Bristol Bay appear to move south through the Aleutian Island passes sometime during the autumn or winter, presumably in response to temperature and food needs. Offshore distribution of Norton Sound juvenile pink salmon is not known. If pink salmon travel down the west coast of Alaska, they may follow a migration route through Bristol Bay that is similar to the routes and methods used by Bristol Bay populations. Juvenile salmon from Norton Sound would also need to migrate past the water plume exiting the Yukon River, which may be powerful enough to alter migration routes or displace fish altogether (Martin et al. 1986). Use of nearshore versus offshore zones for these migrations is not known. Influence of water current direction and strength is also unknown.

Information Needs

- Timing, location, and body size of juvenile pink salmon moving offshore.
- Relationship between offshore movements, food availability, and environmental conditions.

Potential Research Topics – juvenile stage, nearshore marine

- Document timing and interannual variability in saltwater entry by juvenile pink salmon.
- Determine feeding activity, diet, and stomach fullness of juvenile pink salmon.
- Determine the spatial pattern of juvenile pink salmon in estuarine versus adjacent non-estuarine nearshore habitats.
- Identify main predators of fry in the nearshore environment. Summarize known trends of predator abundance as a secondary indicator of juvenile trends.
- Estimate the daily mortality rate of fry in the nearshore environment.
- Examine correlations between mortality and environmental or biological factors such as freshwater runoff, salinity, temperature, or fish density.
- Sample nearshore and offshore waters over time to obtain time series of presence/absence. Measure juveniles to obtain biostatistics (e.g., length, weight, body condition).
- Measure temperature, salinity, and plankton abundance over time to correlate trends with fry movement.
- Examine vertical distribution of juveniles to determine the most likely sources of predation, and the level at which water currents affect the largest proportion of the population.

Marine Stage

Recent studies of salmon in the northern Pacific ocean and Bering Sea have yielded good information on the marine ecology of immature pink salmon, including growth and diet (Davis et al. 2000; Walker et al. 1998; Auburn and Ignell 2000), genetic stock identification (Varnavskaya et al. 1998), and ocean distribution (Ueno et al. 1999; Aydin et al. 2000; Kawana et al. 2001). Yerokhin and Shershneva (2000) estimated energy metabolisms for pink salmon in the Sea of Okhostk, and described the relationships between metabolism, temperature, and migration route. Pink salmon remained inshore through July, and movements were primarily directed for feeding. Starting in August, water temperature began to decrease and pink salmon began moving offshore. Pink salmon continued moving offshore through September and October, at the end of which growth rates decreased and salmon began undertaking long-distance migrations to wintering grounds (Yerokhin and Shershneva 2000).

Compared to other North American pink salmon populations, however, relatively little is known about the marine stage of pinks from Norton Sound. Overall, it is generally assumed that Norton Sound pink salmon migrate south through the Bering Sea, pass through the Aleutian Islands, and reach maturity in the Gulf of Alaska. Once in the southern Bering Sea and in the Gulf of Alaska, Norton Sound stocks would presumably mingle with other stocks. Norton Sound pink salmon are not marked, making it impossible to use tag recaptures to determine their distribution and migration paths.

Otoliths, scale patterns, genetic stock identification have also proven effective at detecting and describing key ecological aspects of pink salmon. Otolith thermal marks were used to estimate ocean distribution of pink salmon from Prince William Sound, Alaska (Kawana et al. 2001) and scale pattern analysis was used to back-calculate growth and size at age of pink salmon from the central Bering Sea (Walker et al. 1998). Genetic stock identification has been used to identify and describe pink salmon populations from Asia (Hawkins et al. 1998; Varnavskaya et al. 1998) and Alaska (Seeb et al. 1998). Despite the utility of these techniques, none appear to have been used to describe pink salmon ecology in Norton Sound to this point. Until such techniques are applied to Norton Sound pink salmon populations, most knowledge of their marine ecology must be inferred from knowledge of pinks from other regions.

Physical and Oceanographic Environment of the Bering Sea and Norton Sound – Water Current, Plankton Production, and Salinity

Surface water currents in the Bering Sea are thought to generally circulate in a counter-clockwise direction, with relatively few large-scale changes among seasons (Mathisen and Coyle 1996). On the eastern edge of the Bering Sea the current flows through the Aleutian Island passes, and northward along the coast of the Bering Sea before reaching Norton Sound. Currents in the Norton Sound region continue north or northwest, depending on the season, at velocities up to 20 cm/s. Current velocity probably increases through the Bering Strait. Water currents also flow north along the western side of the Bering Strait, but velocities appear to be lower (5 to 10 cm/s instead of 20 to 50 cm/s) than on the eastern side (Figure 3).

Across the Bering Sea from Norton Sound, current direction within the Gulf of Anadyr is varied, flowing in all four compass directions at different times and locations. South of the Gulf of Anadyr, the currents along the Russian coast flow south and east at speeds of up to 50 cm/s before reaching the Aleutian Arc (Figure 3). Fish migrating along the western coast towards the Gulf of Alaska could presumably be transported at relatively high speeds.

Surface salinities in the main part of the Bering Sea increase from approximately 31 ppt along the coastlines to 33.5 ppt in the open ocean (Luchin et al. 1999). Peak river runoff in June usually results in minimum salinity in shelf waters in July. The lowest salinities are at the heads of Anadyr Bay (20 ppt) and Norton Sound (< 29 ppt; Luchin et al. 1999). There is little large-scale seasonal change in salinity throughout the Bering Sea.

Primary production in the Bering Sea begins with phytoplankton blooms in the late winter and early spring that stimulate zooplankton feeding and reproduction. Production varies substantially with season and region. Zooplankton biomass peaks between late May and early July, but individual species peak at various times throughout the year. Plankton concentrations rise from approximately 100 mg/m^3 in the winter to over 2,000 mg/m^3 in the spring before declining through the summer and fall (Laughlin et al. 1999). Concentrations throughout the year are generally highest in the deep waters and off the eastern shelf, and lowest in the nearshore zones.

Spring zooplankton species are generally nektonic and dwell at depths of 10 m to 100 m below the surface. Spatial peaks of Bering Sea plankton biomass are in the Gulf of Anadyr, Norton Sound, and Bering Strait, where concentrations can reach 3,200 mg/m^3. Zones of high zooplankton biomass also include a zone from the southeastern Bering Sea north to the Chukchi Sea, and another along the Kamchatkan Coast (Laughlin et al. 1999). These data appear to conflict with the report by Coyle et al. (1996) that 2/3 of the biomass in the upper 200m occurs over the deep basin of the western region.

In the summers since 1997, phytoplankton known as coccolithophores have bloomed over the Alaskan continental shelf of the Bering Sea. In 1997 and 1998, these blooms were extensive, covering nearly the entire continental shelf to within 80 km of the Alaskan coast (Weier 1999). The causes of the coccolithophore bloom are not fully understood, but it is probably a result of anomalous ocean conditions that include warming and changes in water current that have led to changes in nutrient distribution (NOAA 1998). Among other trends, the bloom coincided with reduced seabirds and salmon populations, decreases in the biomass of the diatoms that typically dominate the upper portion of the water column in the region, and changes in the distribution of zooplankton (NOAA 1998). The decreased diatom biomass appears to have caused a zooplankton decrease (Napp et al. 1998) that could have negatively affected salmon in the region, but the role of the coccolithophore bloom in this chain is unknown. Coccolithophores may have also affected the ability of seabirds that visually locate prey, and could have similar effects on foraging salmon. The blooms have been less intense in summers since 1998, but until its causes (e.g., changing climatic conditions) are better understood, its effects on salmon bear watching.

<u>Information Needs</u>

- Physical and biological characteristics that could potentially affect pink salmon distribution and migration through Norton Sound and the Bering Sea.

<u>Potential Future Research Topics:</u>

- Describe the surface water currents within Norton Sound, the Gulf of Anadyr, along the Bering Sea coasts, and along other potential migration routes. Describe how these currents may assist or impede migrating salmon.
- Determine the depth at which the majority of pink salmon migrate and feed.
- Describe physical features such as water current, salinity, and temperature in Norton Sound and the Bering Sea.
- Determine the location and seasonal distribution of biological factors that affect salmon in the Bering Sea – where, when, and how might prey availability and coccolithophores affect migrating salmon?
- Compare Norton Sound environmental features with potentially similar regions – can we infer behavior and strategies of Norton Sound pink salmon from environmentally similar populations?

Marine migration routes

<u>Southward Migrations to the Gulf of Alaska.</u>

Pink salmon from Bristol Bay are thought to enter the Gulf of Alaska in the autumn; pink salmon from Norton Sound probably do not reach the Gulf of Alaska until late in the calendar year because of the increased travel distance. If pink salmon migrate offshore, they may migrate through the Bering Sea to reach the Aleutian Island passes. If they remain in or near the nearshore zones, pink salmon would not enter the open Bering Sea, and would instead travel across Bristol Bay and westward along the north edge of the Alaskan Peninsula before passing through the Aleutian Islands to the Gulf of Alaska.

Juvenile pink salmon were not captured during extensive sampling of the Yukon River mouth, leading Martin et al. (1986) to conclude that the Yukon River water plume displaced juvenile salmon offshore. The absence of juvenile pink salmon from the catch indicates that they may migrate offshore for at least a portion of their southward migration.

<u>Movement Within the Gulf of Alaska</u>

Once in the Gulf of Alaska, all salmon species are thought to migrate in seasonal gyres, typically moving counterclockwise from the southeast to the northwest of their distribution. Salmon from western Alaska may have spatial or temporal overlap with Asian and other North American stocks. Specific spatial and temporal movement patterns of Norton Sound salmon in the Gulf of Alaska are not known. Maturing pink salmon preparing to re-enter the Bering Sea en route to natal spawning sites probably break off from the migratory gyre when migrating alongside the Aleutian Islands or Alaska Peninsula in the late spring or early summer. Migratory paths and distribution of pink salmon in the Gulf of Alaska are probably influenced by a combination of forage resources, genetic behavior, and oceanographic patterns or regimes. Although water current, temperature, and salinity are thought to be the major influences on the oceanic distribution of Pacific salmon, the degree to which these affect pink salmon is not known.

Pink salmon in the Gulf of Alaska occupied two distinct latitudinal zones from 1994 to 1998 (Aydin et al. 2000). Cooler sea surface temperatures (SST) and high concentrations of micronektonic squid marked the southern zone, whereas warmer SST and high concentrations of zooplankton marked the northern zone. Pink salmon were larger in the southern (squid-feeding) zone than in the northern (zooplankton-feeding) zone. The interface of the two zones varied from 51 to 54 degrees north from 1994 to 1998 (Aydin et al. 2000).

In winter, pink salmon distributions in the Gulf of Alaska appear to be compressed into a latitudinal range between the 4 and 8-degree isotherms that is narrow relative to summer distributions (Ueno et al. 1999). Pink salmon may overwinter in this relatively cold zone because the cold water reduces metabolic rates, thereby reducing food requirements at a time when zooplankton numbers drop (Nagasawa 2000b).

<u>Potential Movement Northward (and then Westward) to Asian Coast, then Southward to the Gulf of Alaska.</u>

Although the Asian route would cause Norton Sound salmon to travel farther to reach the Gulf of Alaska than the route along the western Alaska coast would, the greater travel distance could be advantageous if overall migration conditions are better. Juvenile pink salmon would migrate counter-clockwise through the Bering Sea, migrating west to the Asian coastline, then south along the western edge of the Bering Sea, and then east to the Gulf of Alaska. Fish migrating along this counterclockwise route would appear to spend more time migrating with the prevailing currents than would fish migrating clockwise, along the eastern edge of the Bering Sea. As noted above, salinity and forage base (zooplankton) in the Gulf of Anadyr, along the Asian coastline, are largely similar to those in Norton Sound, suggesting that biological trade-offs may be minimal. Juvenile salmon would need to travel only a short distance from Norton Sound to reach the Asian coastline, and would be able to reach Russia's Chukostk Peninsula while remaining in the nearshore zone nearly the whole time.

Once on the Asian coastline, any salmon from Norton Sound would presumably have similar ocean migration strategies as the Anadyr River salmon, which enter Anadyr Sound and are also thought to migrate to the Gulf of Alaska. If Norton Sound stocks were to migrate with Asian stocks from the western Bering Sea for their entire lives, their distribution would be considerably different than for stocks that migrate down the eastern edge of the Bering Sea (i.e., Bristol Bay).

<u>Information Needs</u>

- Migration routes and seasonal distribution of Norton Sound pink salmon.
- General ecology of Norton Sound pink salmon in the open ocean.

<u>Potential Research Topics</u>

- Conduct fish sampling or marking programs, use tag recoveries and stock identification techniques (scales, genetics, etc.) to identify:
    - seasonal and spatial distribution patterns of Norton Sound pink salmon.
    - arrival of pink salmon into the Gulf of Alaska.
    - differences in distribution among Norton Sound populations.
    - diet of pink salmon in the Gulf of Alaska and the Bering Sea.
    - migration routes of pink salmon traveling from Norton Sound to the Gulf of Alaska.
- Compare known trends between Norton Sound and non-Norton Sound populations.

Diet

Pink salmon appear to consume a wide variety of prey, including zooplankton, fish, and invertebrate larvae. Davis et al. (2000) found that fish comprised the largest portion of diets of maturing pink salmon (mean fork length = 456 mm, sd = 20) in the central Bering Sea. Crab larvae and zooplankton were slightly less abundant, followed by more than seven other identifiable taxa. Feeding activity was greater after noon and immediately after sunset, but diet composition did not differ between night and day. For somewhat smaller pink salmon (mean fork length = 120 mm, range = 84-170 mm) from the Alaska Peninsula, Auburn and Ignell (2000) reported that hyperiids were the most substantial prey, by weight, with euphausids and decapod larvae also accounting for a substantial (> 15%) of the prey, by weight, in some locations. In southeast Alaska and Prince William Sound, pink salmon diets had the most overlap with chum salmon in the nearshore, slope, and shelf zones and the most overlap with coho salmon and sockeye salmon in the oceanic zone (Auburn and Ignell 2000).

Information Needs

- Marine diet of Norton Sound salmon.
- Likely sources of competition and diet overlap for sockeye salmon.

Potential Research Topics

- Marine diet of salmon.
- Potential for intra- and inter-specific competition.
- Effects of density on forage success.

Age and growth

Growth can affect fish by influencing forage ability, predator susceptibility, and swimming ability (stamina and speed). Early marine growth rate is also known to affect survival of adult pink salmon in southeast Alaska (Mortensen 2000), but the relative effect of growth rate on survival of Norton Sound pink salmon is not known. There do not appear to be any annual growth estimates of Norton Sound pink salmon stocks. It is assumed that all Norton Sound pink salmon have a two-year life cycle (Menard 2001), similar to most other pink salmon populations (Heard 1991).

Information Needs

- Size at maturity for Norton Sound salmon.
- Effects of environment, competition, and density on growth and maturation.
- Seasonal and annual variability in instantaneous growth rates.

Potential Research Topics

- Examine links between growth and survival of pink salmon in Norton Sound and elsewhere.
- Develop estimates of Norton Sound pink salmon growth by year and compare these to environmental variables (physical and biological).

Survival

Early marine growth, timing of offshore movement, size at offshore movement, and environmental conditions are all thought to influence long-term marine survival of pink salmon (Karpenko 1998). The greatest mortality is thought to occur in the nearshore coastal areas, prior to offshore movement (Heard 1991), and Mortensen et al. (2000) noted that overall marine mortality of pink salmon was correlated with early marine growth rates. Average marine survival estimates (migrant fry to returning adult) for pink salmon have ranged from 1.7% to 4.7% (Heard 1991). Karpenko (1998) reported annual marine mortality ranges from 83.6% to 98% for the six years from 1986 to 1991 for pink salmon from Kamchatka. Sinyakov and Ostroumov (2000) report the availability of survival estimates for 37 brood classes of Kamchatkan pink salmon, but the data were not located for this edition of the RRP. Estimates of marine mortality for pink salmon are relatively straightforward for pink salmon because of their 2-year life cycle (Sinyakov and Ostroumov 2000), but would require a marking program not currently implemented for any Norton Sound salmon.

<u>Information Needs</u>

- Marine survival of Norton Sound pink salmon.
- Effects of age and size on marine survival.
- Causes of marine mortality.

<u>Potential Research Topics</u>

- Develop time series of annual estimates of marine survival.
- Correlation between survival and factors such as environmental processes (temperature, salinity, etc.), biological factors (lengths, weight,), and distribution.
- Identify sources of predation on Norton Sound pink salmon migrating through the Bering Sea and within the Gulf of Alaska.
- Do Norton Sound populations share enough similarities of environment or biology (e.g., similar latitude or oceanographic conditions) with any other stock to place special emphasis on examining that stock?

