Knik Arm Anadromous Fish Study Designs

Knik Arm Salmon Ecology Integrated Research Plan

Prepared for:

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Conservation Planning Assistance
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Executive Summary

Knik Arm is a dynamic glacial estuary that supports a variety of marine life. Knik Arm is located in Upper Cook Inlet and experiences 12 meter (m) tides, extreme suspended sediment loads, strong currents, and seasonal ice scour. The Arm is bounded by the Municipality of Anchorage, the Matanuska-Susitna Borough, two state game refuges, two military bases, an international airport and two commercial ports. Knik Arm functions as a rearing habitat and migratory pathway for several anadromous fish species, including all five species of Pacific salmon, eulachon, and longfin smelt. The Arm thus provides Essential Fish Habitat for these species and for limited numbers of sculpins and flatfish. Several fish species present in Knik Arm are likely prey of Cook Inlet beluga whales listed in 2008 under the Endangered Species Act and the Arm has been proposed as Critical Habitat for the whales by NMFS in December 2009 (NOAA 2009).

A total of 19 current and proposed development projects have been inventoried in Knik Arm that have the potential to impact anadromous fish. In the face of these developments and the pressure from the largest urban center of Alaska, surprisingly little is known about the Knik Arm estuary and the role it plays in anadromous fish life history. The U.S. Fish and Wildlife Service (USFWS) contracted with HDR to assist in developing study designs to assess anadromous fish presence, distribution by habitat type and timing of use in Knik Arm. The first phase of this effort was to identify key research questions to guide the development of these studies. During the initial scoping effort a list of approximately 30 research questions was compiled by the HDR team. To further refine and prioritize these questions an advisory panel of agency experts and selected stakeholders was convened for a workshop held on September 3, 2009. The outcome of this workshop was a prioritized list of the seven research questions that agency experts deemed most important to anadromous fish in the Knik Arm estuary. These questions have guided the development of an integrated research framework incorporating five component studies; CS-1) a synthesis of historic studies in the Knik Arm estuary, CS-2) a comprehensive classification and mapping of habitat types in the estuary, CS-3) temporal and spatial investigations of salmon uses by life history stage related to habitat classifications, CS-4) an analysis of diet and energetics of juvenile salmon in the estuary and CS-5) effect of man made structures and pollutants on salmon.

1. Introduction

Assessing impacts of development- and climate-based pressures to estuarine function is problematic when there is a scarcity of information on marine life in those waters. The Knik Arm estuary (the Arm) is under pressure from a variety of current and proposed development projects and it is unknown whether it is experiencing a climate-induced regime shift. Bounded by the largest urban population center in Alaska, 19 current and proposed development projects have been inventoried in Knik Arm that have the potential to impact anadromous fish. In the face of these pressures, surprisingly little is known about the Knik Arm estuary and the role it plays in anadromous fish life history. In an effort to fill this information gap, the U.S. Fish and Wildlife Service (USFWS) contracted HDR to design a comprehensive research plan investigating anadromous fish presence, distribution by habitat type and timing of use in Knik Arm. This document represents the culmination of that effort.

1.1.Background

Knik Arm (Figure 1) is a 500 square kilometer dynamic glacial estuary that supports a variety of marine life. It is the northern most extension of the Cook Inlet estuary and experiences 12 meter (m) tides, extreme suspended sediment loads, strong currents, and seasonal ice scour (Houghton et al. 2005a, b). The Arm is bounded by the Municipality of Anchorage, the Matanuska-Susitna Borough, two state game refuges, two military bases, and an international airport and contains two commercial ports. The Arm functions as a rearing habitat and migratory pathway for several anadromous fish species, including five species of Pacific salmon.

Little is known about the function and significance of the Arm to marine species; indications are that it functions as a rearing habitat and migratory pathway for forage fish, groundfish, and anadromous species (Houghton et al. 2005 a,b), and that it is important foraging habitat for Cook Inlet beluga whales. Essential Fish Habitat (EFH) has been designated in Knik Arm for Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*), and chum salmon (*O. keta*). Additionally, the Arm has been designated EFH for eulachon (*Thaleichthys pacificus*), a forage fish as well as for three groundfish species: Pacific cod (G*adus macrocephalus*), sculpin (Cottidae spp.), and walleye pollock (*Theragra chalcogramma*). Many of these and other species present in the Arm have been found in stomachs of Cook Inlet beluga whales and thus may play an important role in supporting this population (NMFS 2008). Primary prey species of belugas were identified as primary constituent elements (PCEs) essential to the conservation of Cook Inlet beluga whales (74 FR 63080). These included Chinook, sockeye, chum and coho salmon, eulachon, Pacific cod, walleye pollock (*Theragra chalcogramma*), and saffron cod (*Eleginus gracilis*)—all species known to occur in Knik Arm (74 FR 63080; Houghton et al. 2005 a, b).

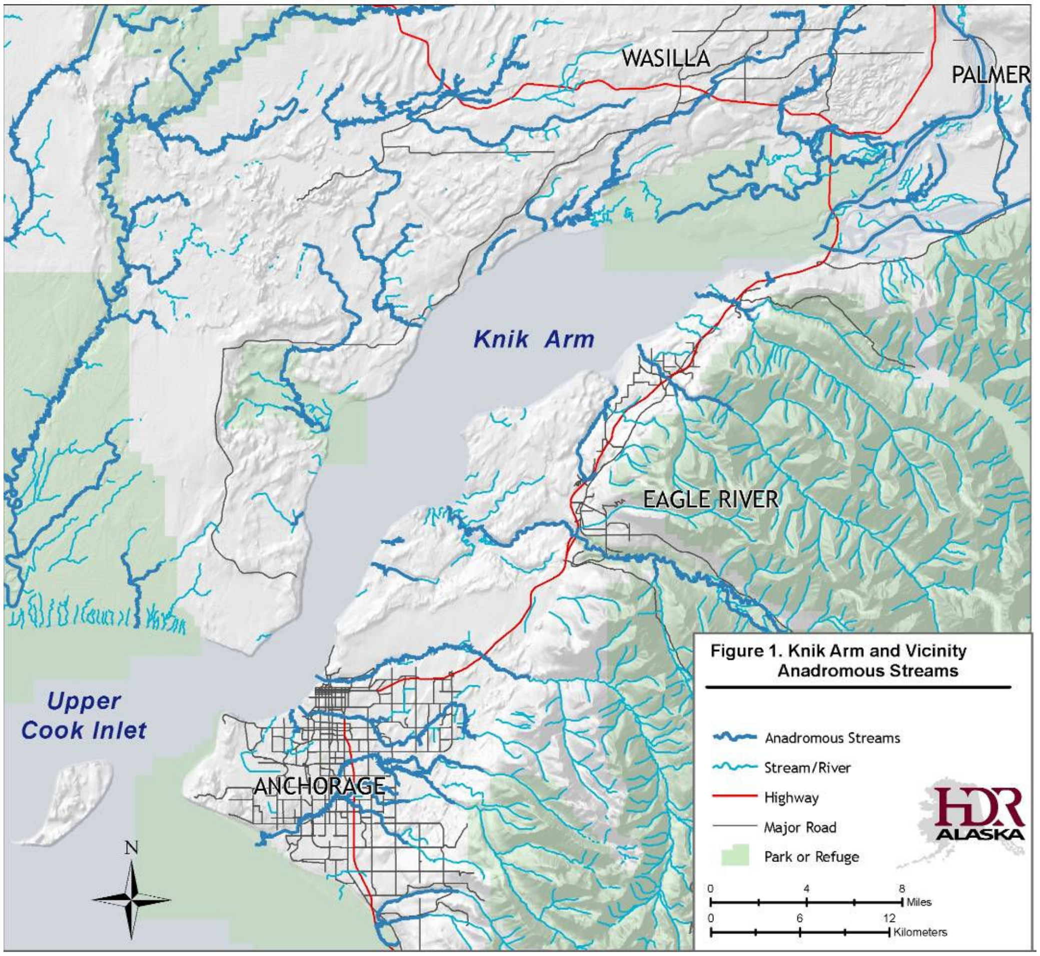

Figure 1. Knik Arm and vicinity

Mudflats, defined as intertidal and subtidal waters of Cook Inlet with depths less than 30 feet (9.1 m) mean low low water (MLLW) and within 5 miles (8 km) of high and medium flow anadromous fish streams were also designated a PCE for the conservation of Cook Inlet beluga whales, since bathymetric features may serve to concentrate fish and shallow depths may allow escape from killer whales (*Orcinus orca*). Mudflats within Knik Arm fall within this category. The Arm is also proposed Critical Habitat for the Cook Inlet beluga whale, which was listed in 2008 under the Endangered Species Act (73 FR 62919; 74 FR 63080). Thus, impacts to estuarine habitat in Knik Arm, from development and climate pressures, may affect recruitment of ecologically, culturally, commercially, and recreationally valuable fish species.

