RISING LAND FALLING FISHERY: THE EFFECTS OF ISOSTATIC REBOUND AND RAPID SUCCESSION ON EAST ALSEK RIVER SOCKEYE SALMON

By

Derrek Marshall Faber

RECOMMENDED:

Chad Soiseth

William Smoker

Milo Adkison, Advisory Committee Chair

William Smoker, Fisheries Division

APPROVED:

Dean, School of Fisheries and Ocean Sciences

Dean of the Graduate School

Apr 3, 2008

Date

RISING LAND FALLING FISHERY: THE EFFECTS OF ISOSTATIC REBOUND AND RAPID SUCCESSION ON EAST ALSEK RIVER SOCKEYE SALMON

A

THESIS

Presented to the Faculty

Of the University of Alaska Fairbanks

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Derrek M. Faber, B.S.

Fairbanks, Alaska

May, 2008

Abstract

This thesis includes research conducted in the Dry Bay Preserve of Glacier Bay National Park in 2005 and 2006 for the U.S. National Park Service. The research mission was to determine the cause of collapse in the East Alsek commercial sockeye fishery. The focus of the study was to determine if the collapse was due to human caused events or if there was a broader ecological basis for the recent downturn in returning sockeye. The East Alsek had undergone a dramatic decline in returning sockeye in recent years and the changing quality and quantity of habitat was thought to be the culprit for this downturn. However, fishery records and other environmental variables were also examined in order to establish a retrospective association between reduced production, ambient environmental conditions, and commercial fishing. The research for this thesis was funded by the U.S. National Park Service under the request of the City and Borough of Yakutat.

Table of Contents

List of Appendices

List of Figures

List of Tables

List of Equations

Acknowledgements

The funding for this research was provided by the U.S. National Park Service. The research depended on the bright minds and strong-backs of many volunteers and dedicated individuals. I would particularly like to thank Craig Murdoch, of the National Park Service for his help in collecting the data used for this study, and for living with me for two summers in a 12 x 12 cabin. That's dedication. Thanks to the volunteers that helped with field-work including Jennifer Wardell (my wife), Jessica Bliss, and Mike Garvin. Thank you Jennifer for letting me indulge my dream of living in the Alaska wilderness for two summers, and joining me for months on end conducting research and eating sockeye. Many professionals also aided in the research and support, particularly my coauthors and committee members, Chad Soiseth (NPS), Milo Adkison (UAF), and William Smoker (UAF). In addition Ranger Jim Capra (NPS), Ranger Wendy Bredow (NPS), Jim Bales (NPS), Rusty Yerxa (NPS), Susan Boudreau (NPS), Lewis Sharman (NPS), Chuck Schroth (Fjord Flying), Les Hartley (Alsek Air), Chris Larsen (UAF), and Erin Hood (UAS), Brittany Gonzales (UAS) and Gordon Haas (UAF). I would also like to thank Alaska Department of Fish and Game for their responsive assistance, and helpfulness, including: Iris Frank (ADFG – Douglas), Gordon Woods (Yakutat), Rhonda Capra (Yakutat), Andy McGregor (Juneau) and John Clark (Juneau). Also, the residents of Dry Bay were kind hosts, including Harold Flowers, Vern Schumacher, Jeff Lowenstein, and The Robbins Family. Thanks also to my Dad, Marsh Faber for offering fishing support as well as his masterful editing. Finally, my heartfelt praise goes to the Brown Bears of Dry Bay; thanks for staying on your side of the stream.

General Introduction

In 2000, the City and Burough of Yakutat, AK passed a resolution to determine the cause of collapse of the East Alsek sockeye salmon fishery due to its "cultural, sociological and economic impact" on local residents (CBY 2000). In the late 1980's and early 1990's, the price of sockeye reached a high of $3.08/lb, and run size of East Alsek sockeye peaked above 275,000 (Figure 0.1. Harvest and escapement record for the East Alsek set-gillnet fishery (Clark et al. 2003). The fishery was a substantial income source for Yakutat residents, and supported as many as 110 fishermen. This terminal set-gillnet fishery was

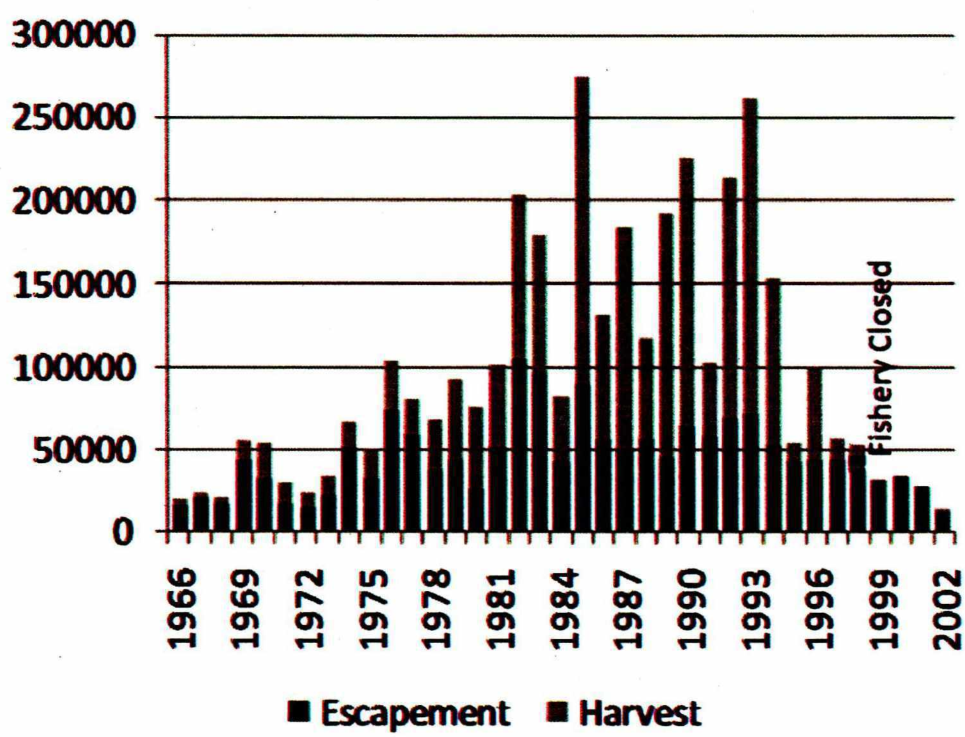

Figure 0.1. Harvest and escapement record for the East Alsek set-gillnet fishery (Clark et al. 2003).

closed in 1999 when it failed to meet escapement goals set by the Alaska Department of Fish and Game (ADFG). Escapement levels were initially set between 26,000 and 57,000 spawning sockeye surveyed through aerial counts (Clark et al. 1995). The sockeye fishery was reopened in 2003 after ADFG revised their escapement goal to a range between 13,000 and 26,000 spawners following a stock recruitment assessment (Clark et al. 2003). Since the reopening, the fishery has supported a modest number of commercial fishermen who have harvested a combined average of 27,000 sockeye per year, far below the peak harvests experienced in the past. This thesis and subsequent research was funded by the National Park Service, stemming from the Yakutat resolution.

Hypothesized causes for the fishery's collapse have been provided by several ADFG biologists. Clark et al. (2003) suggested the paucity of recent returns was due to progressive sedimentation and subsequent colonization by aquatic vegetation atop previously accessible spawning substrate. This effect was thought to have reduced the available spawning substrate, resulting in diminished production of sockeye. The report also suggested that periodic flooding of the East Alsek by the adjacent Alsek River and concomitant silt removal on the East Alsek River through flood scouring might have contributed to high sockeye recruitment and productivity in the 1980's and early 1990's. In contrast, subsequent lack of flooding since 1987 has led to increased sedimentation, reducing spawning substrate quantity and quality, and thereby reducing recruitment. However, substantive ecological and biological evidence to support this hypothesis was limited. A thorough investigation was needed to establish if this hypothesis of reduced flood frequency was indeed valid, or if the reduction in recruitment was due to other factors.

Large-scale geologic, climactic and successional changes have been occurring in the immediate vicinity of the East Alsek River and within the Dry Bay Preserve of Glacier Bay National Park in a brief time period (100 years). These changes have likely influenced the geomorphology and hydrodynamics of the East Alsek, thereby impacting this sockeye population. Glacial rebound, a geologic phenomenon of land 'uplift' due to glacial recession, is reportedly occurring at a rate of 26 mm/year, as recorded at a fixed monitoring sites in close proximity of the East Alsek River (Larsen et al. 2005). Such high uplift has likely contributed to rapid plant community succession on the former glacial outwash plain of Dry Bay by changing the access plants have to groundwater, and the rapid establishment of topsoil. Also, the Alsek and Grand Plateau Glaciers are receding at a rapid rate resulting in a thirteen-fold increase (4,070,813 m^2 in 1906 to 55,314,322 m^2 in 2000) in the size of Alsek Lake. This process acts to reduce sediment deposition downstream of the lake, and also attenuates any flood that originates upstream of the lake. Also, incision of the Alsek channel downstream of the lake may have an impact on the required flood volume necessary to overtop the existing East Alsek flood channel, and eventually flow down the East Alsek River (Ed Neal, USGS hydrologist, personal communication). The location and elevation of the East Alsek headwaters in relation to the Alsek River channel and stage height is an important feature relating to flood frequency.

The combined effects of uplift and lake expansion can influence flow and flooding downstream of Alsek Lake, and may also reduce the frequency of overflow of the Alsek into the East Alsek. The East Alsek River, which originated as a relictual channel of the Alsek, is located within 3 km of the Alsek River. Emanating from groundwater sources, the East Alsek is a low gradient (<1% slope) river that flows from north to south. It is located within the Dry Bay Preserve of Glacier Bay National Park. Historic maps indicate the headwaters of the East Alsek were first separated from the Alsek River sometime between 1906 and 1948. The river meanders 9 km through the relict glacial outwash plain of the Alsek and Grand Plateau Glaciers and empties into an estuarine lagoon fed by the East Alsek and Doame Rivers as well as numerous smaller creeks. Each of these drainages is a former distributary channel of the Alsek River. The East Alsek bisects the estuary orthogonally. The estuary runs from the mouth of the Doame River to the Gulf of Alaska from east to west and is separated from the open ocean by a vegetated dune. The estuary eventually empties into the Gulf of Alaska 10 km east of the mouth of the East Alsek.

Uplift, channel incision, reduced flood frequency and other large scale physical phenomena have had ecological ramifications within the Dry Bay Preserve. Rapid terrestrial plant succession, evident from aerial photography series since 1948, has occurred ever since the East Alsek and Alsek River channels diverged. Bank-side vegetation along the East Alsek has progressed beyond the barren gravel and sand observed and mapped in 1906-1908 (Morse 1908) and now consists of primarily deciduous shrubs and trees, including cottonwood (*Populus spp.)*, willow (*Salix spp.*) and alder (*Alnus spp.*).

The annual leaf-litter generated by these plants contributes to organic matter, and subsequent sediment development and deposition in the East Alsek River. Leaf-litter decays and is processed by aquatic insects, fungus and bacteria to form rich organic sediment. Generated sediment loads can accumulate on spawning gravels if flow is sufficiently low (Cummins et al. 1989) and floods are infrequent. Accumulated sediments contribute to the colonization and establishment of aquatic vegetation by providing a basis for root growth (Wood 1997). Aquatic plants such as white water crowfoot (*Ranunculus aquatilis),* mare's tail (*Hippuris vulgaris)* and at least two mosses (*Cratoneuron filicinum* and *Drepanocladus aduncu*) have become abundant and well-established in the East Alsek River. These aquatic plants also contribute annual inputs of organic material as the plants senescence in the fall. Once aquatic vegetation becomes established in the river, it provides a positive feedback loop between sedimentation and plant growth by slowing existing flows and trapping water borne sediments. Similar feedback loops have been identified in other rivers (Carpenter and Lodge 1986; Dawson 1978; Welton 1980).

The combination of annual inputs of terrestrial leaf-litter, aquatic vegetation growth and senescence, and input of marine-derived nutrients from salmon carcasses are potential sources of fine sediment in the East Alsek. The lack of flood scouring effects to displace both sediment and aquatic plants could thereby influence sockeye production by reducing spawning habitat quantity and quality. More directly, the potential exists for post-spawning, fine sediment deposition to cause high egg and embryo mortality.

Although these various components comprise a relatively complex hypothesis for declining sockeye productivity, there are many more variables that could also have deleterious and synergistic effects. These needed to be studied as well. Region-wide covariation of sockeye salmon recruitment has been observed and linked to regional environmental fluctuations (Peterman et al. 1998), processes which include regional variability in precipitation and air temperature. Early salmonid life history stages have shown particular susceptibility to related oxygen and temperature fluctuations in aquatic habitats (Beacham and Murray 1990, Ringler and Hall 1975) that are physically driven by these processes. Therefore it was necessary to identify and evaluate the life-stages most sensitive to environmental variables such as precipitation and temperature to assess if these factors played a role in the decline of the East Alsek fishery. Lastly, the marine life stage was investigated through a surrogate of condition (growth). The influence of the marine environment on salmon production has been attributed to decadal-scale shifts in productivity and regional sea-surface temperatures (Mueter et al.

2002), necessitating a prolonged time scale to determine the effect of change for a particular population of salmon. Therefore patterns in adult scale-growth were assessed to determine if a relationship existed between survival and first-year marine growth.

In summary, in order to incorporate all these disparate variables into one manageable study, the following four research objectives were addressed: 1) quantify selected sockeye spawning habitat in the East Alsek River relative to sediment deposition and aquatic vegetation, 2) document early (juvenile) life-history attributes of sockeye in freshwater, 3) model the effect of flood patterns in relation to subsequent sockeye recruitment, and 4) model freshwater and marine environmental variables with respect to recruitment. The first chapter addresses the use of habitat by spawning sockeye, and the second chapter examines the population dynamics of East Alsek sockeye in relation to environmental conditions and flooding of the East Alsek by the Alsek River. Finally, Appendix 2 reports the findings on the relationship between scale growth and production of East Alsek sockeye.

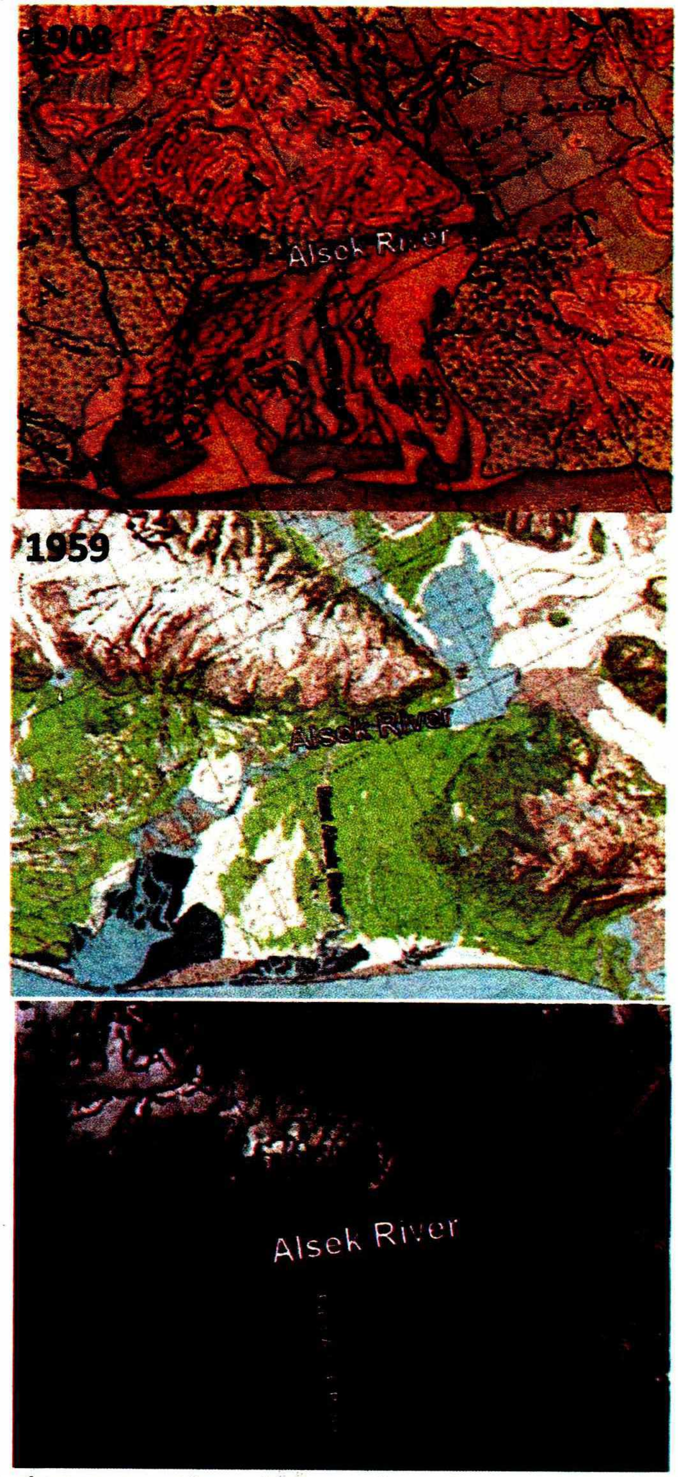

Figure 0.2. Dry bay change over time. Imagery from Morse 1908, USGS 1959, and NASA (Google Earth) 2000. Notice change in Alsek Lake area (from 4,070,813 m^2 in 1906 to 55,314,322 m^2 in 2000) and channelization of Alsek.

Literature Cited

Beacham, T D, and Murray, C B (1990). Temperature, Egg Size, and Development of Embryos and Alevins of Five Species of Pacific Salmon: A Comparative Analysis. *Transactions of the American Fisheries Society*, *119* (6), 927–945.

Carpenter, S R, and Lodge, D M (1986). Effects of submerged macrophytes on ecosystem processes. *Aquatic Botany*, *26*, 341–370.

City and Borough of Yakutat (CBY). (2000, 01 10). Resolution 99-23. City and Borough of Yakutat.

Clark, JH, Burkholder, A, and Clark, JE (1995). Biological escapement goals for five sockeye salmon stocks returning to streams in the Yakutat area of Alaska. Regional Information Report No. 1J95-16. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Douglas, AK 56 pp.

Clark, J H, Woods, GF, and Fleischman, S(2003). *Revised biological escapement goal for the sockeye salmon stock returning to the East Alsek-Doame River system of Yakutat, Alaska.* Alaska Department of Fish and Game, Division of Sport Fish. Special Publication No. 03-04..

Cummins, K W, Wilzbach, M A, Gates, D M, Perry, J B, and Taliaferro, W B (1989). Shredders and riparian vegetation. *Bioscience*, *39*, 24-30.

Dawson, F H (1978). The seasonal effects of aquatic plant growth on the flow of water in a stream. *Proceedings European Weed Research Society 5th symposium on aquatic weeds*, (pp. 71–78). Amsterdam, Netherlands.

Larsen, CF, Motyka, RJ, Freymueller, JT, Echelmeyer, KA, and Ivens, ER (2005) Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 23:548-560.

Morse, F (1908). International Boundary between United States and Canada, From Cape Muzon to Mount St. Elias. Sheet No. 12 [map]. . *Article VI of the convention of 1903. Convention between Great Britain and United States: Signed 1928.*

Mueter, F J, Peterman, R M, and Byper, B J (2002). Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (Oncorhynchus spp.) in northern and southern areas. *Journal of Fisheries and Aquatic Sciences*, *59* (3), 456-463.

NASA. (2007). Image, Alaska, United States, 2000 Satellite Imagery [map]. Eye Alt 11.7mi; generated Derrek Faber; using Google Earth. <http://www.googleearth.com/> (20 Feb. 2007).

Peterman, RM, BJ Pyper, MF Lapointe, MD Adkison, CJ Walters (1998). Patterns of covariation in survival rates of British Columbia and Alaskan sockeye salmon *(Oncorhynchus nerka)* stocks. *Canadian Journal of Fisheries and Aquatic Sciences* 55:2503-2517.

Ringler, N H, and Hall, J D (1975). Effects of Logging on Water Temperature, and Dissolved Oxygen in Spawning Beds. *Transactions of the American Fisheries Society, 104* (1), 111–12.

USGS. (1959). 1:63,000 Yakutat A-2 [map].

Welton, J S (1980). Dynamics of sediment and organic detritus in a small chalk stream. Archives fur Hydrobiologic. *Archives fur Hydrobiologic, 90,* 162-181.

Wood, P J (1997). Biological Effects of Fine Sediment in the Lotic Environment. *Environmental Management, 21* (2), 203-217.

Chapter 1

Spawning Habitat Loss for Ocean-type Sockeye Salmon due to Isostatic Rebound[1]

[1] Faber, DM, C M Soiseth, M Adkison, (2008) Spawning habitat loss for ocean-type sockeye salmon due to isostatic rebound[1]. Transactions of the American Fisheries Society. Vol. Xx (xx), xxx-xxx.

Abstract

We evaluated spawning density of returning sockeye salmon in relation to characteristics of habitat in the East Alsek River. The East Alsek had undergone a dramatic decline in returning sockeye in recent years and the changing quality and quantity of habitat was thought to be the cause for this downturn. Aquatic vegetation and thick sediment are prevalent atop apparently suitable spawning gravels throughout the river. The adjacent Alsek River had periodically flooded the East Alsek channel at least three times in the 1980's, with the last flood in 1987. It was thought that these floods had kept spawning habitat free of sediment and plants that could reduce available spawning habitat or survival of sockeye embryos. The periodicity of Alsek flooding events was likely decreasing due to localized isostatic rebound of 26mm per year. We conducted thorough habitat and spawner density surveys to test this hypothesized mechanism. We found that sockeye avoid spawning in areas with sediment depths greater than 10cm, and the majority of sockeye choose areas with less than 5cm. Sockeye avoided areas with a high coverage of aquatic vegetation, preferring areas with no vegetation. Sockeye preferred spawning in areas with dissolved oxygen concentrations and water temperatures that were lower than average, presumably due to the upwelling groundwater. Water velocity did not appear to affect where sockeye spawned, and sockeye chose shallower water to spawn. Correlations among flow, percent vegetation cover and sediment depth provided evidence of a positive feedback loop between the colonization of aquatic vegetation and sedimentation. In the absence

of large-scale flooding events, this would lead to increases in vegetation and sediment depth over time. Given that East Alsek sockeye were highly selective for spawning habitat with little sediment or vegetation, it is very likely that the rapid sedimentation atop suitable spawning habitat contributed to the reduced production observed.

Introduction

The East Alsek sockeye salmon fishery has shown a dramatic decline in recent years; numbers of sockeye returning to the system have plummeted from highs exceeding 275,000 sockeye in 1985 to a low of 14,200 in 2002. The rapid decline caused the closure of the commercial fishery in 1999. The reason for the rapid decline is unknown; however, area biologists surmised the East Alsek River could no longer sustain high productivity due to a localized hydraulic regime shift (Clark et al. 2003). It is thought the East Alsek is slowly accumulating sediment and aquatic vegetation atop once clean spawning gravels.

East Alsek sockeye are relative newcomers to the East Alsek River. The 1960's and 1970's saw modest returns of sockeye, comparable to today's numbers. The East Alsek once supported a thriving population of chum salmon (ADFG 1984; Heinl et al. 2003), that gave way to the high numbers of returning sockeye in the 1980's and early 1990's. The rapid colonization of the East Alsek River by highly valued sockeye was a boon to the local economy, but the sustainability of the run was now in question.

Historically, the East Alsek experienced periodic flooding events when the adjacent Alsek River overran its banks and spilled into the East Alsek River. The additional flow from the much larger Alsek (mean annual discharge of the Alsek 850 m^3/s; East Alsek 3-5 m^3/s) had the potential to flush sediment and vegetation downstream of spawning grounds and into the Gulf of Alaska, thereby improving existing substrate and exposing additional suitable spawning habitat for sockeye salmon. Similar sediment transport has been observed in other coastal salmon streams (Coats et al. 1985; Gottesfeld et al. 2005). Since 1987, no floods have been documented in the East Alsek River and area biologists have noticed an increase in aquatic vegetation and sediment. Flood frequency is likely diminishing due to local isostatic rebound rates of up to 26mm/year (Figure 1.1, Larsen et al. 2005). We examined spawning habitat selection by East Alsek Sockeye salmon in this rapidly changing environment to establish how the changes in sediment and aquatic vegetation might affect future sockeye returns.

Sedimentation has an important effect on the amount of aquatic vegetation in a lotic environment. Growth of aquatic vegetation can decrease flow velocity and flow patterns by increasing the bed roughness, allowing the further accumulation of sediments at the location of the aquatic vegetation (Carpenter and Lodge 1986; Dawson 1978; Welton 1980). This effect causes a feedback loop where vegetation causes sediments to be deposited and provides substrate for additional aquatic vegetation growth.

Sediment can also have detrimental effects on salmonid embryo survival (Lapointe et al. 2004; Sear 1993). Sediment that is allowed to settle on spawning gravels can entomb eggs and embryos, subjecting them to a low oxygen environment, thereby causing mortality through suffocation (Lisle 1989; Sowden and Powder 1985; Levasseur et al. 2006). Redds are constructed by salmonids so that their morphology allows intragravel flow to egg-pockets due to a pressure gradient that forms from the upstream to downstream direction (Wu 2000). Any interruption of this flow, such as by sediment infiltrating gravel upstream of the egg-pocket, can deprive the eggs of needed flow for oxygen and waste transfer (Lisle and Lewis 1992). However, areas with sufficient upwelling from groundwater may act to mitigate this effect by providing a source of interstitial flow independent of river flow. As a groundwater-fed system, the East Alsek is known to have upwelling sites, but their distribution and areal coverage relative to sockeye spawning habitat were unknown.

Sockeye salmon exhibit a diverse array of spawning strategies (Burgner 1991). Depending upon the population's particular life history, they can spawn in rivers, sloughs, flood-plains and along lake shorelines (Blair et al. 1993; Hendry and Quinn 1997; Lorenz and Eiler 1989; Hall and Wissmar 2004). Sockeye have been shown to spawn in upwelling and downwelling areas, in glacially turbid waters, or in areas that require wind-driven currents to oxygenate embryos (Burger et al. 1995; Lorenz and Eiler 1989; Leonetti 1997; Brannon 1987). Little was known about the population on the East Alsek, in part due to their own unique life history characteristics.

The sockeye of the East Alsek have a life history attribute unusual for sockeye. East Alsek juvenile sockeye forego the traditional one or two year rearing period in freshwater, instead migrating to sea soon after emergence (Clark et al. 2003). Little has been documented on habitat selection, spawning habitat physical attributes, or adaptive traits for this ocean-type life history. These unknowns were of particular interest for how this unique trait might influence East Alsek sockeye production and spawning behavior.

The purpose of this investigation was threefold: 1. To determine if sockeye from the East Alsek River spawn in vegetated or sediment-laden habitat that may possess other attributes favorable for egg survival, 2. To determine if reduced flooding is likely to result in an increase in sedimentation and the establishment of aquatic vegetation, and 3. To assess the capability of existing habitat to support production equivalent to historic large sockeye returns.

Methods

Study Site

The East Alsek River is located within the Dry Bay Preserve of Glacier Bay National Park, Alaska (Figure 1.2). The East Alsek River is approximately 9 km long from its headwaters to an estuarine lagoon. It is a low gradient (<1%), clear water river with vegetated banks. The river can be described as a series of large and comparatively deep pools separated by short stretches of shallow riffles. The pools varied in depth, but were generally deeper than 3 m (one pool > 5 m), and the riffles were typically less than 1m deep at the time of our survey. Flow is relatively low during the spring and summer and increases into the fall and winter, with a measured discharge at the mouth of the river ranging between 2.4 m^3/s to 6 m^3/s (measured from June, 2005 to September, 2006). The stream channel is well established, and has changed little since aerial photography conducted in 1948. Wood riparian vegetation along the banks in 2005-2006 generally consisted of Sitka spruce, willow, alder, and cottonwood that overhung the bank throughout the river.