Immigrant (Adult) Stage

Physical and Oceanographic Environment Encountered by Fish

General physical conditions encountered by mature pink salmon returning through the Bering Sea are summarized in the discussion of immature and maturing salmon, above. The main difference in oceanographic conditions is that mature pink salmon migrating through the Bering Sea presumably move with the current, instead of against it, as they migrate north to Norton Sound.

Distribution

Little is known about the migration of Norton Sound pink salmon through the Bering Sea. Regardless of whether adult pink salmon migrate close to the eastern coast or in the open ocean, strong ocean currents moving north from the Pacific Ocean to the Chukchi Sea probably assist their northward migration. Most knowledge of adult salmon distribution comes from tagging studies (e.g., Myers et al. 1996), but the wide dispersal of sockeye salmon and chum salmon after tagging in the North Pacific makes it difficult to recapture enough fish to determine migration routes through the Bering Sea.

<u>Information Needs</u>

- Migration routes, timing, and travel times of salmon returning to Norton Sound.

Potential Research Topics

- Use newly-developed tagging equipment to identify migratory paths and behavior.
- Combine ocean sampling programs with stock identification techniques to identify spatial and temporal distribution of Norton Sound pink salmon in the Bering Sea and Gulf of Alaska.
- Determine the direction(s) from which adult pink salmon enter Norton Sound.
- Document the dispersal of adult pink salmon within Norton Sound.

Potential Interception Fisheries.

Because little is known about the migration of Norton Sound adult salmon, there is speculation that fish may be harvested in "interception" fisheries before returning to Norton Sound. The South Peninsula June Fishery (also known as the False Pass fishery) has received the most attention as a potential interception fishery, particularly for chum salmon. High seas driftnetting was also listed as a potential interception fishery, but has largely been eliminated in recent years. Until the full distribution of adult and maturing pink salmon is known, it is also conceivable that other fisheries in the North Pacific may intercept Norton Sound pink salmon.

Information Needs

- Locations and relative effects of interception fisheries affecting Norton Sound pink salmon populations.

Potential Research Topics

- Identify locations of potential interception fisheries, ways in which to sample the fisheries, and ways to identify salmon from Norton Sound.

Return Migration and Spawning Ground Access

Pink salmon return to Norton Sound in the months of June, July, and August. Pinks disperse to rivers throughout the Sound, with the largest documented runs typically in the Nome, Eldorado, Fish, Tubutulik, Kwiniuk, Shaktoolik, and Unalakleet rivers (C. Lean 2002, personal communication; Brennan et al. 1999). Entry direction of pink salmon into Norton Sound is not known. The degree to which the salmon from different rivers intermingle and mill before entering their natal streams is also unknown. In general, pink salmon are thought to school and mill as they approach natal streams, and schools composed of mixed stocks are common (Heard 1991). Straying rates of pink salmon are also thought to depend on proximity of other streams, with populations from relatively isolated streams having lower straying rates than populations from streams with easy access to other spawning streams. Pink salmon straying rates are thought to be somewhat higher than other salmon species, and may approach 10% (Heard 1991). Pink salmon travel times and straying rates within Norton Sound have not been estimated.

Information Needs

- Distribution of adult pink salmon within Norton Sound.
- Nearshore and freshwater dispersal of adult pink salmon to spawning grounds.
- Key spawning ground locations.

<u>Potential Research Topics</u>

- Once in Norton Sound, how long do pink salmon mill and what is the estimated change in milling time throughout the season.
- Identify key spawning reaches in the major sockeye salmon rivers – can we reliably locate the majority of useable and unusable areas on any river?
- Describe important spawning ground attributes.
- Quantify the overall amount of spawning habitat in ANY river system or stream.

Life Cycle of Norton Sound Chinook Salmon

Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) are the largest of the Pacific salmon species and have substantial inter-population variability in life histories. Chinook salmon may rear in freshwater for weeks to years, spend one to several years maturing at sea, and have highly variable ocean migratory patterns and freshwater return times (Healey 1991). Many river systems support chinook salmon populations that differ in one or more of these attributes, and thereby achieve at least some degree of reproductive separation. Spawning populations of chinook salmon range from central California to Kotzebue Sound, Alaska on the Pacific coast of North America, and from northern Hokkaido to the Anadyr River on the Asian coastline. Throughout their range, chinook salmon spawning populations tend to be smaller than those of other salmon species, with runs exceeding 100,000 fish in only a few large river systems (Healey 1991).

Two distinct life history variants are the stream-type and ocean-type chinook salmon, which differ in the number of years spent instream as juveniles and in the return timing of adult spawners. Stream type chinook salmon spend more years in stream, undergo more extensive ocean migrations, return to spawn earlier in the calendar year, and have higher fecundities than ocean type chinook salmon. Both types may exist in a given watershed. Most Alaskan populations, and all Yukon River populations, are stream-type (Healey 1991).

Norton Sound is near the northern edge of chinook salmon range in North America. Unlike other salmon species, however, chinook salmon populations on the geographic boundaries of their range are not markedly smaller than populations near the middle of their range. Norton Sound escapements are indexed and actual numbers of returning spawners are unknown. Chinook salmon are most abundant in the Unalakleet and Shaktoolik subdistricts, and returns through 1998 were thought to be increasing in the Norton Bay, Moses Point, and Golovin Bay subdistricts (Brennan et al. 1999). Norton Sound chinook salmon appear to be stream-type, spending one or two winters in freshwater and two to five winters at sea. Age 1.3 and 1.4 chinook were the most abundant age groups, accounting for between 80% and 90% of the chinook captured in the Unalakleet subdistrict marine fishery and the Unalakleet River test fishery in 2000 (Kohler 2001). Chinook with one winter of stream life accounted for 92% to 94% of the samples and chinook with two winters of stream life accounted for the remainder of the samples (Kohler 2001).

Norton Sound chinook salmon spawn primarily from mid-June to mid-August and juveniles typically hatch and migrate seaward in late spring (**Confirm with ADFG Biologists**). Little is known of the marine ecology of chinook salmon from Norton Sound. Adult sockeye salmon and chum salmon have been recaptured in Norton Sound after having been tagged elsewhere (Kerkvliet 1986; Eggers et al. 1989), but there is no such information for adult chinook salmon from Norton Sound. The prevailing assumption is that Norton Sound chinook salmon migrate southward to the Gulf of Alaska, where they overwinter before returning through the Bering Sea to Norton Sound.

Egg Stage

Egg deposition and incubation habitat
The large size of chinook salmon makes them powerful swimmers and capable of migrating and spawning in conditions that may be unsuitable for other salmon species. Chinook salmon may spawn anywhere from lower river reaches near the ocean to stream headwaters. In the Yukon River, chinook salmon migrate as far as 3,200 km inland (Healey 1991). Chinook salmon may spawn in small streams or in large tributaries, in habitat ranging from pools to riffles, and are capable of spawning in glacial water.

The varied spawning habitats are reflected in the range of conditions under which chinook salmon can spawn; water depths can range from 15 cm to 53 cm (DeVries 1997), water velocities can range from 10 cm/s to 150 cm/s (Healey 1991), and literature reports of mean substrate size range from 11 mm to 69 mm mean diameter (Kondolf and Wolman 1993). Chinook salmon in some places appear to select spawning sites with subsurface water flow and there is evidence that they may spawn in water as deep as 700 cm (Healey 1991).

<u>Information needs</u>

- Distribution and amount of spawning habitat available in Norton Sound tributaries.
- Physical characteristics of useable spawning and egg incubation habitat.

Fecundity and production
Fecundities of Norton Sound salmon are unknown, prohibiting any production estimates based on Norton Sound data. In particular, fecundity, sex ratio, egg retention, and fertilization rates have not been estimated for any Norton Sound populations, and must therefore be estimated from information from outside the region.

Chinook salmon fecundities ranged from 3,200 to 10,600 eggs per female in a review of fecundities reported for 44 chinook salmon populations (Beacham and Murray 1993). When standardized to a 730-mm postorbital-hypural length, this range narrowed to 4748 to 8334 eggs per female, and standardized fecundity increased with latitude. Within the Yukon River, coastal populations had higher absolute fecundity than upriver populations (Beacham and Murray 1993). Healey (1991) also concluded that absolute fecundity increases with latitude, but found that the relationship was not significant within stream-type life histories (Healey 1991). Fecundity does not appear to be correlated with the number of years spent at sea. Healey (1991) also reported fecundities in excess of 17,000 eggs for chinook salmon.

Egg retention by spawning chinook salmon appears to be minimal, with values typically less than 1%. Healey (1991) reported cases of 25% egg retention, but considered these unusual and unimportant compared to the number of females that may die unspawned.

Information Needs

- Chinook salmon fecundity – absolute, and relative to size and run timing.
- Total egg deposition by Norton Sound populations.
- **Retention of eggs by spawning chinook salmon?**
- Fertilization proportion of deposited eggs.

Egg development and physiology

Egg size affects fry production by influencing fecundity, embryo development and survival, and the size of alevins and fry (Beacham and Murray 1993). Standardized egg size (diameter and weight) appears to decrease with increasing latitude and with increasing inriver migration distance (Beacham and Murray 1993). Upriver populations of Yukon River chinook salmon had the lowest standardized egg weights of the populations reviewed by Beacham and Murray (1993). Egg size has not been estimated for Norton Sound chinook salmon.

Development times for chinook salmon embryos are typically measured in accumulated temperature units (ATUs), in which one ATU is a full day at which the egg incubates at one degree C above 0. As with other salmon, the total number of ATUs needed to hatch varies among populations and with temperature. Development models indicate 314 to 476 ATUs needed for egg hatching and 365 to 724 ATUs needed for emergence (Beacham and Murray 1990), but these values probably vary substantially among populations. Relative to other salmon species, chinook salmon eggs appear to require more ATUs to both hatching and emergence when temperatures are below 4°C (Beacham and Murray 1990). Embryonic development rates for Norton Sound chinook salmon populations have not been evaluated.

Information Needs

- Egg physical characteristics.
- Egg physiological requirements.

Egg survival

Survival of chinook salmon eggs is thought to be most affected by temperature, oxygen content, and water percolation through the redds (Healey 1991). Egg survival probably varies markedly among populations and years. Healey (1991) considered that empirical estimates of wild chinook salmon egg survival were particularly lacking. In other species, egg survival can also be affected by crowding (when it decreases the fraction of eggs that are deposited in a nest; Schroder 1981), predation, fungus, silt deposition, and incubation time. Egg incubation times dictate the date of emergence, which can be optimal in some years and sub-optimal in others, depending on factors such as flooding, temperature, and food availability. The influence of all these factors on survival of chinook salmon eggs in Norton Sound is unknown.

Models of the relationship between survival and temperature indicate that chinook egg survival is most likely to be affected by low temperature at the embryo stage, and by high temperature at the alevin stage. Embryo survival is highest between 4 °C and 16 °C, whereas alevin survival remains relatively constant from 2 °C until declining at 14 °C (Beacham and Murray 1990). Temperature variability also affects length of both alevin and fry (Beacham and Murray 1990).

Information Needs

- Chinook salmon egg survival rates.
- Key biological and physical factors that affect chinook salmon egg survival in Norton Sound tributaries.

Habitat status and potential restoration needs

Mining, road building, and gravel extraction in Norton Sound have directly damaged habitat and likely reduced salmon populations (Rue 1996; Webb 1988). Mining activities between approximately 1900 and 1930 probably had the greatest affect on stream habitat in the Nome subdistrict of Norton Sound, where chinook salmon are currently the least abundant. The degree to which the habitat degradation is responsible for the low current runs of chinook salmon in the Nome subdistrict is unknown. More recently, road construction and its associated gravel mining have also affected streams such as the Nome River (C. Lean 2002, personal communication). Effective enforcement of stream protection laws was achieved only in the mid-1980s, and is still somewhat limited by lack of enforcement staff.

Historical populations of chinook salmon were probably also affected as much by human exploitation during the gold rush era at the turn of the 20th century as by habitat degradation. Human population growth in this era caused substantial increases in salmon harvests, to support both humans and dog teams, and dried salmon was even used as local currency (Selkregg 1976). Area streams are typically shallow and clear, making salmon populations easy to target and over-harvest. General consensus of opinion is that most salmon-producing streams in the area were over-exploited when the Nome population increased sharply, and it is reasonable to assume that populations of all salmon local rivers were fished to low levels. As with habitat, the effects of exploitation on chinook salmon are unknown because little information exists on historical chinook populations in Norton Sound.

Information Needs

- Location and rehabilitation potential of spawning habitat impacted by anthropogenic disturbance.
- Long-term changes in spawning habitat from natural processes such as erosion.
- Relative effects of different disturbances on spawning habitat quality and quantity (e.g., road building, mining, etc).
- Population effects, including abundance bottlenecks, of harvest and over-exploitation by humans in the early 20th century.

Potential Research Topics – egg stage

- Identify physical characteristics of chinook salmon spawning and egg incubation habitat in Norton Sound tributaries – water velocity, depth, upwelling, substrate size, etc.
- Identify the location and size of chinook salmon spawning grounds in Norton Sound tributaries.
- Estimate fecundity of female chinook salmon.

- Establish relationships between fecundity, body size (length or weight), and other variables.
- Evaluate variability in fecundity in Norton Sound chinook salmon populations.
- Estimate egg deposition per spawner and fertilization proportion to help quantify relationship between spawner abundance and fry production.
- Determine size and yolk content of eggs.
- Quantify thermal units and development times of chinook salmon eggs in Norton Sound tributaries.
- Quantify the survival of eggs, both overall and in stages (deposition to alevin emergence, and alevin emergence to swim-up).
- Identify important sources of egg mortality in Norton Sound tributaries
    - Biological – fungus, predation, displacement by sympatric spawning species, etc.
    - Physical – oxygen delivery, siltation, freezing, dewatering, etc.
- Identify stream reaches whose spawning habitat and fry production has been reduced by anthropogenic disturbance.
- Prioritize reaches with the potential for spawning habitat restoration, and identify methods to restore them.
- Estimate contribution of different anthropogenic disturbances to habitat loss, with the intent to mitigate future effects of these disturbances.
- Gather TEK to estimate “natural” historical changes in spawning habitat availability in Norton Sound tributaries – has there been a marked gain or loss over time?

Juvenile Stage – hatching, freshwater residence, and freshwater emigration

Emergence

Chinook salmon fry are thought to emerge from the gravel predominantly at night, and to have reduced swimming ability while they absorb their remaining yolk. Fry typically migrate downstream after hatching, probably because of this reduced swimming ability during yolk absorption (Healey 1991). Fry hatching close to the ocean may be displaced into the estuary, and may represent those fish that are surplus to the carrying capacity of the riverine habitat (Healey 1991). Stream-type fry are territorial, and have a stronger positive rheotactic response (upstream movement in response to water current) and more territorial behavior than ocean-type fry (Taylor and Larkin 1986). Diel periodicity of fry emergence in Norton Sound under extended summer daylight is unknown.

Information Needs

- Emergence timing of Norton Sound chinook salmon.
- Diel patterns of chinook salmon fry emergence.
- Physical factors affecting emergence patterns and survival.

Freshwater residence – behavior, diet, and mortality

Chinook fry that absorb their egg yolks become fully motile and either continue downstream migration or begin to disperse throughout the stream. Mechanisms controlling whether fry disperse instream or migrate downstream are unclear (Healey 1991). Fry that remain instream for a year distribute across a wide range of habitat types, but are most often influenced by turbidity and water velocity. Chinook fry typically minimize competition with fry of other species, such as coho salmon, by occupying different microhabitats. Chinook fry display strong site fidelity and have been observed defending feeding stations. There is some evidence that chinook fry make repeated movements among stations over a diel cycle (Healey 1991).

Stream-type fry feed principally on larval and adult insects, indicating that they feed primarily in the water column or at the surface. Reported growth rates for age-0 fry range from 0.21 mm/d to 0.62 mm/d (Healey 1991).

Dispersal stimuli and mechanisms for fry that rear instream are not well understood. Peak movement is typically in late spring or early summer, but fry may move at any time. Migration rate have been estimated at 0.3 km and 24 km per day for different populations (Healey 1991). Arctic movements of chinook salmon fry are not well studied, and the effects of ice cover are unknown.