Available information on the physical and biological characteristics of Knik Arm is mostly derived from work related to specific development projects: either to gather baseline information for compliance with the National Environmental Policy Act (NEPA; e.g., Morsell et al. 1983; Houghton et al. 2005a,b; Nemeth et al. 2007), or sampling conducted to satisfy monitoring requirements of regulatory permits (CH2MHill 2006). Another source of information regarding fish in Knik Arm is Traditional Ecological Knowledge (TEK; e.g., Fall et al. 1981; Huntington 2000). In 2009, fisheries studies were conducted for a tidal energy pilot project located off the north shore of Fire Island (Worthington 2009; HDR, in prep); at the time of writing, reports for this project were still in preparation.

1.2. Research Plan Development

The Knik Arm estuary is under pressure from a variety of current and proposed development projects. Among these are loss of estuarine habitat from fill at the two ports, ongoing dredging to maintain a shipping channel, a proposed bridge crossing, a military bombing range located in tidal flats, and effluent and storm water runoff from the surrounding communities. Rather than confine studies to the effects of the footprint of individual projects, the USFWS concluded that a more comprehensive understanding the ecological function of the Knik Arm estuary was needed. To accomplish this, the USFWS contracted with HDR to develop a comprehensive research plan to assess anadromous fish presence, distribution by habitat type and timing of use in Knik Arm.

As part of the initial scoping effort for the research plan development, a total of 19 current and proposed development projects in Knik Arm were inventoried by Brady et al. (2009) in September 2009 (Appendix B). The issues relating to these projects generally center around the loss or modification of estuarine habitats and the unknown affects on fish and predator behavior. A key concept motivating the USFWS for this project is the belief that better knowledge of the ecology of Knik Arm habitats and the fish that use them will lead to more responsive permitting and regulation of future projects. This knowledge will steer regulators and developers to locate future projects in areas that will minimize habitat impacts as well as lead to design modifications that will protect important life history functions for anadromous fish in the estuary.

The second phase of the scoping effort was to identify information needs or gaps to guide the development of key research questions. The USFWS set the focus for the gap analysis on anadromous fish and more specifically salmon. When inventorying development projects, the HDR team compiled a list of approximately 30 research questions relating to anadromous fish ecology. These questions were initially a generalized effort with contributions from the HDR team drawing from their professional expertise. The questions were grouped into five general categories: 1) temporal and spatial distribution, 2) response to anthropogenic pressures, 3) life history, 4) ecosystem function, and 5) miscellaneous.

In September 2009, an advisory panel of agency experts and selected stakeholders participated in a Knik Arm anadromous fish workshop. Agencies represented on this panel included U.S. Fish and Wildlife Service, NOAA Fisheries, U.S. Geological Survey, the Environmental Protection Agency, and three divisions of the Alaska Department of Fish and Game. In addition to agencies, the Native Village of Eklutna participated in this process. The primary objective of the workshop was to refine and focus the 30 research questions. The outcome was a prioritized list of the seven research questions that agency experts deemed most important to anadromous fish in the Knik Arm estuary (Brady et al., 2009).

Table 1. Key research questions regarding anadromous fish in Knik Arm, ranked in order of priority, as identified by the advisory panel from the September 3, 2009 workshop.	
1.	What is the residence time and relative abundance of salmon by life history stage and habitat type in Knik Arm?
2.	How are estuarine and intertidal habitats utilized by salmon in Knik Arm? For example: migration, osmoregulation, rearing, feeding, refuge from predators (for both adults and juveniles).
3.	What are the limitations of previous fisheries studies done in Knik Arm and would a comprehensive analysis of these data sets advance our understanding of salmon ecology and assist in focusing future work in the area?
4.	What are the impacts of existing structures to fish and habitat use in Knik Arm?
5.	What is the impact to salmon and other aquatic organisms from point and non-point discharges of pollutants entering Knik Arm? For example; wastewater, storm drains and airport deicing, Knik River and Glenn-Parks Highway Interchange de-icing agents.
6.	What is the source of carbon in juvenile salmonids (terrestrial, riverborne, salt marsh, marine)? Does it change with residence time in Knik Arm?
7.	What role do invertebrates play in the life history of salmon in Knik Arm?

1.3. Research plan & components

Concurrent with the identification of research questions, a literature review of recent studies in Knik Arm and nearby areas was completed by the HDR team (Prevel-Ramos et al. 2009). Using this information and guided by the prioritized research questions, an investigation framework emerged containing five component studies (Table 2).

Table 2. Component studies of the Knik Arm estuary integrated salmon research plan	
CS-1	Synthesis and comprehensive analysis of existing Knik Arm salmonid data sets.
CS-2	Knik Arm estuarine habitat mapping and classification
CS-3	Salmon relative abundance by life history stage and habitat type
CS-4	Estuarine function and ecology
CS-5	Effects of man-made structures and pollutants on salmon

The first component study (CS-1), *Synthesis and comprehensive analysis of existing Knik Arm salmonid data sets*, is an important complement to the literature review. While there are previous bodies of work in or adjacent to Knik Arm (Morsell et al. 1983, Houghton et al. 2005 a & b, Nemeth et al. 2007), these data sets have not been integrated or analyzed in aggregate.

CS-2, *Knik Arm estuarine habitat mapping and classification,* is a quantitative effort to classify and map habitats in the Knik Arm estuary. The result would be a geo-database that could then be used as the framework for future studies. Fisheries studies (CS-3 and CS-4) can thus be spatially linked to habitats. This geo-database also could provide the spatial framework for further ecological studies relating to marine mammals, birds and invertebrates.

CS-3, *Salmon relative abundance by life history stage and habitat type,* builds from the habitat geo-database to temporally and spatially collect fisheries relative abundance and life history data. The study employs a combination of acoustic and net sampling techniques through a broad field season, thus enabling stratification by species, habitat type, and time.

The field component for CS-3 will collect and preserve fish specimens for CS-4, *Estuarine function and ecology*. This study will employ laboratory techniques to investigate diet, energetics, otolith micro-structure and genetics to address life history questions about the utilization of the Knik Arm estuary.

CS-5, *Effects of man-made structures and pollutants*, addresses the issues of anthropogenic effects on salmonids in Knik Arm. The two primary issues identified in the inventory of development projects were the effects of man-made structures and the effects of pollutants from storm water and wastewater discharges.

The long range goals of this research plan are threefold:

1. To improve our understanding of the effects that development projects in Knik Arm may have on anadromous fish.
2. To develop adequate information to steer new development projects toward the use of designs and/or site selection criteria that will avoid or minimize impacts to anadromous fish.
3. To use the Knik Arm as a pilot study and to develop methodologies for assessing anadromous fish that can be applied to other areas of Cook Inlet and the state.