Habitat designation

From July 17 to August 17, 2005, prior to the presence of spawning Pacific salmon, we delineated polygons that shared similar habitat characteristics in order to assess the use of various habitat types by spawning sockeye. Polygons were delineated by circumnavigating designated habitat using a hand-held Trimble GeoXT™ global positioning system (GPS, Figure 1.3) that recorded the user's position once every second and was generally accurate to within 1-2 m.

Each polygon consisted of an area where the substrate, water depth, presence and type of vegetation, as well as water velocity appeared fairly homogeneous (Figure 1.4), and where the boundaries could easily be identified for spawning surveys. We mapped a total of 54 polygons.

The habitat perimeter of each polygon was uploaded from the GPS into a Global Information System (GIS) database so that physical attributes could be calculated (such as area, location, and perimeter). Each polygon was then subsampled in order to quantify habitat characteristics. Quadrats measuring 0.9 m x 0.9 m were randomly selected along a predetermined zigzag transect within the bounds of each polygon using a gridded wire mesh panel (Figure 1.5). A surveyor achieved random quadrat placement by tossing the quadrat over his/her shoulder. We allocated quadrats among polygons in a size-dependent fashion, with a minimum of 10 and a maximum of 20. A total of 1217 quadrats were allocated among the 54 polygons. Within each quadrat, we measured water velocity (at 60% of depth), water depth, aquatic vegetation cover, plant height, substrate type, substrate composition, dissolved oxygen, specific conductivity, and temperature (Figure 1.5, precision in Table 1.1). All measurements requiring a visual estimate of percent allocation (e.g. vegetation cover percentage, small gravel percentage) were performed by the same researcher to prevent inter-observer variation.

Temperature, dissolved oxygen (DO), and specific conductivity were all recorded using a Yellow Springs Instrument (YSI) meter (Model 556 MPS Multi Probe System) at the level of the substrate. We calibrated the instrument's dissolved oxygen meter prior to each day's field collection, specific conductivity monthly and temperature prior to each year of field work. Water velocity measurements were only taken for 50% of the sample points to maximize efficiency. Mean water column velocity was estimated using a Pygmy™ or Price AA™ water velocity meter over a 50 second time period at 60% of the water depth (Bovee 1997). Water depth, plant height, and sediment depth were measured to the nearest cm at the four corners of the quadrat. Water depth was measured from the top of fine sediment to the water surface, sediment depth was measured from the top of fine sediment to the hard substrate below, and plant height was measured as the height of surrounding vegetation above the stream bottom relative to current flow conditions (Figure 1.5).

Substrate composition was quantified in a multi-step process. First, the relative percent composition of fine sediment or plant cover was recorded (Figure 1.5). If plants were established above the fine sediment, this superseded the sediment composition measurement. Second, the fine sediment and plants were removed from the underlying substrate by fanning the area with a canoe paddle so the underlying substrate composition could be evaluated as necessary. We then determined percent substrate composition of sand (1-2mm), small gravel (2-64mm), large gravel (64-128mm), cobble (128-256mm) and boulders (256mm+). Finally, if the underlying substrate was inaccessible due to an excessive amount of sediment or vegetation, then the composition was estimated by observing adjacent and more accessible substrate.

Mean values for each of the habitat measurements were calculated for each polygon for analysis purposes. To reduce substrate composition to one variable, the weighted mean for the gravel size was calculated using Equation 1.1. Each of the gravel sizes in the equation was the median value for the range of each category.

Spawning distribution and preferred spawning habitat surveys

We conducted in-stream spawning surveys in the fall of 2005 (Aug 27-Sep 1) and 2006 (Sep 7-Sep 15) to quantify the use of spawning habitat by sockeye salmon. The number of spawning sockeye, number of sockeye redds, and number of sockeye carcasses were counted in each polygon. Due to the prevalence of brown bear in the area, three observers served as stream surveyors to count spawning sockeye, redds and carcasses, and one served as boat operator and bear lookout.

Two inflatable rafts were tethered together to provide a stable observation platform so the three observers could stand and observe spawning sockeye. Observers wore polarized sunglasses to reduce surface glare. Surveys were typically conducted in an upstream to downstream direction except in larger pools where currents were not a factor affecting viewing platform maneuverability. Spawning sockeye visibility was good given East Alsek River water clarity (Figure 1.6), although it did vary with weather conditions (e.g. rain, wind, cloud cover, etc.). Raft avoidance behavior by sockeye was minimal. Each surveyor independently counted all non-schooling sockeye, active sockeye redds and sockeye carcasses within each polygon on a hand-click counter. An 'active' redd was one in which a minimum of one sockeye salmon was stationed above or adjacent to the redd, and appeared to be there for the purpose of spawning. Sockeye salmon holding in large schools were omitted from counts, as they did not appear to be actively spawning. These fish generally did not show full breeding colors and were tightly bunched in schools, along the lower reaches of the river.

Observed density was then calculated for each polygon by dividing the mean total from surveyor's observations of spawning sockeye, active sockeye redds or sockeye carcasses by the total area of the polygon (Figure 1.7).

Principal Components Analysis

We analyzed the 9 mean habitat measurements for polygons (temperature, specific conductivity, water velocity, water depth, dissolved oxygen, weighted substrate size, sediment depth, plant height, and the combined substrate and sediment cover) using principal components analysis to identify underlying patterns among generalized polygons within the East Alsek sockeye habitat.

Analysis of habitat use

The relative density of redds per habitat polygon was compared to random habitat measurements within the same polygon. We calculated the fraction of the total area of the river in each habitat category then calculated the fraction of redds in each habitat category. This in effect compared the distribution of the area-weighted habitat measurements to redd weighted measurements in order to assess how sockeye were using the habitat available to them throughout the East Alsek River. The normalized distribution for each habitat measurement was calculated using Equation 1.2.

Results

Correlation of habitat variables

Examination of the correlation matrix provided some insights into the interactions among habitat characteristics. For instance, water velocity was negatively correlated with vegetation cover and sediment cover, sediment depth and the height of aquatic vegetation (r= -0.55, -0.32, -0.37 respectively). Sediment depth was also highly correlated with vegetation height (r=0.71, Table 1.2).

Principal Components Analysis

Principal component analyses provided evidence that East Alsek River spawning sockeye selected habitat free of sediment and vegetation, and away from slower, deeper water (Figure 1.8). Principal component 1 (PC1) was strongly determined by an opposite relationship between water velocity and several habitat variables including water depth, sediment depth, vegetation + sediment percent cover, and vegetation height (Table 1.3). Principal component 2 (PC2) was similarly determined by an opposite relationship between gravel size and several water quality parameters including specific conductivity, temperature, and dissolved oxygen. Group-2 was composed of polygons that defined deeper and slower water habitats with higher sediment and vegetation loads (Figure 1.8). Generally, these features characterized the abundant large, deep pools within the East Alsek River.

When the first two principal components of the habitat correlation matrix were plotted (Figure 1.8), we observed two distinct groupings of habitat polygons. Polygons that defined pools (Group 2, Figure 1.8) tended to be distinct from those that did not (Group 1, Figure 1.8). Only two of 12 glides grouped with group 2, and one polygon designated as a pool and one riffle did not fit into either group. The remainder of the East Alsek River surveyed, 179,766 m^2 (38%) were designated Group 2.

Although redd density was not used in the grouping of habitat types using PCA, no polygon contained in Group 2 had spawning density greater than 0.05 redds/100m^2, whereas all polygons with redd densities greater than two redds/100m^2 were contained within Group 1. These results were consistent for both 2005 and 2006 study years even when analyzed separately.

Sockeye use of habitat for spawning

Results of the spawning surveys were consistent with those of the principal components analyses. Spawning sockeye selected spawning sites in areas with reduced sediment and vegetation, as well as in colder and shallower water than what was available on average throughout the river. The relative use of habitat (e.g. redd density) was compared to the measured habitat variables in each of the 54 polygons. Redd density showed no north to south pattern, suggesting that sockeye did not select spawning habitat as a function of distance traveled, and the survey timing was appropriate (Figure 1.9). Mean values for redd-weighted sediment depth, vegetation height, vegetation cover and temperature were all significantly lower than area-weighted means (Table 1.4).

Redd-weighted values were similar for sediment cover compared to area-weighted means for both survey years, although the percent coverage measurement did not discriminate between shallow and deep sediment (Figure 1.5). Mean values of water velocity and water depth were not significantly different for either year, suggesting sockeye were using the river proportionally to what was available for depth and velocity (Figure 1.10). Statistical significance for both dissolved oxygen and specific conductivity differed between years. When data for both years were combined, neither dissolved oxygen nor specific conductivity had redd-weighted values that were significantly different from area-weighted values.

Sediment depth and vegetation height exhibited the greatest differences between area and redd weighted values (Figure 1.10). Sockeye favored spawning areas with much lower sediment and vegetation loads than what was available to them throughout the river. East Alsek sockeye were also spawning in areas that were cooler, had lower DO and smaller substrate size than the typical available habitat.

There was little difference observed in the redd density weighted distribution of habitat measurements between the 2005 and 2006 survey years despite the 2006 return being two times as large as the 2005 survey. No density dependent shift in habitat preference was observed at these two density levels.

Discussion

The sockeye of the East Alsek River showed definite spawning habitat preference. Preferred sockeye habitat was generally low in sediment and plant cover, exhibited smaller sized spawning gravels, and occurred in upwelling areas. A localized change in hydrology within the East Alsek River, presumably due to glacial rebound and subsequent lack of periodic Alsek River flooding, has likely contributed to a decrease in preferred habitat since the last Alsek flood event.

Availability of spawning habitat can be difficult to assess because selection and actual use is certainly dependent on spawning fish density. As sockeye escapement increases, the use of substandard habitat will also increase, and the densities within preferred habitat may also increase to accommodate more salmon. This study was focused on answering several questions about habitat use by spawning sockeye in the East Alsek River. These questions were: 1) What criteria were sockeye using to select habitat? 2) Was use dependent on vegetation or sediment distribution? 3) Are conditions present that facilitate increasing in sediment deposition or aquatic vegetation growth and distribution?

Cues used by sockeye to select spawning habitat are difficult to determine because a vast combination of these cues are likely to influence a sockeye's final selection of a spawning site. Subsurface flows, slight salinity changes or other cues may influence the choice of spawning habitat (Geist and Dauble 1998; Baxter and Hauer 2000; Burger et al.

1995). In the case of the East Alsek River, it was clear that much of the river had high sediment and plant loads atop gravel suitably sized for spawning salmon. It was possible that these sockeye could act as excavators, building suitable redds by removing sediment and other materials that overlay the substrate. This process has the potential for sockeye to maintain their spawning habitat by excavating the same redd sites from year to year, clearing fine sediment from spawning gravel (Quinn et al. 1995). Although this was probably the case for riffle areas that had sufficient flow to displace sediments downstream, the pool and glide areas of the river lacked sufficient flow to displace sediment once excavated and sockeye salmon did not use these areas.

The low gradient and low flow of the East Alsek River are not conducive for displacing any excavated material downstream of a redd. Moreover, precipitation event flooding effects are unlikely given the relatively flat and low gradient character of this river's watershed. A rise in the hydrograph was consistently detected during autumn of 2005 and 2006. However this rise was not sufficient to create velocities (Miller et al. 1977) that would scour or displace sediment or plant material in the majority of river habitat (within pools and glides). The threshold of sediment displacement (fines and clays) was reached in short riffle sections, where sediment loads were significantly less than those in the pools and glides. The lack of scouring flows occurred even despite above average precipitation during 2006. This suggests that precipitation events alone are unlikely to influence water velocity sufficiently to scour sediment for the majority of the river. The large pools that dominate and comprise most of the existing habitat within the East Alsek River act to trap displaced sediments in these reduced velocity environments. A large-magnitude Alsek River flooding event would most benefit East Alsek River pool reaches to increase available spawning habitat.

Accumulated sediments provide an ideal nutrient-rich substrate for aquatic plants. The correlation of measured habitat variables supports the notion a positive feedback loop between water velocity, vegetation abundance, and sediment deposition exists because water-velocity was negatively correlated with vegetation height and sediment depth. Sockeye selected areas with less plant cover (Figure 1.10). Our evidence suggests the East Alsek will become less suitable for sockeye spawning through time in the absence of scouring flows to periodically displace sediment and aquatic vegetation from current and historic spawning habitat. Moreover, anecdotal evidence from area fishermen suggests that sediment volumes as well as vegetation spatial distribution have increased over time.

Our habitat measurements were suitable for evaluating spawning habitat use by East Alsek sockeye. Spawning sockeye showed an aversion to spawning in areas dominated by high sediment or plant loads. Excavation of sediment greater than 10 cm for the purpose of spawning was determined to be very unlikely; conversely choosing a habitat with less than 5 cm of fine sediment was much more likely (Figure 1.10). This suggests sockeye had definite limits to what they would excavate. Sockeye apparently used other cues to select spawning habitat in addition to vegetation and sediment presence sockeye were spawning in areas that were generally cooler, had smaller spawning gravels and had lower dissolved oxygen levels than what was available. These observations suggest preference for areas with upwelling groundwater, which tends to be cooler on the East Alsek and exhibit reduced oxygen concentration compared with surface flows (Geist 2000).

The criteria sockeye use to select spawning habitat may also change as the density of sockeye populations increases, thereby crowding more spawners in less suitable habitat for spawning or increasing redd superimposition (Smoker, Gharrett, and Stekoll 1998; Fukushima 1996). However, despite spawning counts more than doubling between 2005 and 2006, no change in habitat selection was seen between the two years. Much greater densities may be required to observe a shift in the spawning habitat used, as both years had runs much smaller than during the historical peaks.

The locations of high redd density polygons were intuitive from a hydraulic and/or upwelling perspective. Sockeye redd density was typically high along outer pool margins, because those areas exhibit higher water velocities compared with inner margins and pool cores. Riffles with suitable substrate almost always exhibited high redd densities as did areas downstream of remnant channels. This was especially true in the headwaters reach, presumably due to upwelling flow. Polygons exhibiting high redd densities typically occurred in areas of the river with sufficient flow, either interstitially (through upwelling) or in-stream flow, that would promote good embryo survival.

The criteria required for good embryo survival were generally met, with dissolved oxygen measurements at the substrate between 5—20 mg/L (Davis 1975; Coble 1961). Increased sediment and vegetation are likely the cause of the reduction in production that the East Alsek has undergone in recent years. Sediment has been shown to have detrimental effects on the viability of salmonid embryos (Wu 2000; Cooper 1965; Lisle and Lewis 1992). Sediment deposited after the fall spawning season had the potential to overlay existing redds and entomb eggs, and available spawning habitat was most likely reduced from the last flooding event. However, the habitat measurements that directly relate to embryo survival, such as interstitial flow and interstitial dissolved oxygen concentrations, were inferred from surface measurements and known physical relationships. As inferences, the criteria for embryo survival were not absolutes.

Our analyses (see also chapter 2, this volume) support the idea that flood frequency is decreasing. If so, then the spawning success of East Alsek sockeye salmon will likely be reduced. The ability of sockeye to maintain spawning habitat in this river over the long-term is not likely due to the low gradient and low flow which is insufficient for displacing sediment away from spawning habitat and into the estuary. Flood waters from the Alsek have the potential to be the source of scouring flows that could flush fine sediment from the river into the estuary or even the Gulf of Alaska. Peak flows on the

Alsek were measured at 3653 m^3/s for 2005 and 2006, whereas the peak flow for the East Alsek was measured at 6 m^3/s, only 0.15% of the Alsek River's peak flow (USGS, Alsek River Gage). If only a small proportion of the river overran its banks into the East Alsek, the velocities generated would likely be sufficient to scour gravels and displace sediment and aquatic plants. Unfortunately, the evolving geomorphology of both the Alsek and East Alsek Rivers indicates that such floods will become increasingly infrequent, and consequently the outlook for the East Alsek sockeye salmon population will likely continue to deteriorate.

Literature Cited

Alaska Department of Fish and Game. (1984). *Yakutat comprehensive salmon plan.* Juneau, Alaska: ADF&G.

Baxter, C V, and Hauer, F R (2000). Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (Salvelinus confluentus). *Canadian Journal of Fisheries and Aquatic Sciences , 57* (7), 1470-1481.

Blair, G R, Rogers, D E, and Quinn, T P (1993). Variation in life history characteristics and morphology of sockeye salmon in the Kvichak river system, Bristol Bay, Alaska. *Transactions of the American Fisheries Society , 122,* 550-559.

Bovee, K D (1997). *DATA COLLECTION PROCEDURES FOR THE PHYSICAL HABITAT SIMULATION SYSTEM.* Ft. Collins, CO: U.S. Geological Survey - Biological Resources Division.

Brannon, E L (1987). Mechanisms stabilizing salmonid fry emergence timing. *H.D. Smith, L. Margolis, and C. C. Wood, editors. Sockeye salmon (Oncorhynchus nerka) population biology and future management. , 96.*

Burger, C V, Finn, J E, and Holland-Bartels, L (1995) Pattern of Shoreline Spawning by Sockeye Salmon in a Glacially Turbid Lake: Evidence for Subpopulation Differentiation *Transactions of the American Fisheries Society , 124* (1), 1-15.

Burgner, R L (1991). Life history of sockeye salmon (Oncorhynchus nerka). Pacific salmon life histories. *Sockeye Salmon* (pp. 1-117). Vancouver, BC: UBC Press.

Carpenter, SR, and Lodge, D M (1986). Effects of submerged macrophytes on ecosystem processes. *Aquatic Botany*, *26*, 341–370.

Clark, J H, G F Woods, and S Fleischman (2003) Revised biological escapement goal for the sockeye salmon stock returning to the East Alsek-Doame river system of Yakutat, Alaska. Alaska Department of Fish and Game, Special Publication Series No. 03-04, Anchorage.

Coats, R, L Collins, J Florsheim, and D Kaufman (1985). Channel change, sediment transport, and fish habitat in a coastal stream: Effects of an extreme event. Environmental Management 9(1):35-48.

Coble, D W (1961). Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. *Transactions American Fisheries Society*, *90*, 469-474.

Cooper, A C (1965). *The effect of transported stream sediments on survival of sockeye and pink salmon eggs and alevins.* British Columbia Canada: International Pacific Salmon Commission Bulletin 18.

Davis, J C (1975). Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. *Canadian Journal of Fisheries and Aquatic Sciences*, *32*, 2295-2332.

Dawson, F H (1978). The seasonal effects of aquatic plant growth on the flow of water in a stream. *Proceedings European Weed Research Society 5th symposium on aquatic weeds*, (pp. 71–78). Amsterdam, Netherlands.

Fukushima, M (1996). *Effects of density-dependence, environment and species interaction during spawning and incubation on population dynamics of pink and sockeye salmon in the Auke Lake system, Southeast Alaska. Doctoral dissertation.* Fairbanks, AK: University of Alaska Fairbanks.

Geist, D R (2000). Hyporheic discharge of river water into fall Chinook salmon (Oncorhynchus tshawytscha) spawning areas in the Hanford Reach, Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences*, *57*, 1647-1656.

Geist, D R, and Dauble, D D (1998). Redd site selection and spawning habitat use by fall Chinook salmon: the importance of geomorphic features in large rivers. *Environmental Management*, *22*, 655-669.

Gottesfeld, AS, MA Hassan, JF Tunnicliffe and RW Poirier (2005). Sediment Dispersion in Salmon Spawning Streams: The Influence of Floods and Salmon Redd

Construction. Journal of the American Water Resources Association 41 (5):1237-1239.

Hall, J L, and Wissmar, R C (2004). Habitat Factors Affecting Sockeye Salmon Redd Site Selection in Off-Channel Ponds of a River Floodplain. *Transactions of the American Fisheries Society*, *133* (6), 1480–1496.

Heinl, S C, Zadina, T P, McGregor, A J, & Geiger, H J (2003). *Chum salmon stock status and escapement goals in Southeast Alaska.* 1J03-8. Juneau, AK: Alaska Department of Fish and Game.

Hendry, A P, and Quinn, T P (1997). Variation in adult life history and morphology among Lake Washington sockeye salmon (Oncorhynchus nerka) populations in relation to habitat features and ancestral affinities. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*, 75-84.

Lapointe, M F, Bergeron, N E, Berube, F, Pouliot, M A, and Johnston, P (2004). Interactive effects of substrate sand and silt contents, redd-scale hydraulic gradients, and interstitial velocities on egg-to-emergence survival of Atlantic salmon (Salmo salar). *Canadian Journal of Fisheries and Aquatic Sciences*, *61* (12), 2271-2277.

Larsen, CF, Motyka, RJ, Freymueller, JT, Echelmeyer, KA, and Ivens, ER (2005) Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 23:548-560.

Leonetti, F E (1997). Estimation of surface and intragravel water flow at sockeye salmon spawning beaches in Iliamna Lake, Alaska. *North American Journal of Fisheries Management*, *17* (1), 194-201.

Levasseur, M, Bergeron, N E, Lapointe, M F, and Berube, F (2006). Effects of silt and very fine sand dynamics in Atlantic salmon (Salmo salar) redds on embryo hatching success. *Canadian Journal of Fisheries and Aquatic Sciences*, *63* (7), 1450-1459.

Lisle, TE (1989). Sediment transport and resulting deposition in spawning gravels, North coastal California. Water Resources Research 25(6):1303-1319.

Lisle, T E, and Lewis, J L (1992). Effects of sediment transport on survival of salmonid embryos in a natural stream: A simulation approach. *Canadian Journal of Fisheries and Aquatic Sciences*, *49*, 2337-2344.

Lorenz, J M, and Eiler, J H (1989). Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. *Transactions of the American Fisheries Society*, *118*, 495–502.

Miller, M C, McCave, I N, and Komar, P D (1977). Threshold of sediment motion under unidirectional currents. *Sedimentology*, *24* (4), 507-538.

Quinn, T P, A P Hendry, and L A Wetzel (1995) The influence of life history trade-offs and the size of incubation gravels on egg size variation in sockeye salmon (*Oncorhynchus nerka*). Oikos 74:425–438.

Sear, D. A. (1993). Fine sediment infiltration into gravel spawning beds within a regulated river experiencing floods: Ecological implications for salmonids. *Regulated Rivers and Reservoir Management*, *8*, 373-390.

Smoker, W. W., Gharrett, A. J., and Stekoll, M. S. (1998). Genetic variation of return date in a population of pink salmon: a consequence of fluctuating environment and dispersive selection. *Alaska Fishery Research Bulletin*, *5* (1), 46-54.

Sowden, T. R., and Powder, G. (1985). Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. *Transactions of the American Fisheries Society*, *114*, 804–812.

Welton, J. S. (1980). Dynamics of sediment and organic detritus in a small chalk stream. Archives fur Hydrobiologic. *Archives fur Hydrobiologic*, *90*, 162-181.

Wu, F. C. (2000). Modeling embryo survival affected by sediment deposition into salmonid spawning gravels: Application to flushing flow prescriptions. *Water Resources Research*, *36* (6), 1595-1603.

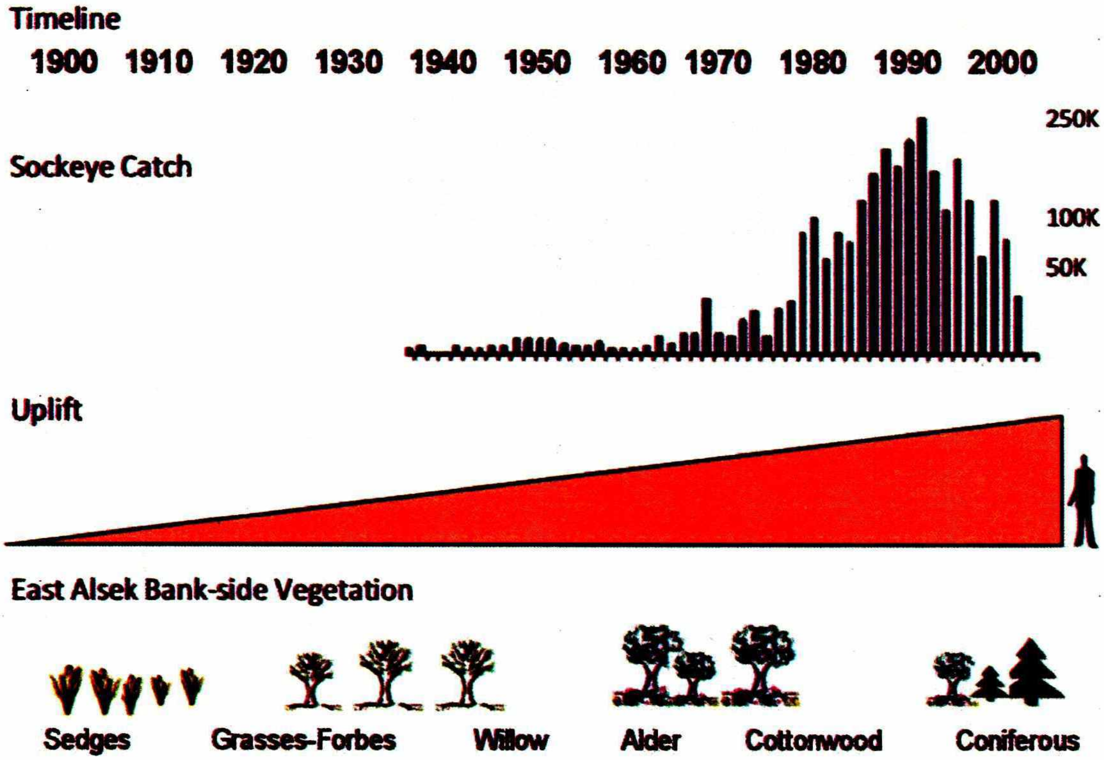

Figure 1.1 Timeline of sockeye catch, uplift and plant succession for the East Alsek River. The man represented to the right of the uplift figure is 1.8 m tall, and uplift was assumed to progress at 26mm/year from 1900.

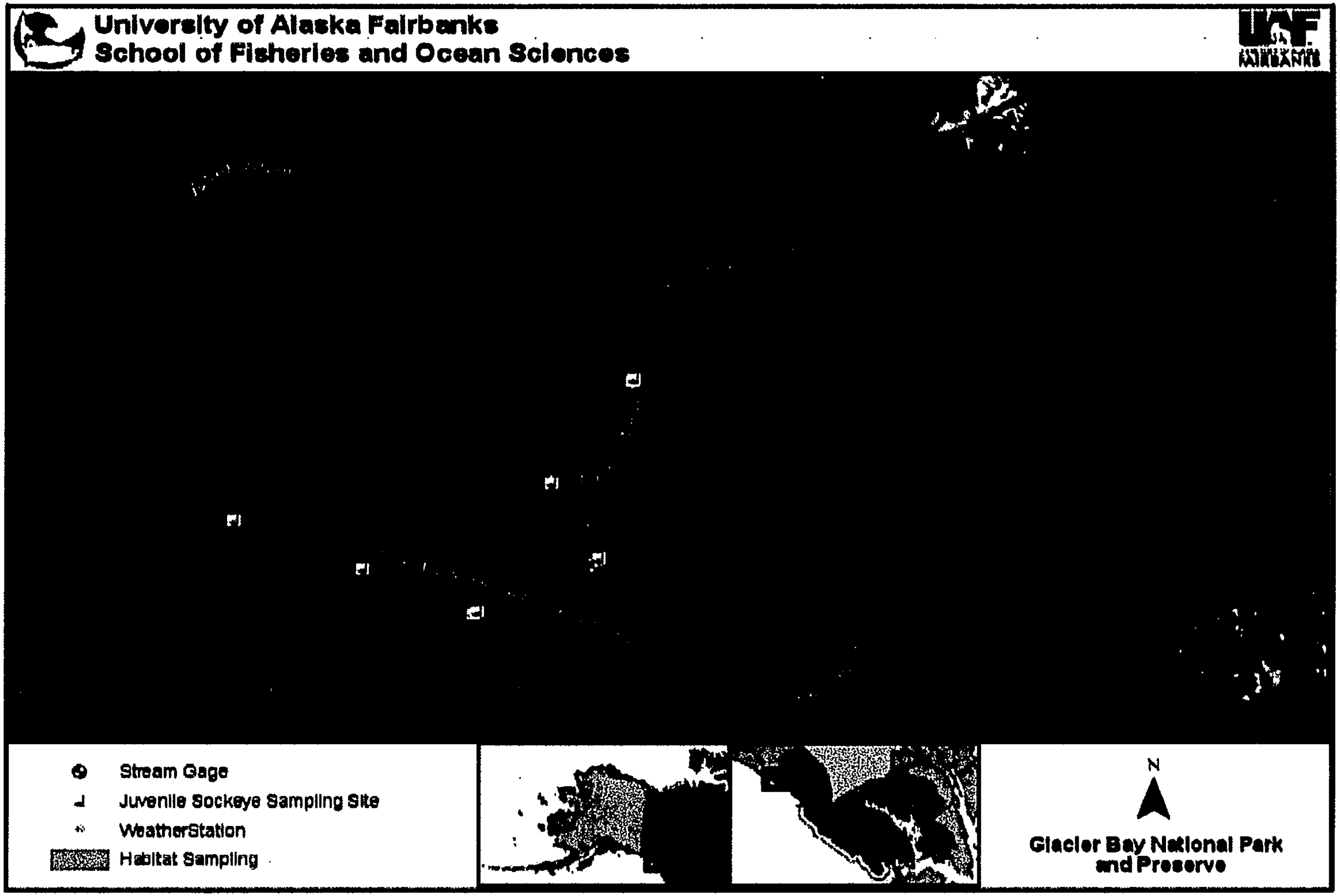

Figure 1.2 The East Alsek River study site showing the flood channels connecting the Alsek River to the East Alsek River.