Survival rates of chinook salmon from fry to smolt have ranged from 10% to 30%, with some indication that survival is higher for populations rearing in headwaters than downriver areas (Healey 1991). The main cause of mortality is thought to be predation, with important predators being sculpins and other salmonids. Although bird predation can be important in other salmon species, Healey (1991) did not cite birds in his review of chinook fry predators. Potential sources of predation on chinook fry in Norton Sound include birds, juvenile coho salmon, grayling, and sculpins. Effects of overwinter ice on fry survival have not been studied.

Freshwater emigration
Yearling smolts typically begin migrating in early spring, presumably in response to increased water flow and temperature. Estimated downstream movement of chinook salmon smolts have ranged from 21 km/d to 37 km/d, and appear to increase with increased water discharge (Healey 1991).

<u>Information Needs</u>

- Issues and information needs for chinook salmon are the same as for coho salmon, described above.

<u>Potential Research Topics – Fry stage, hatching and freshwater migration</u>

- Potential research topics for chinook salmon are the same as for coho salmon, described above.

Juvenile stage - nearshore marine

Entry into marine and estuarine waters
Chinook salmon smolts use estuaries as initial rearing areas after migrating from salt water. Timing of saltwater entry varies, and is probably a function of hatch timing, downriver migration distance, and whether fish are ocean-type or stream-type (Healey 1991). Consequently, entry into saltwater can be from early spring to summer. Entry timing of chinook salmon into Norton Sound has not been studied, but is thought to happen in late spring, as ice melts and is flushed

from the system. Martin et al. (1986) found few juvenile chinook in the Yukon River estuary while sampling in late June; although the data did not allow description of the outmigration timing from the Yukon River, Martin et al. noted that the low abundance in late June was consistent with the belief that smolts leave the Yukon delta before then.

Diet, growth, and survival

Chinook salmon appear to be opportunistic feeders in estuaries, capable of feeding during both day and night and on a wide range of prey. Stream-type chinook salmon are typically large enough to consume small fish (including coho salmon fry, sticklebacks, and juvenile herring) in addition to insects and zooplankton. Healey (1991) reviewed several diet studies and reported that diets of juvenile chinook salmon in estuaries is more similar to non-salmon such as herring, perch, and sand lance than it is to other salmon. As chinook salmon grow and move towards deeper water, their diet shifts away from invertebrates and towards larval and juvenile fishes.

Although direct comparisons are difficult, growth rates of stream-type juvenile chinook salmon appear similar in estuaries and rivers. Growth rates of stream-type chinook salmon are approximately 0.5 mm/d, which is slightly less than the peak growth rates for ocean-type chinook (Healey 1991).

Predators of juvenile chinook salmon in the nearshore area are presumably similar to other salmon species, which include other fish, diving birds, and marine mammals (Heard 1991; Willette et al. 2001). Three beluga whales that were captured in Norton Sound, near Elim, on June 12, 1977 had no chinook salmon in their stomachs (Lowry et al. 1985).

Information Needs

- Entry timing into saltwater.
- Behavior of chinook salmon fry upon entering saltwater.
- Role of estuaries as transition zones between fresh and salt water.
- Length of time spent in estuaries and in nearshore coastal zone.
- Timing of movement offshore.
- Diet and growth of juvenile chinook salmon in nearshore environments.
- Sources of chinook salmon mortality.

Distribution

In British Columbian estuaries, juvenile chinook moved daily with the tide, moving onshore with the high tide to feed in marshes, then moving out as the tide ebbed. Stream-type juveniles are typically larger than ocean-type, and are capable of using deeper areas of the estuary. Stream-type juvenile chinook may spend less time in estuaries because their large size makes them more capable of eating prey found offshore and more resistant to offshore predators. Juvenile chinook salmon appear to rear in southern estuaries (e.g., British Columbia, Washington, California, and Oregon) until late summer or early fall (Healey 1991). The seasonal timing of offshore movement by western Alaskan populations has not been documented. Brief netting in nearshore areas in late June and early July captured juvenile pink and chum salmon, but no chinook (Tetra Tech 1981).

Migration and potential offshore movement

Ocean-type chinook salmon are smaller than stream-type chinook salmon when reaching the estuary, and tend to spend a longer time rearing in the estuary, sometimes for months. Chinook salmon that move offshore tend to do so by moving directly to open water, instead of moving laterally along shore like pink and chum salmon (Heard et al. 2001). Chinook movement offshore is likely related to body size, and the accompanying differences in prey requirements and predator avoidance (Healey 1991).

Information Needs

- Timing, location, and body size of juvenile chinook salmon moving offshore.
- Relationship between offshore movements, food availability, and environmental conditions.

Potential Research Topics – juvenile stage, nearshore marine

- Document timing and interannual variability in saltwater entry by juvenile chinook salmon.
- Determine feeding activity, diet, and stomach fullness of chinook salmon juveniles.
- Determine the spatial pattern of juvenile chinook salmon in estuarine versus adjacent non-estuarine nearshore habitats.
- Identify main predators of fry in the nearshore environment. Summarize known trends of predator abundance as a secondary indicator of juvenile trends.
- Estimate the daily mortality rate of fry in the nearshore environment.
- Examine correlations between mortality and environmental or biological factors such as freshwater runoff, salinity, temperature, or fish density.
- Sample nearshore and offshore waters over time to obtain time series of presence/absence. Measure juveniles to obtain biostatistics (e.g., length, weight, body condition).
- Measure temperature, salinity, and plankton abundance over time to correlate trends with fry movement.
- Examine vertical distribution of juveniles to determine the most likely sources of predation, and the level at which water currents affect the largest proportion of the population.

Marine Stage

Recent studies of ocean distribution (Ueno et al. 1999) and stock identification (Urawa et al. 1998; Wilmot et al. 1992) have yielded introductory information on the marine ecology of immature chinook salmon. **Get more references, and more subjects.**

Compared to other North American chinook salmon populations, however, relatively little is known about the marine stage of chinook from Norton Sound. Overall, it is generally assumed that Norton Sound chinook salmon migrate south through the Bering Sea, pass through the Aleutian Islands, and reach maturity after spending one or more years in the Gulf of Alaska. Once in the southern Bering Sea and in the Gulf of Alaska, Norton Sound stocks would presumably mingle with other stocks. Norton Sound chinook salmon are not marked, making it impossible to use tag recaptures to determine their distribution and migration paths. Chinook salmon from western Alaska are thought to be present on both the east and west sides of the Bering Sea, and to migrate south through the Aleutian Islands and into the Gulf of Alaska (Healey 1991).

Scale pattern analysis and protein electrophoresis have also proven useful for broad-scale discrimination among stocks of chinook salmon from the Yukon River (Wilmot et al. 1992). Genetic collections by ADF&G have included chinook salmon from the Unalakleet River of Norton Sound (Crane et al. 1996).

Physical and Oceanographic Environment of the Bering Sea and Norton Sound – Water Current, Plankton Production, and Salinity

Surface water currents in the Bering Sea are thought to generally circulate in a counter-clockwise direction, with relatively few large-scale changes among seasons (Mathisen and Coyle 1996). On the eastern edge of the Bering Sea the current flows through the Aleutian Island passes, and northward along the coast of the Bering Sea before reaching Norton Sound. Currents in the Norton Sound region continue north or northwest, depending on the season, at velocities up to 20 cm/s. Current velocity probably increases through the Bering Strait. Water currents also flow north along the western side of the Bering Strait, but velocities appear to be lower (5 to 10 cm/s instead of 20 to 50 cm/s) than on the eastern side (Figure 3).

Across the Bering Sea from Norton Sound, current direction within the Gulf of Anadyr is varied, flowing in all four compass directions at different times and locations. South of the Gulf of Anadyr, the currents along the Russian coast flow south and east at speeds of up to 50 cm/s before reaching the Aleutian Arc (Figure 3). Fish migrating along the western coast towards the Gulf of Alaska could presumably be transported at relatively high speeds.

Surface salinities in the main part of the Bering Sea increase from approximately 31 ppt along the coastlines to 33.5 ppt in the open ocean (Luchin et al. 1999). Peak river runoff in June usually results in minimum salinity in shelf waters in July. The lowest salinities are at the heads of Anadyr Bay (20 ppt) and Norton Sound (< 29 ppt; Luchin et al. 1999). There is little large-scale seasonal change in salinity throughout the Bering Sea.

Primary production in the Bering Sea begins with phytoplankton blooms in the late winter and early spring that stimulate zooplankton feeding and reproduction. Production varies substantially with season and region. Zooplankton biomass peaks between late May and early July, but individual species peak at various times throughout the year. Plankton concentrations rise from approximately 100 mg/m^3 in the winter to over 2,000 mg/m^3 in the spring before declining through the summer and fall (Loughlin et al. 1999). Concentrations throughout the year are generally highest in the deep waters and off the eastern shelf, and lowest in the nearshore zones.

Spring zooplankton species are generally nektonic and dwell at depths of 10m to 100m below the surface. Spatial peaks of Bering Sea plankton biomass are in the Gulf of Anadyr, Norton Sound, and Bering Strait, where concentrations can reach 3,200 mg/m^3. Zones of high zooplankton biomass also include a zone from the southeastern Bering Sea north to the Chukchi, and another along the Kamchatkan Coast (Loughlin et al. 1999). These data appear to conflict with the report by Coyle et al. (1996) that 2/3 of the biomass in the upper 200m occurs over the deep basin of the western region.

In the summers since 1997, phytoplankton known as coccolithophores have bloomed over the Alaskan continental shelf of the Bering Sea. In 1997 and 1998, these blooms were extensive, covering nearly the entire continental shelf to within 80 km of the Alaskan coast (Weier 1999). Causes of the coccolithophore bloom are not fully understood, but it is probably a result of anomalous ocean conditions that include warming and changes in water current that have led to changes in nutrient distribution (NOAA 1998). Among other trends, the bloom coincided with reduced seabird and salmon populations, decreases in the biomass of the diatoms that typically dominate the upper portion of the water column in the region, and changes in the distribution of zooplankton (NOAA 1998). Decreased diatom biomass appears to have caused a zooplankton decrease (Napp et al. 1998) that could have negatively affected salmon in the region, but the role of the coccolithophore bloom in this chain is unknown. Coccolithophores may have also affected the ability of seabirds that visually locate prey, and could have similar effects on foraging salmon. Blooms have been less intense in summers since 1998, but until the causes (e.g., changing climatic conditions) are better understood, the effects on salmon bear watching.

<u>Information Needs</u>

- Physical and biological characteristics that could potentially affect chinook salmon distribution and migration through Norton Sound and the Bering Sea.

<u>Potential Future Research Topics:</u>

- Describe the surface water currents within Norton Sound, the Gulf of Anadyr, along the Bering Sea coasts, and along other potential migration routes. Describe how these currents may assist or impede migrating salmon.
- Determine the depth at which the majority of chinook salmon migrate and feed.
- Describe physical features such as water current, salinity, and temperature in Norton Sound and the Bering Sea.
- Determine the location and seasonal distribution of biological factors that affect salmon in the Bering Sea – where, when, and how might prey availability and coccolithophores affect migrating salmon?
- Compare Norton Sound environmental features with potentially similar regions – can we infer behavior and strategies of Norton Sound chinook salmon from environmentally similar populations?

Marine migration routes

<u>Southward Migrations to the Gulf of Alaska</u>

Chinook salmon from Norton Sound probably do not reach the Gulf of Alaska until late in the calendar year because of the travel distance. If chinook salmon migrate offshore, they may migrate through the Bering Sea to reach the Aleutian passes. If they remain in or near the nearshore zones, chinook salmon would not enter the open Bering Sea, and would instead travel across Bristol Bay and westward along the north edge of the Alaskan Peninsula before reaching the passes to the Gulf of Alaska.

<u>Movement Within the Gulf of Alaska</u>

Once in the Gulf of Alaska, all salmon species are thought to migrate in seasonal gyres, typically moving counterclockwise from the southeast to the northwest of their distribution. Salmon from western Alaska may have spatial or temporal overlap with Asian and other North American stocks. Specific spatial and temporal movement patterns of Norton Sound salmon in the Gulf of Alaska are not known. Maturing chinook salmon preparing to re-enter the Bering Sea en route to natal spawning sites probably break off from the migratory gyre when migrating alongside the Aleutian Islands or Alaska Peninsula in the late spring or early summer. Migratory paths and distribution of chinook salmon in the Gulf of Alaska are probably influenced by a combination of forage resources, genetic behavior, and oceanographic patterns or regimes. Although water current, temperature, and salinity are thought to be the major influences on the oceanic distribution of Pacific salmon, the degree to which these affect chinook salmon is not known.

When compared to summer distributions, winter distributions of many salmon species in the Gulf of Alaska appear to be compressed into a narrow latitudinal range between the 4 and 8-degree isotherms (Ueno et al. 1999). Salmon may overwinter in this relatively cold zone because the cold water reduces metabolic rates, thereby reducing food requirements at a time when zooplankton numbers drop (Nagasawa 2000c). Chinook salmon, however, were found north of the 4 °C isotherm, in waters ranging from 1 °C to 3 °C; Ueno et al. (1999) noted the different distribution of chinook salmon, but were unable to explain why they differed from other species of salmon.

Chinook salmon captured in the North Pacific Ocean at approximately 47° 04' N, 179° 17' W on May 1, 2000 were analyzed using genetic stock identification to determine their regional origin. The greatest proportion (44%) of the 55 chinook salmon was of Russian origin, with the second-largest proportion (23%) being from western Alaska. The 90% confidence estimate for western Alaskan chinook salmon ranged form 5% to 36% (Wilmot et al. 2000). Based on this point sample, western Alaska chinook salmon appear to range west of the Gulf of Alaska and they appear to intermingle with Russian populations of chinook salmon. Age and size of the chinook salmon were not provided (Wilmot et al. 2000).

<u>Potential Movement Northward (and then Westward) to Asian Coast, then Southward to the Gulf of Alaska</u>

Although the Asian route would cause Norton Sound salmon to travel farther to reach the Gulf of Alaska than the route along the western Alaska coast would, the greater travel distance could be advantageous if overall migration conditions are better. Juvenile chinook salmon would migrate counter-clockwise through the Bering Sea, migrating west to the Asian coastline, then south along the western edge of the Bering Sea, and then east to the Gulf of Alaska. Fish migrating along this counterclockwise route would appear to spend more time migrating with the prevailing currents than would fish migrating clockwise, along the eastern edge of the Bering Sea. As noted above, salinity and forage base (zooplankton) in the Gulf of Anadyr, along the Asian coastline, are largely similar to those in Norton Sound, suggesting that biological trade-offs may be minimal. Juvenile salmon would need to travel only a short distance from Norton Sound to reach the Asian coastline, and would be able to reach Russia's Chukostk Peninsula while remaining in the nearshore zone nearly the whole time.

Once on the Asian coastline, any salmon from Norton Sound would presumably have similar ocean migration strategies as the Anadyr River salmon, which enter Anadyr Sound and are also thought to migrate to the Gulf of Alaska. If Norton Sound stocks were to migrate with Asian stocks from the western Bering Sea for their entire lives, their distribution would be considerably different than for stocks that migrate down the eastern edge of the Bering Sea (i.e., Bristol Bay).

Information Needs

- Migration routes and seasonal distribution of Norton Sound chinook salmon.
- General ecology of Norton Sound chinook salmon in the open ocean.

Potential Research Topics

- Conduct fish sampling or marking programs, use tag recoveries and stock identification techniques (scales, genetics, etc.) to identify:
  - seasonal and spatial distribution patterns of Norton Sound chinook salmon.
  - arrival of chinook salmon into the Gulf of Alaska.
  - differences in distribution among Norton Sound populations.
  - diet of chinook salmon in the Gulf of Alaska and the Bering Sea.
  - migration routes of chinook salmon traveling from Norton Sound to the Gulf of Alaska.
- Compare known trends between Norton Sound and non-Norton Sound populations.

Diet

Diets of larger, immature and maturing chinook salmon appear to vary with year as well as season and region. Among the many diet studies reviewed by Healey (1991), herring, sand lance, and squid were consistently reported as major components of chinook salmon, with the importance of sand lance and herring increasing with latitude. Healey (1991) also noted that predation by chinook salmon on other salmon species was rare.

Information Needs

- Marine diet of Norton Sound salmon.
- Likely sources of competition and diet overlap for chinook salmon.

Potential Research Topics

- Marine diet of Norton Sound chinook salmon.
- Potential for intra- and inter-specific competition.
- Effects of density on forage success.