For reasons both fiscal and practical, most of the effort in developing study descriptions has been directed towards CS-1, CS-2 and CS-3. The USFWS contract anticipated and was funded at a level to develop three study components. Each of the studies in this plan builds from information generated in the previous study. Consequently the first studies are presented in more detail. These three studies form the foundation for further research and have been developed with sufficient content to be submitted as grant proposals/applications in order to fund and perform work.

Due to fiscal limitations, CS-4 and CS-5 are presented in concept format. These concepts are included to spur partnerships and development ideas for future detailed study plans and funding applications.

1.4. Alignment of research plan with other planning efforts

Many of the research questions prioritized by the September 3, 2009 panel are shared by the research priorities and information needs identified in broad strategic planning efforts. For example, the Mat-Su Salmon Habitat Partnership identifies the need for estuarine research in its Strategic Action Plan (Smith and Anderson 2008). The work proposed in this research plan is specifically responsive to conservation strategies in the plan's objective 8.1 *salmon use of Cook Inlet* and objective 8.2 *conserve estuaries for salmon.*

This work would help carry out conservation actions of the NMFS' Cook Inlet Beluga Whale Conservation Plan, specifically Objective 5: a. *conduct baseline studies assessing coastal development by documenting available marine habitats* (NMFS 2008). This work would also assess and classify part of the nation's fish habitats, and encourage regional habitat planning guided by the best available information, science, and strategies advocated in the National Fish Habitat Action Plan, from the Association of Fish and Wildlife Agencies (AFWA 2006).

These efforts are timely since development of coastal areas of Cook Inlet is ongoing and environmental change may already affect the region.

1.5.Potential funding sources:

While the USFWS has funded the development of this research plan, funds have not been allocated to complete this work. Undertaking this research initiative will require coordinated partnerships and leveraging funds from a variety of sources (federal, state and private). Two research granting authorities that could potentially contribute to the initiative are indentified below.

The Alaska Sustainable Salmon Fund (AKSSF) (www.akssf.org) is the statewide program managed by ADF&G utilizing Pacific Coastal Salmon Recovery Funds (PCSRF) appropriated to the State of Alaska by congress. This fund was established in 2000 to provide annual grants to states and tribes for salmon conservation and recovery efforts. Authorized uses for this fund include maintenance of salmon populations necessary for tribal fisheries and habitat restoration and protection. In the FFY09 Call for Proposals, the AKSSF identified under its strategic focus for habitat in Southcentral Alaska the following information need (1A-6-SC): *Evaluate estuarine conditions that affect salmon and steelhead productivity in estuarine areas that have been subject to human-induced perturbations.* The next AKSSF call for proposals will likely be issued in mid to late September of 2010. Proposals to the AKSSF must demonstrate a 33% non-federal match.

The North Pacific Research Board (NPRB) was established by congress in 1997 to recommend marine research initiatives to the US Secretary of Commerce from the Environmental Improvement and Restoration Fund. The enabling legislation calls for funds to be used to: *"…conduct research activities on or relating to the fisheries or marine ecosystems in the north Pacific Ocean, Bering Sea, and Arctic Ocean (including any lesser related bodies of water)…[with]…priority on cooperative research efforts designated to address pressing fishery management or marine ecosystem information needs."* The objectives of the proposed work align with the NPRB Science Plan and fish habitat research priorities identified in the 2010 Request for Proposals. The NPRB provides an annual call for proposals with a proposal submission date in November.

The National Fish and Wildlife Foundation (NFWF). Under its keystone grant program the NFWF administers the Alaska Fish and Wildlife Fund. The NFWF together with agency and private donor partners, requests proposals to further conservation of species and habitats in Alaska and in its near coastal waters. Their October 2009 request included the following focus areas.

- ***Conduct habitat and species studies*** identified as priority research needs that will inform management decisions ….
- ***Benefit species of special concern***, including polar bears, Pacific walrus, sea otters, beluga whales, wild salmon, eulachon…

Eligible applicants include local, state, federal, and tribal governments; 501(c)3 registered non-profit conservation organizations; and educational institutions. The 2009 grant awards are anticipated to range in size from $25,000 - $100,000. (Grants greater than $100,000 are considered on a case-by-case basis.) A minimum 1:1 match of non-federal funds or in-kind/contributed goods and services is required for projects to be eligible for Federal funds and is encouraged for all proposals.

The National Fish Habitat Action Plan (NFHAP). Funding is provided through the USFWS to approved NWFHP partnerships to fund projects consistent with their respective Strategic Action Plans. For the Mat-Su Salmon Habitat Partnership, proposed projects must address the conservation strategies in its Strategic Action Plan (Smith and Anderson 2008); and as previously noted, this work is responsive to several objectives in that plan. In 2009 $300,000 was available and eligible projects must:

- Address a fish habitat resource need.
- Provide measurable benefits towards improved fish habitat in the Mat-Su Basin.
- Be consistent with the National Fish Habitat Action Plan.
- Be consistent with the “Mat-Su Basin Salmon Strategic Action Plan” and its associated “Prioritization of Strategic Actions Identified in the Mat-Su Basin Salmon Strategic Action Plan, 2008”.
- Be submitted by at least one organizational member of the Mat-Su Salmon Partnership.
- Provide substantial in-kind or cash match (50% of total project cost is desired. Projects with less than 50% will be considered, but may be ranked lower than comparable projects with a full match. Match may be of either Federal of non-federal origin).

2. Synthesis and Comprehensive Analysis of Existing Knik Arm Salmonid Datasets (CS-1)

Table 3. Key research question addressed by CS-1.
• What are the limitations of previous fisheries studies done in Knik Arm and would a comprehensive analysis of these data sets advance our understanding of salmon ecology and assist in focusing future work in the area?

2.1. Synopsis

Several field studies have been conducted of juvenile salmonids and other fish in Knik Arm beginning with the spring 1983 surveys for the then proposed Knik Arm Crossing (Morsell et al. 1983). The full extent of available studies has been reviewed and summarized by HDR (2010) as part of a contract with the USFWS. The most recent and intensive studies were those by Houghton et al. (2005a, b) who conducted coordinated surveys for the Knik Arm Bridge and Toll Authority (KABATA) and the Port of Anchorage (POA). While the field work of these two studies was fully integrated, contractual constraints dictated that data analyses were segregated into two separate reports, each reflecting primarily those data funded by each separate organization. As a result, the data have not been fully integrated and analyzed as one data set. At the September 3, 2009 workshop panel, it was recommended that "data mining" would provide a better understanding of the timing, habitat use, and general ecology of juvenile salmonids in Knik Arm. For example, tow net sampling in mid-channel areas was conducted and reported from May through July 2005 under the KABATA program (Houghton et al. 2005a) and in August and September 2005 under the POA program (Houghton et al. 2005b); these data have not been analyzed together. Similarly, under the KABATA program, 7 to 10 sites were beach seined from July through November 2004 and from April through July 2005. During the same periods under the POA program, 3 to 5 additional sites were sampled, with sampling continuing through September 2005. These data also have not been analyzed in aggregate, nor have they been compared in detail with similar data, collected by the same investigator with identical gear in 1983 (Morsell et al. 1983). An additional data set that will be considered for comparative purposes was gathered by Houghton et al. (2007) in Turnagain Arm in June and July 2006. To do this work, approval must be secured from both KABATA and POA for use of these data.

2.2. Goal

The intent of the proposed study is to analyze and synthesize all of the data from the two recent Knik Arm studies, and to compare this information with Knik Arm data from Morsell et al. (1983), Turnagain Arm data from Houghton et al. (2007), and more recent LGL work (Nemeth et al. 2007) to provide the most complete existing picture of what is known and not known about fish use and ecology in upper Cook Inlet in general and Knik Arm in particular.