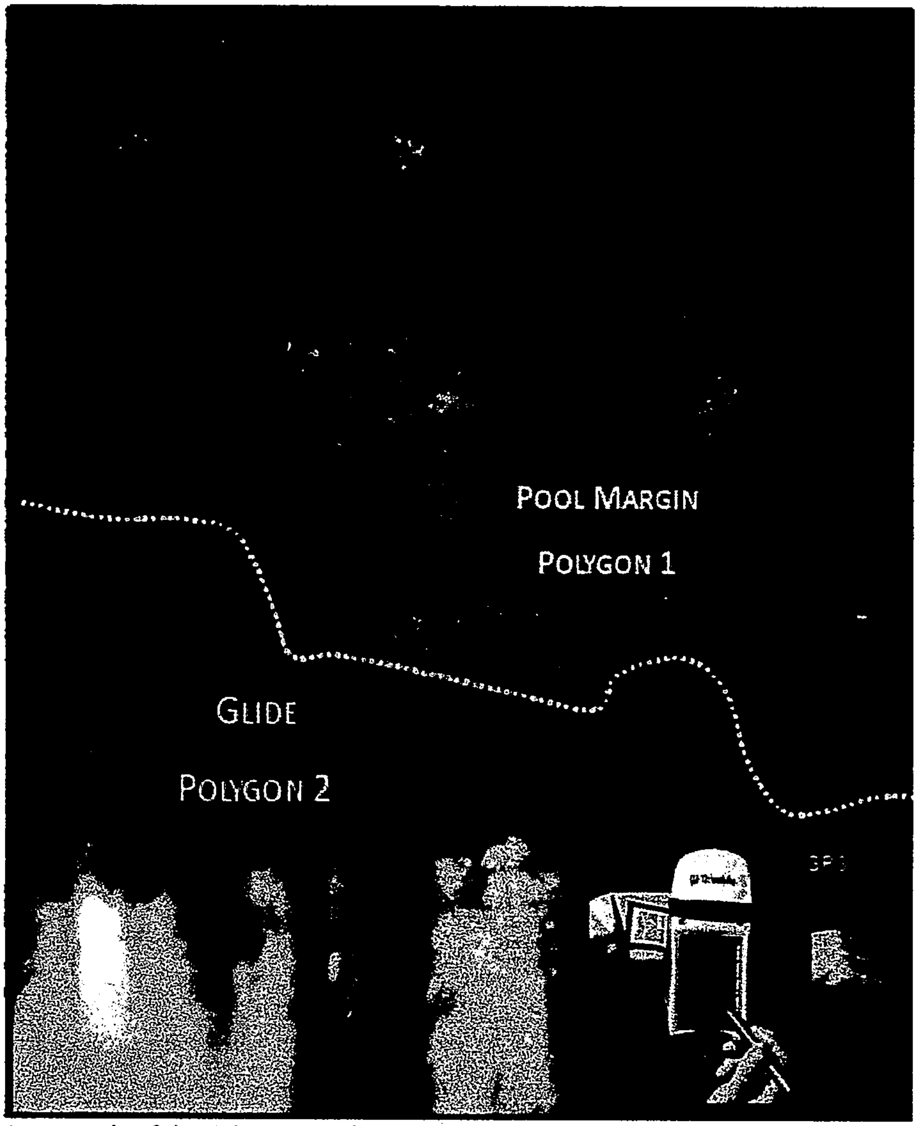

Figure 1.3 An example of the delineation of polygons. The border of each polygon was walked with a GPS in order to quantify the area of a polygon.

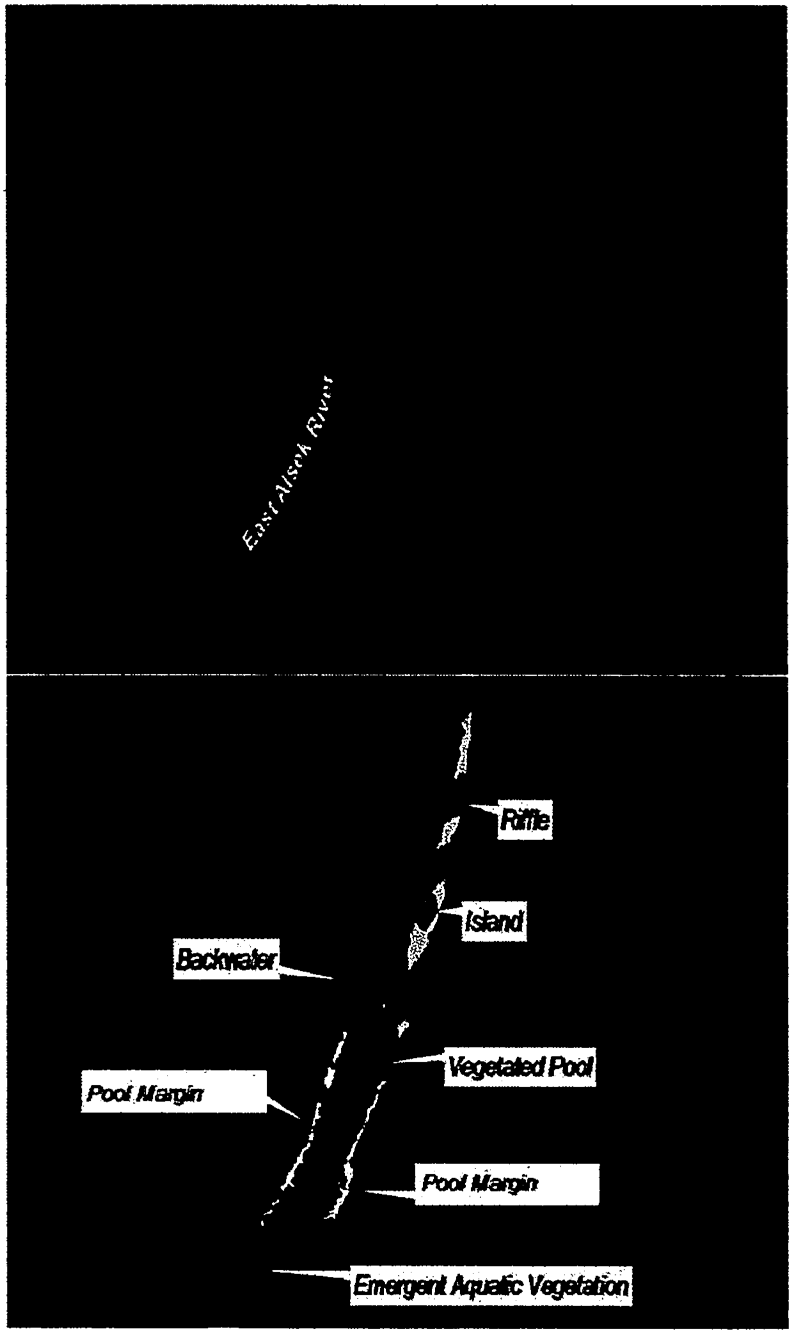

Figure 1.4 A portion of the East Alsek River (left) and its subdivision into habitat polygons. The mean spawner and redd density were computed for each polygon and compared to the habitat attributes (sediment depth, velocity, etc.).

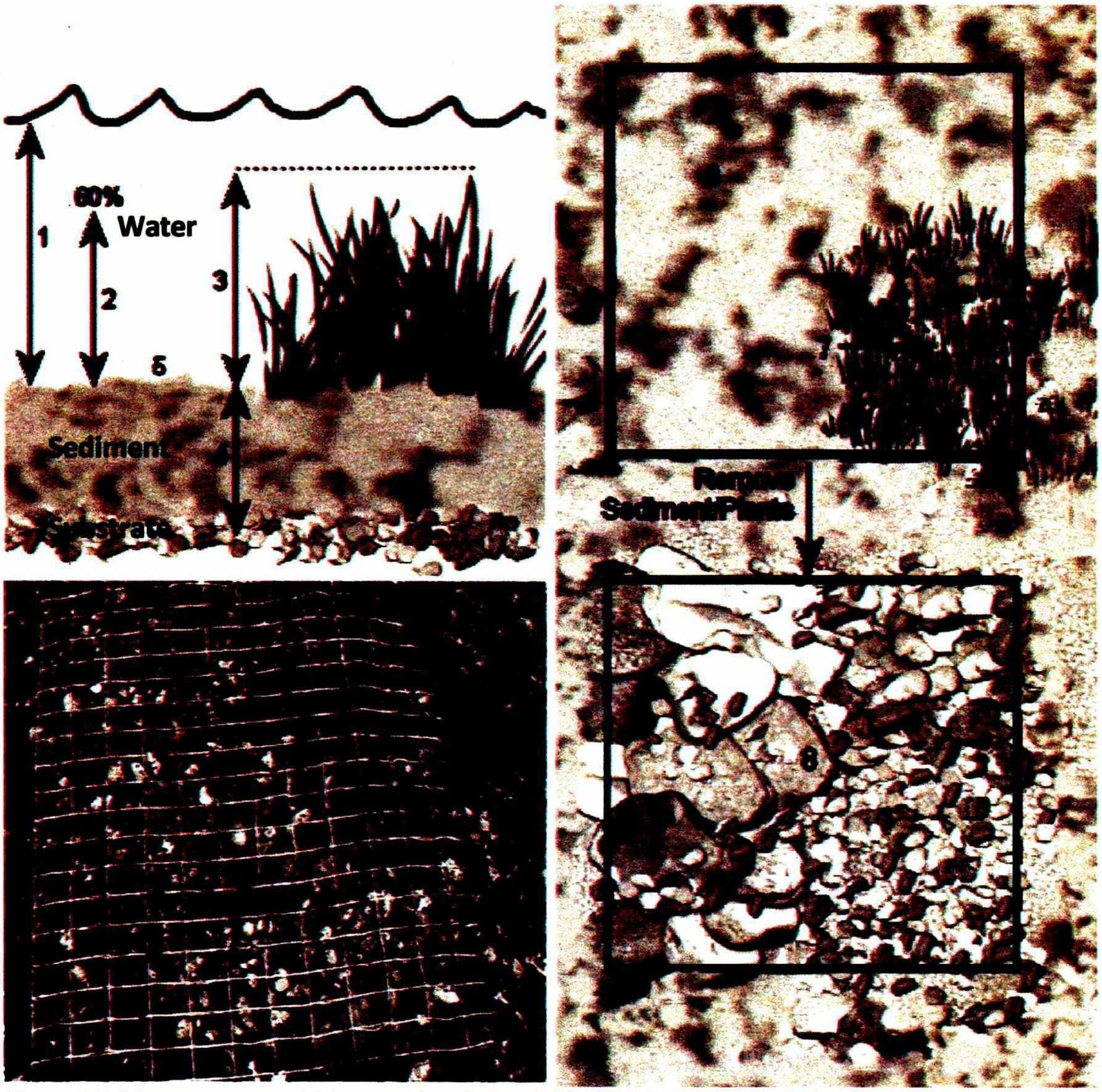

Figure 1.5 Measurements within a quadrat (lower left) of habitat characteristics shown in a profile view (above left), and overhead view (right) for 1. Water Depth (cm) 2. Water Velocity (60% water depth, m/s) 3. Plant Height (cm) 4. Sediment Depth (mm) 5. Dissolved Oxygen (mg/L), Specific conductivity (uS/cm) and Temperature (°C) 6. Percent cover - sediment (%) 7. Percent cover - vegetation (%) 8. Percent cover (%), Sand (1-2mm), Small Gravel (3-64mm), Large Gravel (65-128mm), Cobble (129-256mm), and Boulder (257mm+).

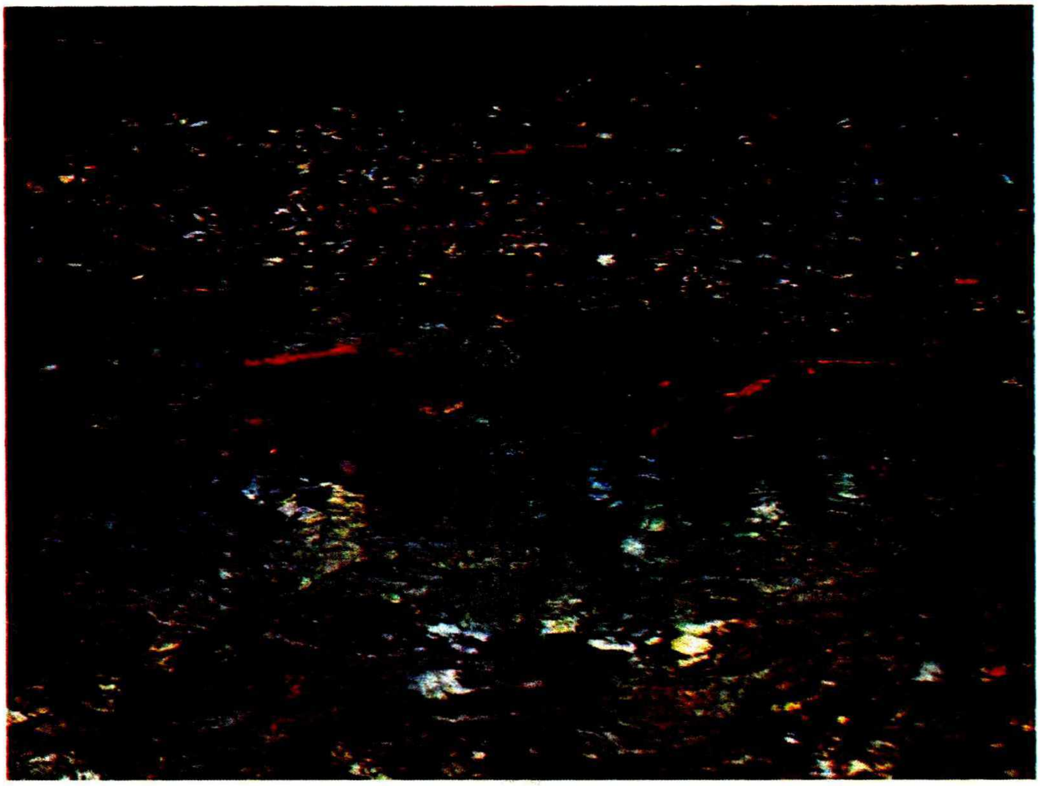

Figure 1.6 Spawning sockeye within an East Alsek River riffle. Surveys of spawning activity were aided by clarity of East Alsek water.

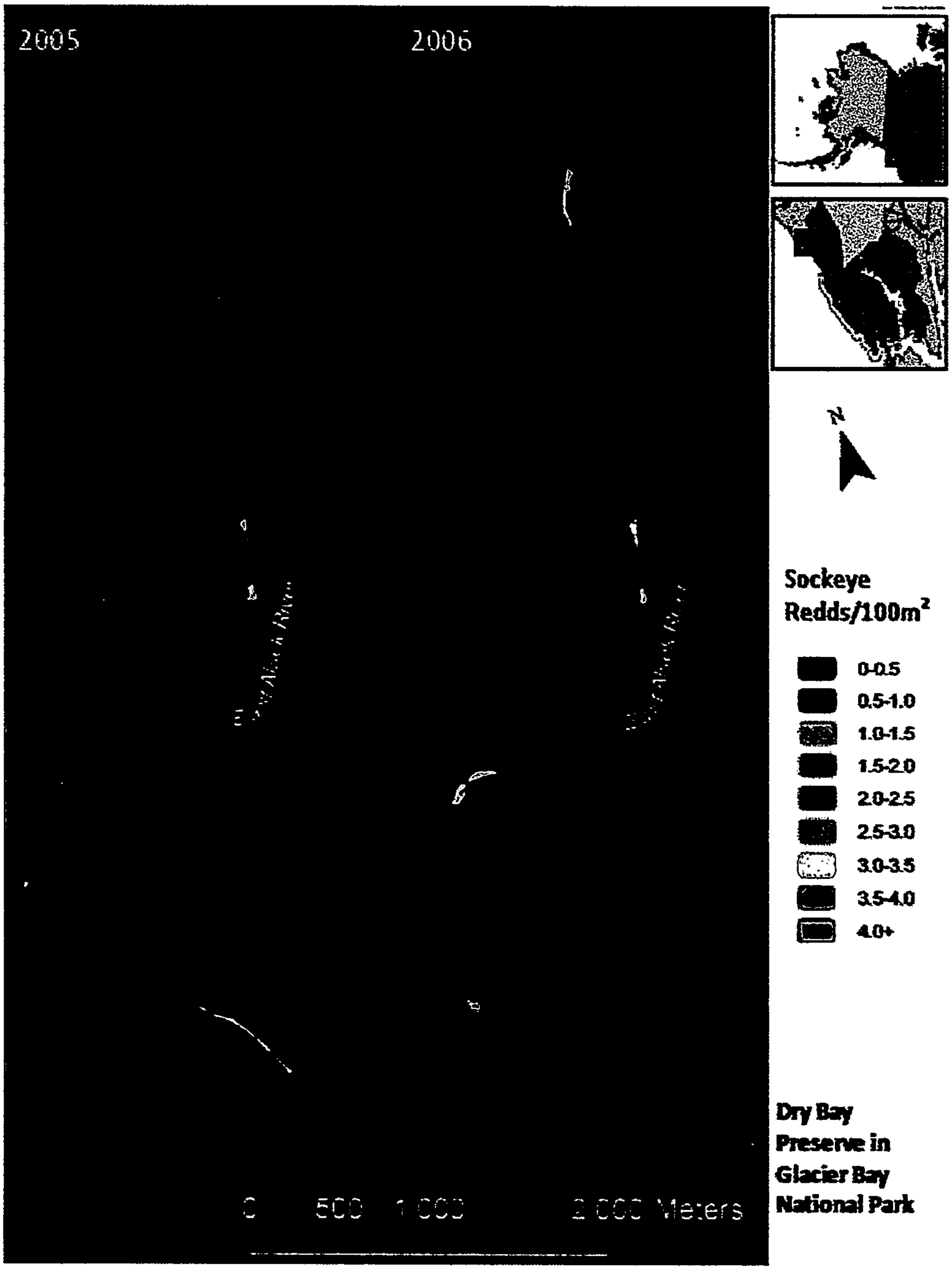

Figure 1.7 Observed redd densities of spawning sockeye salmon in habitat polygons in the East Alsek River, for 2005 and 2006. Densities are displayed by sampled polygon.

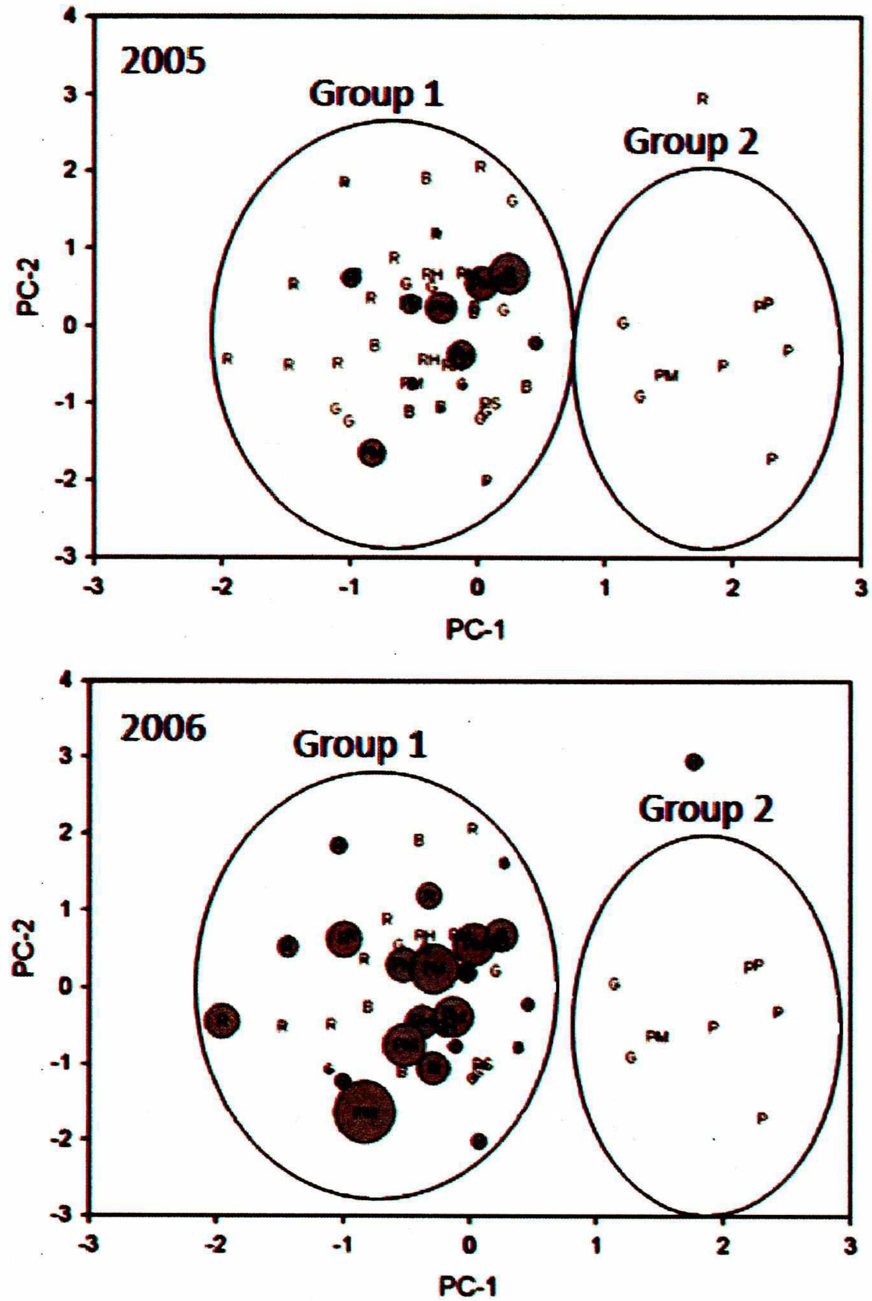

Figure 1.8 Principal component graphs of mean habitat characteristics for all 54 polygons surveyed. Redd density per sample year is also displayed as a function of circle size. A generalized description of polygon habitat is provided for reference, where P, G, R, B, PM, PS, RH represent Pool, Glide, Riffle, Backwater, Pool Margin, Shallow Pool and Riffle Head respectively.

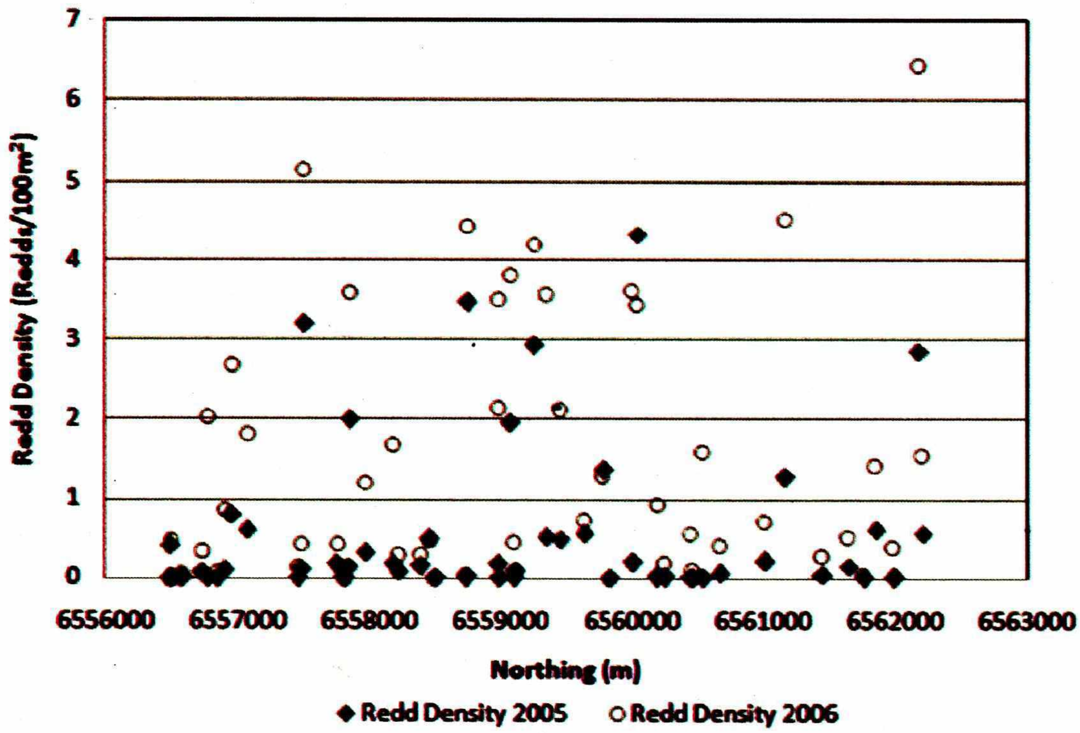

Figure 1.9 Display of Northing coordinates in relation to the 2005 and 2006 redd density.