Age and growth

Growth can affect fish by influencing forage ability, predator susceptibility, and swimming ability (stamina and speed). Age at maturity has been negatively correlated with size of chinook salmon at the end of their first year of life (Healey 1991). Data from multiple sources (Healey 1991) suggest that ocean- and stream-type chinook salmon have similar growth rates during their ocean life stage. Although there is evidence that growth rate slows during winter months, this may be accentuated by the annual loss of larger fish from the sampling pool as these fish return to spawn. There do not appear to be any annual growth estimates of Norton Sound chinook salmon stocks.

Information Needs

- Size at age and at maturity for Norton Sound salmon.
- Effects of environment, competition, and density on growth and maturation.
- Seasonal and annual variability in instantaneous growth rates.

Potential Research Topics

- Examine links between growth and survival of chinook salmon in Norton Sound and elsewhere.
- Develop estimates of Norton Sound chinook salmon growth by year and compare these to environmental variables (physical and biological).

Survival

Ricker (1976) reviewed studies of salmon mortality at sea and considered chinook salmon to have an average annual mortality of 20% during their ocean phase. Differences in mortality between ocean- and stream-type chinook are not well studied, but Healey (1991) noted that it is logical to assume that mortalities are higher for ocean-type because of their smaller size at ocean entry.

Information Needs

- Marine survival of Norton Sound chinook salmon.
- Effects of age and size on marine survival.
- Causes of marine mortality.

Potential Research Topics

- Develop time series of annual estimates of marine survival.
- Correlation between survival and factors such as environmental processes (temperature, salinity, etc.), biological factors (lengths, weight,), and distribution.
- Identify sources of predation on Norton Sound chinook salmon migrating through the Bering Sea and within the Gulf of Alaska.
- Do Norton Sound populations share enough similarities of environment or biology (e.g., similar latitude or oceanographic conditions) with any other stock to place special emphasis on examining that stock?

Immigrant (Adult) Stage

Physical and Oceanographic Environment Encountered by Fish

General physical conditions encountered by mature chinook salmon returning through the Bering Sea are summarized in the discussion of immature and maturing salmon, above. The main difference in oceanographic conditions encountered by mature chinook salmon migrating through the Bering Sea is they presumably move with the current, instead of against it, as they migrate north to Norton Sound.

Distribution

Little is known about the migration of Norton Sound chinook salmon through the Bering Sea. Regardless of whether adult chinook salmon migrate close to the eastern coast or in the open ocean, their northward migration is probably assisted by strong ocean currents moving north from the Pacific Ocean to the Chukchi Sea. Most knowledge of adult salmon distribution comes from tagging studies (e.g., Myers et al. 1996), but the wide dispersal of salmon after tagging in the North Pacific makes it difficult to recapture enough fish to determine migration routes through the Bering Sea.

<u>Information Needs</u>

- Migration routes, timing, and travel times of salmon returning to Norton Sound.

<u>Potential Research Topics</u>

- Use newly developed tagging equipment to identify migratory paths and behavior.
- Combine ocean sampling programs with stock identification techniques to identify spatial and temporal distribution of Norton Sound chinook salmon in the Bering Sea and Gulf of Alaska.
- Determine the direction(s) from which adult chinook salmon enter Norton Sound.
- Document the dispersal of adult chinook salmon within Norton Sound.

Potential Interception Fisheries

Because little is known about the migration of Norton Sound adult salmon, there is speculation that fish may be harvested in "interception" fisheries before returning to Norton Sound. The South Peninsula June Fishery (also known as the False Pass fishery) has received the most attention as a potential interception fishery, particularly for chum salmon. High seas driftnetting was also listed as a potential interception fishery, but has largely been eliminated in recent years. Until the full distribution of adult and maturing chinook salmon is known, it is also conceivable that other fisheries in the North Pacific may intercept Norton Sound chinook salmon.

<u>Information Needs</u>

- Locations and relative effects of interception fisheries affecting Norton Sound chinook salmon populations.

<u>Potential Research Topics</u>

- Identify locations of potential interception fisheries, ways in which to sample the fisheries, and ways to identify salmon from Norton Sound.

Return Migration and Spawning Ground Access

Chinook salmon return to Norton Sound in the months of June and July, and most inriver escapement is complete before August (Kohler and Knuepfer 2002). Chinook salmon disperse to rivers throughout the Sound, with the largest documented runs typically in the Fish, Tubutulik, Kwiniuk, Shaktoolik, and Unalakleet rivers (Brennan et al. 1999). The direction chinook salmon enter Norton Sound is not known. The degree to which the salmon from different rivers intermingle and mill before entering their natal streams is also unknown. Straying rates of chinook salmon are generally thought to be low, but may vary with age and sex (Healey 1991). Chinook salmon travel times and straying rates within Norton Sound have not been estimated.

Information Needs

- Distribution of adult chinook salmon within Norton Sound.
- Nearshore and freshwater dispersal of adult chinook salmon to spawning grounds.
- Key spawning ground locations.

Potential Research Topics

- Once in Norton Sound, how long do chinook salmon mill and what is the estimated change in milling time throughout the season.
- Identify key spawning reaches in the major sockeye salmon rivers – can we reliably locate the majority of useable and unusable areas on any river?
- Describe important spawning ground attributes.
- Quantify the overall amount of spawning habitat in ANY river system or stream.

HARVEST MANAGEMENT

Policies and Regulations Governing Harvest Management

Both state and federal agencies have regulatory authority over fisheries in Norton Sound. The primary agency is the State of Alaska's Department of Fish and Game, which manages subsistence, commercial, sport, and personal use fisheries. Since October 1999, federal land managers (BLM, FWS, NPS, and FS) have assumed authority over subsistence fisheries on federal lands. State and federal agencies are working co-operatively on subsistence fisheries issues to avoid duplication in research, monitoring, or management and to minimize disruption of subsistence fisheries or confusing differences in regulation. The main difference between the two agencies management of subsistence fisheries is the ability of the federal government to, in times of limited resources, restrict use to Federally qualified rural users only. State managers must allow subsistence fishery access to all Alaskans in times of shortage using only their ability to reduce time and area except in time of severe restrictions when a tiered approach to participation is allowed. Tiers of participation are based on historic use rather that residency (Tier II fisheries).

Subsistence fisheries in Norton Sound generally operate in state managed waters. Federal lands exist on the Seward Peninsula and consist mainly of the headwaters of salmon streams away from ongoing fisheries. The one exception is the extension of the Yukon Delta National Wildlife Refuge into Norton Sound to include the Pikimiktalik River (Figure 2). The Unalakleet River is also a BLM administered wild and scenic river and flows through BLM administered lands.

For the state of Alaska, the Board of Fisheries (BOF) adopts regulations that are applied by staff in the Division of Commercial Fisheries for subsistence and commercial fisheries and by Sport Fish Division for sport and personal use fisheries. The BOF was created for purposes of conservation and development of the fisheries resources of the state. Members are appointed by the governor and approved by the legislature. The BOF participates in a public process, accepting regulatory proposals and testimony from the ADF&G, local Fish and Game Advisory Committees, and the public, which they act upon at public meetings. The BOF ultimately adopts regulations to establish fishing seasons, quotas, bag limits or harvest levels, legal gear requirements, and in general regulating subsistence, commercial, sport, and personal use fisheries as needed for conservation, development and utilization. Within legislative constraints the BOF can allocate the resource among user types (subsistence, commercial, sport, and personal use).

Several important policies, statutes, and regulations guide the ADF&G in its management of Alaska's salmon fisheries. Actual powers and duties for management have been granted to the Commissioner of ADF&G (AS Sec. 16.05.050) and reside most importantly in the ability to summarily open or close seasons or areas or to change weekly closed periods on fishing by means of emergency orders (AS Sec. 16.05.060). Authority to issue emergency orders has been delegated to local staff per division, area, and fishery of responsibility. By emergency order, existing regulations are modified (open or close time and area) to meet harvest guidelines, escapement goals, and other aspects of BOF regulatory management plans. Another important policy is the salmon escapement goal policy, first signed in 1992, which directs the department, to manage Alaska's salmon fisheries for maximum sustained yield (MSY) to the extent possible unless otherwise directed by regulation. To this end the department will aggressively pursue the further development of escapement enumeration programs, inseason fishery management programs, and scientific methods to determine escapement levels that produce MSY. The role of ADF&G and BOF in setting escapement goals is described in regulation, by the adoption, in 2001 of the Policy for Statewide Salmon Escapement Goals (5AAC 39.223). Biological escapement goals (BEGs) would be set where data exist to estimate spawners at MSY. Sustainable escapement goals (SEGs) would be set when total return data do not exist but escapement indicated by an index or an escapement estimate, is known to provide for sustained yield over a 5 to 10 year period. Sustained escapement thresholds (SETs) would be set as the level of escapement below which the ability of the salmon stock to sustain itself is jeopardized. ADF&G sets BEGs, SEGs, and SETs, and notifies the public and the BOF at it's regular meeting for that area. The BOF will set optimal escapement goals (OEGs) if deemed necessary for social, economic, or allocative reasons. These terms are described in another important regulation, the states' Policy for the Management of Sustainable Salmon Fisheries (5AAC 39.223). The five principles of this policy are summarized in the introduction and serve as a guide for this report. Application of this policy has required ADF&G to report to the BOF the extent to which management is consistent with the policy principles and criteria for those salmon stocks and fisheries under consideration for regulatory changes. Additionally habitat status or concerns, identification of any salmon stock or populations that present a concern related to yield, management, or conservation and descriptions of management and research options to address salmon stock or habitat concerns are included.

Application of the Policy for the Management of Sustainable Salmon Fisheries resulted in the declaration of several stocks of concern for Norton Sound (Bue 2000a, b) at the 2001 BOF meeting. The Nome Subdistrict (Figure 1) chum salmon stock was classified a management concern (Bue 2000a), which arises from a chronic inability despite specific management measures to maintain escapements within bounds of its goal. The Golovin Bay and Moses Point Subdistrict (Figure 1) chum salmon stock was classified as a yield concern (Bue 2000b), which arises from a chronic inability, despite specific management measures, to maintain expected yields or harvestable surplus above a stock's escapement need. At the 2001 BOF meeting chum salmon escapement goals developed under ADF&G policy and by regulation were reported to the board and public (Table 7).

Other statewide regulation and statutes governing Norton Sound Fisheries include the subsistence use and allocation of fish and game (Sec. 16.05.258) and the allocation criteria (5 AAC 39.205). The subsistence use and allocation statute directs the BOF to identify fish stocks or portions that are customarily and traditionally taken or used for subsistence. They are then directed to determine the amount reasonably necessary, to provide reasonable opportunity and in times of shortages adopt regulations that eliminate other consumptive uses in order to provide subsistence opportunity. The allocation criteria give direction to the BOF in what to consider when allocating harvests among non-subsistence users.

Regulations have also been adopted specifically pertaining to Norton Sound salmon commercial fisheries (5AAC Chapter 4). Commercial fishing districts and subdistricts are defined in regulation. Regulations define the commercial fishing season, fishing periods, gear specifications and closed waters among other things. From the last BOF meeting escapement goal ranges from Clark (2001b) were placed in regulation for the Nome Subdistrict (5 AAC 04.358) and specified as Optimal Escapement Goals (OEGs) following the statewide escapement goal policy. For the Golovin Bay and Moses Point Subdistricts the BOF placed in regulation OEGs, which represent an additional 15% to the BEG proposed by the department (Clark 2001a). This management plan for Golovin Bay and Moses Point Subdistricts also specifies that the chum salmon harvest may not exceed 15,000 before mid-July or pink or coho salmon directed fisheries may occur only if escapement and subsistence needs will be met for chum salmon.

Similar regulations have also been adopted specifically pertaining to Norton Sound subsistence fisheries (5AAC Chapter 1, Article 3). Fishing seasons, fishing periods, lawful gear and its identification have been set and closed waters described in regulation. Subsistence fishing permits are also required for the waters from Cape Douglas to Rocky Point (5 AAC 01.180), representing an area larger than the Nome Subdistrict. A Tier II subsistence fishery has also been defined for the Nome Subdistrict (5AAC 01.190). This would occur if the harvestable surplus of chum salmon is insufficient to provide reasonable opportunity for subsistence fisheries in the Nome Subdistrict, the BOF has eliminated non-subsistence consumptive uses, and further restrictions are necessary to assure the stock is maintained and managed on a sustained yield bases. Tier II permits are allocated based on the customary and direct dependence on chum salmon and the ability of the subsistence user to obtain food if subsistence use is restricted or eliminated. This chum salmon management plan directs the ADF&G to manage for the BEG range to rebuild these stocks so Tier II fisheries are no longer necessary. No commercial fishery will be allowed until Tier I (open to “all Alaskans) subsistence fisheries occur for four-years. Tier II subsistence fisheries have occurred in the Nome area since 1999.

Commercial Fisheries

Commercial salmon fishing in Norton Sound has occurred in all six subdistricts (Figure 1), first beginning in the Unalakleet and Shaktoolik Subdistricts in 1961. Currently, little commercial fishing occurs outside those two subdistricts, due to market constraints, lack of buyers, or low abundance. Norton Sound fisheries are managed on the basis of comparative commercial catch data, escapement counts, weather conditions, and processor capacity or availability. A single factor or combination of factors may result in issuance of emergency orders affecting fishing seasons, fishing periods, allowable mesh size, and open or closed areas.

Commercial harvests by district and subdistrict have been reasonably well monitored and estimated on a weekly and annual basis. Annual subsistence harvests are estimated by surveys, returned permits and are known less well. ADF&G has used counting towers, weirs, sonar, and aerial surveys to monitor salmon escapement into selected rivers at various times since the inception of commercial fishing (Appendix 1). Age, sex, and size data have been collected at times from commercial fisheries and at escapement monitoring projects.

Salmon fisheries in Norton Sound are managed conservatively due to the lack of inseason information on run strength close to the area where commercial fishing occurs. Current inseason management relies on comparative commercial catch data, run timing assessment, and escapement counts from towers or weirs when available later in the season. In addition the department uses test net (Unalakleet River) catch rates and subsistence interview information to manage salmon fisheries in the Unalakleet and Shaktoolik subdistricts. Improvements in the existing management system (data collection, predictive models, escapement goals, fishing schedules) could result in higher sustainable yields if the harvestable surplus were identified earlier while harvesting of quality salmon could occur.

Harvest and Escapement of Norton Sound Chum Salmon

Commercial fishing for chum salmon has occurred at various levels in all subdistricts in Norton Sound. Five-year average (1996 - 2000) chum salmon harvest was 22,363 fish in the commercial fishery and 25,631 in the subsistence fishery (Bue 2000). The most recent (2000) escapement indices for the Nome District were generated from nine aerial surveys (13 rivers total), six towers, and one test fishery (Bue 2000). Estimated average escapement of chum salmon to Subdistrict 1 was 43,300 from 1974 to 2000 (Clark 2001b).

The majority of adult chum salmon returning to Norton Sound are estimated to be a total of four or five years old (three and four years spent at sea; Clark 2001a). Average adult chum salmon weight ranges between 6.5 and 7.9 pounds between 1990 and 1998 (Brennan et al. 1999).

Most escapement monitoring projects (weirs, towers, and sonar) have targeted chum and pink salmon for enumeration. Chum salmon are important to commercial and subsistence fisheries, they enter first but have run timing, which overlaps in greatly with pink salmon.

Harvest and Escapement of Norton Sound Coho Salmon

ADF&G has used counting towers, weirs, and aerial surveys to monitor escapement on various rivers since the inception of commercial fishing in 1961, but not primarily for coho salmon, which are a later arriving species. Aerial surveys are often hampered by poor weather conditions and counting towers and weirs begun to monitor chum and pink salmon lack funding to operate throughout the coho salmon migration. Age, sex, and size data have been collected opportunistically from commercial and test fisheries. Consequently, there is little opportunity to estimate age structures, sizes, and escapement indices throughout the region. However, there is currently little information available on age structure of coho salmon, and there is doubt among some researchers and many local residents as to the validity or accuracy of annual escapement indices.

The average Norton Sound coho salmon harvest for the five years from 1995-1999 was 57,956 fish. Of these, 38,127 were caught in the commercial fishery and 19,829 in the subsistence fishery. Although 1999 was the lowest commercial harvest since 1978, the overall long-term returns appear to be more robust than for chum salmon. Commercial catch average for the ten years from 1990-1999 was 56,184 coho salmon. From 1995 to 1999, over 86% of the total Norton Sound coho salmon harvest (commercial and subsistence) was in the Unalakleet and Shaktoolik subdistricts (Bue and Menard 2000).