2.3. Objectives

1. To maximize the value of existing data by conducting a thorough analysis and synthesis of these data to develop the best available understanding of the timing and distribution of juvenile salmonids and other fish in Knik Arm.

2. To clearly state the limitations of those data and to identify uncertainties and data gaps in the studies. This information will provide the best available starting point for further studies in the Arm.

2.4.Methods/Approach

As noted above, the two large data sets include data that have been gathered with identical or comparable approaches over several years. The basic approach for this study is to integrate and synthesize existing data that are maintained by Pentec Environmental (the natural resources arm of Hart Crowser, Inc.) from the KABATA and POA studies (Houghton et al. 2005a, b). The existing data sets have been thoroughly checked for errors in the course of reporting under each program. The formats of these data sets for each gear type are fully compatible and can be readily merged for analysis and synthesis.

Excel will be used to consolidate and sort data and to create charts and tables of fish and invertebrate catch by date, location, and tidal condition. Catch per Unit Effort (CPUE) of fish captured by beach seine and tow net will be calculated for each station, date, and tide status by dividing the total number of each species caught by the number of sets made during the specified sampling effort. Monthly length frequency histograms will also prepared using Excel such that the X-axis represents the length interval sampled and the Y-axis is the number of fish measured within that length interval.

Dietary analyses were conducted to evaluate the dietary condition of each fish sampled in terms of instantaneous ration (the ratio of stomach content weight to fish weight) as well as the importance of each prey item. The Index of Relative Importance (IRI) of prey items in the diet of the fish species sampled was calculated according to Cailiet (1976) using the equation:

$$\mathbf{IRI = (\%N + \%W) * \%FO,}$$

Where N is percent of a particular prey item relative to the total number of prey items, W is the percent biomass that each prey item comprised, and %FO, the Frequency of Occurrence, is the percent of stomachs in which the taxon was identified.

The dietary overlap between pairs of species was evaluated for Chinook and chum using a modified Schoener's index, called the Percent Similarity Index (PSI). The PSI is the sum of the proportional volumes of individual prey categories in common between two predators and is calculated according to the formula (Buckley et al. 1999):

$$\mathbf{PSI = \sum[min\ (p_{xi}, p_{yi})]}$$

Where p is the percentage (or proportion) of prey i in predators x and y. The PSI ranges from 0 to 100 percent, where 0 percent indicates no overlap and 100 percent indicates complete overlap in diet of the two predators.

The diets of juvenile salmonids collected during the summer of 2005 will be compared with data collected by Morsell et al. (1983) to evaluate possible changes in dietary composition over time.

SPSS SigmaStat 2.0 will be used to perform statistical analyses. Null hypotheses (Ho) will be of the form:

Ho: There is no difference in CPUE of species X between or among time periods, locations, tidal condition, etc.

Null hypotheses will be tested using the Kruskal-Wallis non-parametric one-way analysis of variance (ANOVA) of ranks (Zar 2004). The Mann-Whitney U test, a non-parametric ANOVA for two independent groups, will be used for evaluating whether the CPUE at reference sites (KA 11, PS 3) are significantly different from developed sites. The results of all statistical tests will be evaluated at a significance level of 0.05, with the null hypothesis rejected when $p < 0.05$.

Important questions that will be evaluated using the entire data set, and, where appropriate, qualitative comparisons with other data from Morsell et al. (1983), Houghton et al. (2007), and Nemeth et al. (2007), include the following:

- Have there been any important changes in fish species presence or relative abundance from 1983 to the present time?
- Have there been changes in prey selection by chum or Chinook salmon between 1983 and the present time?
- Is there a predominance of movement of juvenile salmonids down the east side or west side of the Arm?
- Are juvenile salmonids of various species and life history strategies more abundant in shoreline vs. midwater areas; developed vs. undeveloped shorelines; mud vs. gravel shorelines?
- Is the abundance of juvenile salmonids along shorelines greater during one tidal stage than another?

Finally, the results will be used to revisit the other research questions developed under the larger HDR contract with USFWS, to reassess the limitations on our existing knowledge of salmon use of Knik Arm, and to refine the design of proposals for future research.

2.5. Schedule

Once authorized, this work could be completed within 2 to 3 months since all of the necessary data already reside on the Pentec server in files that will require little preparation for analyses.

2.6. Budget

Estimated cost for this work is $36,500. An optional meeting in Anchorage to present results would cost an additional $6,500.

2.7. Deliverables

Two deliverables will be prepared under this task:

First, a detailed technical report will be produced comparable to those separate reports of the 2004-2005 studies (Houghton et al. 2005a, b). This report will include summaries and analyses of all of the existing available data from all gear types. The raw data files will also be included in electronic format as appendices so that this important information is available for future uses. This report and its appendices will be made publicly available after the completion of the manuscript (below).

The second product will be a manuscript describing the most important findings of the analysis that is suitable for publishing in peer reviewed literature. This will make information on Knik Arm fish use more widely available to the scientific community. Depending on the timing of authorization of the work, results may also be presented at an appropriate scientific meeting such as the annual Alaska Marine Science Symposium.

3. Knik Arm Estuarine Habitat Mapping and Classification (CS-2)

Table 4. Key research questions addressed by CS-2.
• What is the residence time and relative abundance of salmon by life history stage and habitat type in Knik Arm?
• How are estuarine and intertidal habitats utilized by salmon in Knik Arm? For example: migration, osmoregulation, rearing, feeding, refuge from predators (for both adults and juveniles).

3.1. Synopsis

This study will classify and spatially delineate estuarine habitats to a Coastal and Marine Ecological Classification Standard (CMECS) Level 5 scale (1-100 m^2) (Madden et al. 2005). Intertidal habitats will be classified using a combination of synthetic aperture radar (SAR) and high altitude aerial optical imagery captured at low tide. Coastline imagery from ShoreZone (http://alaskafisheries.noaa.gov/habitat/shorezone/szintro.htm) will be used to supplement classifications along shorelines. Subtidal habitats will be classified using interferometric multibeam and side scanning backscatter acoustics with bottom classification software. Direct field observations will be used for real time calibration and to develop standardized classification protocols. Random validation sampling will be used to determine classification error. The project will produce a GIS delineation of approximately 500 square kilometers (km^2) of estuarine habitats extending from the entrance of Knik Arm north to the mean high tide line. This GIS will provide the framework for future studies described in the USFWS Knik Arm Salmon Ecology Integrated Research Plan and potentially for multi-species studies outside the scope of the USFWS plan.

This mapping and classification component will form the foundation from which to build future work. We have preliminarily identified six general habitat types (marsh, mud, sand, gravel/cobble, glacial river influenced, open water/sub-tidal benthic) within which there are may be multiple sub classifications. For example mud habitats might be partitioned by tidal zone; high intertidal mud (contiguous with marsh in many areas and where polychaete worms may be abundant), mid, and lower intertidal mud sub-divided by presence or absence of tidal channels. A seventh habitat type of interest and concern is artificial, for which there are at least two subtypes: sloped (usually riprap) and vertical (sheet pile, rock wall, permanently moored vessel). Finally, given the reported importance of terrestrial insects in the diet of Knik Arm juvenile salmonids and the potential importance of terrestrial leaf litter to the carbon base of the Arm (Houghton et al. 2005b), a complete mapping of habitat features important to juvenile salmonids must reflect riparian condition.

3.2. Goals

Specific goals of this work are to:

- Construct a GIS baseline of estuarine habitats in Knik Arm to a CMECS Level 5 scale (1-100 m^2).
- Enable future quantitative analysis of the functional ecology of Knik Arm by habitat type, including: fish community composition, presence by life history stage, migration,

osmoregulation, rearing, and feeding. These parameters are proposed for examination in companion studies not included in this study.