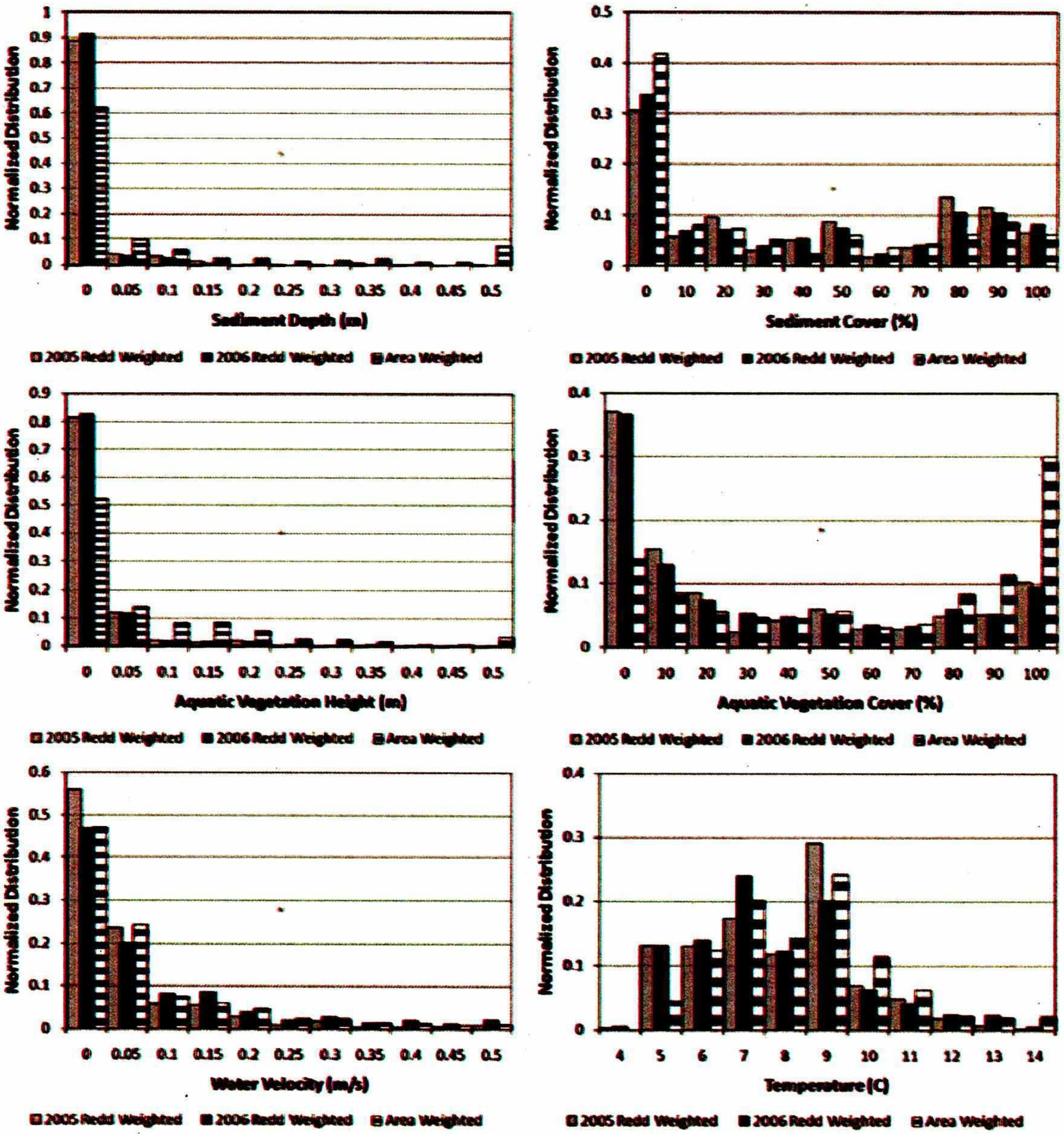

Figure 1.10 Normalized distribution of habitat measurements for 2005 redd-weighted, 2006 redd-weighted and area weighted habitat measurements. Axis values show the lower boundary of each bin.

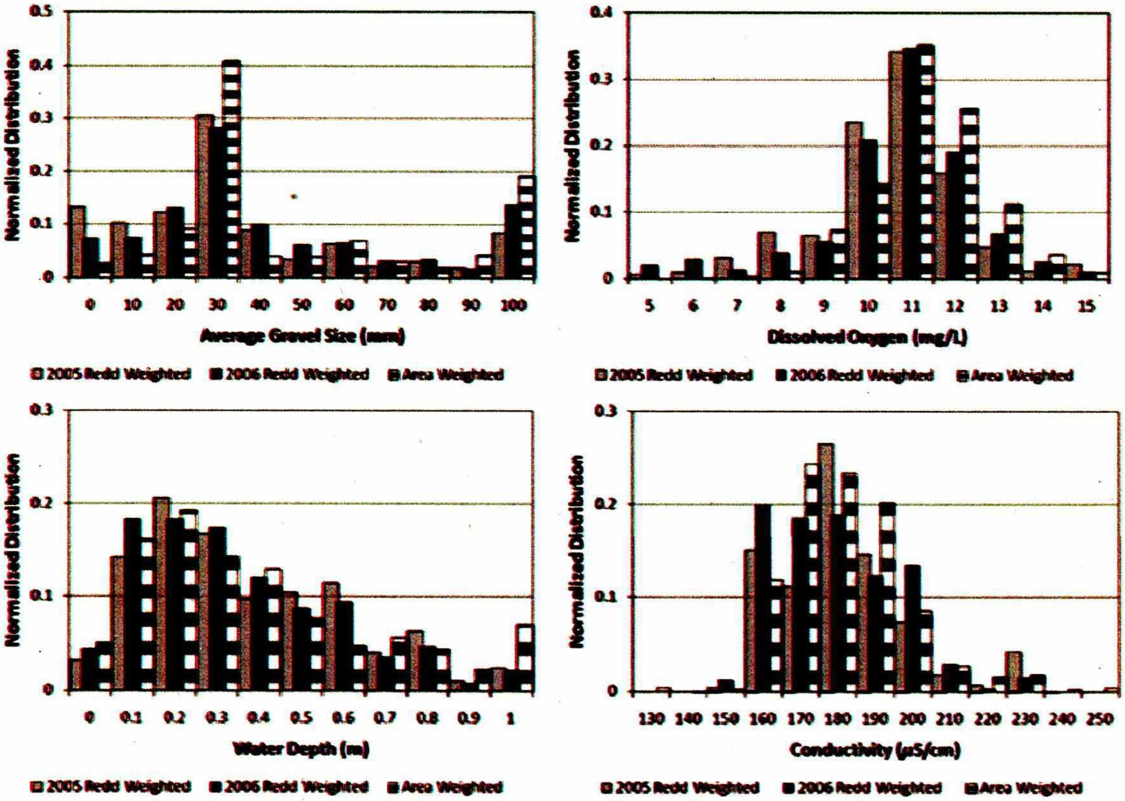

Figure 1.10 continued.

Table 1.1 Precision of habitat measurements taken in each polygon and summarized for later analysis.

Habitat Variable	Precision and classification
Water depth	1 cm
Silt/fines depth	1 mm
Vegetation height from substrate	1 cm
Substrate % composition	1% Vegetation and 1% Silt/fines
Substrate beneath Vegetation or Silt/fines	
	1% Sand (1-2mm)
	Small Gravel (2-64mm)
	Large Gravel (64-128mm)
	Cobble (128-256mm)
	Boulder (256+mm)
Water velocity (60% water-column)	0.02 m/s**
Dissolved Oxygen (DO)	0.01 mg/L
Conductivity	1 µS
Temperature at Substrate	0.1° C

** One revolution on pygmy™ velocity meter

Table 1.2 Correlation (r) matrix of mean habitat measurements.

	Vegetation % + Sediment % Cover	Geometric Mean of Gravel Size	Average Depth	Water Velocity	Vegetation Height	Sediment Depth	Conductivity	Temperature	Dissolved Oxygen
Vegetation % + Sediment % Cover									
Mean of Gravel Size	-0.08								
Average Depth	0.15	0.04							
Water Velocity	-0.55	0.04	-0.30						
Vegetation Height	0.53	-0.04	0.47	-0.37					
Sediment Depth	0.46	0.19	0.54	-0.32	0.71				
Conductivity	0.13	-0.45	0.06	-0.06	0.03	-0.05			
Temperature	0.16	-0.53	-0.14	0.05	0.36	0.00	0.41		
Dissolved Oxygen	-0.07	-0.09	-0.11	0.27	0.23	0.02	0.10	0.55	

Table 1.3 Eigenvectors of habitat measurement variables.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Eigenvalue	2.82	2.19	1.32	0.92	0.57	0.47	0.31	0.24	0.16
Vegetation % + Sediment % Cover	0.44	0.01	-0.22	-0.49	0.22	0.25	0.57	0.27	0.1
Geometric Mean of Gravel Size	-0.05	-0.48	0.38	-0.16	0.57	-0.22	-0.26	0.36	0.13
Average Depth	0.36	-0.19	0.04	0.7	-0.17	-0.23	0.31	0.35	0.22
Water Velocity	-0.38	0.15	0.42	0.27	0.12	0.68	0.23	0.24	-0.07
Vegetation Height	0.52	0.07	0.26	-0.03	-0.15	0.1	-0.29	0.23	-0.7
Sediment Depth	0.48	-0.17	0.25	0.12	0.14	0.38	-0.16	-0.6	0.33
Conductivity	0.1	0.41	-0.37	0.37	0.71	-0.04	-0.11	-0.04	-0.17
Temperature	0.15	0.59	0.12	-0.13	-0.14	0.01	-0.4	0.36	0.54
Dissolved Oxygen	0.03	0.4	0.59	-0.09	0.12	-0.47	0.41	-0.28	-0.07

Table 1.4 Weighted mean and standard deviation for each measured habitat characteristic. Redd weighted survey results from 2005 and 2006 were compared to area weighted values using a standardized t-test with unequal variances.

	Area Weighted		Redd Weighted 2005		Redd Weighted 2006	
Conductivity (µS/cm)	186	(19)	192*	(53)	185	(27)
Dissolved Oxygen (mg/L)	11.9	(1.4)	11.6	(2.8)	11.5*	(2.6)
Mean Substrate Size (mm)	72	(60)	55*	(67)	62*	(54)
Sediment % cover	33	(38)	42*	(27)	41*	(28)
Sediment depth (m)	0.11	(0.3)	0.02**	(0)	0.02**	(0.03)
Temperature (°C)	9	(2.5)	8.4*	(3.3)	8.4*	(3.3)
Vegetation % cover	61	(36)	32*	(36)	34*	(33)
Vegetation Height (m)	0.1	(0.2)	0.03**	(0)	0.03**	(0.05)
Water Depth (m)	0.46	(0.4)	0.42	(0.2)	0.39	(0.2)
Water Velocity (m/s)	0.09	(0.1)	0.06	(0.1)	0.09	(0.16)

*p < = 0.05**p <= 0.01

Equation 1.1 Equation to determine the mean size of gravel per quadrat.

$$\bar{x} = \left[(\text{Sand }\%) \times 1\ mm\right] + \left[(\text{Small Gravel }\%) \times 33\ mm\right] + \left[(\text{Large Gravel }\%) \times 96\ mm\right] + \left[(\text{Cobble }\%) \times 192\ mm\right] + \left[(\text{Boulder }\%) \times 256\ mm\right]$$

Equation 1.2 Equation to determine weight of habitat variables used for spawning habitat use according to redd density in 2005, 2006, and compared to the total area sampled.

$$x_K = \frac{1}{\sum_{j=1}^{n} A_j} \sum_{j=1}^{n} \sum_{i=1}^{nj} \left[\frac{y_{ij} A_j}{n_j} \right]$$

y_{ij} =1 if y_{ij} falls into bin K, 0 otherwise

A_j =area of polygon, or total number of redds in polygon (equals area × density)

n_j =number of quadrats in polygon j

Indices

K=bin of histogram

j=Polygon

i=quadrat within polygon j

Chapter 2

Spawning Habitat Degradation due to Decreased Flooding as a Consequence of Isostatic Rebound[2]

[2] Faber, DM, M Adkison, C M Soiseth (2008) Spawning Habitat Degradation due to Decreased Flooding as a Consequence of Isostatic Rebound[2]. North American Journal of Fisheries Management. Vol. Xx (xx), xxx-xxx.

Abstract

We evaluated population trends of East Alsek River sockeye salmon near Yakutat Alaska in relation to freshwater and marine conditions. This study was conducted to determine the reason for a recent downturn in production of this population of ocean-type sockeye. The East Alsek River once saw returns of over 275,000 sockeye salmon, but recent returns have failed to meet escapement goals. We assessed the influence of environmental conditions such as temperature, number of freezing days, precipitation and the North Pacific index on critical life stages of these sockeye salmon. Also, periodic Alsek flood events were evaluated in conjunction with spawner/recruit data using a customized spawner/recruit model. The most compelling evidence suggests that the lack of periodic Alsek River flooding accounts for the boom in production observed in the 1980's as well as the more recent decline since the mid 1990's. The lack of flooding from the much larger Alsek River has likely led to increased sedimentation and aquatic vegetation that impacts East Alsek sockeye survival. Additionally, valuable life history information was derived from this study of ocean-type sockeye. We calculated that embryos from this fall run hatch in January and emerge from the gravel in April. Juvenile sockeye then grow to 55 mm - 75 mm (fork length) from April through July when they outmigrate to the Gulf of Alaska.

Introduction

Changes in environmental conditions can have a direct impact on the population size and population growth rate of sockeye salmon by influencing survival. From spawning, embryo development and emergence in their natal streams, to wide ranging movements throughout the Pacific Ocean, sockeye experience a broad variety of environmental conditions. We examined the effect of a few of these environmental factors on the salmon returning to the East Alsek River near Yakutat Alaska.

East Alsek River sockeye salmon have shown dramatic fluctuations in abundance over the past 40 years, from high returns of 275,000 fish in 1985 to lows of 14,200 fish in 2002. A recent drop in sockeye numbers below the escapement goal of 26,000-56,000 fish caused the closure of the commercial fishery in 1999. Alaska Department of Fish and Game (ADFG) re-evaluated their escapement goal for the East Alsek, and in 2003 the commercial fishery reopened with a new goal of 13,000-26,000 fish (Clark et al. 2003).

In the early 1900's the East Alsek was one of three distributary channels of the Alsek to the Gulf of Alaska (Figure 2.1; Morse 1908). Sometime between 1908 and 1948, the channel of the East Alsek was isolated from the Alsek when another channel established itself as the primary route for the Alsek to the Gulf of Alaska. The East Alsek channel maintained its own flow from upwelling groundwater after its isolation (Morse 1908; USGS 1959). However, the East Alsek is still connected to the Alsek through overflow flood channels. Periodic flooding has occurred via these channels, the most recent documented in 1987 (J. Lowenstein, Johnny's East River Lodge, personal communication). Sparsely documented accounts suggest more frequent flooding in the years immediately following the establishment of the East Alsek River, including five floods documented between 1964 and 1981 (Smith et al. 2006).

As a newly formed river, the East Alsek River was also only recently colonized by Pacific salmon. Chum salmon (*Oncorhynchus keta*) established themselves as the dominant Pacific salmon species in the East Alsek River until the mid 1970's (Heinl et al. 2003). Their early colonization and dominance may have been due to the presence of upwelling flow throughout the river, a known habitat attribute that chum salmon identify for spawning (Geist et al. 2002). Upon the rise of sockeye, chum salmon became less abundant but still occupy the river. There are also modest runs of coho (*O. kisutch*) and pink salmon (*O. gorbuscha*). However, it was the commercially valuable sockeye that garnered the greatest attention from commercial fishermen.

East Alsek sockeye do not require a freshwater lake for rearing. This rare life history is known as ocean-type, as they migrate to the ocean the same year that they hatch. Similarly, 0-check, refers to the lack of a 1st year freshwater annulus evident on adult scales). Sockeye whose offspring rear in a lake are well-represented in the literature (Burgner 1991; Fukushima 1996; Blair et al. 1993; Burger et al. 1995). Much less is known about sockeye with ocean type life history. We explored mechanisms that would influence the production potential of this population.

There are many influences on the production of salmon in their natal streams. For instance, the effects of temperature, precipitation, and marine conditions on survival and production have been examined in Pacific salmon populations (Gargett 1997; Hendry and Quinn 1997; Beamish and Bouillon 1993; Bradford 1995; Edmundson and Mazumder 2001). These in addition to periodic flooding were the variables we chose to evaluate for East Alsek sockeye.

Temperature has been shown to have a profound influence on all the Pacific salmon species, from influencing embryo development and hatch timing to directly affecting physiology. Temperature has been linked to increased growth of juvenile sockeye in lakes throughout Alaska and British Columbia (Edmundson and Mazumder 2001). Higher temperatures with sufficient food resources allow larger sockeye smolt to enter ocean water, thereby improving their ocean survival (Henderson and Cass 1991). Temperature is directly related to development timing of eggs and emergence of fry (Brett 1971).

Precipitation directly affects the freshwater environment for sockeye. Precipitation can determine the amount of habitat available for spawning. Water flow also affects embryo viability thru oxygen supply and waste removal (Baxter and Hauer 2000; Coble 1961; Geist 2000). It directly affects the quantity of organic inputs into freshwater environments, which can increase forage for juvenile salmon (Kawaguchi and Nakano 2001). Because of their small size and poorly developed swimming ability, the early life stages of salmon are particularly influenced by water conditions such as velocity and temperature.

Excessive precipitation can cause higher river velocities which can displace juveniles to environments with differing influences on survival (Fleming and Jensen 2002). Depending on the circumstances, precipitation events can cause an increase in survival by displacing juveniles into areas with greater food resources, or cause a decrease in survival by subjecting juveniles to greater numbers of predators.

Precipitation can increase upwelling of groundwater into a stream. Upwelling can influence habitat selection by and habitat availability to spawning adults (Geist 2000; Geist and Dauble 1998; Hall and Wissmar 2004). Upwelling also provides consistent interstitial flow which aids embryo viability and survival. In the case of the East Alsek River, whose source is primarily groundwater, precipitation directly influences the groundwater elevation (Lamb 1945, Soiseth et al. 2005).

Marine conditions have been shown to have a substantial impact on the production of Pacific salmon (Bradford 1995; Beamish and Bouillon 1993; Fleming and Jensen 2002; Mantua et al. 1997), but can be difficult to evaluate with regard to a particular salmon population because of localized variability. The productivity of forage species for newly emigrated sockeye has been shown to fluctuate with changes in ocean current patterns and temperature within the Gulf of Alaska, which can subsequently influence sockeye survival. The Pacific Decadal Oscillation (DO), the North Pacific Index, and coastal sea surface temperatures are indices of the state of the marine environment which have been shown to be related to decadal-scale fluctuations in salmon productivity (Cole 2000; Downton and Miller 1998).

Flooding can have an immediate physical impact on habitat and survival for all life stages that use the fresh water environment. In some cases, flooding has become an essential component to a fish's life history. Colorado pikeminnow (*Ptychocheilus lucius)* for instance require backwater areas for spawning. Backwaters on the Colorado River are formed by periodic flooding events that change channel morphology and create these areas (Patten et al. 2001). Flooding often produces flows with sufficient velocities to scour and displace substrate downstream and change channel morphology (Collieret al. 1997). This has been demonstrated in southeast Alaska where fall flooding has shown to displace sediments from spawning substrates (Sidle 1985), which can increase embryo and fry survival (Chapman 1988; Wu 2000; Thorne and Ames 1987). Clark et al. (2003) speculated that the increase in sockeye production was due to periodic flushing of sediment from spawning gravels of the East Alsek River during flooding events by the much larger Alsek River. Given the physical habitat alteration that can result, flood records for the Alsek River were investigated to determine if a relationship existed between Alsek River overflow flood events and sockeye production.

The purpose of this study was to investigate environmental influences on East Alsek sockeye production. To that end, we examined the freshwater life-history characteristics of East Alsek sockeye and their unusual ocean-type behavior through field investigation. Using spawner/recruit analyses, we investigated whether temperature, precipitation, or marine conditions influenced particular life-stages of sockeye; or if these variables acted in aggregate to influence the survival and production of sockeye. Finally, we examined Alsek River flood events and their effects on East Alsek sockeye production.

Methods

Study Site

The East Alsek River is located within the Dry Bay Preserve of Glacier Bay National Park (Figure 2.2). The East Alsek River and associated estuarine lagoon were the focus of sampling and research efforts; however groundwater, water quality, weather, and water temperature measurements were taken throughout the Dry Bay Preserve as a part of a separate, supporting study (Soiseth et al. 2005). The East Alsek River is approximately 9 km long from its headwaters to an estuarine lagoon. It is a low gradient, clear water river with vegetated banks. The river can be described as a series of large deep pools separated by short stretches of shallow riffles. The pools vary in depth, but are generally deeper than 3 m (one pool > 5 m), and the riffles are typically less than 1m deep during spring and summer flows. Flow was relatively low, with a measured discharge at the mouth of the river from June 16th to August 25th, 2005 ranging between 2.4 m^3/s to 6.0 m^3/s. The vegetation along the banks in 2005 and 2006 generally consisted of Sitka spruce (*Picea sitchensis*), willow (*Salix spp.*), alder (*Alnus spp.*), and cottonwood (*Populus spp.)*, which overhung the bank throughout the river. The stream channel is well established, and has changed little since an aerial photo survey conducted in 1948. In contrast, the estuarine lagoon has changed greatly since the 1948 aerial photos, where most of the change was attributed to a 1959 earthquake that merged estuaries of the Doame River and East Alsek River to form one large lagoon.

In 2005 and 2006 the East Alsek/Doame lagoon had sparsely vegetated banks surrounded by grass covered sand dunes. The lagoon extends approximately 10 Km from the mouth of the East Alsek River to where it meets the Gulf of Alaska. It also extends another 6 Km to the mouth of the Doame for a total of 16 Km of estuary. The estuarine lagoon varied in depth and width depending on the tide and precipitation. From 1998 aerial photos, we estimated the lagoon to be 1 km at the widest and 50 m at the narrowest portions.

General Methodology

Basic information on the fresh-water life history of juvenile East Alsek sockeye was gathered for model development. The duration and timing of residence of differing life stages was needed to link environmental conditions or flooding to the recruitment of sockeye in the East Alsek River. Ambient environmental conditions present at the time of the egg, fry, and juvenile life stages of East Alsek sockeye residence in the river, estuary, and North Pacific were calculated. Spawner/recruit models were then constructed that incorporated environmental conditions present at the time sockeye occupied a particular habitat. Precipitation, temperature, number of days below freezing, and the North Pacific Index (NPI) were examined to determine if they might explain sockeye recruitment trends observed in the East Alsek River since 1970, including the recent downturn in the late 1990's. In addition, a flood effect model was constructed that incorporated known flood events in the Alsek River. As a control, this flood effect model was also applied to four other Yakutat area rivers where the Alsek River would not have caused flooding.

Freshwater residence of East Alsek Sockeye

The timing of the egg stage (pre-hatch), fry stage (alevin to fry) and juvenile (fry to smolt) life stages were determined to the nearest month based on field observation and sampling. The appropriate months for each life stage were compared to the corresponding average recorded monthly values of temperature, precipitation, freezing days, and the North Pacific Index. The egg incubation time period was estimated using a published relationship between temperature and egg hatch time from the time of spawning (Velsen F. P. 1980). The average daily stream temperature was used to calculate the number of temperature units or Celsius degree-days experienced by eggs. Three temperature loggers (Onset Inc.) recorded temperature at the river substrate every hour and were evenly distributed between the headwaters and the river mouth. Spawning time was assumed to range from August 15 to October 15 (Clark et al. 1995).

After hatching, the offspring were considered 'fry' until they emerged from the gravel with their yolk-sac completely absorbed. This time period was also calculated from stream temperature data using literature values (Mead and Woodall 1968; Figure 2.3). This was also confirmed in the field; the size of juvenile salmon collected in the first sampling period in June was consistent with fry having just emerged from the gravel (Mead and Woodall 1968). The life-stage following emergence was defined to be the 'juvenile' life-stage, and comprised the months from emergence until the time of smolting when juvenile sockeye completed their seaward migration (Figure 2.4). The duration of this life stage was determined from the observed timing of declines in catch per unit effort from seine hauls taken in the estuary.

In order to evaluate their residence patterns and spatial distribution, we periodically captured juvenile sockeye throughout the river and estuary. Six sampling sites were established within the East Alsek River, including three sites located within pool-type habitats and three sites located in riffle-type habitats. Pool and riffle sites were adjacent to one another along the river. Three additional sites were located in the estuarine lagoon downstream of the East Alsek River for a total of 9 collection sites (Figure 2.2). The nine sites were sampled at three week intervals beginning on June 4, 2005 and ending September 1, 2005, and then again from June 1, 2006 to August 31, 2006. A 4.5 m x 1.8 m fine mesh (6.4mm) beach seine was used to sample river sites and a larger 12.2 m x 1.8 m fine mesh (3.2mm)beach seine was used to sample estuarine lagoon sites (Figure 2.5).

Our sampling effort at each site depended on our success in capturing juvenile sockeye. We sampled for a maximum of five seine tows at each site or until we captured a minimum of 30 juvenile sockeye salmon, whichever came first. Each seine tow consisted of a 90 second sampling effort, where two individuals fished the seine along the substrate, either in an upstream or downstream direction. The seine was pursed at the end of the 90 second interval so the fish would be contained within the net. The pursed seine was then taken to the shoreline where any fish contained within the net were placed in buckets for processing. If we caught more than 30 sockeye, the remaining sockeye were counted and released. Weight was recorded as wet weight before each fish was placed in ethanol (preservative) using an electronic scale accurate to 0.1 g. Length was recorded from the fish's nose to fork using calipers accurate to within 0.1 mm. All other species were counted and returned to the water at the place of capture.

Condition and growth of juvenile sockeye

Analyses of the juvenile sockeye collections sought to determine the rearing locations of juvenile sockeye, as well as the time and size at which juvenile sockeye enter Gulf of Alaska waters. The fork length, weight and condition factor of juvenile sockeye were summarized by their collection site, date of sample and collection period. Groups of sample dates were used for among site comparison. The samples were further analyzed to determine the relationship between weight, length, and condition factor, over time and by collection site. Condition factor, a mathematical function of length and weight, was calculated as the (weight/length^3) x 100,000 (Beckman et al. 2000). Samples were analyzed for each collection site to determine if a temporal increase in size was detectable. Also, samples at both river and estuary locations were pooled to determine if differences in length, weight or condition existed. Juvenile sockeye collection samples were pooled by sample time period to determine if there were differences in length, weight, or condition by location on the river. All analyses were conducted using a parametric one-way ANOVA using equal or unequal variances, depending on the appropriateness of each test.

Environmental Data Collection

The influence of local precipitation and temperature on conditions in the East Alsek River was examined by comparing local Dry Bay temperature and precipitation with water temperature and flow of the East Alsek River. Ambient temperature and precipitation were monitored using an Onset Micro-weather station deployed in Dry Bay, approximately 2 km from the river. Precipitation data was compared to groundwater elevation at four piezometers and also compared to the Alsek and East Alsek stage height in order to establish which water source, precipitation or the Alsek River, had the greatest influence on the groundwater source of the East Alsek River (Soiseth et al. 2005).

Monthly precipitation and temperature data were compiled from a Yakutat (NOAA weather) observation station to compare with the meteorological data collected over the two seasons in Dry Bay. Monthly totals for precipitation and monthly temperature averages were compared and analyzed using a Pearson correlation test (Zar 1999). This provided a necessary comparison of Dry Bay weather to Yakutat weather so that the long-term Yakutat weather data could be used as a surrogate for the sparser Dry Bay weather data when necessary.

Modeling of environmental effects on life-stages

We examined the effect of environmental variables on the spawner/recruit relationship using equation 2.1 (Quinn and Deriso 1999). The environmental variables included temperature, precipitation, freezing days, and the North Pacific Index (NPI) where appropriate. The environmental conditions present during each of the freshwater or marine life stages were pooled over the months encompassing each life stage (Table 2.1).

Fifteen separate spawner-recruit models (Eq. 2.1) were created using a standard Ricker model, as well as a modified Ricker that incorporated each of the environmental indices appropriate for each life stage investigated: egg, fry, juvenile and 1st year marine. Spawner abundance was estimated using Alaska Department of Fish and Game (ADFG) aerial counts multiplied by 3/2 (Clark et al. 2003). The number of recruits was calculated using age-structured estimates provided by ADFG scale samples from fish collected on the East Alsek spawning grounds (Clark et al. 2003). Alpha, beta and gamma were estimated for the model by minimizing the sum of squared residuals between the predicted and observed ln(R/S), using Excel™ Solver™. The small sample Akaike Information Criterion (AICc) was calculated for each model; a smaller AICc value indicated a better model (Akaike 1974; McQuarrie, and Tsai 1998).