The majority of coho salmon returning to Norton Sound appear to have spent two winters in freshwater and one at sea. In the Unalakleet Subdistrict in 1985, 78% of the coho salmon sampled were age 2.1, 17% were age 1.1, and the remaining 5% were age 3.1 (Hamner 1987). Mean length of female spawners was 576 cm. In the Unalakleet Subdistrict in 1991, 81% of the coho salmon were age 2.1, 14% were age 1.1, and the remaining 5% were age 3.1 (Lingnau 1992). Mean length of female spawners ranged from 569 mm to 589 mm across age classes and sampling gear type.

Harvest and Escapement of Norton Sound Sockeye Salmon

Sockeye salmon are typically found in very small numbers throughout Norton Sound, and not abundant enough to support a commercial fishery. Those few sockeye salmon reportedly harvested represent catches incidental to chum and pink salmon directed fisheries. Brennan et. al (2002) reported the recent 5-year average harvest of 59 sockeye salmon (1995-1999). Sockeye salmon are much more important to the subsistence fishery though the harvestable surplus of the monitored stocks is small.

Sockeye salmon escapement has been monitored in two systems both of which are in the Nome Area. Sockeye salmon spawning near and having reared in Salmon Lake have been counted as returning adults from a tower located on the Pilgrim River (Appendix 1, Figure 2). Those returning to Glacial Lake (Figure 2) are counted as they pass through a weir at the outlet of the lake (Appendix 1) having passed up the Sinuk River from Norton Sound.

Age, sex, and length information for adult sockeye salmon returning to monitored sockeye salmon systems were collected in 1977, 1995, and 1996 (Todd and Kyle 1997). Salmon Lake sockeye salmon returned as 92% age 2.3 in 1996 and 67% age 2.3 in 1995. Samples collected in 1977 estimated the adult return to Glacial Lake to be 76% age 2.3. Scales were also collected from smolt migrating from Salmon Lake indicating freshwater residency to range from 99% age

1 in 1996 to 67% age-1 smolt in 1995. Glacial Lake smolts have ranged from 99% age 1 in 1996 to 49% age 1 in 1995. In Salmon Lake age-1 smolt averaged 3.5 g and age-2 average 5.6 g (Todd and Kyle 1997).

Harvest and Escapement of Norton Sound Pink Salmon

The average Norton Sound pink salmon harvest for the five years from 1995-1999 was 271,917 fish. Of these, 231,424 were caught in the commercial fishery and 40,494 in the subsistence fishery. Commercial catch average for the ten years from 1990-1999 was 230,387 pink salmon. Though pink salmon are prevalent throughout Norton Sound, from 1995 to 1999 over 70% of the total pink salmon harvest (commercial and subsistence) was from the Unalakleet and Shaktoolik subdistricts. The mean weight of pink salmon in the commercial fishery has varied from 2.2 pounds in 2000 to 4.0 pounds in 1968 (Brennan et. al 2002). Pink salmon weights in the 1990s were always less than 3 pounds compared to an average 3.2 for the 1980s and 3.4 pounds for the 1970s and 1965-1969 period.

Since the mid-1980s returns of pink salmon have been much larger in even years (Brennan et al. 2002). Although no pink salmon stock in Norton Sound has been declared a stock of concern, Brennan et al. (2001) concluded that even-year pink salmon returns have been trending downward.

Pink salmon are monitored at most of the same weir and tower projects operated to count chum salmon. BEGs have not been set for most pink salmon stocks, though fisheries are managed from escapement targets for rivers in the Nome, Golovin, and Moses Point area with escapement monitoring projects.

Harvest and Escapement of Norton Sound Chinook Salmon

Norton Sound harvests averaged slightly more than 15,000 chinook salmon for the 5 years from 1994 to 1998, with approximately 60% of the harvest from commercial and 40% from subsistence fisheries (Brennan et al. 1999). In 2000, however, runs decreased substantially and an average of only 323 chinook per year were commercially harvested from 2000 to 2002 (ADF&G 2002). Shaktoolik and Unalakleet subdistricts are the only ones with regular commercial fisheries that target chinook salmon – in other subdistricts, chinook have usually taken inadvertently in fisheries targeting other species.

Harvest and Escapement Information Needs

Some of the most basic information needed to understand the productive capacity of Norton Sound salmon stocks (and why it changes) will be stock-specific escapement and subsequent production from that escapement. Collectively, these data are described as brood tables and include the number of returns by age class from each escapement or "brood" year. Inputs to brood tables are annual stock-specific catches and escapement, apportioned by age class. Once constructed, brood tables provide information on, and insight into, the absolute production levels (total returns by year), relative production among systems at different spawning levels (returns per spawner), and on how these variables change with time and environmental conditions. Ultimately, brood table information can be used to identify biological escapement goals (BEGs). In addition, the programs used to obtain brood table information (catch and escapement monitoring programs) can be used to help manage fisheries. Currently there is very limited brood table data for Norton Sound salmon populations. Clark (2001 a,b) developed brood year return data for chum salmon through expansion of aerial survey data and assumption of age composition data. Recommended escapement goals derived from these data were deemed short-term starting points for developing adaptive strategies for setting escapement goal appropriate to the uncertainty in the data and need to be revised as soon as possible based on additional analysis (Mundy et al. 2001).

The lack of brood table information for Norton Sound salmon stocks is the result of several factors:

1. The area is remote and it is expensive to obtain these data.
2. There are numerous small to medium-sized salmon-producing rivers (~40) flowing into Norton Sound, making complete monitoring annual catch and escapement logistically difficult and expensive.
3. Harvesting is spread across a wide area making it difficult and expensive to sample harvests for age and other biological information.
4. Several fisheries in Norton Sound capture salmon from several stocks at the same time, making it difficult to attribute harvest (i.e., production) to a particular stock.

Given the importance of brood tables to understanding biological productivity, it is clear that a major data gap in Norton Sound is basic catch and escapement monitoring programs. However, determining the level of effort and location of catch and escapement programs is much less clear. Given the abundance and value of Norton Sound salmon stocks and the current state of monitoring technology, it does not appear feasible (or possible?) to build brood tables for every stock.

<u>Information Needs</u>

- Analysis of the cost, benefit, and efficacy of salmon escapement methods on different rivers and river types in Norton Sound.
- Exploitation rates of different species and stocks in Norton Sound fisheries.
- Brood tables for chum, coho, sockeye, pink and chinook salmon and the spawner or recruit information needed to build such tables.
- Determine which are the key stocks of chum, coho, sockeye, pink or chinook salmon to monitor as representative of a larger area or stock grouping.

<u>Potential Research Topics</u>

- Design and develop a salmon catch and escapement monitoring program for Norton Sound that is commensurate with the value of the fishery or species and can be used to develop long-term brood tables and provide information to better manage the stocks as a whole (e.g., inseason measures of harvest and abundance).

- Evaluate the contribution of individual stocks to mixed stock fisheries accurate, and assess the accuracy of current estimates.
- Assess the sensitivity of brood table analyses to current harvest assumptions (e.g., exploitation rates).
- Compare the effectiveness, cost, and benefit of escapement estimates among Norton Sound tributaries. Assess the trade-offs between developing accurate and precise brood tables for a few stocks versus developing less precise brood tables for a large number of stocks.
- Identify techniques and technologies to estimate escapement to prioritized tributaries.

Subsistence Fisheries

Subsistence fisheries in Norton Sound are an important component of the harvest and, as discussed in the introduction, an important part of the life of the people in the region. From 1993 to 1997, and average of 25,900 chum and 17,600 coho salmon were harvested by the subsistence fishery (Brennan et al. 1999). More information on the Norton Sound subsistence fisheries will be added in the next update of this document.

HATCHERY ACTIVITIES

Hatchery Locations and Programmatic Concerns

Concerns about using hatchery programs to enhance wild salmon populations have been well documented throughout the years (e.g., Kapucinski and Lannan 1984; Kelly et al. 1990). These include the potential for negative biological interactions between hatchery and wild fish, artificially increased pressure in a mixed stock (e.g., hatchery and wild) fishery, and the sometimes dramatic failures of specific stocking programs to increase overall salmon biomass. If marine survival conditions are poor, or if ocean carrying capacity has been reached, many argue that financial resources may be better spent on research to understand the factors affecting production than on hatchery supplementation. Kelly et al. (1990), for example, noted that a five-fold increase in hatchery production in Washington State between 1960 and 1985 failed to increase overall commercial catch, presumably because unknown marine factors limited the absolute numbers of salmon able to return to the commercial fishery.

Successful hatchery production can have the unintended effect of increasing the harvest pressure on wild fish when the increased production increases the total harvest effort in the region. Exploitation rates that are suitable for hatchery fish may be too high for wild fish to sustain. It is usually impossible to differentiate between wild and hatchery fish in a mixed-stock fishery. As a result, hatchery supplementation may have the lowest impact on wild fish when the hatchery fish can be harvested in a single-stock, terminal fishery.

The interaction between hatchery and wild chum salmon from western Alaska is not well known. Juvenile hatchery fish could theoretically affect wild chum salmon through disease transmission, competition for food or space, hybridization, or increased harvest pressure (Kelly et al. 1990).

Most of the potential effects can be grouped into those that are density dependent or genetic. Stomach contents of hatchery chum salmon in marine waters were negatively correlated with fish density, indicating intensified intraspecific competition (Fukuwaka and Suzuki 2000). Klovatch (2000) documented an unusual phenomenon of "flabby muscles" in juvenile chum salmon along the Russian coast. Salmon exhibiting this syndrome had an elongated body shape and noticeable soft, or flabby, muscle tissue. The phenomenon was more prevalent in smaller fish and in less–mature fish (45-60 cm, generally) and was correlated with levels of releases from hatcheries. The flabby-muscle condition was less frequent later in the year and among older fish, indicating that fish either recover from it or suffer increased mortality. One hypothesis for the condition is that intraspecific competition caused by high chum densities forced less competitive fish onto lower quality and poorer prey, such as prey with pathogens.

Coho salmon hatchery programs share the same concerns described for chum salmon hatchery programs, above. These include the potential for negative biological interactions (inter- and intra-specific) between hatchery and wild fish, artificially increased pressure in a mixed stock (e.g., hatchery and wild) fishery, and the possible inability of a specific stocking program to increase overall salmon biomass. Where the post-stocking environment has an acute mortality bottleneck or has reached carrying capacity, increased hatchery production may not increase the number of returning spawners. In such cases, financial resources may be better spent identifying survival limitations than on hatchery supplementation. Kelly et al. (1990), for example, note that a five-fold increase in hatchery production in Washington between 1960 and 1985 failed to increase overall commercial catch, presumably because unknown marine factors limited the absolute numbers of salmon able to return to the commercial fishery.

Successful hatchery production can have the unintended effect of increasing the harvest pressure on wild fish when the increased production increases the total harvest effort in the region. Exploitation rates that are suitable for hatchery fish may harvest wild fish at such rates that escapement goals are not reached. In is usually impossible to differentiate between wild and hatchery fish in a mixed stock fishery. As a result, hatchery supplementation may have the lowest impact on wild fish when the hatchery fish are harvested in a single-stock, terminal fishery.

The interaction between hatchery and wild coho salmon from western Alaska is not well known. Juvenile hatchery fish could theoretically affect wild coho salmon through disease transmission, competition for food or space, hybridization, or increased harvest pressure (Kelly et al. 1990). Most of the potential effects boil down to those that are density dependent or genetic. In places where coho salmon feed on chum fry, increased hatchery coho salmon production could have substantial effects on chum salmon fry survival.

Aquaculture has the potential to cause detrimental genetic changes in wild populations (Waples 1991). Strays from hatcheries may result in outbreeding depression through dilution of locally adapted genes (Reisenbichler et al. 1983) or even disruption of co-adapted gene complexes (Emlen 1991; Gharrett and Smoker 1993). Purposeful supplementation of wild populations by artificial augmentation of a part of the population may increase inbreeding (Ryman and Laikre 1991) or result in selection of genes suited for artificial environments (Reisenbichler and McIntyre 1977).

Information Needs

- Effects of salmon stocking on harvest rates for wild salmon.
- Competitive and genetic effects of hatchery stocking on wild Norton Sound salmon.
- Stocking strategies (e.g., location, timing, or size at stocking) that reduce or eliminate potential negative effects on wild salmon.
- Straying rates of salmon stocked in Norton Sound rivers.

Potential Research Topics

- The contribution of hatchery salmon to Norton Sound fisheries.
- Changes in wild salmon exploitation due to changes in harvests of hatchery salmon.
- Factors affecting the productivity of Norton Sound salmon.
- Genetic and competitive effects of hatchery salmon on wild salmon.
- Stocking strategies (e.g., altered size, location, or time) that reduces or eliminates negative interactions between hatchery and wild salmon.
- Rates of hatchery straying, and the variation among years and locations.

RESEARCH PLAN

The following table summarizes the state of knowledge for Norton Sound salmon by life cycle stage. Levels of knowledge are: 1, good; 2, some available; 3, very limited; 4, none.

Life Cycle Stage	Chum	Coho	Pink	Chinook	Sockeye
Egg	4	4	4	4	4
Fry – freshwater	3	3	4	4	2
Fry – estuarine and marine	3	3	4	4	4
Marine	4	4	4	4	4
Immigrant (Adult)	2	2	2	2	2

Egg Stage

Questions

1. Which physical variables (water velocity, depth, upwelling, substrate size, etc.) are most important for salmon spawning and egg incubation in Norton Sound tributaries? What are the useable ranges of these variables?
2. Where are key spawning grounds in Norton Sound tributaries? How much area is suitable for spawning?
3. What is the fecundity of female salmon by species, and what are the relationships between fecundity and length or weight for each species? How much variability exists among populations?
4. What is the total annual deposition of fertilized salmon eggs by species in Norton Sound?
5. How large are Norton Sound salmon eggs, and what is the yolk content?

6. What are the thermal unit requirements and development times of salmon eggs in Norton Sound tributaries?
7. What is the survival rate of eggs, from deposition to alevin emergence, and from alevin emergence to swim-up?
8. Which of the following, if any, are important causes of salmon egg mortality in Norton Sound tributaries: fungus, predation, displacement by sympatric spawning species, oxygen delivery, siltation, freezing, or dewatering?
9. On which stream reaches have spawning habitat and fry production been reduced by anthropogenic disturbance?
10. Which stream reaches contain spawning habitat most suitable for restoration, and which methods would be needed to improve their habitat?
11. Can TEK be used to identify "natural" historical changes in spawning habitat availability in Norton Sound tributaries?

Information needed

1. Identify variables that are known to influence salmon spawning habitat, such as water velocity, water depth, groundwater upwelling, and substrate size. Measure the ranges of these variables on salmon spawning grounds in Norton Sound.
2. Quantify present ground use by locating spawning grounds and measuring the surface areas and densities of salmon redds. Quantify unused or potential spawning ground habitat by modeling variable measurements from Question 1, above. Use a habitat classification or stratification scheme to improve estimates in different stream types.
3. Measure egg content from ripe female salmon, and correlate fecundity with body measurements. Sample in locations that allow estimates for specific populations to compare differences among populations.
4. Estimate total annual deposition of fertilized eggs by estimating escapement, sex ratios, fecundity, and fertilization rates.
5. Collect and measure size and other characteristics of Norton Sound salmon eggs.
6. Record fertilization dates, hatch times, and interim water temperatures to estimate thermal unit requirements and development times of salmon eggs.
7. Bury egg incubation trays in streams and uncover at predetermined times to estimate survival rates to alevin and swim-up stages.
8. Evaluate dead eggs in incubation trays to estimate fungus presence. Correlate egg mortality with measurements of environmental conditions. Sample stream during winter to determine siltation, freezing, and dewatering.
9. Identify streams on which data or TEK of historic spawning grounds exists.
10. Determine habitat suitability based on measurements of important variables (see Item 1, above). Rank impacted streams based on quantity of suitable habitat and prospects for restoration. Consult habitat restoration experts to determine restoration methods, and factor recommendations into prioritization ranks.
11. Design and implement studies that draw on local TEK to estimate long-term changes in spawning habitat.

Fry Stage – hatching and freshwater emigration

Questions

1. When do alevins emerge from gravel and begin swimming up in the water column? How long does this process last for a given population? Do the majority of alevins emerge at night or during the day?
2. What is the rheotactic response of newly emerged fry? Are fry swept downstream or do they maintain position in the current? What degree of control do fry have as they migrate downstream?
3. How long do chum salmon fry spend in freshwater after hatching? Are migrations continuous or interrupted? How much variability in movement behavior is there among streams?
4. Is there a correlation between freshwater survival and brood year strength?
5. How large are the effects of predation, fry size, food availability, and parasite infestation on freshwater survival?
6. Do downstream-migrating fry feed and, if so, what do they feed on?