The comprehensive mapping of estuarine habitats in Knik Arm will provide a framework to be used by other studies to analyze ecological function of Knik Arm for fish, invertebrates, beluga whales, and shorebirds.

We propose to use a combination of remote sensing methods including SAR, aerial imagery, and interferometric backscatter acoustics, to describe fish habitat in Knik Arm. Aerial and satellite imagery and acoustical equipment will be used to gather data on approximately 500 km^2 of the Arm. The study area consists of the waters of Knik Arm, extending northward from the north tip of Fire Island to the mean high tide line. A ground-truth sampling regime will quantify accuracy of the applied classifications (Figure 1).

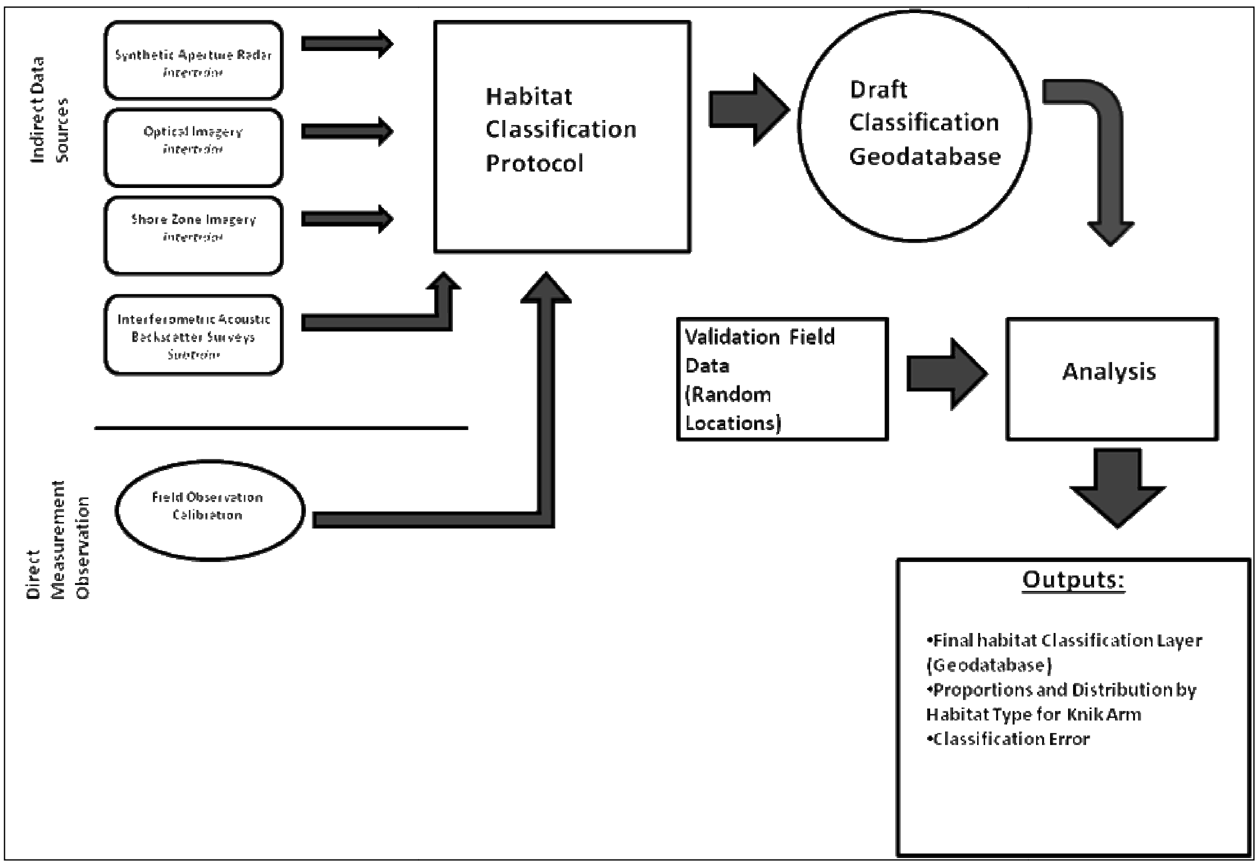

Figure 2. Knik Arm habitat classification process, using synthetic aperture radar (SAR), aerial imagery, and interferometric backscatter acoustics.

3.3. Objectives

Specific objectives to be addressed in this study are:

1. Classify approximately 300 km^2 of intertidal habitats in Knik Arm using calibrated delineation of low tide optical and radar data

2. Classify approximately 200 km^2 of subtidal habitats using interferometric acoustic backscatter techniques
3. Construct a GIS with habitat delineations as a foundation for future research.

3.4.Methods/Approach

3.4.1. Objective 1 –Classification of Intertidal Habitats - Approach

We will classify intertidal areas in Knik Arm in GIS using a combination of synthetic aperture radar (SAR) and optical imaging. Visual interpretation of radar and optical imagery will be the primary method used to classify and calculate a proportional breakdown and spatial distribution of intertidal habitats in Knik Arm. Three types of existing imagery have been identified as suitable for the intertidal habitat classification process: remote-sensing data, aerial photography, and oblique photography.

Two nationally recognized classification systems, Alaska ShoreZone Coastal Mapping and Imagery project (ShoreZone) and the Coastal and Marine Ecological Classification Standard (CMECS), will be used to establish a habitat classification framework and spatial database structure for future Cook Inlet work to build upon. We have preliminarily identified six general habitat types (marsh, mud, sand, gravel/cobble, glacial river influenced, open water/sub-tidal benthic) within which there may be multiple sub classifications. For example, mud habitats might be partitioned by tidal zone; high intertidal mud (contiguous with marsh in many areas and where polychaete worms may be abundant), mid, and lower intertidal mud sub-divided by presence or absence of tidal channels. A seventh habitat type of interest and concern is artificial, for which there are several subtypes including sloped (riprap) and vertical (sheet pile, rock wall, permanently moored vessel).

The first step of the classification process will use remotely sensed Phased Array L-band Synthetic Aperture Radar (PALSAR) data acquired from Japan's Advanced Land Observing Satellite (ALOS) mission. PALSAR is an L-band SAR capable of detailed, all-weather, day-and-night observation, and repeat-pass interferometry (ASF 2009). This satellite passes over Knik Arm daily and the most recent data associated with the lowest summer tidal stage will be selected. PALSAR imagery will be the primary method for delineating the boundary between the intertidal and subtidal zones. While these data do not have the resolution of optical data, it will provide a recent depiction of the intertidal topography.

Aerial photography will be used to provide additional detail and verify classifications assigned based on the PALSAR data. Historic black and white aerial photography collected during low tide in June of 1980 and will be supplemented with recent 2009 low elevation oblique video and still images collected at low tide for the ShoreZone project.

Knik Arm imagery will be acquired from Aero-metrics Inc. (Anchorage, Alaska) and/or the Alaska Satellite Facility of the Geophysical Institute at the University of Alaska, Fairbanks. Once suitable imagery is acquired, scientists will designate habitat units based primarily on physical characteristics of geomorphology and bottom substrate texture. Designated habitat units will then be digitized in ArcGIS and all classifications will be entered into a database. Biological information collected during future studies will provide an additional level of classification.

A critical component of this work would be an objective evaluation of the habitat model. Visual classification protocols will be developed through 1) visiting representative habitats in Knik Arm to ground-truth habitat classifications 2) developing a set of rules to follow when visually delineating habitat boundaries from imagery, and 3) standardizing habitat classification as applied to observed or sensed habitats through using these rules. Following classification, a number of randomly selected locations from each habitat type as classified by the visual classification protocols will be ground-truthed to physically determine the actual habitat type. A matched pairs comparison of the habitat classifications obtained from the model and field sampling will then be made and model error will be determined.