Modeling flood effects on sockeye recruitment

A modified Ricker spawner-recruit model was also constructed to incorporate the effects of known Alsek flooding events (Equation 2.2). The model preserved density-dependent effects inherent in Ricker type spawner-recruit models, and incorporated persistent benefits of flood events in the carrying capacity parameter (β). The documented events included two accounts (1981 and 1987) from the owner of a fishing lodge located at the East Alsek River mouth (Lowenstein, personal communication). Two other flooding accounts (1980 and 1983), were documented from ADFG reports (Smith et al. 2006) that also corroborated the 1981 flood account. Since flooding events were not well documented prior to 1979, the model was evaluated using only data after 1979. The discharge or duration of individual flood events was lacking, and the model did not take these factors into account.

The same model that incorporated flood events was used on four additional ocean-type sockeye populations located nearby in the Yakutat forelands (Table 2.3). This was an effort to determine whether any flood effects seen in the East Alsek Model were due to a combination of regional events that corresponded with Alsek flood events rather than to the direct effects of flooding. The AICc was again used to evaluate the performance of this model in comparison to standard Ricker models without flood effects.

Recruitment trends in Yakutat Area Rivers

Trends in recruitment were examined for four nearby Yakutat Area Rivers (the Italio, Situk, Akwe, and Lost Rivers) and these were compared to trends in the East Alsek River. To remove the confounding effects of density, each river was modeled using a standard Ricker spawner/recruit model and the residuals for each year were examined for trends (Geiger 2004). The residuals for the five separate control rivers in each year (because of missing data, in some years there were less than four controls) were then sorted, and the percentile rank of the East Alsek River residual relative to the others was calculated. This provided an independent measure of how the East Alsek sockeye recruitment compared to other ocean type sockeye populations in the same vicinity.

Results

Duration of freshwater residence stages

The resident time periods of egg, fry, and juvenile life stages for East Alsek sockeye salmon are displayed by month in Figure 2.3, for 2005 and 2006. We estimated a mean hatch date of January 26 and a mean date of fry emergence of April 30. Therefore we used September through January as the egg incubation period (Figure 2.4), and conservatively used January to March as the duration of the fry stage.

Juvenile sockeye were captured from the onset of the sampling season, beginning June 1, until a steep reduction in numbers in early July. The juveniles caught in the river during this early time period were free of yolk sacs but were still very small (26mm to 30mm) in both years of the study, suggesting recent emergence from spawning gravels. This observation corresponds with our predicted date of emergence based on published incubation-temperature relationships for sockeye (Mead and Woodall 1968).

We collected a total of 3426 and 3572 juvenile sockeye from all nine collection sites throughout the summer of 2005 and 2006 respectively. The catch-per-unit effort (CPUE) for these fish decreased throughout the sampling season, suggesting a drop in relative abundance in both the river and estuary (Figure 2.5). Both sampling years saw a dramatic decrease in CPUE in early July. Very few sockeye were caught during August and September within the river or estuary, indicating that the juveniles outmigrated to the Gulf of Alaska prior to this time. Of the total number of juvenile sockeye caught, only 93 (3% of total) sockeye and 142 (4% of total) sockeye were caught within the river between August to September, 2005 and 2006 respectively. This confirms that East Alsek sockeye are ocean-type sockeye, and migrate to the ocean during their first year of life. The size of juvenile salmon in the estuary was somewhat larger than in the river, but didn't change significantly over the season, suggesting that juvenile sockeye use the estuary as a transitional environment to grow quickly and exit into the Gulf of Alaska.

Other species

A minimum of eight other species were also captured during seine tows in the river and estuary. These included juvenile coho (*O. kisutch),* king (*O. tshawytscha)*, pink (*O. gorbuscha*), and chum (*O. keta*) salmon, as well as both adult and juvenile forms of Dolly Varden char (*Salvelinus malma),* starry flounder (*Platichthys stellatus*), sculpin (*Cottus armatus, Leptocottus spp.*), threespined stickleback (*Gasterosteus aculeatus)*, and sandlance (*Ammodytes hexapterus*). Sample collections were dominated by juvenile sockeye and juvenile coho within the river, but exhibited greater diversity within the estuarine waters of the East Alsek Lagoon (Figure 2.6). We observed a peak in three-spined stickleback catch within the estuary during the mid summer as well as an increase in starry flounder and sculpin composition as the season progressed.

Condition and growth of juvenile sockeye

During the collection period, juvenile sockeye ranged in size from 26 mm to 104 mm. At estuary collection sites, sockeye sizes ranged between 0.45 g and 10 grams (wet weight) and between 35 mm and 103mm (FL). There was an increase in sockeye fork length and weight at the river collection sites in the early summer months, followed by a plateau later in the summer (Figures 2.7-2.87; ANOVA, $p<0.05$). The same increase was not detected within the estuarine lagoon; juvenile sockeye collections for estuarine locations did not show any growth or significant change in condition factor throughout the season.

Weight and length of juvenile sockeye was clearly larger at estuarine collection sites than at river collection sites (Figure 2.7 and 2.8; ANOVA, $p<0.01$). There was no significant difference in fork length, weight or condition factor between sample sites in either the river or lagoon (Figure 2.10).

Environmental influences

Dry Bay and Yakutat records were highly correlated (r^2=0.99 each) for both monthly average temperature and number of days below freezing over 15 months of data. Precipitation monthly averages were not as highly correlated, but the correlation was still statistically significant (r^2=0.77, n = 14, p = 0.05). Precipitation records in 2006 were more correlated than in 2005 (r^2=0.99, and r^2=0.56 respectively). Given the significant correlation, the longer period of record from Yakutat NOAA weather station were used as surrogate data for the environmental effect modeling of East Alsek River sockeye recruitment.

Modeling of environmental effects on life stage

The only environmental effects model to perform better than the standard model was one using precipitation during the juvenile life-stage (Table 2.3, Figure 2.10). This model appeared to perform well in the first 20 years of the data; however, during the last 10 years it did not explain the sudden downturn in recruitment (Figure 2.10).

Modeling flood effects on sockeye recruitment

Incorporating flood effects significantly improved the Ricker model in predicting East Alsek sockeye recruitment (Table 2.4, Figure 2.11). The parameter estimates for the standard Ricker model suggested a very large maximum recruitment for East Alsek sockeye (Table 2.4). However, the estimated value from the flood was more reasonable and this model did well at reproducing both the early 1980's recruitment as well as the downturn in recruitment seen in the 1990's (Figure 2.11). The East Alsek sockeye population was also the only population of five local sockeye populations (Akwe, Lost, Italio, and Situk) that had a better AICc value for the model that introduced a flood effect (Equation 2.2; Figure 2.12).

Recruitment trends in Yakutat forelands rivers

Stock productivities, as indexed by the residuals of the East Alsek stock-recruitment relationship were consistently among the highest among residuals of five Yakutat Area rivers prior to 1990 (Figure 2.13). However, after 1990 the rank of East Alsek recruitment residuals fell to last place. This suggests that East Alsek sockeye stock productivity was following localized trends in recruitment, and not region-wide trends. A lack of flooding in the East Alsek is coincident with the reduction in rank of productivity for the East Alsek, supporting the idea that East Alsek River sockeye benefited from the previous cluster of flooding events.

Discussion

Evidence was found that flooding positively influences the recruitment of East Alsek sockeye. After exploration of local environmental effects, basin-wide population trends in sockeye production and marine conditions, the most compelling explanation for the recent downturn in East Alsek sockeye production is the absence of large-scale flooding events. In the past, these events originated when the Alsek River overflowed onto the spawning grounds of the East Alsek River. Several mechanisms associated with these scouring flows may explain why flooding boosts production in this system.

Sediment and aquatic vegetation compose a substantial proportion of habitat available to sockeye for spawning (Chapter 1). Flooding from the Alsek likely raised the East Alsek River velocity to a level capable of scouring fine sediments and vegetation and displacing them downstream to the estuary and Gulf of Alaska. The resultant displacement would have several effects, it would: 1) increase available spawning habitat, 2) introduce additional nutrients into the estuary for rearing juveniles, and 3) reduce the deposition of sediment atop eggs, a known source of mortality (Chapman 1988).

We found that the flood effect was the best explanation of recruitment for East Alsek River sockeye. This model greatly outperformed the standard Ricker model. In contrast, models incorporating other environmental variables were not supported. The one environmental effect that was supported could not explain the sudden downturn in recruitment that the East Alsek sockeye experienced in the late 1990's whereas the flood effect model predicted both the rise and fall in sockeye recruitment. Additional support for the flood-effect hypothesis was derived from the comparison of East Alsek sockeye recruitment to that of four local rivers. None of these rivers showed a pattern of decline and fall related to East Alsek flooding, as would be expected if some regional environmental effect were producing a spurious correlation between East Alsek flooding and sockeye productivity.

Between the first recorded flood in 1980 and the last flood recorded in 1990, the East Alsek sockeye productivity (as residuals from a stock-recruitment relationship) was generally the highest among four other ocean-type sockeye populations in Yakutat Area Rivers. However, after 1990, the East Alsek productivity quickly dropped to last place for all five rivers examined. Assuming region wide environmental effects and marine conditions would impact these populations similarly, the years spanning known flood events on the East Alsek stand out in opposition to the trends on the four local rivers, giving further credence to increased production due to flooding.

Density dependence can occur when one production variable, such as habitat, is limiting the production potential of the population. When we examined the Ricker models in an attempt to predict East Alsek sockeye recruitment, density-dependence was not evident for this population of sockeye. Given the limited habitat available on the 9km river, and the varied escapements that the population has experienced since 1970 of between

14,200 and 250,000 fish, this is not an expected result. The range of escapements provided sufficiently contrasting data to observe a density-dependent effect if habitat was a limiting factor in production. However, if the amount of available habitat varied over this time period due to the habitat-altering effects of flooding and sedimentation, then density dependence could not be tracked using the traditional stock-recruitment models.

Despite the strong evidence for a flood affecting recruitment, there are some limitations to our analyses. For instance, the flood effect model was based upon a cluster of flood events that occurred from 1980-1987. If any change in marine condition or other environmental event also occurred during that time period (other than flooding), the flood model might be spuriously supported. The cessation of foreign-fleet offshore gillnetting following the Magnuson-Stevens Fisheries Management and Conservation Act in 1976 also coincides with the steep rise in production of the East Alsek River sockeye. The 1980's were also a part of an Alaskan-wide trend of increased salmon production, widely attributed to favorable ocean conditions during that decade (Mantua et al. 1997). The combination of these effects would provide East Alsek sockeye increased marine survival, resulting in greater returns to the river. However, patterns in the East Alsek differed from those in neighboring rivers, which should also be subject to these influences.

Precipitation was shown to have an immediate effect on groundwater and East Alsek flow (Soiseth et al. 2005), but the data from Yakutat that was used to model this effect was less correlated with Dry Bay precipitation than that of temperature (r^2=0.77). Reasons for this discrepancy could be due localized meteorological and hydrological differences. The lack of a long term precipitation record in Dry Bay is a drawback to the accuracy of the environmental effects model that describes the impact of precipitation on production.

Hatch and emergence timing were taken from studies of stocks in British Columbia (Mead and Woodall 1968). The relationship between temperatures and hatch and emergence times for these sockeye stocks may differ from that of the population of sockeye on the East Alsek River. However, our seine samples corroborate the emergence timing estimates we calculated.

Finally, the population data for this study was derived from aerial surveys of escapement in concert with harvest data. Aerial surveys are notoriously noisy in their nature. On the other hand, the East Alsek is an ideal system for this type of survey due to the clarity of the river and the shallow water distribution of sockeye, making sockeye counts fairly accurate even under poor conditions. Nonetheless, the lack of a weir, counting tower, or sonar station for another source of escapement data undoubtedly introduced noise into the spawner/recruit data used in our analyses.

Despite these qualifications, the evidence suggests that a recent lack of flooding has resulted in a downturn in East Alsek Sockeye production. Local land uplift due to glacial recession is a likely contributing factor to the change in the East Alsek flood frequency. This uplift has influenced the vegetation and hydrology in a relatively short time span. Historic maps of the area from 1850 to present (Morse 1908; USGS 1959; NASA 2007) show how the Dry Bay area has changed from a barren and braided outwash delta to the mixed-shrub and coniferous forest of today. These maps similarly show the East Alsek shifting from a distributary channel of the Alsek to a river unto itself. These dynamic changes are likely to continue, with unknown consequences to the sockeye of the East Alsek.

A few other notable results were derived from this research. The only model to outperform the standard Ricker model was one incorporating precipitation during the juvenile life stage. An increase in precipitation correlated with an increase in recruitment. Increased precipitation can introduce additional organic input into an aquatic system thereby providing terrestrial insects or other forage for juvenile sockeye (Kawaguchi and Nakano, 2001). In the case of the East Alsek River, the increased precipitation might also displace juveniles from the cooler river environment into the warmer estuarine environment. Given enough food, higher temperature is more favorable for rapid growth (Soiseth et al. 2005).

We consistently observed fish as small as 30 mm into the month of July, suggesting a prolonged emergence of sockeye. This can be explained by a protracted spawning period coupled with the variable temperature regime (Figure 2.5). We estimated that late spawning sockeye (October/November), would not produce emergent fry until June or July, whereas the sockeye that spawn just a month earlier would produce offspring that would emerge in April and May. This late emergence may have survival consequences for the fry if they outmigrate as smaller individuals,

In summary, our investigation points to periodic flooding from the Alsek River as the primary cause of the excellent returns observed in the 1980's and 1990's. No flood has occurred in the last 20 years, and the probability of further flooding is decreasing as the land is uplifted. It seems likely that the resultant loss of habitat to sedimentation and growth of aquatic vegetation will further reduce productivity of this stock. However, the continued evolution of the streamside vegetation and streambed could result in novel characteristics with unexpected consequences to the sockeye salmon stock.

Literature Cited

Akaike, H (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control* 19 (6): 716–723.

Baxter, CV, and Hauer, FR (2000). Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (Salvelinus confluentus). *Canadian Journal of Fisheries and Aquatic Sciences*, *57* (7), 1470-1481.

Beamish, RJ., and Bouillon, DR (1993). Pacific salmon production trends in relation to climate. *Canadian Journal of Fisheries and Aquatic Sciences*, 1002-1016.

Beckman BR, Larsen DA, Sharpe C, Lee-Pawlak B, Schreck CB, et al. (2000) Physiological Status of Naturally Reared Juvenile Spring Chinook Salmon in the Yakima River: Seasonal Dynamics and Changes Associated with Smolting. Transactions of the American Fisheries Society: Vol. 129, No. 3 pp. 727–753

Blair, GR, Rogers, DE, and Quinn, TP (1993). Variation in life history characteristics and morphology of sockeye salmon in the Kvichak river system, Bristol Bay, Alaska. *Transactions of the American Fisheries Society*, *122*, 550-559.

Bovee, KD (1997). *DATA COLLECTION PROCEDURES FOR THE PHYSICAL HABITAT SIMULATION SYSTEM.* Ft. Collins, CO: U.S. Geological Survey - Biological Resources Division.

Bradford, MJ (1995). Comparative review of Pacific salmon survival rates. *Canadian Journal of Fisheries and Aquatic Sciences*, *52*, 1327-1338.

Brett, JR 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). American Zoologist 11:99–113.

Burger, CV, Finn, JE, and Holland-Bartels, L (1995). Pattern of Shoreline Spawning by Sockeye Salmon in a Glacially Turbid Lake: Evidence for Subpopulation Differentiation. *Transactions of the American Fisheries Society*, *124* (1), 1-15.

Burgner, RL (1991). Life history of sockeye salmon (Oncorhynchus nerka). Pacific salmon life histories. *Sockeye Salmon* (pp. 1-117). Vancouver, BC: UBC Press.

Carpenter, SR, and Lodge, DM (1986). Effects of submerged macrophytes on ecosystem processes. *Aquatic Botany*, *26*, 341–370.

Chapman, DW (1988). Critical review of variables used to define effects of fines in redds of large salmonids. *Transactions of the American Fisheries Society*, *117*, 1-21.

Clark, JH, Burkholder, A, and Clark, JE. (1995) Biological escapement goals for five sockeye salmon stocks returning to streams in the Yakutat area of Alaska. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Divisions, Regional Informational Report 1J95-16, Juneau.

Clark, JH, Woods, GF and Fleischman, S (2003) Revised biological escapement goal for the sockeye salmon stock returning to the East Alsek-Doame river system of Yakutat, Alaska. Alaska Department of Fish and Game, Special Publication Series No. 03-04, Anchorage.

Coble, DW (1961). Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. *Transactions American Fisheries Society , 90,* 469-474.

Cole, J (2000) Coastal sea surface temperature and coho salmon production off the north-west United States Fisheries Oceanography 9 (1), 1–16

Collier, MP, Webb, RH, and Andrews, ED (1997). Experimental flooding in Grand Canyon. *Scientific American* .

Cooper, A C (1965). *The effect of transported stream sediments on survival of sockeye and pink salmon eggs and alevins.* British Columbia Canada: International Pacific Salmon Commission Bulletin 18.

Davis, J C (1975). Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. *Canadian Journal of Fisheries and Aquatic Sciences , 32,* 2295-2332.

Dawson, FI (1978). The seasonal effects of aquatic plant growth on the flow of water in a stream. *Proceedings European Weed Research Society 5th symposium on aquatic weeds*, (pp. 71-78). Amsterdam, Netherlands.

Downton, MW, Miller KA (2000) Relationships between Alaskan salmon catch and North Pacific climate on interannual and interdecadal time scales. Canadian Journal of Fisheries and Aquatic Sciences. 55(10): 2255–2265

Edmundson JA, Mazumder A (2001) Linking Growth of Juvenile Sockeye Salmon to Habitat Temperature in Alaskan Lakes. Transactions of the American Fisheries Society: Vol. 130, No. 4 pp. 644–662

Egglishaw, HJ, and Shackley, PE (1977). Growth, survival and production of juvenile salmon and trout in a Scottish stream, 1966-75. *Journal of Fish Biology*, *11* (6), 647-672.

Fleming, IA, and Jensen, AJ (2002). Fisheries: Effects of Climate Change on the Life Cycles of Salmon. *Causes and consequences of global environmental change*, *3*, 309-312.

Fukushima, M (1996). Effects of density-dependence, environment and species interaction during spawning and incubation on population dynamics of pink and sockeye salmon in the Auke Lake system, Southeast Alaska. Doctoral dissertation. Fairbanks, AK: University of Alaska Fairbanks.

Fukuwaka, M, and Kaeriyama, M (1997). Scale analyses to estimate somatic growth in sockeye salmon, Oncorhynchus nerka. *Canadian Journal of Fisheries and Aquatic Sciences*, *54* (3), 631-636.

Gargett, A E (1997). The optimal stability `window': a mechanism underlying decadal fluctuations in North Pacific salmon stocks? *Fisheries Oceanography*, *6* (2), 109-117.

Garrett, J W, Bennett, D H, Frost, F O, and Thurow, R F (1998). Enhanced Incubation Success for Kokanee Spawning in Groundwater Upwelling Sites in a Small Idaho Stream. *North American Journal of Fisheries Management*, *18* (4), 925-930.

Geiger, HJ and McPherson, S. (2004). Stock status and escapement goals for salmon stocks in Southeast Alaska. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Special Publication No. 04-02, Anchorage

Geist, D R (2000). Hyporheic discharge of river water into fall Chinook salmon (Oncorhynchus tshawytscha) spawning areas in the Hanford Reach, Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences*, *57*, 1647-1656.

Geist, D R, and Dauble, D D (1998). Redd site selection and spawning habitat use by fall Chinook salmon: the importance of geomorphic features in large rivers. *Environmental Management*, *22*, 655-669.

Geist DR, Hanrahan TP, Arntzen EV, McMichael GA, Murray CJ, et al. (2002) Physicochemical Characteristics of the Hyporheic Zone Affect Redd Site Selection by Chum Salmon and Fall Chinook Salmon in the Columbia River. North American Journal of Fisheries Management: Vol. 22, No. 4 pp. 1077–1085

Groot, Cornelius and Margolis, Leo, eds., 1991. "Pacific Salmon Life Histories," University of British Columbia Press.

Hall, J L, and Wissmar, R C (2004). Habitat Factors Affecting Sockeye Salmon Redd Site Selection in Off-Channel Ponds of a River Floodplain. *Transactions of the American Fisheries Society*, *133* (6), 1480–1496.

Heinl, S C, Zadina, T P, McGregor, A J, and Geiger, H J (2003). *Chum salmon stock status and escapement goals in Southeast Alaska.* 1J03-8. Juneau, AK: Alaska Department of Fish and Game.

Henderson, MA; Cass, AJ (1991) Effect of smolt size on smolt-to-adult survival for Chilko Lake sockeye salmon (Oncorhynchus nerka) Canadian Journal of Fisheries and Aquatic Sciences 48 (6) 988-994.

Hendry, A P, and Quinn, T P (1997). Variation in adult life history and morphology among Lake Washington sockeye salmon (Oncorhynchus nerka) populations in relation to habitat features and ancestral affinities. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*, 75-84.

Hilborn, R, Quinn, T P, Schindler, D E, and Rogers, D E (2003). Biocomplexity and fisheries sustainability. *PNAS*, *100* (11), 6564-6568.

Johansen, M, Elliott, J M, and Klemetsen, A (2005). A comparative study of juvenile salmon density in 20 streams throughout a very large river system in northern Norway. *Ecology of Freshwater Fish*, *14* (1), 96-110.

Kawaguchi, Y, and Nakano, S (2001). Contribution of terrestrial invertebrates to the annual resource budget for salmonids in forest and grassland reaches of a headwater stream. *Freshwater Biology*, *46* (3), 303-316.

Lamb, H (1945) Hydrodynamics Courier Dover Publications.

Lapointe, M F, Bergeron, N E, Berube, F, Pouliot, M A, and Johnston, P (2004). Interactive effects of substrate sand and silt contents, redd-scale hydraulic gradients, and interstitial velocities on egg-to-emergence survival of Atlantic salmon (Salmo salar). *Canadian Journal of Fisheries and Aquatic Sciences*, *61* (12), 2271-2277.

Leonetti, F E (1997). Estimation of surface and intragravel water flow at sockeye salmon spawning beaches in Iliamna Lake, Alaska. *North American Journal of Fisheries Management*, *17* (1), 194-201.

Mantua, NJ, Hare, SR, Zhang, Y, Wallace, JM, and Francis, RC (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78: 1069–1079.

McQuarrie, A D R and Tsai, CL, (1998). *Regression and Time Series Model Selection.* World Scientific.

Mead, R W, and Woodall, W L (1968). *Comparison of sockeye salmon fry produced by hatcheries, artificial channels and natural spawning areas.* International Pacific Salmon Fisheries Commission Progress Report.

Morse, F (1908). International Boundary between United States and Canada, From Cape Muzon to Mount St. Elias. Sheet No. 12 [map]. . *Article VI of the convention of 1903. Convention between Great Britain and United States: Signed 1928.*

NASA. (2007). Image, Alaska, United States, 2000 Satellite Imagery [map]. Eye Alt 11.7mi; generated Derrek Faber; using Google Earth. <http://www.googleearth.com/> (20 Feb. 2007).

Patten, D T, Harpman, D A, Voita, M I, and Randle, T J (2001). A Managed Flood on the Colorado River: Background, Objectives, Design, and Implementation. *Ecological Applications*, *11* (3), 635-643.

Quinn II, T J and Deriso R B (1999) Quantitaive Fish Dynamics. Oxford University Press, Oxford & New York, 542p.

Sidle, RC (1985). Transport of sediment and organic material in streams of coastal Alaska. Pp. 305-326 in Sigbjarnarson (ed.) Iceland Coastal and River Symposium Proceedings.

Smith, J J, Reed, D, Tracy, M, and Clark, J H (2006). *A mark-recapture experiment to estimate the escapement of sockeye salmon in the East Alsek River, 2005.* Juneau, AK: Alaska Department of Fish and Game. Fishery data series No. 06-71.

Soiseth, C, C Murdoch, and D Faber (2005). Results of weather and water monitoring in the Dry Bay Preserve, Glacier Bay National Park 2005. National Park Service report:30 pp.

Thorne, RE and JJ Ames. (1987). A note on variability of marine survival of sockeye salmon (Oncorhynchus nerka) and effects of flooding on spawning success. Canadian Journal of Fisheries and Aquatic Sciences. 44(10):1791-1795.

USGS. (1959). 1:63,000 Yakutat A-2 [map].

Velsen, F P (1980). Embryonic development in eggs of sockeye salmon, Oncorhynchus nerka. Ottowa: Deptartment of Fisheries and Oceans.

Welch, D W, A I Chigirinsky, and Y Ishida (1995) Upper thermal limits on the oceanic distribution of Pacific salmon (*Oncorhynchus* spp) in the spring. Canadian Journal of Fisheries and Aquatic Sciences. 52:489-503.

Wu, F (2000). Modeling embryo survival affected by sediment deposition into salmonid spawning gravels: Application to flushing flow prescriptions. Water Resources Research 36(6): 1595–1603.

Zar, JH (1999) Biostatistical analysis-Fourth Edition. Prentice-Hall, Englewood Cliffs, NJ.

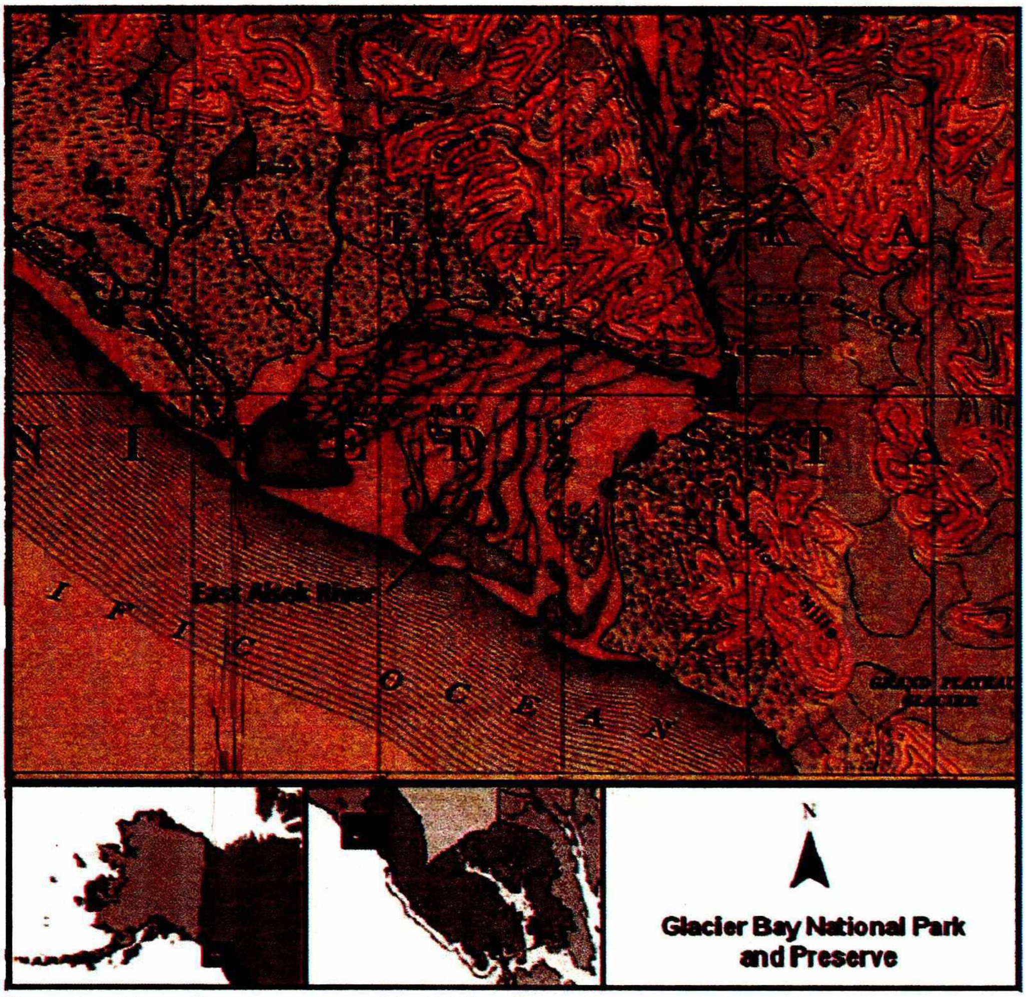

Figure 2.1 Map of Dry Bay surveyed by William Morse between 1906 and 1908. Dry Bay area is depicted as a barren outwash plain, void of trees or shrubs. The Alsek distributary channel that is now the East Alsek River is shown with an arrow.