Information needed

1. Timing of alevin emergence, diel emergence patterns, and duration of population swim-up.
2. Reaction of fry to water current, and data on holding or displacement behavior at different water current velocities
3. Instream distribution of fry, especially among different habitat types (riffle, slough, pool, eddies) and streams (headwater vs. mainstem, long vs. short).
4. Freshwater survival and adult escapement estimates of specific year classes.
5. Presence and effects of predators; size of fry in freshwater; food availability and fry feeding behavior; parasite presence and infestation rates; freshwater mortality estimates.
6. Stomach and diet analysis of fry

Fry stage – nearshore marine

Questions

1. When do salmon fry enter Norton Sound estuaries, and how much does the timing vary among rivers and years?
2. What is the diet of salmon fry in nearshore environments, and how much food is available?
3. How important are estuarine habitats for salmon fry?
4. What are the important predators of salmon in the nearshore environment, and how much is known about their distribution and abundance?
5. What is the daily mortality rate of fry in the nearshore environment?
6. Is mortality correlated with environmental or biological factors such as freshwater runoff, salinity, temperature, or fish density?

7. Do salmon fry move offshore or migrate along the coast? Is migration timing correlated with size or body condition?
8. Are salmon fry movements from nearshore to offshore correlated with temperature, salinity, or plankton abundance?
9. At what depth are most fry distributed and how does depth affect fry susceptibility to predators and water currents?

Information needed

1. Time series data on fry entry into different Norton Sound estuaries.
2. Salmon fry diet, stomach fullness, and prey availability in nearshore environments.
3. Distribution patterns of salmon fry in estuarine and adjacent non-estuarine environments. Data on fry response to different salinity treatments.
4. Diet and distribution of potential salmon fry. Historical data of predator abundance and distribution
5. Fry survival or mortality data nearshore environments.
6. Data of mortality and trends in freshwater runoff, salinity, temperature, and fish density.
7. Distribution and movement data, and their correlation with fry length or body condition.
8. Data of fry distribution and movement, temperature, salinity, or plankton abundance.
9. Depths at which fry feed and migrate. Water current and predator distribution data.

Marine Stage

Questions

1. What are the water current directions and velocities (at relevant depths) along potential migration routes in Norton Sound, the Gulf of Anadyr, along the Bering Sea coasts, and along other potential migration routes? What are the ramifications for potential migration routes and salmon distribution?
2. At what depths do the majority of salmon migrate and feed? How much variability is there among places and seasons?
3. What are the basic measurements of salinity and temperature in Norton Sound and the Bering Sea at different times of the year?
4. What are the spatial and temporal distribution patterns of coccolithophores and salmon prey in the Bering Sea. How might these distributions affect salmon?
5. Does Norton Sound have similar environmental characteristics to other bodies of water (e.g., Gulf of Anadyr)? If so, are there similarities in the salmon populations from the two regions?
6. What are the seasonal and spatial distribution patterns among different populations of Norton Sound salmon, especially with regard to arrival into the Gulf of Alaska? What are the migration routes of salmon traveling from Norton Sound to the Gulf of Alaska?
7. Are patterns observed for Norton Sound populations mirrored in distant populations, such as on Asian coastline?

8. What is the marine diet of Norton Sound salmon, and how does it vary by species, region, season, and age?
9. What are potential sources of intra- and inter-specific competition, and how susceptible are different species or populations to these effects?
10. How does density affect forage success, growth, and maturity of salmon?
11. Is annual growth of Norton Sound salmon correlated with environmental or biological variables?
12. What is the annual survival of Norton Sound populations?
13. Is survival correlated with factors such as temperature, predation, size, body condition, and feeding regions?
14. What are the primary predators of salmon migrating through the Bering Sea and within the Gulf of Alaska?
15. What is the relative mortality by age and life stage? For example, does survival in the second year influence Norton Sound returns more than survival in the third?
16. Do Norton Sound populations share enough similarities of environment or biology (e.g., similar latitude or oceanographic conditions) with any other stock to place special emphasis on examining that stock?

Information needed

1. Information of water current directions and velocities (at relevant depths) along potential migration routes in Norton Sound, the Gulf of Anadyr, and along the Bering Sea coasts.
2. Vertical distribution data over time and space.
3. Salinity and temperature profiles of Norton Sound and Bering Sea ecosystems.
4. Information on spatial and temporal patterns of coccolithophores and salmon prey in the Bering Sea.
5. Comparisons of Norton Sound and distant regions, along with time series of salmon population data from the respective regions.
6. Data from fish sampling marking programs, tag recoveries, or stock identification techniques (scales, genetics, etc.) designed to identify:
    a. seasonal and spatial distribution patterns of Norton Sound salmon,
    b. arrival of salmon into the Gulf of Alaska,
    c. differences in distribution among Norton Sound populations,
    d. diet of chum salmon in the Gulf of Alaska and the Bering Sea, and
    e. migration routes of salmon traveling from Norton Sound to the Gulf of Alaska.
7. Salmon population patterns from Norton Sound and from distant populations.
8. Salmon diet data from the Bering Sea and Gulf of Alaska.
9. Estimates of salmon density along migration routes and diet overlap.
10. Data on salmon density, forage success, age at maturity, and growth.
11. Annual survival estimates, growth, and environmental variables.
12. Time series of annual estimates of marine survival.
13. Annual survival estimate and data on environmental conditions (temperature, etc.), predator abundance, salmon size, and salmon body condition.
14. Predation abundance and distribution data.
15. Estimates of mortality by age and life stage.

16. Similarities of environment, biology, or life history between Norton Sound and distant populations.

Immigrant Stage

Questions

1. What is the escapement of salmon to biologically important Norton Sound salmon streams?
2. What are the basic biological statistics of salmon returning to spawn – age, sex ratio, length, etc.?
3. What are the migratory paths and behavior of adult salmon returning to Norton Sound?
4. What are the entry and dispersal patterns of adult salmon returning to Norton Sound?
5. What are the potential interception fisheries encountered by migrating salmon, and how can the interceptions be quantified?
6. Once in Norton Sound, how long do salmon mill and what is the estimated change in milling time throughout the season?
7. What are key spawning reaches in the major Norton Sound salmon rivers – can we reliably locate the majority of useable and unusable areas on any river?

Information needed

1. Reliable escapement information.
2. Annual and long-term data on salmon age, sex, length, etc.
3. Identify migratory paths and behavior using state-of-the-art tagging equipment.
4. Spatial patterns of adult salmon entering Norton Sound.
5. Locations of potential interception fisheries, and suitable methods for sampling the fishery and identifying stocks.
6. Milling time and locations of salmon in Norton Sound.
7. Spawning ground timing and access. Important spawning ground attributes.

Harvest Management

Questions

1. What is the contribution of the various salmon stocks to each fisheries area, and does it vary by date?
2. What spawning densities are actually achieved in poorly monitored streams?
3. What are the escapement estimates on Norton Sound rivers? How can these estimates be improved?
4. Would changes in the escapement goals result in increased production?
5. What are the effects of measurement error present in brood year tables used to set escapement goals?

Information needed

1. Exploitation rates of individual stocks within each mixed stock fishery. Suitable methods for identifying individual stocks in the commercial fishery.
2. Evaluation of the accuracy of different spawning ground assessment methods.
3. Assessment of escapement indices, and of the accuracy of extrapolations among streams and methods. Cost/benefit analysis of enumeration methods on small, medium, and large rivers.
4. Long-term estimates of production and escapement, particularly brood tables.
5. Assessment through simulation or modeling the effect of measurement error on the establishment of escapement goals particularly at MSY.

Economics

Questions

1. How would various methods for reducing the costs of harvesting (permit buybacks, co-ops, etc.) affect the number of participants in the fishery and their profits?
2. What allocation of each species to subsistence or commercial use provides the maximum benefit to the people of the region, and how does this change with salmon abundance?
3. What factors limit processor interest in purchasing the commercially caught salmon from these fisheries?
4. What factors limit the involvement of local residents and communities in processing and marketing the commercially caught salmon from these fisheries?

Information needed

1. Analysis of the different components of harvest participation and economics.
2. Harvest, distribution, and consumption data by species and fishery (subsistence or commercial).
3. Factors affecting market price and processor valuation of harvested salmon.
4. Analysis of factors influencing community involvement in salmon fisheries, including access, seasonal timing, equipment, and economic incentive.

Hatchery activities

Questions

1. Will the release of hatchery fish increase the participation and harvest in mixed-stock commercial fisheries? If so, what the ramifications for increasing harvest rates on depressed wild stocks?
2. Do hatchery fish compete with wild salmon for food or space? If so, at what points in the salmon life cycle?
3. Can hatchery fish interbreed with wild salmon? If so, what are the potential negative genetic effects? Can these potential effects be modeled in advance?
4. Which rivers systems are most likely to reduce the potential competitive, genetic, or exploitation effects of hatchery fish on wild salmon?

5. What are the stray rates of hatchery stocked fish from different rivers in Norton Sound? How much do these rates vary among rivers and years?

Information needed
1. Potential effects of salmon stocking on harvest pressure on wild salmon.
2. Competitive effects of hatchery stocking on wild Norton Sound salmon.
3. Genetic effects of hatchery stocking on wild Norton Sound salmon.
4. Systems in which hatchery fish are least likely to compete or interact with wild salmon.
5. Straying rates of salmon stocked in Norton Sound rivers.

PROCESS FOR PRIORITIZING PROJECTS

Gaps in scientific knowledge about what controls salmon production in Norton Sound serve as a starting point for deciding what needs to be done now and in the future. The gaps point to the information gathering projects that are needed to answer each question, but there are so many information gaps that priorities need to be established for filling them. Defining priorities requires establishing standards that can be used to understand the need and urgency for a project. The combination of the priority of the question, the cost of the project, and the available funding will define the recommended list of projects to be implemented.

Standards for Project Selection

A standard is something set up and established by an authority, such as the Steering Committee, as a rule for measuring a project’s value, so that a funding decision may be made. There are two basic standards to be addressed, need and feasibility. Needs may be broken down into three basic categories and categories may be further divided into as many subcategories as necessary.

Standard 1: Need (50)
- Standard 1.1 Scientific (15)
  - 1.1.1 Builds on the experience and information of previous and other current projects (3)
  - 1.1.2 Fills critical (multiple needs for information) gap (5)
  - 1.1.3 Status (2)
    - 1.1.3.1 Advances understanding of trends and population viability of salmon stocks
  - 1.1.4 Process (3)
    - 1.1.4.1 Focused on uncovering mechanisms underlying trends in abundance
  - 1.1.5 Linkages (2)
    - 1.1.5.1 Promotes understanding multiple species, trends of other species, i.e. bears, beaver
    - 1.1.5.2 Promotes understanding of interactions among salmon species
- Standard 1.2 Management (15)
  - 1.2.2 Operational (8)

1.2.2.1 Ability to support a management action
1.2.2.2 Contributes to evaluation and improvement of existing projects
1.2.3 Allocation (2)
1.2.3.1 Clarifies interactions among competing uses and/or ways to reduce these conflicts
1.2.4 Planning (5)
1.2.4.1 Demonstration-type project that leads the way
1.2.4.2 Prospective, anticipating where the populations are moving, vs. retrospective, managing in the past.
1.3 Standard 1.3 Economic and Social (20)
1.3.2 Economic (10)
1.3.2.1 Potential short-term (w/in 10 years) economic benefits
1.3.3 Social (10)
1.3.3.1 Benefits (economic, subsistence) to local people

Standard 2: Feasibility (50)
Standard 2.1 Scientific (20)
2.1.1 Methods and Technologies (8)
2.1.2 Personnel (6)
2.1.3 Infrastructure (6)
Standard 2.2 Management (10)
2.2.1 Logistics
Standard 2.3 Cost (20)
2.3.1 Short-term (initial capitalization)
2.3.2 Long-term (depreciation and operation)
2.3.3 Leverages other funding sources

Guidelines for Scoring

Scoring would be by a point system where specific standards are each given a maximum number of points. More points would be assigned to the most critical standards. A tentative point system is listed above as numbers in parentheses following specific criteria.

Reviewers would be asked to assign points to proposed projects for each standard. The summed scores would then be the project's rank. A possible addition to the above system would be points reserved for a consensus-driven group discussion after initial review by individuals.

LIST OF PRIORITIZED PROJECTS

Short-Term

{work in progress to be developed}

Long-term

INFORMATION ON THE AUTHORS

Scientific Technical Committee Members

Milo Adkison (Member) is an Assistant Professor at the Juneau Center, School of Fisheries and Ocean Sciences. He specializes in the application of quantitative methods such as mathematical modeling and Bayesian statistics to problems in salmon biology and management. He's a former resident of Dillingham who spent several years as crew in the Bristol Bay salmon fishery.

Linda K. Brannian (Member) recently became the Regional Research Supervisor for the Arctic-Yukon-Kuskokwim Region of the Division of Commercial Fisheries, ADF&G. Linda began her career nearly 20 years ago with the department as the Regional Biometrician for AYK, followed by experience as Regional Biometrician for salmon, herring, shellfish and groundfish for Bristol Bay, Cook Inlet, and Prince William Sound and as the Regional Management Biologist for Cook Inlet salmon/herring and shellfish/groundfish throughout Central Region. She has spent her career designing and implementing research and assessment projects for salmon, herring, groundfish, and shellfish. Linda has a Masters and B.S. from the School of Fisheries, University of Washington.

Russell R. Holder (Member) is a fisheries biologist for the U.S. Fish and Wildlife Service in Fairbanks with the Yukon River federal subsistence fisheries management program. Russ obtained his undergraduate degree in Fisheries from Oregon State and his graduate degree in Fisheries from the University of Alaska, Fairbanks. He began his fisheries career with the Alaska Department of Fish and Game, accumulating over 20 years of experience in Interior and Western Alaskan salmon culture, management, and research.

Michael Link (Member) has spent two decades designing and implementing salmon research and management programs in Alaska, the Yukon and British Columbia. He has been employed with LGL Limited, an international consulting firm specializing in fisheries and wildlife research and management, almost continuously since 1992. In 1999, Michael spent one year working for the Alaska Department of Fish and Game as research project leader for Bristol Bay salmon and herring. His professional experience has focused on designing and implementing projects to assess the abundance and biological characteristics of salmon populations. In addition, Michael has spent much of his career assisting native and regional organizations to conduct high-caliber fisheries research and assessment programs. In the 1990s, he designed and directed a large-scale research and management program on the Nass River (BC) for the Nisga'a Lisims Government. This award-winning program was instrumental in the negotiation and settlement of the first modern-day treaty in British Columbia. More recently, Michael has been working with the Native Village of Eyak (Cordova, AK) to design and conduct two challenging salmon assessment projects on the Copper River. He is currently the Director of the Bristol Bay Science and Research Institute where he works with communities in Western Alaska to get meaningfully involved in fisheries research and management activities. Michael has an interdisciplinary degree in Natural Resource Management from Simon Fraser University. His academic work focused on integrating knowledge of fisheries science and management with economics to improve fisheries management.

Phillip R. Mundy (Chair) has been working in the conservation and management of salmon in Alaska each year since 1976. His first job in Alaska was to work with salmon harvest managers in King Salmon and Dillingham to find new ways to use information from test fisheries to design fishing regulations for Bristol Bay. Phil went on to do similar work with salmon harvest managers in Soldotna, Emmonak, Chignik, Bethel, Yakutat, and Lynn Canal. Phil also has life long experience in advising Native Americans on fisheries management. As one of the first biologists to work for the tribes to implement treaty fishing rights on Puget Sound following the final Boldt decision, Phil helped found the salmon fishery management programs at Point No Point Treaty Council and the Northwest Indian Fish Commission. He also worked for the Columbia River Inter-Tribal Fish Commission as manager of its research program. Phil has a Ph.D. in Fisheries from the University of Washington and he lives in Anchorage.

Matt Nemeth (Staff Scientist**)** is a fishery biologist and project manager with LGL Alaska Research Associates, Inc. in Anchorage. Matt has been retained part-time by the Norton Sound STC to assist with the writing and editing of sections of the Research and Restoration Plan. Matt's primary duty outside of the STC is to work with regional partners to develop and manage salmon research, stock assessment, and TEK studies in south central and western Alaska. He has been involved in salmon research since the mid-1990s, and holds a B.A. in Biology from Oberlin College and an M.S. in Natural Resources (fisheries emphasis) from Cornell University.