Ground-truth efforts will be accomplished opportunistically either on foot or by boat during low tides. The extent of the ground-truth effort will be dependant on the number of habitat types identified. Preliminary information suggests that up to ten habitat types will be identified.

3.4.2. Objective 2 – Classification of Subtidal Habitats - Approach

The turbid water of Knik Arm prohibits using imagery to classify underwater habitat; therefore, acoustic data will be used to classify the benthic habitat of Knik Arm. While optical classifications allow high resolution delineation of habitats, they provide very low spatial coverage, thus making optical habitat mapping an inefficient and costly approach. High resolution, bathymetry and co-registered backscatter acoustic systems allow wide swaths of benthic habitat to be mapped with resolving power of centimeters to kilometers. This task will employ a survey vessel equipped with an interferometric swath bathymetry system (GeoSwathPlus 250 kHz). The swath system measures both bathymetry and seabed acoustic backscatter from a hull-mounted transducer, providing co-registered depth soundings and side scan sonar information in water depths ranging from 1-75m. Acoustic backscatter is very sensitive to changes in substrate or sediment composition and will reflect or absorb sound energy depending upon the seafloor type. Mosaics of this “fused” data set provide a rapid and cost-effective technique to map substrate distributions over fairly large areas. We will conduct acoustic backscatter surveys to image subtidal areas of Knik Arm. These will be processed and habitats will be classified in GIS in the same manner as above, but using the CMECS system, especially developed by NOAA for subtidal and marine areas.

Horizontal and vertical control will be obtained with dual-channel GPS (Trimble RTK) and referenced to the World Geodetic Survey 1984, Universal Transverse Mercator (or State Plane) and local Mean Lower Low Water (MLLW), respectively. Vessel and transducer motion will be measured and corrected in real-time using an (Ixsea Octans or Applanix POS-MV) motion sensor. In contrast to fixed-angle algorithms utilized by beam-forming multibeams, interferometric swath systems determine angle and travel time for every sampling interval (~50 millisecond). Measuring angles from phase shifts at rapid sampling intervals provide a more dense number of soundings at the outer ranges resulting in a wide horizontal swath (approximately 8-10 times the water depth) in shallow water and resolution of three-dimensional features ranging in size from centimeters to kilometers.

The acoustic survey data can be interpreted by Kongsberg Maritime computer software (Kongsberg, Norway) based on ground-truth information. Substrate samples will be collected from the study area at intervals along each transect using a standard grab or with a rock dredge, as appropriate for the substrate. Samples will be processed onboard the vessel to determine dominant substrate character, grain size, and the presence of biological organisms. The ground-truth data will be used to “train” the software to recognize multiple textures and produce classified maps.

3.4.3. Objective 3 – Delineation of Habitats - Approach

We will employ two methods for the preliminary delineation of habitats. The first method will utilize heads up digitizing techniques for a supervised delineation of the processed PALSAR imagery and the 1980 aerial imagery. The habitat classification framework established in Objective 1 will be created in GIS (File Geodatabase). Visual classification protocols will be followed and tracked in the geodatabase. Scientists will assign each GIS polygon and linear feature with a habitat type and sub-habitats as appropriate. In some cases, still images can be linked to polygons to supplement classification. We will also follow topology rules during polygon editing to ensure a seamless habitat classification network.

The second method will use outputs from the acoustic backscatter surveys. Because outputs will only map and classify subtidal habitat along the survey transect, an interpolation method will be used to predict the entire subtidal area. Once the point locations along the survey transect are classified using the CMES system we will use either an Inverse Distance Weighted or Kriging interpolation in Spatial Analysis to predict the entire subtidal area. Kriging may be a better option as we could assess the error of the predicted habitat. This raster output will be converted to a polygon layer following the same classification framework as above.

The three outputs from these delineation methods will be overlaid in GIS using rules set in the habitat model to produce a preliminary delineation of habitats representing the current conditions in Knik Arm.

3.4.4. Evaluation of Classification Error

An objective evaluation of the accuracy of the classification protocol is a critical component of this work. Habitat classification of randomly selected locations from each type will be physically verified in the field, enabling comparison of the habitat classifications obtained remotely using the protocol and during field sampling. Ideally, there would be a high degree of agreement between the model and field sampling which would indicate that the satellite/aerial imagery and sonar information could be used to classify the habitat.

The initial approach to the evaluation of the habitat model will be similar to the methods described for matched pairs by Agresti (1996). Table 5 illustrates how the paired data could be displayed. For a perfect model, all of the numbers would be along the diagonal (for example, Mud-Mud, Gravel-Gravel, Cobble-Cobble) and the off-diagonal cells would contain zeros. Numbers in the off-diagonal indicate disagreement (for example the table below indicates there were two sites classified by the model as mud, which when physically examined, were actually gravel).

Individual cells will eventually be estimated as probabilities. For the example above, there are 20 verification visits per habitat type which can easily be expanded to each observation being worth 5% probability. For the example (Table 5), there is a 10% chance that the model will classify a gravel site as mud.

Table 5. Hypothetical matched pairs analysis table for evaluation of intertidal habitat model.

	Ground Sampling			
Satellite/Aerial	**Mud**	**Gravel**	**Cobble**	**Total**
Mud	18	2	0	20
Gravel	2	17	1	20
Cobble	0	1	19	20
Total	20	20	20	60

3.4.5. Anticipated products

1. Methods and protocols to apply habitat classifications to estuarine habitats using remote and acoustic sensing.
2. Description of proportional area and distribution of different habitats in Knik Arm.
3. Habitat classification layer geodatabase enabling functional ecological analyses by further studies. The habitat geodatabase will be posted to the Alaska State Geo-spatial Data Clearinghouse (http://www.asgdc.state.ak.us/) for public access upon project completion.

3.5.Schedule

Milestones for this project will include: completion of acoustic backscatter surveys in June or July, completion of preliminary delineation of habitats in July or August, completion of habitat classification validation in August, completion of proportional and aerial analyses of habitats in December, completion of final report and metadata submission in March (following year), dissemination of results through posting of habitat geodatabase to the Alaska State Geo-spatial Data Clearinghouse in March.

3.6.Budget

The total costs for this project are estimated at $302,360. Salary costs totaling $161,000, include a project manager, technical analyst and writer, field crews, a GIS specialist and controller. Satellite and aerial imagery form the University of Alaska Geophysical Institute are estimated at $15,000. General supplies and consumables (fuel, sampling supplies, printing costs, technology fees, etc.) total $15,370. Contractual fees totaling $95,400 cover costs for; a survey vessel, the GeoSwath acoustic system including classification software, a field acoustician and post processing quality assurance. Biometrics consultation is budgeted at $5,500. General contracting fees are estimated at $10,090.

3.7.Deliverables

- Completion of report with spatial distribution and proportions by habitat type
- GIS mapping system (spatial database framework) for organization and analysis of future studies.
- A Geodatabase available to other research efforts through the Alaska Geospatial Data Clearing House

4. Salmon Relative Abundance by Life History Stage and Habitat Type (CS-3)

Table 6. Key research questions addressed by CS-3.
• What is the residence time and relative abundance of salmon by life history stage and habitat type in Knik Arm?
• How are estuarine and intertidal habitats utilized by salmon in Knik Arm? For example: migration, osmoregulation, rearing, feeding, refuge from predators (for both adults and juveniles).

4.1. Synopsis

The majority of information on juvenile salmonid use of various habitats in Knik Arm to date has been inferred from replicated beach seines fished along shorelines, and townet sampling in the mid-channel (Morsell et al. 1983, Houghton et al. 2005a, b). Nemeth et al. (2007) used split beam acoustic equipment to assess abundances of fish in surface waters and deeper in the water column, coupled with surface trawl sampling for identification of species present. Similar methods were employed by HDR (2010) at the proposed tidel energy site near Fire Island. This study (in conjunction with CS-4) will provide an improved understanding of how juvenile salmonids move through (or reside in) Knik Arm, and the relative importance of various habitats to juvenile salmonids and co-ocurring fish during their time in Knik Arm. The study design will employ a combination of acoustic and net capture methods.