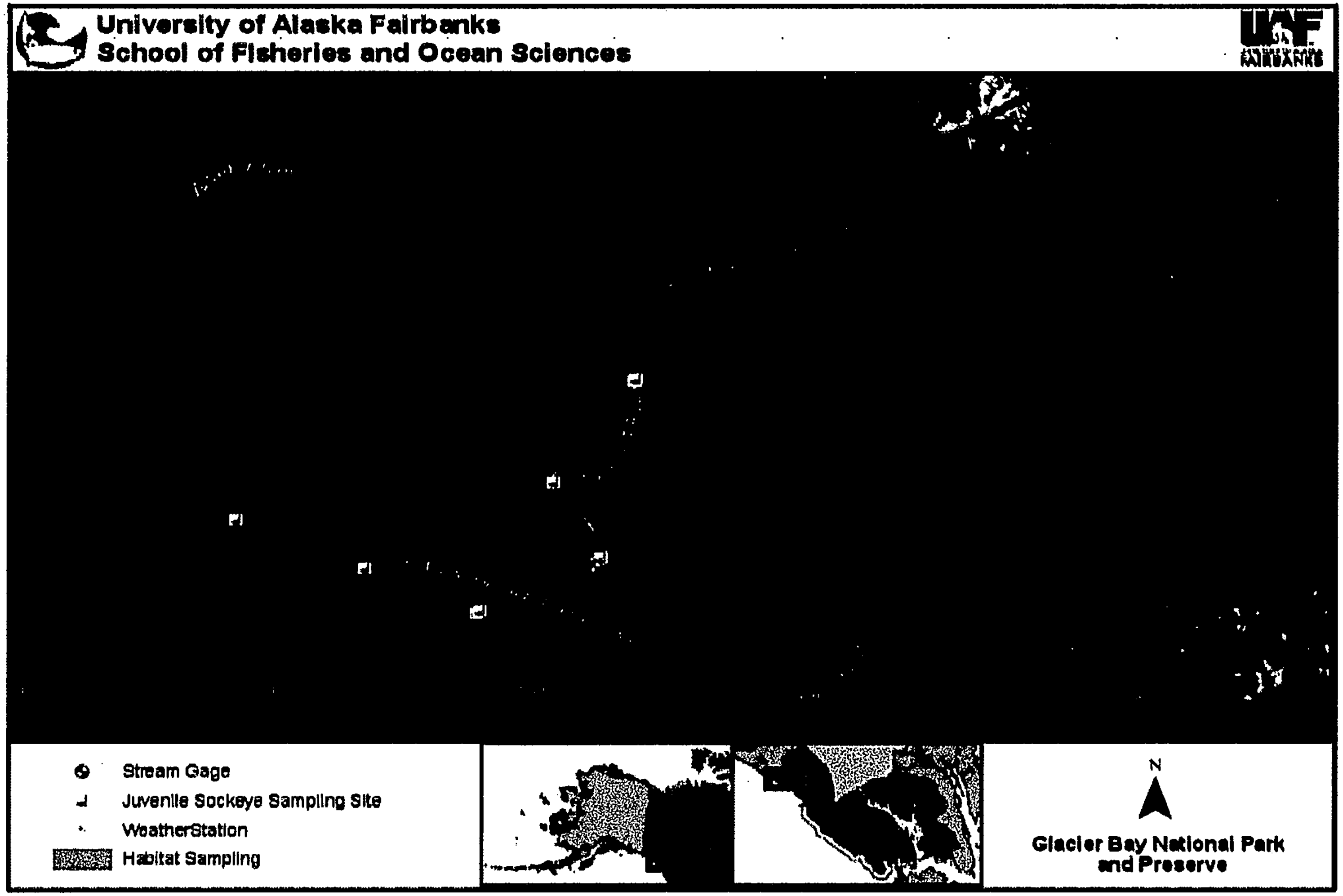

Figure 2.2 Contemporary map of Dry Bay from a 2000 LandSat 7 image. Map shows location of Alsek overflow channels; the last time Alsek water entered the East Alsek River was 1987.

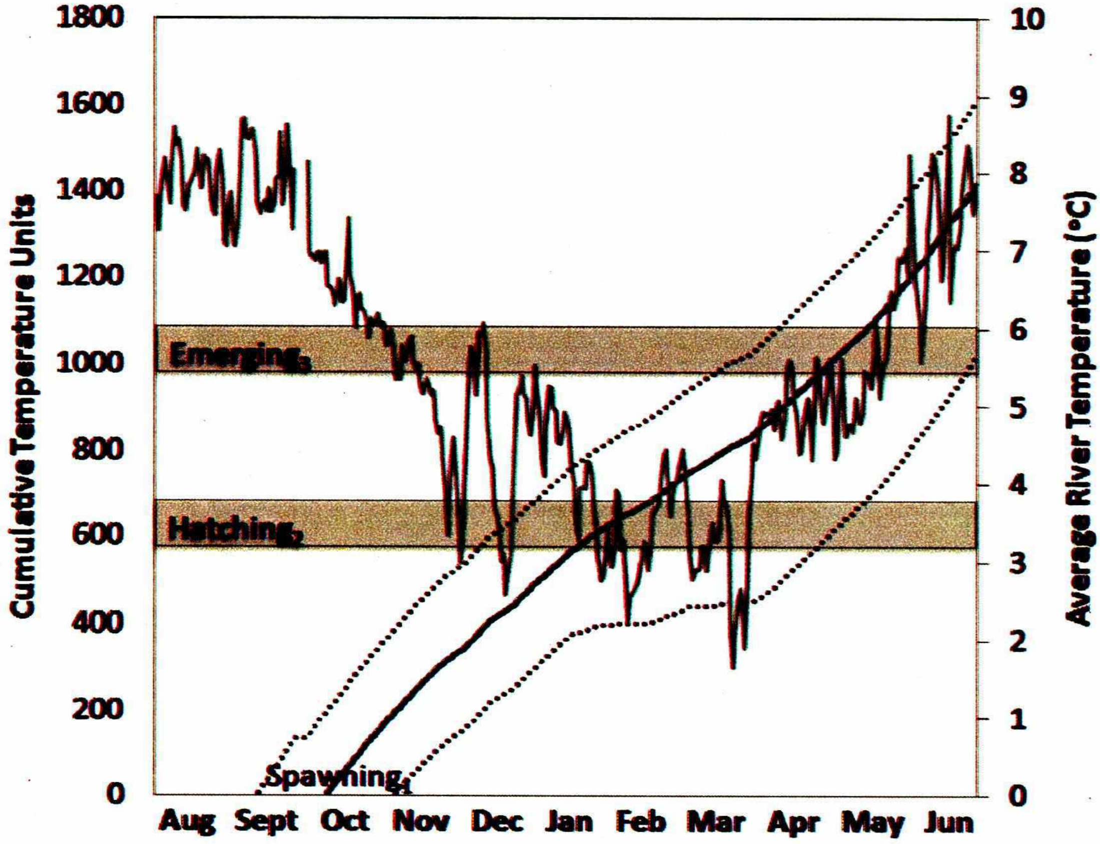

Figure 2.3 Average temperature from 2005 and 2006 temperature for three temperature loggers equally distributed from the mouth to the East Alsek River headwaters (solid line). Dotted lines are the bounds of cumulative temperature units with respect to eggs deposited from Aug 15 to October 15. Hatching time and emergence time (shaded bars) correspond to literature estimates of temperature units required for hatch and emergence.

[1] Clark et al. 2003; [2] Velsen 1980; [3] Mead and Woodall 1968

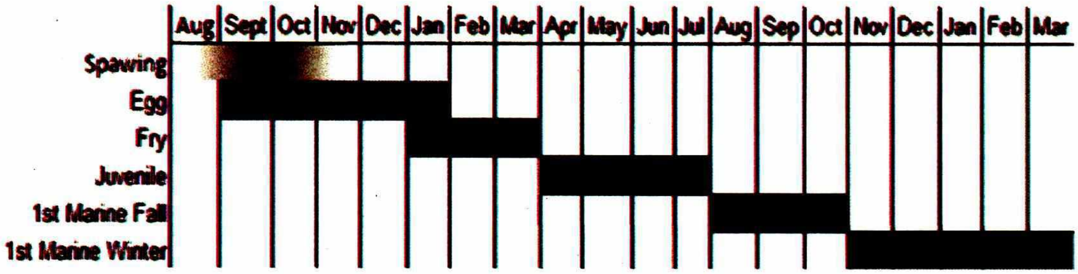

Figure 2.4 Estimated duration of each life-stage.

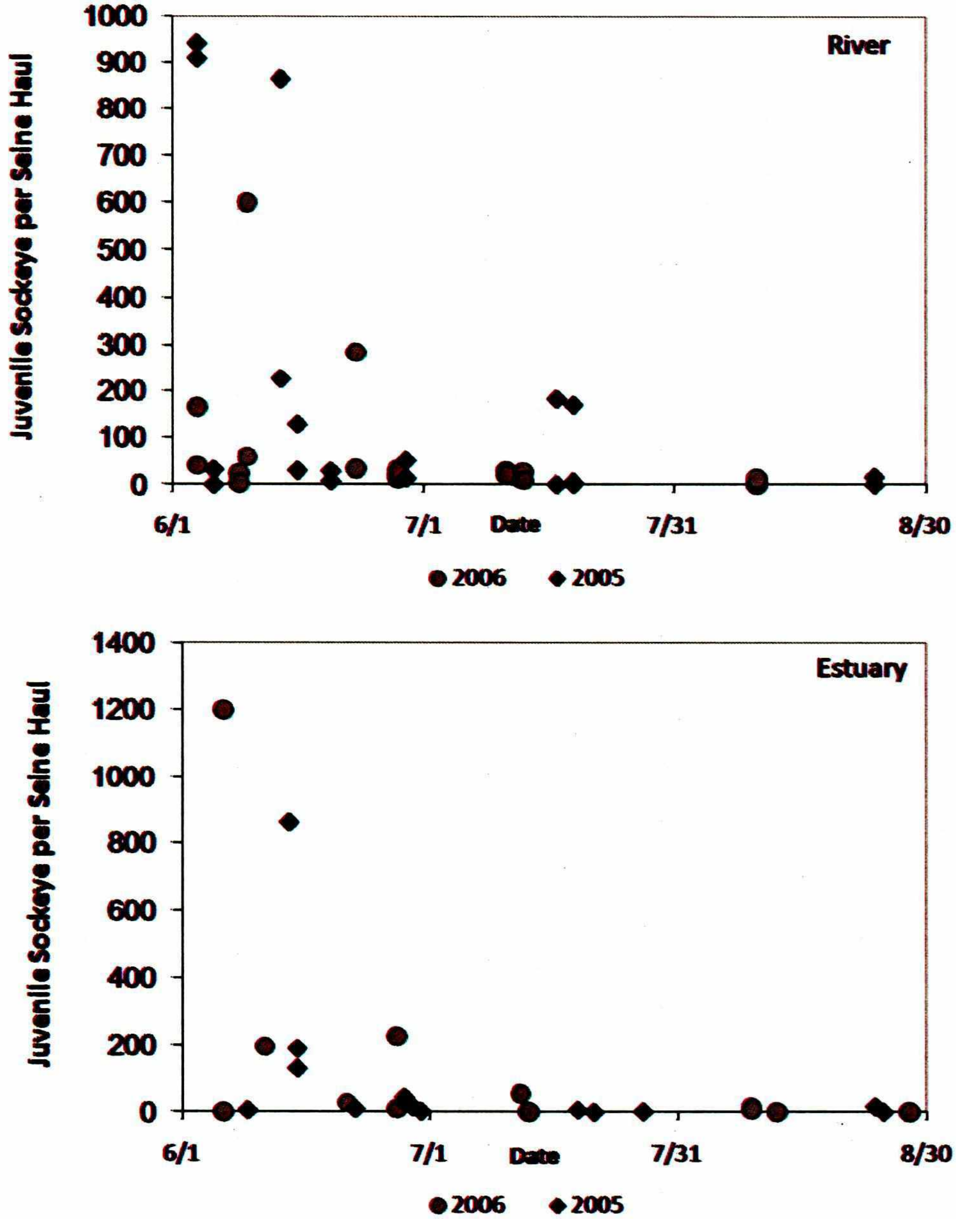

Figure 2.5 Catch per unit effort data for all juvenile sockeye sampled in the river (above) and estuary (below) relative to date sampled. Samples in 2005 are displayed as diamonds; samples taken in 2006 are circles.

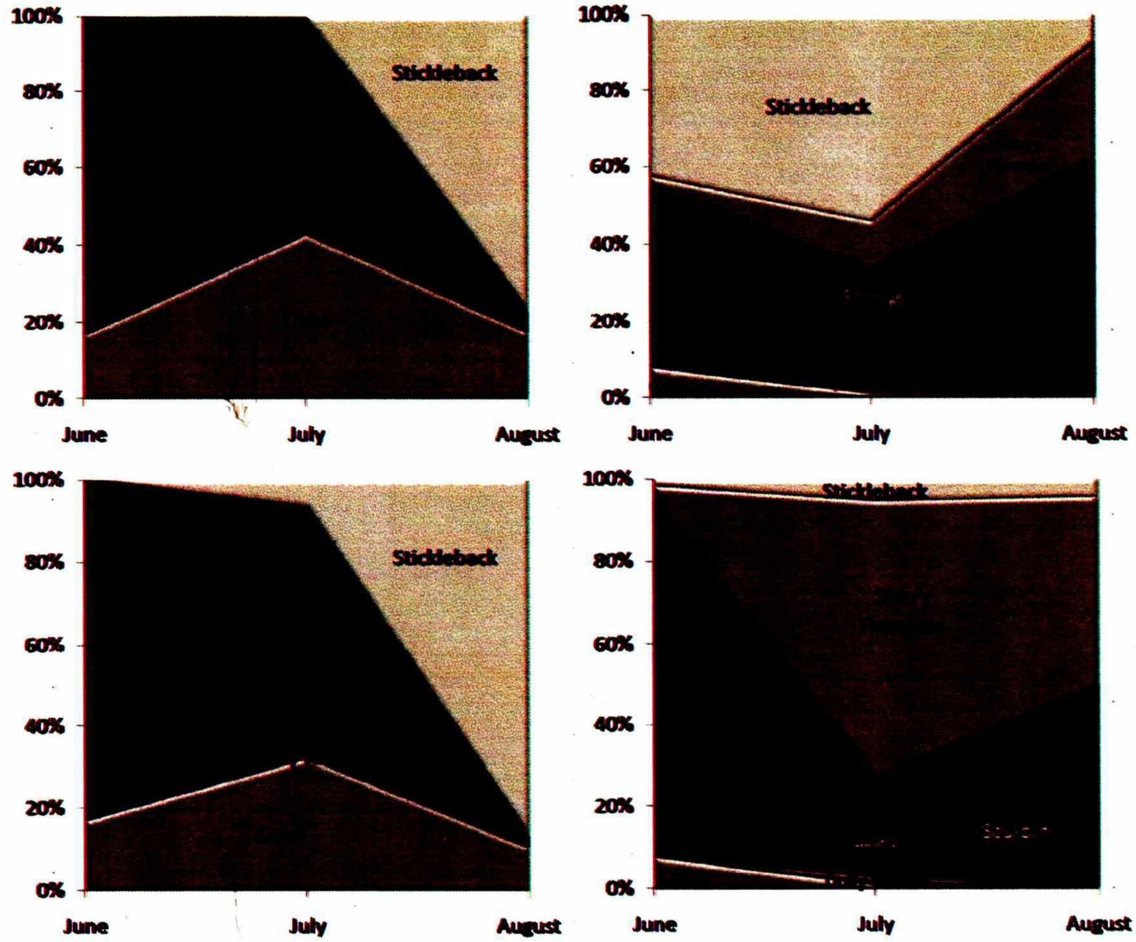

Figure 2.6 Species composition of seine samples taken in the river (left) and Estuary (right) for 2005 (above) and 2006 (below).

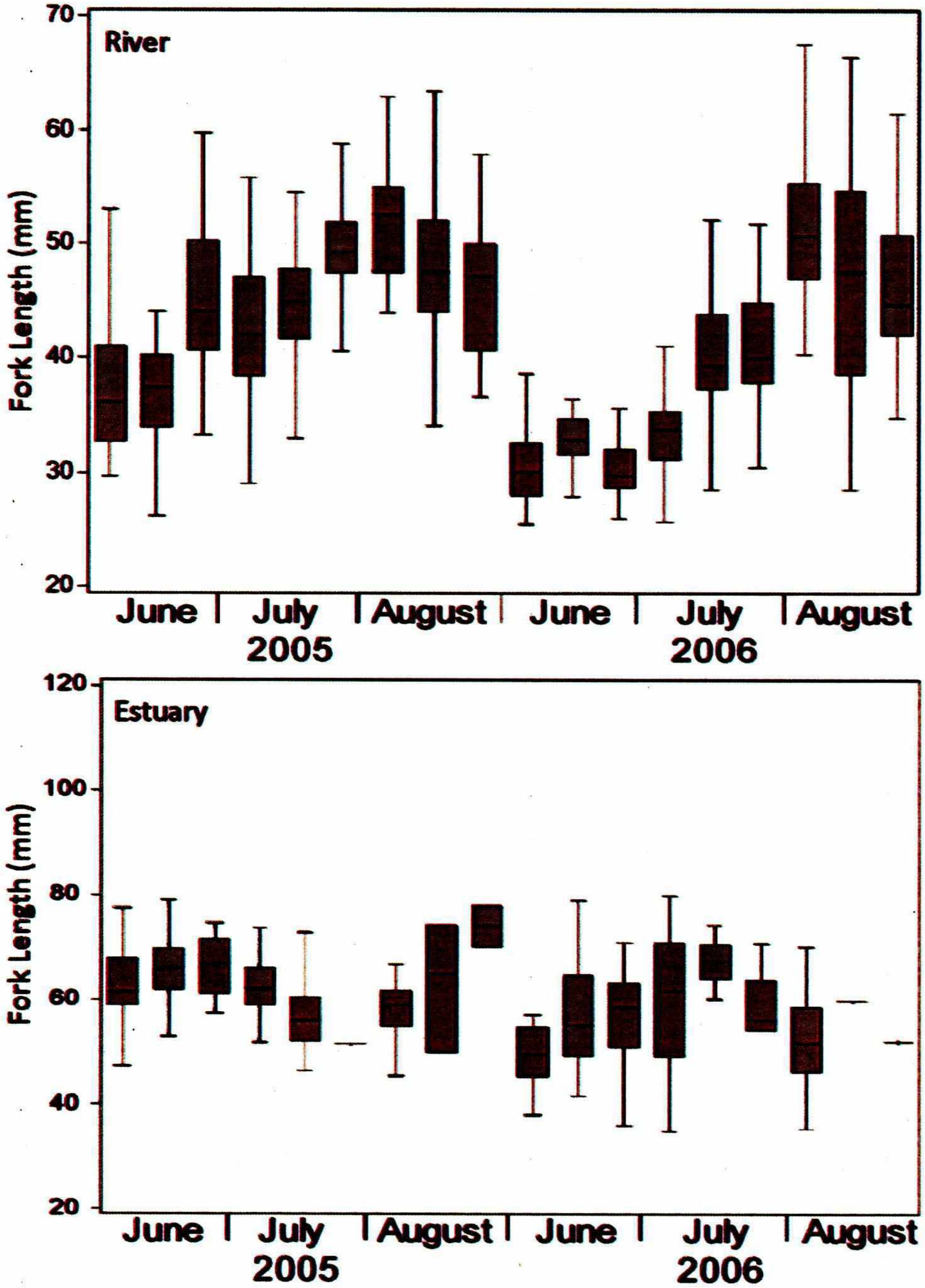

Figure 2.7 Box-plots of juvenile sockeye fork-length for all samples collected in the river and estuary during 2005 and 2006 summer months.

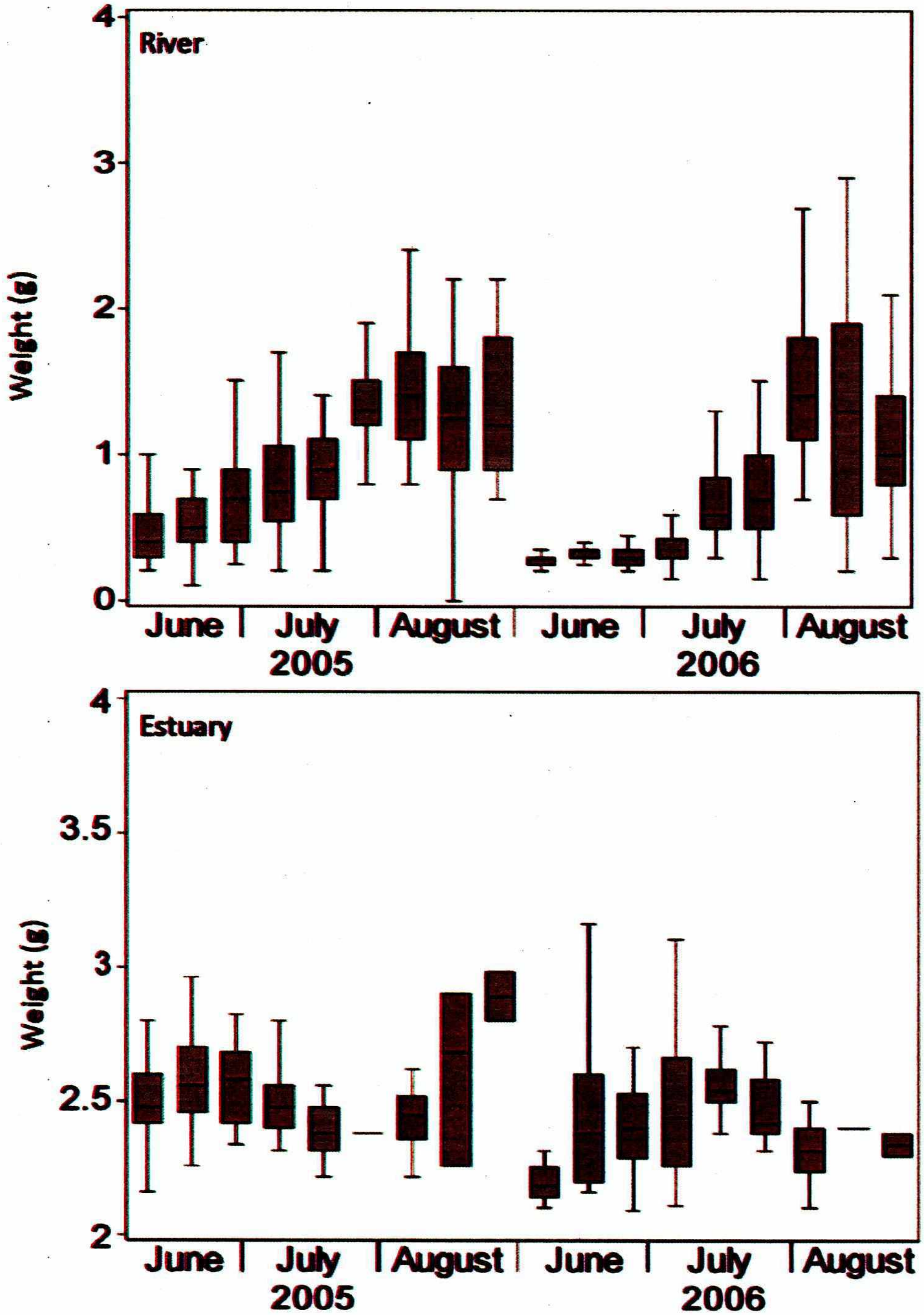

Figure 2.8 Box-plots of juvenile sockeye weight for all samples collected in the river and estuary during 2005 and 2006 summer months.

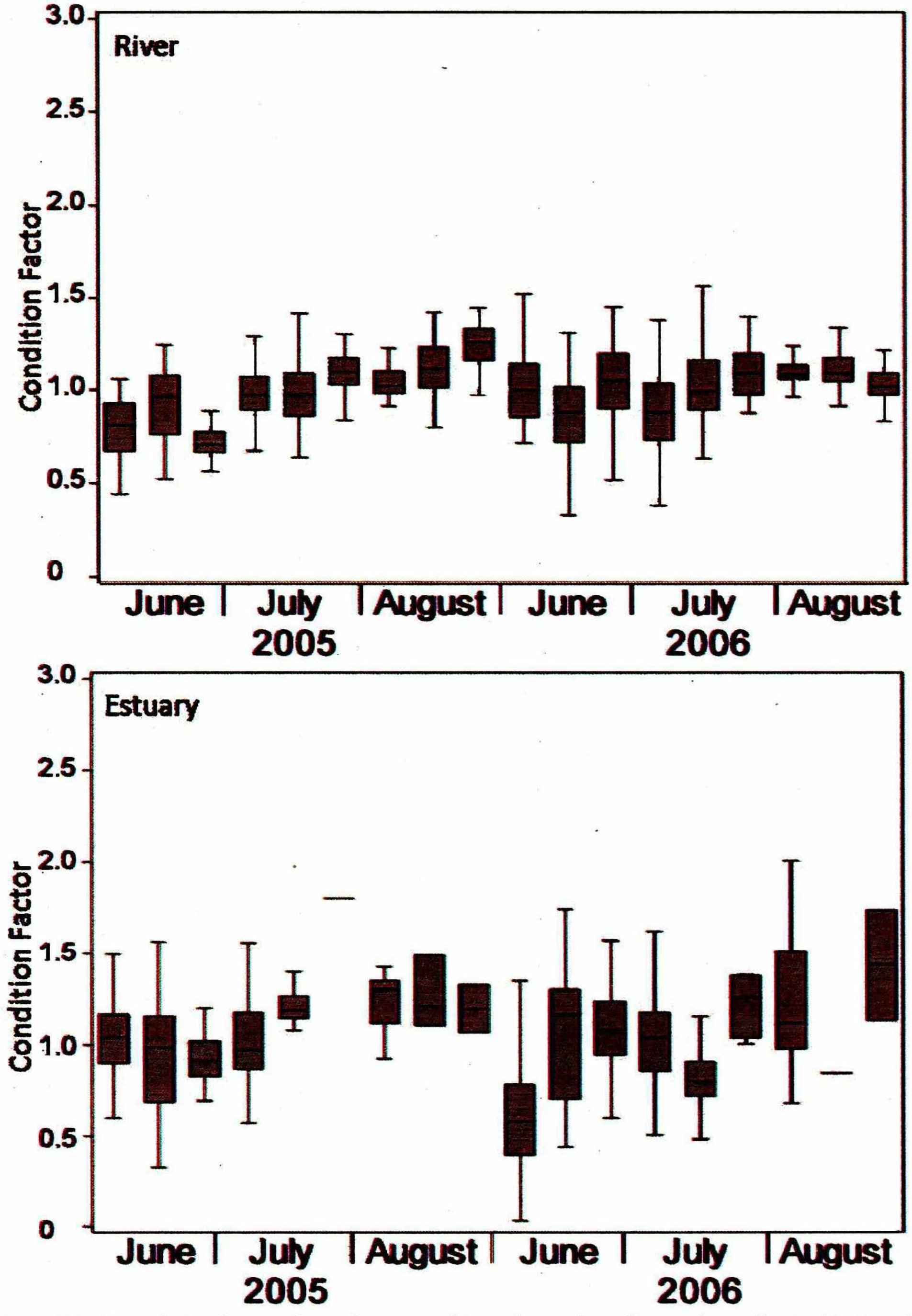

Figure 2.9 Box-plots of juvenile sockeye condition factor for all samples collected in the river and estuary during 2005 and 2006 summer months.