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Table 1**.** Population of communities in the Nome Census Area.[a]

Location	1990	1997	Annual Average Growth Rate
Brevig Mission city	198	261	4.0%
Council	8	0	
Elim city	264	291	1.4%
Golovin city	127	152	2.6%
Koyuk city	231	272	2.4%
Nome city	3,500	3,595	0.4%
Port Clarence CDP	26	24	-1.2%
St. Michael city	295	341	2.1%
Shaktoolik city	178	226	3.5%
Solomon	6	0	
Stebbins city	400	513	3.6%
Teller city	232	265	1.9%
Unalakleet city	714	803	1.7%
White Mountain city	180	193	1.0%
Total for Norton Sound	6,359	6,936	1.3%
Nome Census Area [b]	8,288	9,178	1.5%

[a] *Source: Alaska Department of Labor, Research and Analysis Section. (Windisch-Cole 1998)*

[b] As defined by the US Census Bureau to include St. Lawrence Is, Diomede Is, Wales, and Shishmaref

Table 2. Fish and animals harvested for subsistence in Norton Sound, 1980-2001.

Salmon
- Chinook Salmon
- Chum Salmon
- Coho Salmon
- Pink Salmon
- Sockeye Salmon

Non-Salmon Fish
- Arctic Grayling
- Burbot
- Capelin
- Char
- Cisco, Bering
- Cod, Arctic
- Cod, Pacific
- Cod, Saffron
- Dolly Varden
- Flounder
- Halibut
- Herring, Pacific
- Northern Pike
- Sculpin
- Sheefish
- Smelt, Rainbow
- Whitefish, Broad
- Whitefish, Humpback
- Whitefish, Round
- Wolffish

Marine Invertebrates
- Clam sp.
- Crab, King
- Crab, Tanner
- Mussel sp.
- Sea Cucumber
- Seaweed and Kelp sp.
- Shrimp sp.
- Whelk

Large Land Mammals
- Brown Bear
- Caribou
- Moose
- Muskox
- Reindeer - Feral
- Wolf
- Wolverine

Small Land Mammals
- Arctic Ground Squirrel
- Beaver
- Fox, Arctic
- Fox, Red
- Hare, Arctic
- Hare, Snowshoe
- Land Otter
- Lynx
- Marmot
- Marten
- Mink
- Muskrat
- Porcupine
- Weasel

Marine Mammals
- Polar Bear
- Porpoise, Harbor
- Seal, Bearded
- Seal, Spotted
- Seal, Ribbon
- Seal, Ringed
- Steller Sea Lion
- Walrus
- Whale, Belukha
- Whale, Bowhead
- Whale, Gray

Resident Birds
- Grouse, Spruce
- Owl, Snowy
- Ptarmigan, Rock
- Ptarmigan, Willow

Migratory Birds (and eggs)
- Crane, Sandhill

Ducks
- American Wigeon
- Bufflehead
- Canvasback
- Eider, Common
- Eider, King
- Eider, Spectacled
- Eider, Steller
- Goldeneye, Common
- Harlequin
- Long-tailed Duck
- Mallard
- Merganser, Common
- Merganser, Red-Breasted
- Northern Pintail
- Northern Shoveler
- Scaup, Greater
- Scaup, Lesser
- Scoter, Black
- Scoter, Surf
- Scoter, White-winged
- Wigeon
- Teal, Green-Winged

Geese
- Brant
- Canada Geese
- Emperor Geese
- Snow Geese
- White-fronted Geese

Seabirds & Loons
- Auklet, Crested
- Auklet, Least
- Auklet, Parakeet
- Cormorant, Pelagic
- Guillemots
- Gull, Glaucous
- Gull, Glaucous-Winged
- Gull, Herring
- Gull, Mew
- Gull, Sabines
- Loon, Arctic
- Loon, Common
- Loon, Red-Throated
- Loon, Yellow-Billed
- Murre, Common
- Murre, Thick-Billed
- Puffin, Horned
- Puffin, Tufted

Shorebirds
- Arctic Tern
- Black Legged Kittiwake
- Common Snipe
- Plover

Swan, Tundra

SOURCES: Alaska Department of Fish and Game, Community Profile Database, Alaska Fisheries Database.

Table 3. Employers with 25 or more employees in the Nome Census Area.[a]

1997 Rank		Location/ Headquarters	Annual Average Employment
1	Bering Strait School District	Unalakleet	473
2	Norton Sound Health Corporation	Nome	412
3	Kawerak Inc.	Nome	156
4	Nome Public Schools	Nome	125
5	Alaska Gold Company	Nome	68
6	Ryan Air Service	Nome	63
7	Stebbins City Council	Stebbins	55
8	City of Nome	Nome	51
9	Bering Straits Regional Housing Authority	Nome	45
10	Nome Joint Utilities	Nome	45
11	Alaska Commercial Company	Nome	44
12	Alaska Department of Corrections	Nome	42
13	Alaska Department of Transportation and Public Facilities	Nome	41
14	MJW Inc. (Board of Trade Saloon)	Nome	41
15	Olson Air Service Inc.	Nome	39
16	Shishmaref IRA	Shishmaref	39
17	Bering Air Incorporated	Nome	37
18	Cape Smythe Air Service Inc.	Nome	34
19	City of Teller	Teller	30
20	Gambell Common Council	Gambell	27
21	Nome Nugget Inn	Nome	27
22	University of Alaska Fairbanks	Nome	27
23	Golovin Fire Department Bingo Account	Golovin	26
24	City of Brevig Mission Brevig	Mission	25
25	City of St. Michael St.	Michael	25
26	Alaska Airlines Inc.	Nome	25

[a] Source: Alaska Department of Labor, Research and Analysis Section (Windisch-Cole 1998).

[b] Note: Firms with identical employment ranked by unrounded employment.

Table 4. Value of fisheries in the Norton Sound District, 1962 - 2000.[a]

	Gross Value of Catch to Fishers		
Year	Salmon	Red King Crab	Herring
1962	$105,800.00		
1963	$104,000.00		
1964	$51,000.00		
1965	$21,483.00		
1966	$68,000.00		
1967	$44,038.00		
1968	$63,700.00		
1969	$95,297.00		
1970	$99,019.00		
1971	$101,000.00		
1972	$102,225.00		
1973	$308,740.00		
1974	$437,127.00		
1975	$413,255.00		
1976	$285,283.00		
1977	$528,610.00	$229,000	
1978	$814,221.00	$1,897,000	
1979	$876,547.00	$1,878,000	
1980	$583,388.00	$890,000	$500,000
1981	$758,471.00	$1,172,000	$1,500,000
1982	$988,588.00	$405,000	$1,000,000
1983	$1,038,967.00	$537,000	$1,400,000
1984	$721,055.00	$395,000	$900,000
1985	$822,056.00	$427,000	$1,400,000
1986	$539,576.00	$600,000	$2,900,000
1987	$504,631.00	$491,000	$2,600,000
1988	$754,751.00	[a]	$3,900,000
1989	$274,817.00	$739,000	$2,300,000
1990	$497,623.00	[b]	$3,600,000
1991	$425,430.00	[c]	$2,400,000
1992	$448,395.00	$130,000	[c]
1993	$322,117.00	$430,000	$1,500,000
1994	$864,882.00	$646,000	$300,000
1995	$356,912.00	$926,000	$4,200,000
1996	$340,347.00	$519,000	$4,500,000
1997	$363,907.48	$184,000	$600,000
1998	$358,982.00	$41,000	$200,000
1999	$76,860.00	$73,000	$600,000
2000	$149,907.00	$715,000	$800,000

[a] Source: Brennan et al. 2002

[b] Information not available.

[c] No fishery conducted.

Table 5. Subsistence harvest by fisheries in the Norton Sound District, 1963 - 2000.[a]

	Subsistence Harvest (Number of Individuals)	
Year	Salmon	Red King Crab
1963	34,365	[b]
1964	24,843	[b]
1965	55,289	[b]
1966	38,687	[b]
1967	42,279	[b]
1968	51,201	[b]
1969	36,804	[b]
1970	54,126	[b]
1971	37,801	[b]
1972	31,247	[b]
1973	22,867	[b]
1974	21,868	[b]
1975	24,305	[b]
1976	26,973	[b]
1977	44,279	[b]
1978	51,730	12,506
1979	46,456	224
1980	93,422	213
1981	77,082 [c]	360
1982	88,460 [c]	1,288
1983	- [d]	10,432
1984	- [d]	11,220
1985	- [d]	8,377
1986	- [d]	7,052
1987	- [d]	5,772
1988	- [d]	2,724
1989	- [d]	6,126
1990	- [d]	12,152
1991	- [d]	7,366
1992	- [d]	11,736
1993	- [d]	1,097
1994	126,745 [c,e]	4,113
1995	113,611 [c,e]	4,059
1996	134,050 [c,e]	1,679
1997	81,370 [c,e,f]	745
1998	100,480 [c,e,f]	8,622
1999	61,078 [c,e]	7,533
2000	77,485 [c,e]	5,723

[a] Source: Brennan et al. 2002
[b] Information not available.
[c] These figures also include subsistence estimates data from Stebbins and St. Michael.
[d] Subsistence surveys not conducted.
[e] Subsistence harvest estimate from Div. of Subsistence survey.
[f] Subsistence totals include Savoonga and Gamble.

Table 6. Commercial catch by fisheries in the Norton Sound District, 1961 - 2000.[a]

	Commercial Catch		
	Salmon	Red King Crab	Herring
Year	Number	Pounds	Pounds
1961	101,801		
1962	232,431		
1963	233,863		
1964	164,671		
1965	40,524		
1966	100,345		
1967	74,818		
1968	124,409		
1969	178,972		
1970	178,218		
1971	141,977		
1972	149,494		
1973	176,797		
1974	315,829		
1975	251,861		
1976	193,063		
1977	257,325	520,000	
1978	531,948	2,090,000	
1979	350,401	2,930,000	2,586,000
1980	444,337	1,190,000	4,904,000
1981	441,734	1,380,000	8,742,000
1982	511,208	230,000	7,866,000
1983	456,420	370,000	9,164,000
1984	342,159	390,000	7,144,000
1985	180,200	430,000	7,096,000
1986	230,400	480,000	10,388,000
1987	136,283	330,000	8,164,000
1988	225,132	[a]	9,344,000
1989	92,811	250,000	9,482,000
1990	131,665	[b]	12,758,000
1991	156,789	[c]	11,344,000
1992	199,933	70,000	c
1993	263,670	330,000	10,068,400
1994	1,108,184	320,000	1,920,400
1995	181,392	320,000	13,524,400
1996	571,241	220,000	12,340,000
1997	79,141	90,000	7,952,000
1998	641,396	30,000	5,247,200
1999	23,051	20,000	5,492,000
2000	217,873	[b]	8,942,800

[a] Source: Brennan et al. 2002
[b] Information not available.
[c] No fishery conducted.

Table 7. Biological escapement goals for Norton Sound chum salmon stocks.

Salmon Stock	BEG Range	Report Reference
Kwiniuk River Chum Salmon	10,000–20,000	Clark 2001a
Tubutulik River Chum Salmon	8,000–16,000	Clark 2001a
Norton Sound Subdistrict One Chum Salmon	23,000–35,000	Clark 2001b
Sinuk River Chum Salmon	4,000–6,200	Clark 2001b
Nome River Chum Salmon	2,900–4,300	Clark 2001b
Bonanza River Chum Salmon	2,300–3,400	Clark 2001b
Snake River Chum Salmon	1,600–2,500	Clark 2001b
Solomon River Chum Salmon	1,100–1,600	Clark 2001b
Flambeau River Chum Salmon	4,100–6,300	Clark 2001b
Eldorado River Chum Salmon	6,000–9,200	Clark 2001b

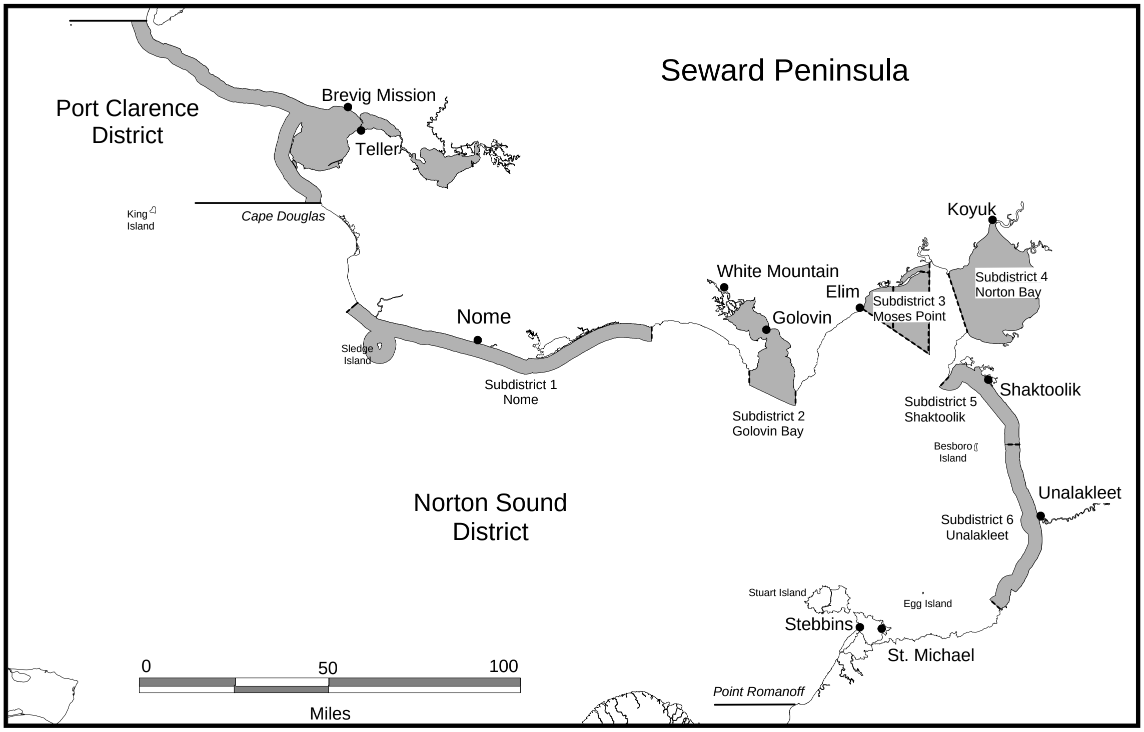


Figure 1. The commercial salmon fishing districts and subdistricts of Norton Sound and Port Clarence.