4.2. Goal

Determine relative abundance by life history stage of salmon for several of habitat types present in Knik Arm.

4.3. Objectives

1. Determine relative abundance by life history stage of salmon for selected sites representative of the range of habitat classifications described in Study 2.
2. Determine relative fish density in representative habitat sites from early spring (ice out) through late fall (ice in)
3. Allocate acoustic targets to salmon species and age/size (life stage) categories, and calculate the error of this allocation. Acoustic targets will be correlated with actual species present by sampling with nets provide data for comparison of CPUE (relative abundance by species) with target density, and for comparison of length frequencies of target sizes vs. size and species of fish present.

4.4. Methods/Approach

4.4.1. Sample locations.

Sampling locations will be established in habitats representative of the various habitat classifications defined under CS-2. It is anticipated that there will be ten classes of habitats in the Knik Arm estuarine study area. A minimum of three study sites will be established per habitat class, making a total of 30 investigation sites. Sites will incorporate an acoustic transect path paired with net sampling stations. The area of acoustic coverage will incorporate approximately 4 square km, while the net sampling areas will incorporate tow paths or beach seine sites locatd within these areas. Site selection will be based on the following criteria:

1. Representation of the habitat class to be sampled
2. Position relative to a given "patch" of habitat (data on fish use from sampling in an ecotone, or near the edge of a patch, would be difficult to link to a given habitat characteristic)
3. Availability of historic data
4. Feasibility and safety of sampling

4.4.2. Sampling effort.

Number of stations will be allocated among habitat types by relative amount of each habitat type in the Arm. It is assumed that both shoreline and open water stations will be sampled to incorporate each habitat type. Sampling will be conducted from April through September with 2 sampling events each in May and June during the period of maximum juvenile salmon use for a total of 8 sampling periods. All station types may not be sampled in all sample periods; for example, ice may preclude work in the upper Arm during April sampling when work is possible in parts of the lower Arm.

The overall sampling approach for this study component will employ a combination of acoustic and net sampling. Primary tools will be dual frequency identification sonar (DIDSON) and split beam acoustic equipment to enumerate fish, determine their relative size, and track their patterns of movement. At each station and for each sampling event, net sampling will be used to ground truth the fish/signal identifications from the acoustic surveys. The intent will be to net sample, to the degree practicable, the water mass that is being viewed by the acoustic gear.

In open water habitats, broad areas over various depths and along various shore types will be systematically sampled with a split beam acoustic system. To ground truth open water sampling, for a portion of the survey at each station, a pair trawl (tow net) will be deployed such that it is fishing the water immediately behind the acoustic field being sampled. Early in the season, surface tow netting may be precluded by presence of ice at some stations. All fish captured will be identified and measured. Fish or tissues, as appropriate, will be collected and preserved for stable isotope, otolith microstructure, energetics and genetic work to be conducted in conjunction with CS-4. Stomachs will be collected and preserved in conjunction with CS-4, especially those of potential predators on juvenile salmonids.

During all field work, crews will document presence and species of potential predators on juvenile salmonids; evaluate stomach content of fish species that could be potential predators captured in net fishing. Crews will record and report all sightings of beluga whales to NMFS. Basic water quality parameters (dissolved oxygen, water temperature, salinity, conductivity, pH, turbidity) will also be collected (surface, mid-depth, and near bottom) for a representative location during each sampling event.

4.4.3. Passive (acoustic) Sampling

This study will utilize vessel-mounted split-beam hydroacoustic sonar in mobile surveys to gather information on fish spatial distributions and abundance in study area. The advantage of the hydroacoustic technology is that sampling does not adversely affect fish (passive sampling), data can be collected over the entire water column, and over a large area in a short amount of time. The split-beam technique provides an accurate position of each acoustic target (representing fish) and also provides estimates of individual fish target strength, a measure that roughly corresponds to the physical size of the fish. One of the limitations of the hydroacoustic technology is the lack of species identification. Thus, the acoustic data collection will be supplemented with fish collections using net sampling methods described above.

Acoustic sampling sites will consist of approximately 1-5 km long transects, positioned perpendicular to flow across the study area. Transects would be spaced approximately 500 m apart. Sampling will be stratified to evaluate tidal cycle and will include spring/summer/ and fall sampling to evaluate seasonal trends.

The hydroacoustic surveys will utilize two split-beam scientific echo sounder using 200 kilohertz (kHz) narrow beam transducers with low side lobes, or similar model transducer. The 200 kHz transducer provides the longer range information appropriate for deep water conditions of the sample area while avoiding potential acoustic sensitivities of beluga whales. The anticipated target detection ranges on the 200 kHz transducer are in excess of 100 m. One transducer will be mounted in the vertical position (down-looking), the entire water column traveled will be ensonified and information will be collected to near bottom. To adequately sample the near-surface area, a second transducer will be deployed in the side-looking orientation. Data from the initial surveys will be evaluated to determine if the one down-looking transducer sufficiently samples surface-oriented fish. A Global Positioning System (GPS) will be connected to the hydroacoustic system to collect positional data to geo-reference all XYZ positional target data. Navigation software will be used on a separate GPS linked laptop to guide the survey vessel through predetermined transects.

The vessel will travel at approximately 3 knots (3.5 mi/hr, 5.6 km/hr) and the sonar will collect up to 5 samples per second. At 100-foot depth, the width of the sonar beam would be 10 feet based on a 6° acoustic beam. Within the beam, size categories of fishes will be determined based on the acoustic size of the fish echoes.

On beaches and adjacent to hardened shorelines (riprap, sheet pile), the approach will be to establish the DIDSON equipment deployed from a skiff, looking parallel to the shoreline. Depth of the water, and depth of the equipment below the water surface will be determined in the field for optimal performance given the beach geometry of each sampling location. The DIDSON will be run for a minumum of 20 minutes, at the end of which, a net appropriate for the site will be set to fish through the field of the DIDSON. Beach seines will be used on beaches where this gear is suitable. On armored shorelines, fyke net trapping will likely be used to collect fish for ground truthing.

4.4.4. Active (Net) Sampling

Active sampling will be used to verify acoustic targets (see below), to sample areas in which this gear cannot be used safely or effectively (e.g., some shallow intertidal areas), and to collect samples for use in CS-4. A combination of beach seines, fyke nets, mid-water trawls, surface trawls (a modified Isaac Kid style trawl or similar) and variable mesh gillnets may be used to sample fish in Knik Arm, using comparable methods to those of Houghton et al. (2005 a, b) and HDR (2010 *in prep*). Beach seines may be set from a boat using the parallel-set method (e.g, Houghton et al. 2005a, b; Nemeth et al. 2007), or set by hand in areas too shallow to set by boat. Mid-water tows will be made from a boat.

Fish captured will be identified to species and counted. Voucher specimens may be preserved by freezing for identification of difficult specimens. Larval fish will be identified to family. Fish lengths will be measured to the nearest millimeter for the first 20 fish of each species per set. Salmonids will be measured to fork length and total length of other fish will be measured. A subsample of each fish species caught will be weighed; scale samples will be taken from a subsample of all salmonids caught. Target sample sizes for weights and scale samples will be determined based on the level of field effort. Adult and juveniles of salmon species will be treated as separate species for the purpose of catch processing.

A target number of specimens will be preserved for diet, otolith, calorimetry, and other analyses for use in CS-4.