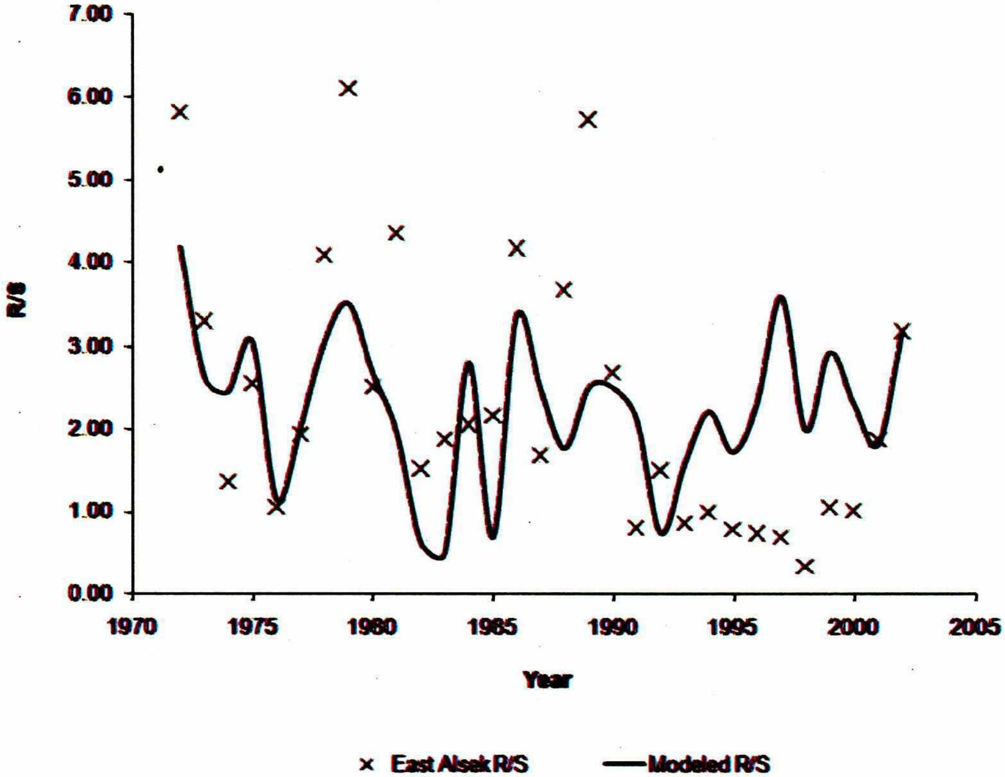

Figure 2.10 Predicted recruits/spawner vs. observed recruits/spawner using the cumulative precipitation during the juvenile life stage as a predictor.

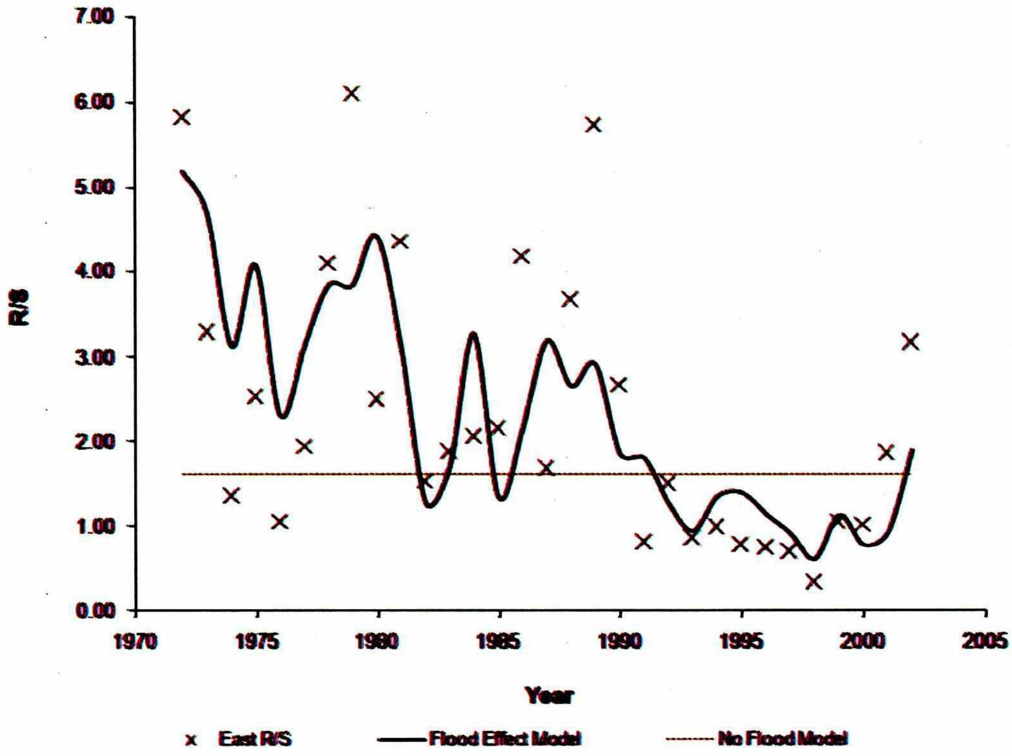

Figure 2.11 Predicted recruits/spawners with and without a flood effect in comparison to observed data for the East Alsek River. Floods occurred in 1980, 1981, 1983, and 1987.

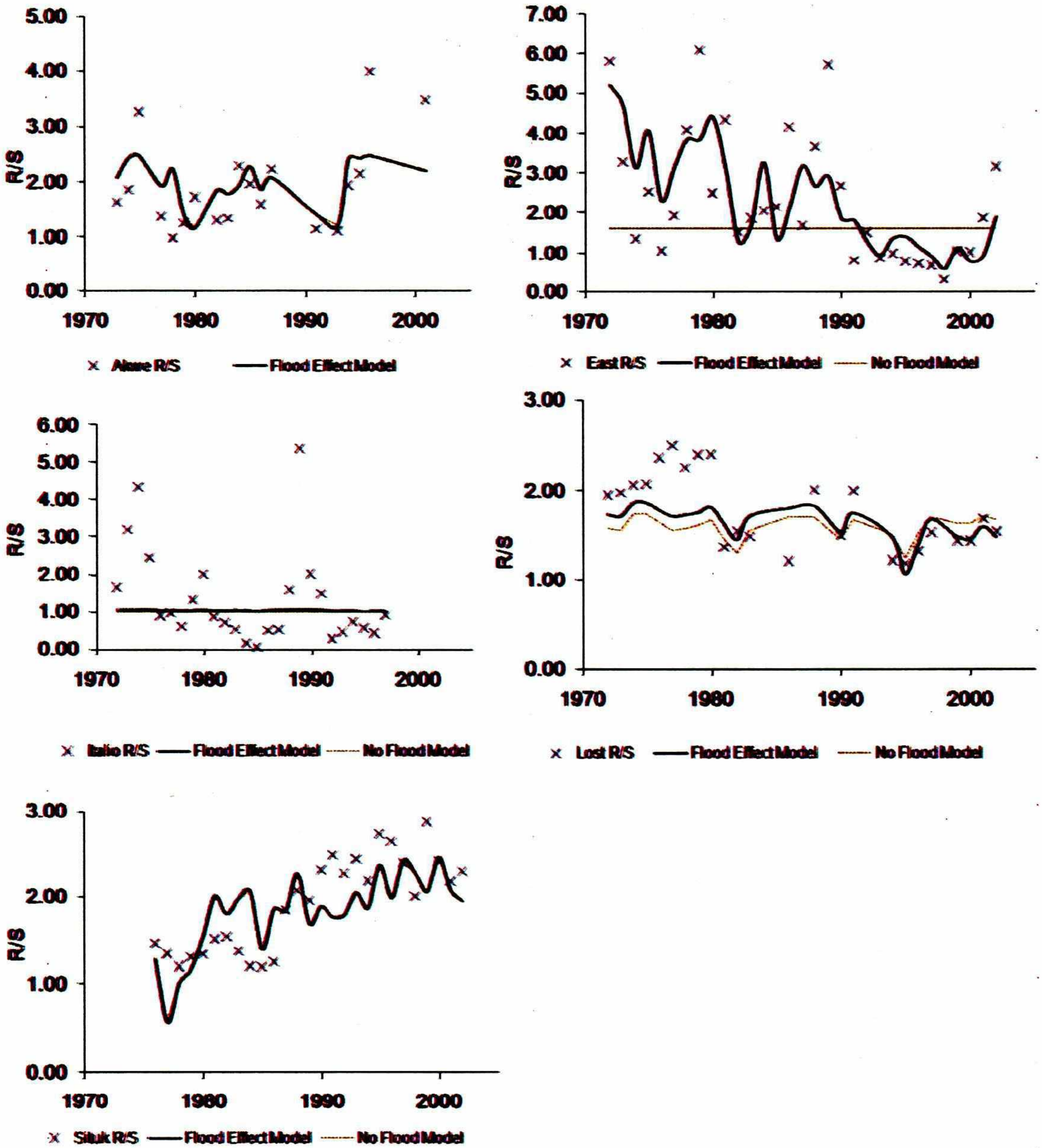

Figure 2.12 Predicted recruits/spawners with and without a flood effect in comparison to observed data for five Yakutat area rivers (Akwe, East Alsek, Italio, Lost and Situk Rivers). Floods were introduced into the model for 1980, 1981, 1983, and 1987.

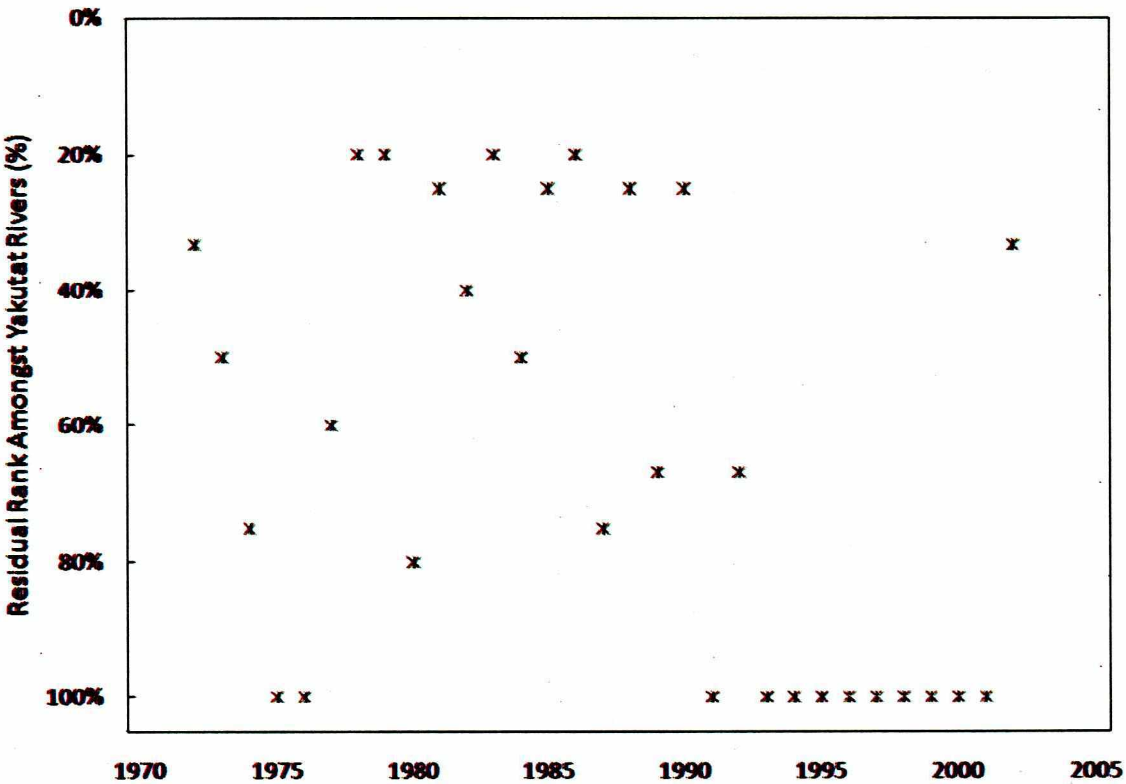

Figure 2.13 Relative rank of the East Alsek stock-recruitment residuals in comparison to residuals of four nearby sockeye populations (some years fewer than four were available), on the Akwe, Italio, Lost and Situk rivers. A rank of 100% indicated the worst relative recruitment, and a rank of 20% was best relative recruitment.

Table 2.1 Spawner/recruit and environmental data for the East Alsek River.

				Cumulative Precipitation (mm)			Mean Temperature (°C)			Freezing Days			North Pacific Index	
Year	Escapement	Years from flood	Recruits	Sep-Jan	Jan-Mar	Apr-Jul	Sep-Jan	Jan-Mar	Apr-Jul	Sep-Jan	Jan-Mar	Apr-Jul	Aug-Oct	Nov-March
1972	15000	N/A	67380	11.34	9.20	7.75	0.49	-3.35	7.42	23	24	0	15.63	9.50
1973	22500	N/A	74250	8.87	6.20	5.88	-0.23	-4.81	7.38	28	30	0	13.23	9.06
1974	52500	N/A	71400	22.37	8.92	10.21	2.49	-3.98	6.94	14	25	0	15.93	10.02
1975	33000	N/A	83620	16.59	5.99	4.58	0.87	-2.74	7.31	24	19	1	13.13	10.08
1976	75000	N/A	79910	24.88	14.86	8.81	4.24	2.13	8.32	3	2	0	14.09	5.96
1977	52500	N/A	100850	13.78	9.17	8.96	0.36	-0.30	8.31	29	11	0	13.80	6.52
1978	37500	N/A	153375	15.89	12.54	9.29	1.82	-4.06	8.18	18	27	0	11.77	10.56
1979	37500	N/A	226750	15.34	9.21	10.21	2.84	-0.13	9.17	17	11	0	14.58	7.70
1980	27000	0	67770	18.18	14.47	6.76	4.48	3.44	9.57	9	1	0	14.73	4.42
1981	52500	0	228375	16.47	3.49	8.77	1.74	-4.11	6.88	22	25	1	15.93	10.60
1982	185000	1	160650	15.93	9.62	9.62	2.59	0.48	8.93	11	8	0	16.23	3.48
1983	97500	0	133300	13.89	15.43	6.76	1.34	1.11	7.67	18	6	0	13.38	6.28
1984	43500	1	89620	17.83	17.80	9.70	2.93	0.30	6.46	10	8	1	16.57	10.08
1985	90000	2	194400	19.10	14.86	7.80	1.43	0.09	7.31	15	8	2	13.88	4.78
1986	55500	3	232435	20.77	16.27	12.75	3.38	0.00	7.98	7	8	0	14.88	5.98
1987	51000	0	86190	30.74	13.32	10.08	2.72	-0.43	7.96	12	10	0	14.47	8.14
1988	57000	1	208198	22.07	4.98	8.78	1.46	-4.96	8.53	19	30	0	14.63	11.72
1989	45000	2	257850	23.17	14.67	9.15	2.68	-2.41	9.39	14	28	0	14.48	10.92
1990	63000	3	168840	17.89	14.46	12.04	0.30	-1.91	8.32	28	16	0	13.40	11.22
1991	57000	4	46740	25.83	28.86	9.97	3.94	0.50	8.50	4	8	0	14.17	6.48
1992	64500	5	57385	18.91	5.40	4.38	0.20	-2.33	9.76	25	19	0	14.67	8.74
1993	67500	6	58725	18.14	11.51	9.73	3.38	-2.07	8.94	9	10	0	14.67	10.36
1994	49600	7	49800	18.32	9.25	8.93	0.61	-3.07	8.94	25	24	0	13.47	8.56
1995	42000	8	33080	12.86	9.65	6.21	1.20	-3.52	8.51	28	25	1	15.67	7.76
1996	43000	9	31500	13.53	16.21	8.18	0.37	-4.59	9.14	23	11	0	13.93	8.66
1997	42000	10	29400	16.62	8.74	11.09	3.13	0.57	8.26	9	9	0	15.73	5.48
1998	45000	11	15375	11.29	9.55	7.64	1.42	-2.70	7.54	17	19	1	14.40	9.46
1999	29250	12	30887	23.56	10.82	7.71	1.83	-1.04	7.92	14	12	0	14.88	8.42
2000	31500	13	32343	16.95	13.03	6.46	3.64	0.48	7.75	3	7	0	14.67	7.08
2001	25500	14	47785	13.37	8.96	3.93	2.12	-2.07	6.57	12	16	3	13.63	9.20
2002	14000	15	45181	12.15	8.81	5.85	4.03	0.20	8.39	7	8	1	13.67	5.06

Table 2.2 Spawner/recruit data used to construct spawner/recruit models for five Yakutat Area rivers. Double asterisks indicate data that was unavailable.

	Akwe		East		Italio		Lost		Situk	
Year	Escapement	Return	Escapement	Return	Escapement	Return	Escapement	Return	Escapement	Return
1972	**	**	15000	87300	14946	24490	4308	8384	**	**
1973	10000	16207	22500	74250	9463	30167	4615	9110	**	**
1974	2000	3695	52500	71400	6309	27412	1846	3794	**	**
1975	1000	3252	33000	83820	7000	17159	1846	3822	**	**
1976	**	14274	75000	79500	22250	19985	3385	7992	116989	170519
1977	14000	19089	52500	101850	24358	23307	4649	11585	216631	290343
1978	6000	5899	37500	153375	33797	20147	4308	9677	146884	175525
1979	30000	37130	37500	228750	17700	23248	3846	9203	128879	167752
1980	40000	68762	27000	67770	14000	28231	2769	6649	95424	127191
1981	**	**	52500	228375	24000	20462	6354	8670	61774	92887
1982	16000	20769	105000	160650	18000	12671	9231	14211	75501	115744
1983	18000	23897	97500	183300	18000	9569	4615	6827	63645	87029
1984	13800	31604	43500	89610	19604	3253	**	**	58188	69953
1985	5000	9761	90000	194400	28000	1850	**	**	107586	128086
1986	15740	24922	55500	231435	7600	3742	2323	2814	71543	88863
1987	10000	22250	51000	86190	12800	6631	**	**	72720	133944
1988	**	**	57000	209190	5400	8539	2308	4624	46160	95418
1989	**	**	45000	257850	1100	5901	**	**	83676	163563
1990	**	**	63000	168840	2600	5263	6308	9401	69372	160805
1991	30000	34172	57000	46740	2884	4264	2846	5673	77922	194157
1992	**	**	64500	97395	10338	2929	**	**	76015	172801
1993	37860	41907	67500	58725	6700	3103	**	**	59282	144989
1994	2000	3860	48600	48600	5100	3725	5311	6489	70984	155113
1995	2000	4284	42000	33180	5400	3030	10388	12312	40911	111855
1996	1000	3975	42000	31500	3101	1335	5463	7212	63285	167305
1997	**	**	42000	29400	2757	2505	2354	3602	38182	91739
1998	**	**	45000	15375	**	**	**	**	46078	92087
1999	**	**	29250	30887	**	**	3502	5014	58632	168646
2000	**	**	31500	32343	**	**	3454	4954	36322	87953
2001	7000	24294	25500	47785	**	**	2215	3715	57692	125550
2002	**	**	14200	45181	**	**	2769	4269	65383	150269

Table 2.3 Model parameters for Ricker spawner/recruit models applied to the East Alsek Sockeye population. Environmental effects were defined as the average condition during the residence period of a particular life stage of sockeye. AIC values indicate a model with a better fit than the standard model.

	SSQ	α	β	γ	AIC_c
Standard Ricker					
All	71.48	1.35	1.07E-05	N/A	64.13
Precipitation					
Egg	71.39	1.41	1.01E-05	-0.005	66.11
Fry	69.34	1.59	8.58E-06	-0.030	65.51
Juv	62.78	0.62	2.40E-05	0.150	*63.45*
All	71.38	1.42	9.93E-06	-0.003	66.11
Temperature					
Egg	71.13	1.97	1.08E-05	-0.017	66.03
Fry	67.68	2.51	1.01E-05	-0.041	65.01
Juv	71.15	0.00	1.12E-05	0.029	66.04
All	69.88	3.07	1.01E-05	-0.047	65.67
Freezing Days					
Egg	69.60	1.16	1.10E-05	0.012	65.58
Fry	66.84	1.00	1.02E-05	0.020	64.75
Juv	69.52	1.48	1.26E-05	-0.168	65.56
All	68.10	1.04	1.04E-05	0.009	65.13
North Pacific Index					
First Fall	71.42	1.62	1.05E-05	-0.02	66.12
First Winter	71.04	1.55	1.05E-05	-0.03	66.01

Table 2.4 Parameter estimates and AICc values for five Yakutat Area rivers with ocean-type sockeye populations modeled using a Ricker type model with and without flood effect. Lowest AICc for each river is in bold.

Model		Akwe	East	Italio	Lost	Situk
Flood	AICc	6.65	**15.29**	42.32	9.03	-3.51
	SSQ	1.00	4.94	19.59	0.48	1.31
	α	0.92	1.85	0.05	0.68	1.20
	β	5.13E+04	7.40E+04	1.02E+06	3.24E+04	1.23E+05
	γ	0.00	0.12	0.27	0.08	0.00
No Flood	AICc	**5.80**	28.94	**41.73**	**2.73**	**-4.07**
	SSQ	1.00	10.94	19.60	0.62	1.31
	α	0.93	0.47	0.00	0.62	1.20
	β	4.98E+04	2.50E+08	3.98E+10	2.57E+04	1.23E+05

Equation 2.1 The model used to incorporate environmental influences on the East Alsek sockeye population.

$$\ln\left(\frac{R}{S}\right) = \alpha - \frac{S}{\beta} + \gamma E + \varepsilon$$

R = Recruits

S = Spawners

α = Maximum recruits/spawners

β = density dependent effect

γ = Environmental parameter scalar

E = Environmental factor (e.g. average precipitation)

ε = Normally distributed random error

Equation 2.2 The Ricker-type flood effect model that uses known flood events to predict recruitment on the East Alsek River.

$$\ln\left(\frac{R}{S}\right) = \alpha - \left(\frac{S}{\beta_t}\right) + \varepsilon$$

$$\beta_t = \beta e^{-\gamma T}$$

R = recruits

S = spawners

α = maximum recruits/spawner

β = maximum possible recruitment

γ = rate of decline in maximum possible recruitment

T = years since last flood

ε = normally distributed random error

General Conclusions

Several key conclusions are summarized from this research. The conclusions pertain to the unique life history of East Alsek sockeye as ocean-type sockeye salmon, and to the effects of environmental fluctuations, including flooding, on the population dynamics of East Alsek sockeye.

Life History of East Alsek River Sockeye Salmon

1. Juvenile East Alsek sockeye (ocean type) outmigrate to the Pacific Ocean at a size between 55mm and 75mm.
2. A prolonged emergence of fry from the gravel exists between March and June. This process was dependent on the timing of spawning sockeye and the temperature regime in the river.
3. Adult East Alsek sockeye prefer to spawn in:
    a. Areas with less than 10 cm of sediment (< 5cm strongly preferred).
    b. Areas that are colder and with less dissolved oxygen than the surrounding river, presumably at upwelling water sites.
    c. Substrate that is smaller than the average size on the East Alsek.
    d. Shallower habitat on the East Alsek River.
    e. Areas that have similar water velocities to those available throughout the East Alsek River.

   f. Areas with much less vegetation cover than what is available on average throughout the river.

4. The primary composition of sockeye taken in the East Alsek/Doame fishery was dominated by 0-check (ocean-type) sockeye prior to 2001, and dramatically shifted to primarily 1-check (lake-type) sockeye after 2001. Presumably due to a shift from East Alsek dominated catch to a catch dominated with Doame River sockeye.

Population Dynamics

1. When precipitation, freezing days, temperature, and the North Pacific Index were compared to population trends of East Alsek sockeye, only one pattern emerged.
   a. Precipitation seemed to affect the juvenile life stage of East Alsek River sockeye, but did not predict overall downturn in recruitment.
2. Population trends in East Alsek recruitment were strongly related to flooding events in the past 30 years when modeled with a Ricker-type population dynamics model.
   a. The lack of flooding events was consistent with low recruitment, and years immediately following Alsek flood events were consistent with high recruitment.

b. This trend was likely due to rapid accumulation of sediment and aquatic vegetation atop suitable spawning substrate in the East Alsek River in the absence of flooding.

3. Analysis of region wide-trends in ocean-type sockeye recruitment for the East Alsek River and four other nearby sockeye streams supported East Alsek sockeye were responding uniquely localized hydrological conditions (e.g. Alsek flooding).
4. The East Alsek commercial fishery had a noticeable change in age composition (Appendix 2). This change in composition likely represents a shift in stock composition of the fishery. It has likely changed away from East Alsek River dominated catch to a more equal catch of both East Alsek River sockeye and Doame River sockeye.

In conclusion, continuing uplift and corresponding river incision in concert with decreasing groundwater levels will continue to negatively affect sockeye salmon spawning habitat in the East Alsek River. The quantity and quality of spawning habitat will continue to diminish over time as Alsek River flooding events become less probable. However, sockeye salmon are excellent excavators that should maintain riffle and marginal pool spawning gravels to perpetuate the East Alsek River population, albeit in numbers lower than historic returns.

Appendix 1

Table A1.1 Summary table of habitat measurements for the East Alsek River sampled polygon.