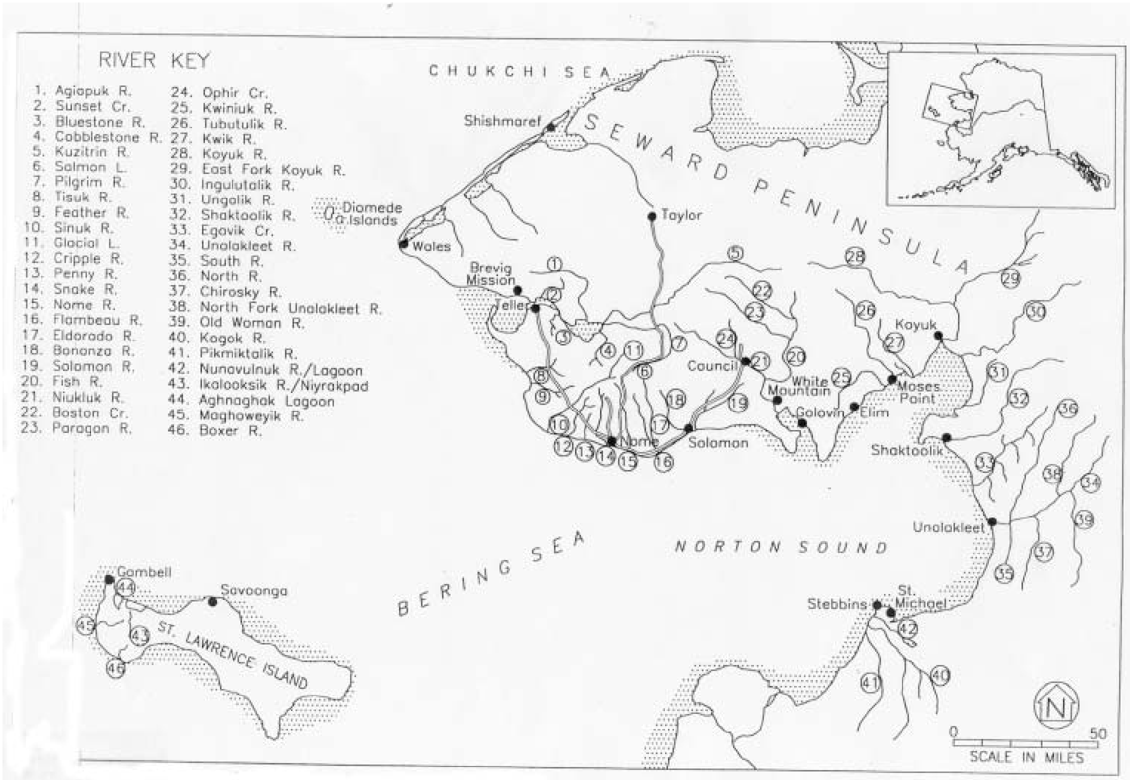
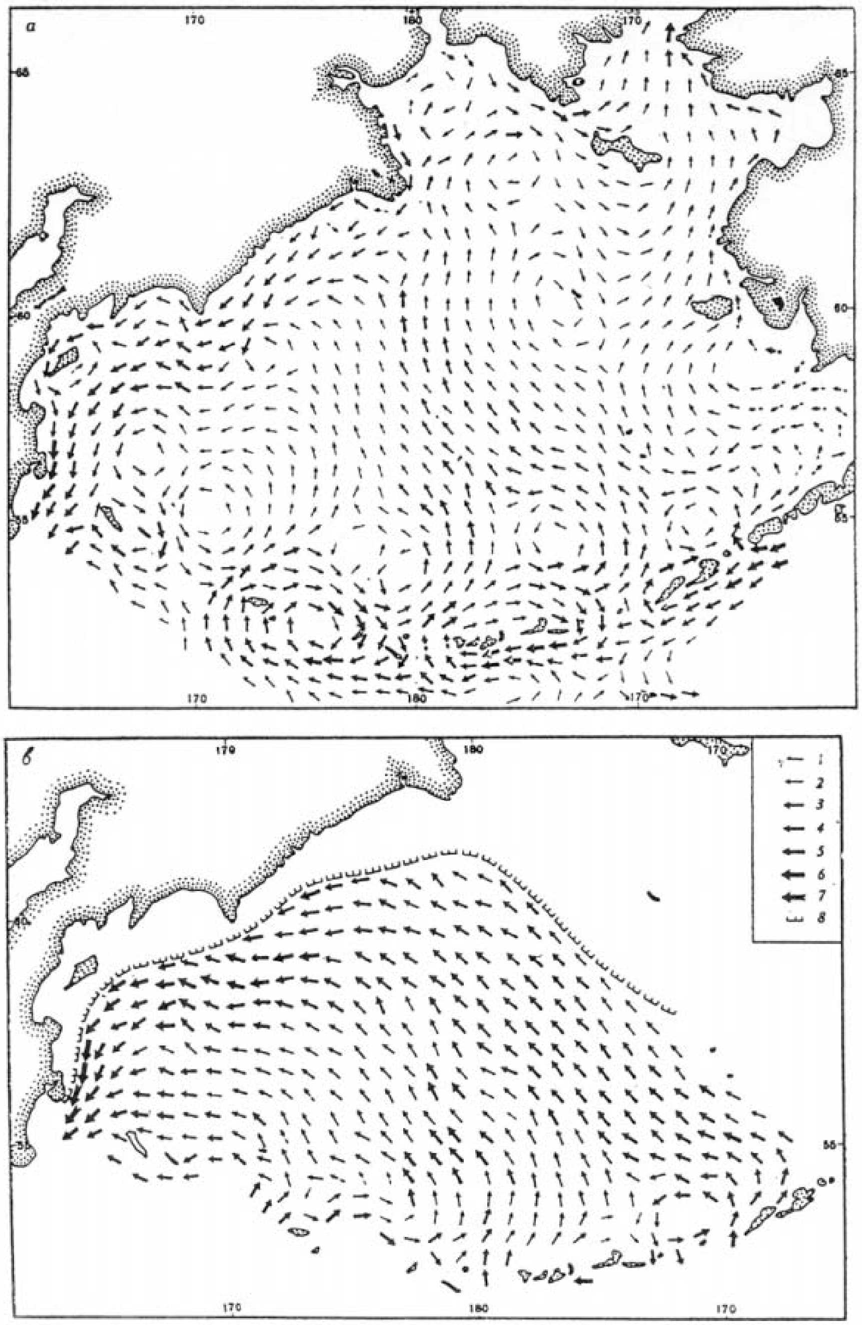


Figure 2. River systems with salmon in the Norton Sound District and surrounding areas, from Rue (1996).



Resulting currents at the surface. ***Above:*** *Summer;* ***Below:*** *winter. Current speed (cm / sec): 1 is less than 1; 2 is from 1 to 5; 3 is from 5 to 10; 4 is from 10 to 20; 5 is from 20 to 35; 6 is from 35 to 50; 7 is more than 50.*

Figure 3. General water current patterns and velocities in the Bering Sea and its subregions. Figure take from Mathison and Coyle 1996 (Figure 5.12).

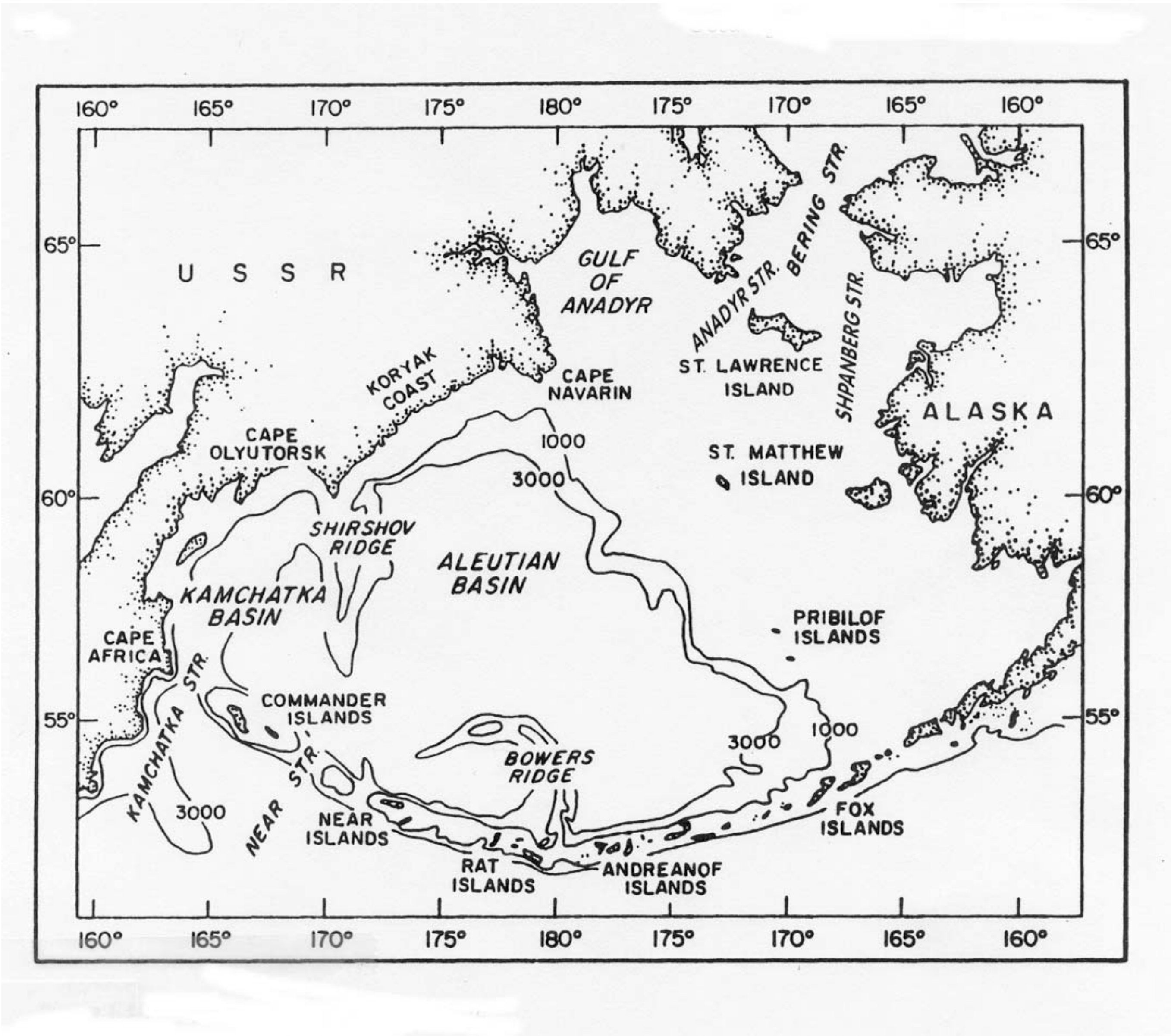


Figure 4. Bathymetric map of the Bering Sea. Figure taken from Mathison and Coyle 1996 (Figure 1.1).

Appendix 1. Historic and current salmon projects in the Norton Sound Area. An asterisk (*) denotes a project funded by the Norton Sound Disaster grant in 2001 or 2002.

Project Name (current or last used)	Years of Operation	Main Agency[2]	Project Reports (RIR or Other)[a]
Harvests			
Commercial Catch and Effort Assessment			
Norton Sound	61-current	ADFG/CF	3A01-22 *3A01-05*
Commercial ASL Sampling			
Unalakleet Commercial Sampling (ASL)	62-63,67-current	ADFG/CF	3A01-22 *3A01-05*
Shaktoolik Commercial Sampling (ASL)	86,89-91,94,96,98,	ADFG/CF	3A99-31
Moses Point Commercial Sampling (ASL)	62-63,67-69,75,77-78,82-83,85-91	ADFG/CF	TRF 89-13 *3A92-13*
Golovin Commercial Sampling (ASL)	63,85-86	ADFG/CF	TRF 89-09
Nome Commercial Sampling (ASL)	78,80	ADFG/CF	AWL Rpt. #16
Subsistence Harvests			
Catch and Effort Assessment	63-82,94-current	ADFG/S	3A01-22. *3A01-05*
Sport Fish Catch and Effort Assessment		ADFG/SF	
Escapement[1]			
* Kwiniuk River Tower	65-current	ADFG/CF	3A01-17
* Niukluk River Tower	79,95-current	ADFG/CF	3A01-28
* Eldorado River Tower	95-current	ADFG/CF	3A01-14
Nome River Tower	93-95	ADFG/CF	3A95-35
* Nome River Weir	96-current	ADFG/CF	3A01-21
* Snake River Tower	95-current	ADFG/CF	3A01-19
Glacial Lake Weir	2000-current	US - BLM	
Pilgrim River Tower	97 – 2000	KC, ADFG/CF	3A01-23
* North River Tower	72-74,84-86,96-current	KC, ADFG/CF	3A01-18
Shaktoolik River Tower	90,96-98	ADFG/CF	3A98-09
Chirosky River Tower	75-76	ADFG/CF	
Pikmiktalik Tower	92	ADFG/CF	
Nunakogak Tower	92	ADFG/CF	
Tubutulik River Tower	80	ADFG/CF	NS/Kot SaEsc Report 23
Kachauvik River Tower	77	ADFG/CF	
Unalakleet Sonar	82-83	ADFG/CF	NS/Kot SaEsc Report 36
Aerial Surveys	58-current	ADFG/CF	3A01-22 *3A01-05*

Appendix 1. Continued (Page 2 of 3).

Project Name (current or last used)	Years of Operation	Main Agency[b]	Project Reports (RIR or Other)[a]
Test Fishing			
Unalakleet TF	81-current	ADFG/CF	3A01-32
Population Estimates			
Tagging-			
Unalakleet Chinook and Chum	72-75,78-79,98-99	ADFG/CF	AYK Region Stock Sep. Report 7
Shaktoolik Chinook and Chum	79	ADFG/CF	AYK Region Stock Sep. Report 7
Nome Subdistrict Chum	78-79	ADFG/CF	AYK Region Stock Sep. Report 7
* Fish River radiotelemetry , chum salmon	2002	ADFG/CF	In preparation
Tagging (salmon subsequently caught in Norton Sound)			
Area M	1960, 1987	ADFG/CF	FRB 91-01
Hooper Bay	1985	BSF	Kerkvliet 1986 [c]
Smolt Enumeration			
Smolt Enumeration-Pilgrim River	97-current	ADFG/CF	In preparation
Stock Identification			
Genetic Collections (GSI) [d]			
Area M study- Chum Salmon	93-96	ADFG/CF	Crane and Seeb 2000; Seeb and Crane 1999a; Seeb et al 1997
Chinook, Unalakleet River	92, 93	ADFG/CF	Crane et al. 1996
Chum, Norton Sound and NS rivers	91-96	ADFG/CF	Seeb and Crane 1999b
Pink, Norton Sound, NS rivers	91, 94	ADFG/CF	Olsen et al. 1998
Sockeye, Salmon Lake	2001	ADFG/CF	In preparation
Scale Patterns Analysis (SPA)			
Norton Sound Chum	78	ADFG/CF	
Enhancement			
Incubation Boxes			
Hobson Creek, Nome River	91-98, 2000	ADFG/CF	
Boulder Creek, Snake River	91-98	ADFG/CF	
Kwiniuk River	98-current	ADFG/CF	
Coral Creek	98-current	ADFG/CF	
Anvil Creek Ponds Snake River	98-current	ADFG/CF	
Salmon Lake (enhancement monitoring)	97-current	ADFG/CF	
Shovel Creek Solomon River	95-98	ADFG/CF	
Eldorado River	??	ADFG/CF	
Sinuk River	98	ADFG/CF	

Appendix 1. Continued (Page 3 of 3).

Project Name (Current or last used)	Years of Operation	Main Agency[b]	Project Reports (RIR or Other)[a]
Lake Fertilization			
Salmon Lake	97-2001	ADFG/CF	2A01-16 *5J96-02*
Eight Norton Sound Rivers	mid-90's	ADFG/CF	
Incubation Facilities			
Hobsen Creek Recirculating Incubation	99-2000	ADFG/CF	
Special Projects			
Coho Hooking Mortality Study	2001	ADFG/SF	In preparation
* Weir site investigation for 10 NS rivers	2001-2002	ADFG/CF	3A01-33
Norton Sound Environmental Monitoring	2002	Kawerak	
Habitat capability production models for coho salmon in Norton Sound	2002	NSEDC/LGL	In preparation
Fecundity sampling of chum and coho	2002	NSEDC/LGL	In preparation
Shorline movements and early life history of juvenile salmon in Norton Sound	2002	NSEDC/LGL	In preparation
Survival rates of chum salmon eggs in spawning grounds, and artificial incubators in Norton Sound	2002	NSEDC/LGL	In preparation
Norton Sound salmon information database	2002	ADFG/CF	

[a] Secondary sources for information on a project are in *italics*.
Regional Information Reports (RIR) for the AYK Region (3) begin as 3AYY-## and are available at the ADF&G Anchorage and the ARLS Library.
Technical Fishery Report (TFR) series are available at ARLS and ADF&G Juneau Libraries.
The Fishery Research Bulletin (FRB) series and RIRs 5JYY- are available at ARLS and ADF&G Juneau Libraries.
All other reports except where noted as non-departmental reports are in the precursor series to the RIR and available at ADF&G, Anchorage.

[b] Agency abbreviations:

ADFG/CF=	Commercial Fisheries Division	USFWS =	U.S. Fish and Wildlife Service
ADFG/SF =	Sport Fish Division	BSFA =	Bering Sea Fishermen's Association
ADFG/S =	Subsistence Division	KC =	Kawerak Corporation
NSEDC=	Norton Sound Economic Development Corporation		
LGL=	LGL Limited Environmental Research Associates		

[c] Non-department reference:
Kerkvliet, C.M. 1986. 1986 Hooper Bay salmon tagging study. Bering Sea Fisherman's Association, Anchorage.

[d] Genetic References:
Crane, P.A., W.D. Templin, and L.W. Seeb. 1996. Genetic stock identification of Alaska chinook salmon. Regional Information Report No. 5J96-17, Alaska Department of Fish and Game, Anchorage, Alaska.

Crane, P. A. and L. W. Seeb. 2000. Genetic analysis of chum salmon harvested in the South Peninsula, post June

fishery, 1996-1997. Regional Information Report No. 5J00-05, Alaska Department of Fish and Game, Anchorage, Alaska.

Olsen, J. B., L. W. Seeb, P. Bentzen, and J. E. Seeb. 1998. Genetic interpretation of broad-scale microsatellite polymorphism in odd-year pink salmon. Transactions of the American Fisheries Society 127: 535-550

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