Polygon	Gravel Size (mean, mm)	n	Water Depth (m)	n	Water Velocity (m/s)	n	Vegetation Height (m)	n	Sediment depth (m)	n	Sediment % cover	n	Vegetation % cover	n	Conductivity (µS/L)	n	Temperature (°C)	n	Dissolved Oxygen (mg/L)	n
1	24	20	0.40	25	0.25	10	0.05	25	0.00	25	22	25	53	25	190	20	9.0	20	11.2	20
2	36	30	0.34	15	0.04	6	0.01	15	0.02	15	83	15	42	15	194	30	8.5	30	10.41	30
3	34	20	0.27	25	0.06	11	0.00	25	0.03	25	30	25	16	25	190	20	7.4	20	10.15	20
4	33	10	0.34	15	0.08	5	0.07	15	0.04	15	33	15	64	15	188	10	8.7	10	11.18	10
5	38	35	0.29	45	0.34	10	0.08	45	0.00	45	21	45	64	45	199	35	8.7	35	11.38	35
7	33	20	0.20	26	0.24	11	0.02	26	0.01	26	27	26	78	26	197	20	9.3	20	11.8	20
8	37	10	0.22	15	0.02	8	0.04	15	0.06	15	56	15	48	15	201	10	8.9	10	11.79	10
9	39	20	0.30	25	0.07	14	0.05	25	0.01	25	25	25	91	25	205	20	11.9	20	14.42	20
10	30	10	0.24	13	0.02	8	0.00	13	0.01	13	99	13	1	13	200	10	8.2	10	10.06	10
11	31	20	0.46	25	0.11	15	0.02	25	0.00	25	27	25	44	25	206	20	10.9	20	12.97	20
12	38	20	0.28	25	0.30	15	0.01	25	0.00	25	11	25	47	25	210	20	12.5	20	13.44	20
13	19	20	0.41	26	0.06	14	0.03	26	0.01	26	53	26	24	26	184	20	10.0	20	12.07	20
14	76	20	0.60	25	0.02	16	0.20	25	0.33	25	8	25	88	25	194	14	11.0	14	13.62	14
15	35	20	0.32	23	0.06	13	0.07	23	0.01	23	27	23	70	23	191	20	11.1	20	10.79	20
16	43	15	0.20	18	0.11	12	0.04	18	0.01	18	11	18	72	18	191	15	10.8	15	11.12	15
17	35	10	0.29	13	0.18	12	0.08	13	0.01	13	4	13	35	13	202	10	13.9	10	13.87	10
18	17	20	0.23	33	0.00	23	0.29	33	0.05	33	25	33	75	33	177	20	19.4	20	17.16	20
20	36	20	0.13	25	0.10	13	0.05	25	0.00	25	17	25	73	25	202	19	16.3	19	12.52	19
21	34	20	0.36	23	0.11	14	0.06	23	0.05	23	10	23	77	23	191	20	10.4	20	11.47	20
22	25	15	0.38	18	0.06	11	0.01	18	0.01	18	56	18	32	18	182	15	9.5	15	11.48	15
23	36	20	0.38	25	0.05	15	0.14	25	0.13	25	9	25	92	25	187	20	9.5	20	11.15	20
24	42	20	0.27	25	0.13	15	0.05	25	0.01	25	9	25	67	25	186	20	9.9	20	11.72	20
25	32	20	0.71	29	0.01	19	0.29	29	0.18	29	13	29	92	29	199	20	9.8	20	11.29	20
26	17	20	0.48	27	0.03	17	0.01	27	0.01	27	52	27	13	27	190	20	8.8	20	11.14	20
27	25	10	0.11	13	0.01	8	0.01	13	0.01	13	78	13	19	13	188	10	6.1	10	9.97	10
29	31	20	1.38	25	0.02	16	0.16	25	0.19	25	0	25	99	25	204	20	8.5	20	11.16	20
30	39	18	0.31	28	0.22	18	0.02	28	0.01	28	23	28	7	28	184	20	9.6	20	12.53	20
31	50	16	0.63	18	0.17	11	0.04	18	0.01	18	34	18	41	18	169	16	7.2	16	11.67	16
32	63	15	0.32	18	0.08	11	0.03	18	0.01	18	48	18	52	18	173	15	7.4	15	11.01	15
33	127	20	0.75	27	0.06	17	0.16	27	0.47	27	31	27	81	27	170	20	7.8	20	11.47	20
34	63	20	0.50	25	0.00	15	0.22	25	0.16	25	26	25	79	25	175	20	8.2	20	10.84	20
35	61	20	0.42	24	0.01	14	0.01	24	0.03	24	56	24	38	24	191	20	8.3	20	9.89	20
36	105	10	0.25	13	0.00	8	0.01	13	0.01	13	55	13	54	13	205	10	7.7	10	6.22	10
37	57	20	0.25	27	0.28	17	0.01	27	0.00	27	17	27	24	27	184	20	8.9	20	12.85	20
38	50	20	0.29	23	0.11	13	0.03	23	0.02	23	65	23	44	23	190	20	10.3	20	12.6	20
39	63	20	0.45	25	0.06	15	0.07	25	0.08	25	53	25	55	25	183	20	8.5	20	11.66	20
40	89	20	0.49	23	0.03	14	0.19	23	0.32	23	52	23	62	23	185	20	9.2	20	11.72	20
41	102	20	0.43	25	0.00	16	0.07	25	0.01	25	53	25	61	25	188	20	7.2	20	10.59	20
42	88	20	0.45	25	0.01	15	0.03	25	0.04	25	40	25	46	25	239	20	6.8	20	13.53	20
43	107	20	0.25	25	0.39	15	0.00	25	0.00	25	17	25	37	25	173	20	7.0	20	12	20
44	154	20	0.28	26	0.11	16	0.07	26	0.05	26	65	26	50	26	175	20	7.4	20	11.49	20
45	110	20	0.31	25	0.05	15	0.21	25	0.21	25	46	25	68	25	177	20	7.1	20	11.72	20
46	125	10	0.32	15	0.21	10	0.00	15	0.03	15	44	15	5	15	167	10	6.3	10	11.84	10
47	135	8	0.27	11	0.15	7	0.00	11	0.01	11	68	11	8	11	166	8	6.2	8	11.63	8
48	101	20	0.25	25	0.27	15	0.01	25	0.01	25	43	25	12	25	170	20	7.2	20	12.11	20
49	114	20	0.31	25	0.04	15	0.03	25	0.07	25	76	25	50	25	173	20	7.2	20	11.38	20
50	46	20	0.34	27	0.02	17	0.01	27	0.01	27	56	27	19	27	166	20	6.2	20	11.29	20
51	151	20	0.21	25	0.22	15	0.01	25	0.01	25	40	25	40	25	179	20	8.2	20	12.8	20
52	105	20	0.20	25	0.16	15	0.01	25	0.00	25	60	25	28	25	177	20	7.8	20	16.51	20
53	81	10	0.18	15	0.02	10	0.01	15	0.01	15	49	15	63	15	161	10	6.7	10	10.33	10
54	74	21	0.31	26	0.07	16	0.04	26	0.05	26	70	26	55	26	171	21	6.4	21	11.42	21
55	120	15	0.37	18	0.05	11	0.06	18	0.03	18	57	18	56	18	173	15	6.1	15	11.35	15
56	160	13	0.72	18	0.01	12	0.08	18	0.02	18	4	18	60	18	170	13	5.7	13	10.57	13
57	100	5	0.62	8	0.01	5	0.00	8	0.00	8	20	8	0	8	168	5	5.4	5	10.16	5

Table A.2 Summary of observed spawning densities per polygon for 2005 and 2006 survey years.

Polygon	2005 Sockeye Density (fish/100 m²)	2006 Sockeye Density (fish/100 m²)	2005 Redd Density (redds/100 m²)	2006 Redd Density (redds/100 m²)	Polygon area (m²)
1	0.00	0.00	0.00	0.00	6313
2	0.00	0.00	0.00	0.00	927
3	0.46	1.07	0.39	0.47	4019
4	0.00	0.00	0.00	0.00	921
5	0.00	0.03	0.00	0.05	1842
7	0.15	0.75	0.06	0.34	13042
8	0.00	0.24	0.00	0.08	1241
9	0.24	1.88	0.10	0.86	3007
10	0.00	4.19	0.00	2.03	492
11	2.52	6.84	0.79	2.68	9488
12	1.87	5.09	0.59	1.81	8849
13	6.84	13.00	3.46	4.44	7080
14	0.04	0.08	0.02	0.03	37510
15	1.39	1.70	0.49	0.48	6108
16	0.45	1.79	0.15	0.30	5319
17	0.00	0.00	0.00	0.00	8651
18	1.81	6.14	0.17	1.68	1557
20	0.14	1.13	0.07	0.29	8086
21	0.91	3.94	0.31	1.21	4103
22	7.12	9.06	1.98	3.60	2815
23	0.33	0.70	0.13	0.14	13097
24	0.50	1.58	0.17	0.43	20567
25	0.00	0.33	0.00	0.15	36169
26	9.51	15.03	3.19	5.14	10383
27	0.05	0.00	0.00	0.00	1694
29	0.23	0.94	0.10	0.42	17709
30	4.31	9.45	1.94	3.83	14912
31	0.00	8.71	0.00	3.51	1101
32	0.50	5.31	0.16	2.15	1193
33	0.20	0.19	0.08	0.08	34271
34	0.00	1.01	0.00	0.46	14416
35	9.39	10.01	2.91	4.20	2311
36	0.90	11.73	0.51	3.57	588
37	1.17	5.39	0.47	2.12	7861
38	1.19	1.78	0.55	0.73	5425
39	3.27	3.13	1.36	1.30	9482
40	0.00	0.00	0.00	0.00	6625
41	0.01	2.71	0.01	0.94	5248
42	10.62	9.29	4.31	3.44	6323
43	0.94	9.26	0.19	3.61	3121
44	0.04	0.52	0.01	0.20	16864
45	0.00	0.48	0.00	0.11	7357
46	0.64	1.43	0.00	0.55	721
47	0.00	3.53	0.00	1.80	415
48	0.12	1.15	0.05	0.41	9670
49	0.49	1.56	0.20	0.71	18699
50	2.31	10.00	1.27	4.53	2595
51	0.04	0.75	0.03	0.28	8344
52	0.25	1.21	0.13	0.52	5965
53	0.00	0.09	0.00	0.04	2095
54	1.15	3.25	0.59	1.42	14089
55	0.02	0.91	0.01	0.39	7915
56	0.97	3.86	0.54	1.54	12611
57	4.44	15.13	2.84	6.45	914

Appendix 2

Freshwater-age of East Alsek/Doame Fishery

Sockeye scale data was analyzed from readings of East Alsek sockeye scales by ADFG's Mark, Tag and Age Lab in Juneau, Alaska. Scales archived in their scale collection originated from the East Alsek/Doame River commercial fishery and the East Alsek spawning grounds. Results from the analysis indicate that the primary composition of sockeye taken in the East Alsek/Doame fishery was dominated by 0-check (ocean-type) sockeye prior to 2002, and dramatically shifted to primarily 1-check (lake-type) sockeye after 2002 (Figure A2.1). This shift was likely due to a shift from an East Alsek dominated catch to a catch dominated by Doame River sockeye. East Alsek juvenile sockeye were shown to exit the river and estuary and move into the North Pacific by the end of July following spring and early summer (see Chapter 2). The existence of the Doame River fish, a known population of 1-check (lake-type) sockeye (Clark et al. 2003), likely explain this shift in catch composition. However several other small sockeye stocks from other adjoin tributary streams and lake systems are thought to contribute to this mixed stock fishery.

Scale growth analysis

East Alsek sockeye scales were analyzed from ADFG's collection of archived scales. Relative scale growth was compared to population variables such as recruits/spawner, as well as to environmental variables in order to determine if a relationship existed between scale-growth and deterministic factors (Figures A2.2-A2.3).

Scales were retrieved from adult sockeye at the spawning grounds of the East Alsek River, as well as from the East Alsek fishery by ADFG. Occipital length and sex of each fish was recorded. Scales were subsampled from existing scale samples, where scales or scale-pressed acetates were available. A total of 50 scales from each sex were analyzed for spawning years 1982, 1984, 1985, 1986, 1987, 1994, 1995, 1997, 1998, 2000, 2001, 2002. Scales were processed using Optimas™ software to determine freshwater residence. Scales from each fish were designated 1-check if a freshwater annulus existed, or 0-check if no freshwater annulus existed. The growth of each scale was then determined by measuring the number and distance between scale circuli to each annulus. This enabled calculation to broodyear, and backcalculation of sockeye occipital length at each annulus (Fukuwaka and Kaeriyama[3] 1997; Tables A2.1-A2.2). The average backcalculated length for pooled recruitment years was compared to recruitment and escapement for each broodyear by sex and type of sockeye (e.g. 0-check or 1-check; Figures A2.2-A2.3), as well as to average temperature, precipitation, and North Pacific index for the first year of ocean residence.

---

[3] Fukuwaka M, and M Kaeriyama (1997) Scale analyses to estimate somatic growth in sockeye salmon, *Oncorhynchus nerka* Canadian Journal of Fisheries and Aquatic Sciences. 54(3): 631–636

The use of scales to evaluate 1st year marine survival did not produce significant results. Many factors may influence this outcome. Some have hypothesized that juvenile salmon achieve a critical size at which survival is significantly enhanced[4]. This would confound any use of adult scales for evaluating retrospective growth or survival effects.

---

[4] Beamish, RJ and C Mahnken (2001)A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change Progress in Oceanography (49)1-4, 423-437

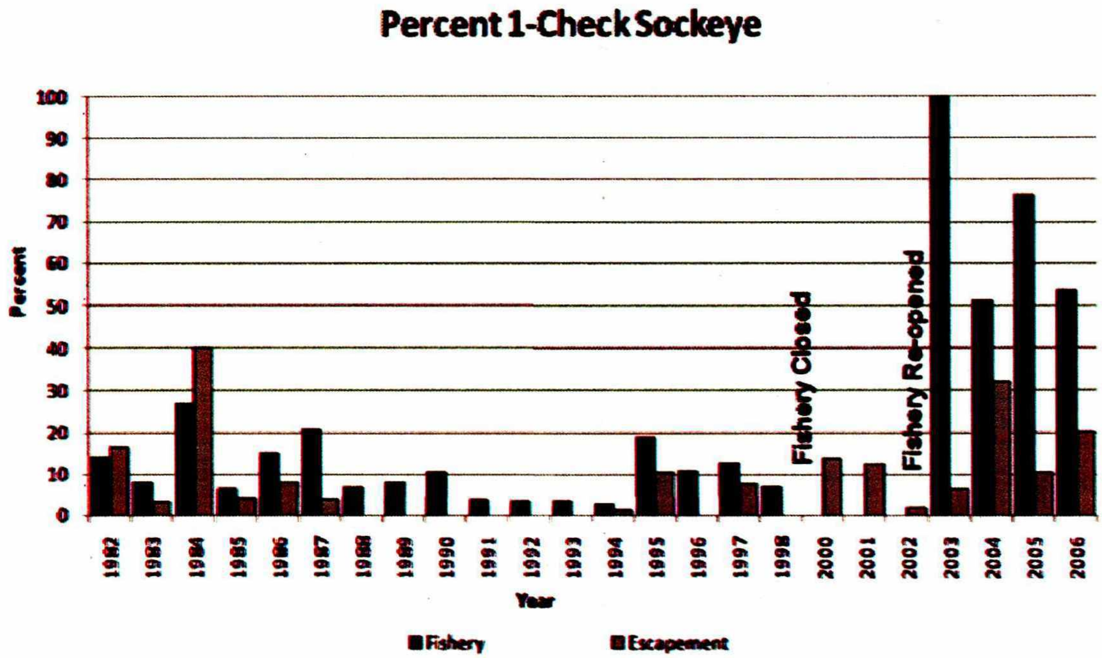

Figure A2.1 Percent composition of 1-check sockeye taken from fishery samples (East Alsek/Doame combined fishery) and East Alsek escapement samples from the spawning grounds of the East Alsek River plotted over time. Notice dramatic shift in composition after the reopening of the fishery.

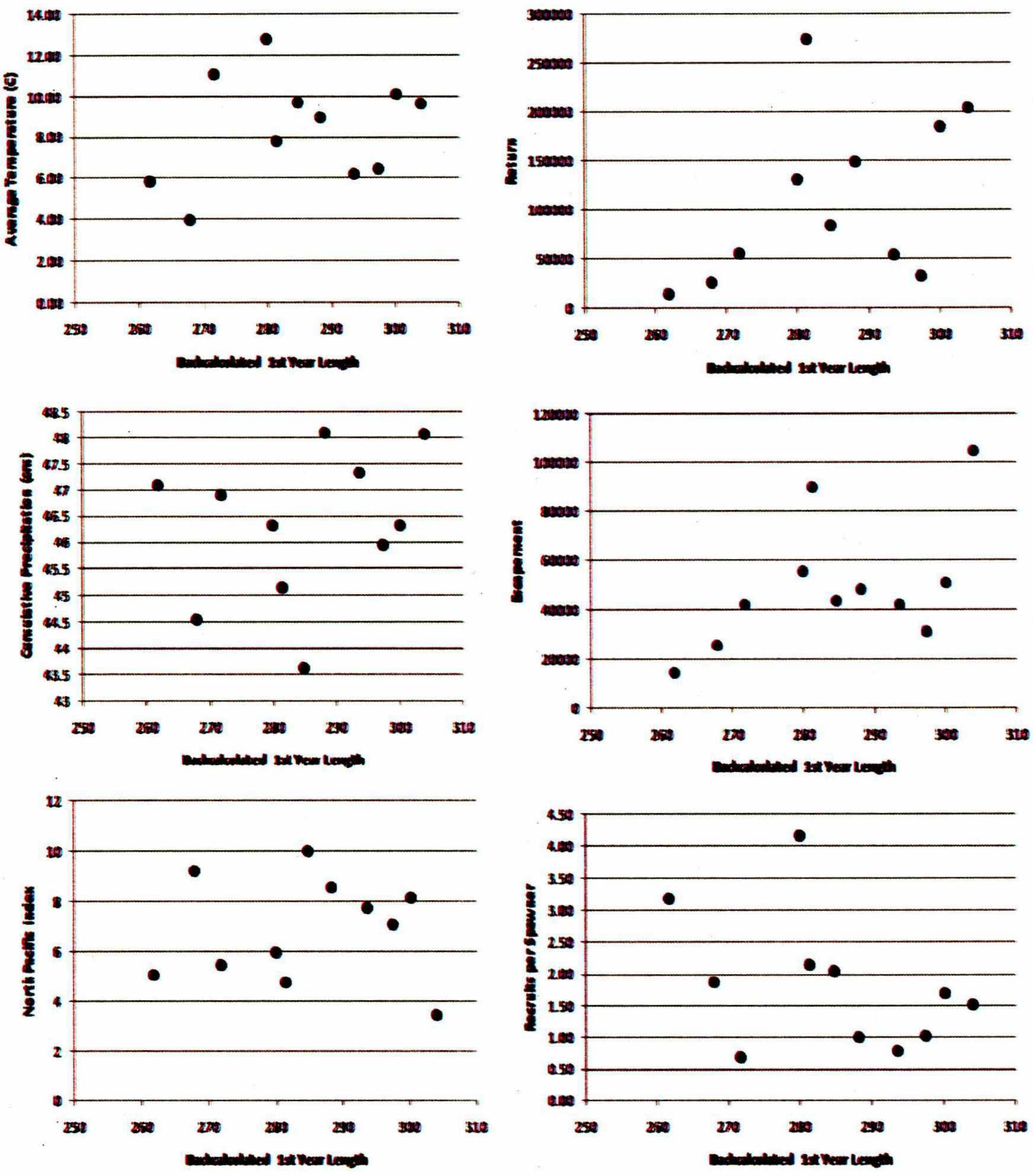

Figure A2.2 Occipital length (mm) at age 1 of 0-check female sockeye backcalculated from scales collected on the spawning grounds of the East Alsek River in comparison to environmental and population variables. Precipitation and temperature were summarized from Yakutat historical weather data (NOAA) for the months spanning August to July of the first year of freshwater residence. The North Pacfic Index was the average index for the first winter of saltwater residence of juvenile salmon (September—March).

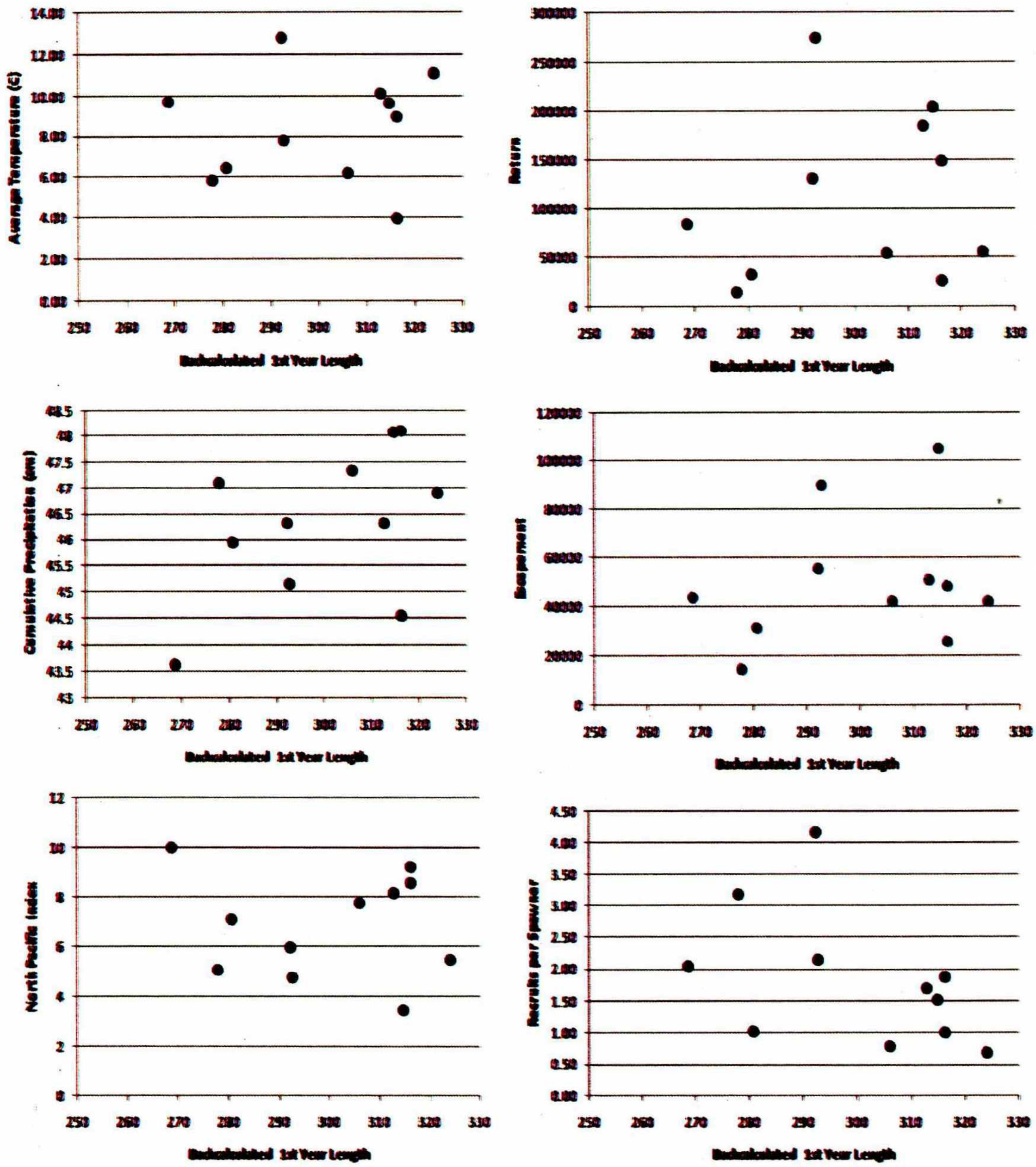

Figure A2.3 Occipital length (mm) at age 1 of 0-check male sockeye backcalculated from scales collected on the spawning grounds of the East Alsek River in comparison to environmental and population variables. Precipitation and temperature were summarized from Yakutat historical weather data (NOAA) for the months spanning August to July of the first year of freshwater residence. The North Pacfic Index was the average index for the first winter of saltwater residence of juvenile salmon (September—March). Population variables were referenced to brood-year.

Table A2.1 Scale widths between annuli for East Alsek sockeye, listed by broodyear. Sockeye scale samples were collected from spawning grounds by ADFG biologists.

Male 0-check	Scale Growth (mm)			
Broodyear	Year 1	Year 2	Year 3	Year 4
1979	1.051	0.698	0.212	0.000
1980	1.043	0.646	0.000	0.000
1981	0.899	0.695	0.444	0.008
1982	1.031	0.706	0.216	0.000
1983	1.020	0.715	0.174	0.000
1984	1.001	0.729	0.148	0.005
1985	1.081	0.711	0.000	0.000
1986	1.003	0.063	0.000	0.000
1991	1.053	0.730	0.122	0.000
1992	0.936	0.616	0.202	0.000
1993	0.978	0.450	0.000	0.000
1994	1.194	0.762	0.214	0.000
1995	0.992	0.455	0.039	0.000
1996	0.751	0.027	0.000	0.000
1997	0.940	0.720	0.264	0.013
1998	1.029	0.764	0.114	0.003
1999	0.955	0.722	0.220	0.000
2000	1.014	0.635	0.036	0.000

Male 1-check	Scale Growth (mm)			
Broodyear	Year 1	Year 2	Year 3	Year 4
1978	0.240	0.787	0.801	0.240
1979	0.284	0.842	0.655	0.055
1980	0.309	0.707	0.773	0.226
1981	0.432	0.739	0.747	0.064
1982	0.322	0.759	0.812	0.065
1983	0.306	0.756	0.596	0.305
1984	0.337	0.938	0.621	0.081
1990	0.384	0.855	0.816	0.000
1991	0.248	0.777	0.697	0.082
1992	0.307	0.751	0.790	0.092
1993	0.348	0.690	0.895	0.094
1994	0.299	0.885	0.722	0.076
1996	0.336	0.648	0.554	0.041
1997	0.348	0.833	0.703	0.102
1998	0.311	0.709	0.838	0.158
1999	0.304	0.736	0.769	0.024

Female 0-check	Scale Growth (mm)			
Broodyear	Year 1	Year 2	Year 3	Year 4
1979	0.950	0.834	0.341	0.000
1980	1.152	0.559	0.045	0.000
1981	1.063	0.816	0.198	0.000
1982	1.062	0.677	0.223	0.030
1983	1.025	0.802	0.170	0.005
1984	1.042	0.747	0.159	0.002
1985	0.974	0.537	0.000	0.000
1991	1.079	0.739	0.188	0.000
1992	1.026	0.674	0.191	0.000
1993	1.082	0.599	0.054	0.000
1994	1.135	0.722	0.379	0.018
1996	0.889	0.780	0.407	0.000
1997	0.966	0.743	0.143	0.004
1998	0.982	0.754	0.273	0.006
1999	1.021	0.807	0.199	0.000
2000	1.056	0.691	0.020	0.000

Female 1-check	Scale Growth (mm)			
Broodyear	Year 1	Year 2	Year 3	Year 4
1978	0.325	1.009	0.758	0.307
1979	0.288	0.920	0.602	0.040
1980	0.307	0.710	0.803	0.267
1981	0.332	0.711	0.736	0.144
1982	0.269	0.772	0.696	0.235
1983	0.297	0.792	0.821	0.055
1984	0.290	0.775	0.746	0.212
1990	0.354	0.688	1.151	0.319
1991	0.304	1.027	0.874	0.134
1992	0.471	0.851	0.550	0.074
1993	0.280	0.897	0.665	0.194
1994	0.360	0.801	0.739	0.234
1996	0.353	0.731	0.819	0.077
1997	0.324	0.815	0.669	0.199
1998	0.339	0.797	0.687	0.161
1999	0.440	0.774	0.723	0.081
2000	0.233	0.946	0.457	0.000

Table A2.2 Backcalculated mean occipital lengths for the first year of scale growth of East Alsek sockeye, listed by broodyear. Sockeye scale samples were collected from spawning grounds by ADFG biologists.

Male 0-check

Broodyear	N	Backcalculated Length 1st Year (mm) Min	Max	Mean
1979	31	66	437	256
1980	9	80	399	293
1981	22	65	380	204
1982	30	64	368	251
1983	42	64	393	255
1984	65	54	386	292
1985	2	278	307	293
1986	1	282	282	282
1987	1	313	313	313
1991	44	78	430	319
1992	30	77	436	273
1993	17	195	485	323
1994	29	68	392	219
1995	9	100	387	309
1996	2	57	343	200
1997	7	183	391	302
1998	28	74	402	268
1999	22	99	361	261
2000	2	237	252	244

Male 1-check

Broodyear	N	Backcalculated Length 1st Year (mm) Min	Max	Mean
1978	1	73	73	73
1979	3	64	91	74
1980	23	53	280	100
1981	2	61	215	138
1982	6	59	136	98
1983	2	298	354	326
1990	1	108	108	108
1991	6	62	300	110
1993	2	74	115	94
1996	1	133	133	133
1997	3	80	127	103

Female 0-check

Broodyear	N	Backcalculated Length 1st Year (mm) Min	Max	Mean
1979	16	64	322	210
1980	25	239	436	336
1981	18	80	337	209
1982	31	49	459	212
1983	76	54	368	239
1984	75	37	555	272
1985	2	337	348	342
1986	1	232	232	232
1991	72	70	386	285
1992	42	103	420	282
1993	21	189	364	301
1994	36	59	327	192
1997	23	88	425	294
1998	52	72	474	229
1999	30	63	365	224
2000	4	221	328	288

Female 1-check

Broodyear	N	Backcalculated Length 1st Year (mm) Min	Max	Mean
1978	3	62	103	78
1979	6	57	95	79
1980	16	49	174	86
1981	1	286	286	286
1982	3	81	101	88
1983	4	66	313	187
1990	1	70	70	70
1991	3	62	294	145
1992	4	62	252	121
1993	3	59	233	118
1996	6	63	338	182
1997	8	50	292	135
1998	4	60	112	91
1999	1	346	346	346