4.4.5. Data Analysis.

Fish sampling data from beach seining, tow nets and fyke nets will be analyzed as in Houghton 2005a, b. Acoustic data from the split beam system will be analyzed using Echo View software (www.echoview.com). Fish tracks will be displayed on an echogram, reviewed and edited under the direction of a qualified acoustician. Data will be stored in a database containing the following attributes for each individual fish target: target strength, positional information for the target (x, y, z coordinates), transect ID, date and time. Fish lengths will be estimated for acoustic targets using Love's Any Aspect Equation (Love, 1977).

Fish capture data will be allocated to time and depth strata that correspond with the acoustic data. Length frequencies for each species will be generated for each time and depth stratum and then time, depth and length parameters from fish captures will be used to assign fish species to acoustic targets. All acoustic and fish capture analysis will be conducted in close consultation with a project biometrician and acoustician.

To determine habitat use by fish, three-dimensional positions of fish target data in cross sections extending across each study site will be determined (Appendix C). Cross sections will be divided into cells and within each cell, the frequency of occurrence of fish targets, and their associated lengths, will be calculated. This analysis will be spatially stratified to examine differences in habitat usage by habitat classification (from CS-2) and temporally to examine seasonal differences.

4.5.Schedule

Feburary – March	Project initiation, permitting, logistical planning
Late April	Initial sampling event, 10 days, conditions dependant
May – June	Two 10 day sampling event per month, all sites
July -September	One 10 day sampling event per month.
October –November	Data processing, GIS analysis
December – January	Reporting

Note that because of the inherent interannual and intraannual variability of salmon populations, a minimum of 3 years of this effort should be considered.

Budget

Estimated cost for this work is $890,000. The following assumptions were made in budgeting this work:

- Eight sampling events (April; 2 in May; 2 in June; July; August; September)
- Ten field days for each sampling event for a total of 80 field days.
- Field crew size of 5 biologists plus acoustician; 80 days @ 10 hrs/day
- Vessel support:
    - 18 foot Skiff and operator for seining; 80 days at $700/day = $56,000
    - 28 foot vessel for acoustic sampling and trawl netting; 80 days at $2000/day = $160,000.
- Lease costs for acoustic equipment and acoustic consultation = $120,000.
- Project management, biometrics, acoustic data post processing, database management, QA/QC, GIS analysis and reporting.

4.6.Deliverables (in conjunction with CS-4)

- A final report presenting findings will be prepared by the project investigators. Copies will be distributed to state libraries and ARLIS
- GIS datalayers incorporating data into mapped habitats
- Master’s thesis or Ph.D. dissertation
- A manuscript to a peer reviewed fisheries journal.
- Presentations at the national meeting of the American Fisheries Society and/or the Alaska Marine Science Symposium.

4.7. Collaboration

This component study provides an oportunity for collaboration with the Native Village of Eklutna (NVE). NVE village site and lands occur along the shoreline of Knik Arm. Local traditional knowledge (LTK) provided by NVE participants will aid in identification of timing and distribution of fish in the Knik Arm estuary. NVE collaborators could provide LTK for harvest methods and could provide skiffs and boat operators for use in conjunction with the acoustic and net sampling. NVE residents have valuable experience on the waters on Knik Arm, and could provide a good deal of assistance in navagating through the upper Arm's complex system of channels and sand bars.

This study is intended to be conducted in conjunction with CS-4 and in collaboration with the University of Alaska, School of Fisheries and Ocean Sciences, with a graduate student funded by this project. The work would be incorporated into that person's Master's thesis or Ph.D. dissertation. As part of the graduate program the student will submit at least one manuscript to a peer reviewed fisheries journal. Additionally, they will be required to give presentations at both the national and Alaska chapter meetings of the American Fisheries Society or the Alaska Marine Science Symposium. A final report presenting findings will also be prepared by the project investigators for the funding bodies. Copies will be distributed to state libraries and ARLIS.

5. Function and Ecology of the Knik Arm Estuary for Juvenile Salmon Life History (CS-4)

Table 7. Key research questions addressed by CS-4.
• What is the residence time and relative abundance of salmon by life history stage and habitat type in Knik Arm?
• How are estuarine and intertidal habitats utilized by salmon in Knik Arm? For example: migration, osmoregulation, rearing, feeding, refuge from predators (for both adults and juveniles).
• What is the source of carbon in juvenile salmonids (terrestrial, river-borne, salt marsh, marine)? Does it change with residence time in Knik Arm?
• What role do invertebrates play in the life history of salmon in Knik Arm?

5.1. Synopsis

This study would use fish samples collected in CS-3 and the habitat classifications applied to Knik Arm in CS-2 to answer several questions regarding the ecology and life history of juvenile salmon in Knik Arm. Residence time of juvenile salmon in Knik Arm before returning to freshwater, or movement seaward farther south into Cook Inlet can be somewhat inferred from results of CS-1 and CS-3. Houghton (2005a, b) observed that juvenile salmon captured in the Arm increased in size over time during the spring and summer. However, it is unknown whether the pattern in length frequency histograms over time simply reflects larger fish outmigrating into the Arm later in the year (contrary to patterns sometimes reported in the literature), or if indeed, the fish migrate seaward. Additionally, little is known regarding the behavior of juvenile salmon in Knik Arm. This study would explore the function of Knik Arm in juvenile salmon life history using several laboratory-based methods. This project description is presented in concept only due to the limited scope of the USFWS contract.

5.2. Goal

To understand and describe the functions of Knik Arm estuarine habitats in juvenile salmon life histories.

5.3. Objectives

1. Determine residence time of juvenile salmon in Knik Arm
2. Identify relative importance of food web components for juvenile salmonids captured in various habitats in Knik Arm
3. Identify habitat features supporting production of prey in various habitats within the Arm (e.g., fluvial, aerial (riparian), marsh, benthic marine, pelagic marine)

5.4. Methods

- Perform stomach content analysis (fullness, major taxa, number, and dry weight) to determine diets
- Analyze mean energy density using bomb calorimetry or similar approach to determine energetics of prey items
- Identify trophic dependencies of dominant prey taxa (e.g., aquatic insect type, terrestrial insect type, benthic omnivore/herbivore) to better understand Knik Arm food web
- Derive age/habitat use from otolith aging and micro-structure characteristics
- Perform genetic analysis – to link sockeye, chum and Chinook local river baselines (where available).
- Use stable isotope ratios to estimate sources of carbon in juvenile salmonids in Knik Arm over time (marine vs. riverine)
- Develop conceptual habitat-based food web model.

5.5.Schedule

October – December	Lab analysis - field collections from CS-3
January – June	Data analysis and reporting

5.6.Budget

No estimate of cost has been completed for this project. Cost components will include a graduate student stipend, laboratory processing costs, salaries for sample preparation, data entry, data QA/QC, biometrics, editorial reviews, and publication fees.

5.7.Deliverables (in conjunction with CS-3)

- A final report presenting findings will also be prepared by the project investigators. Copies will be distributed to state libraries and ARLIS
- GIS datalayers incorporating data into mapped habitats
- Master’s thesis or Ph.D. dissertation
- A manuscript to a peer reviewed fisheries journal.
- Presentations at the national meeting of the American Fisheries Society and/or the Alaska Marine Science Symposium.

5.8. Collaboration

This study is intended to be conducted in conunction with CS-3 and in collaboration with the University of Alaska, School of Fisheries and Ocean Sciences, with a graduate student funded by this project. The work would be incorporated into that person's Master's thesis or Ph.D. dissertation. As part of the graduate program the student will submit at least one manuscript to a peer reviewed fisheries journal. Additionally, the student will be required to give presentations at both the national and Alaska chapter meetings of the American Fisheries Society or the Alaska Marine Science Symposium. A final report presenting findings will also be prepared by the project investigators for the funding bodies. Copies will be distributed to state libraries and ARLIS.

6. Effects of Man-made Structures and Pollutants on Salmon Life History (CS-5)

Table 8. Key research questions addressed by CS-5.
• What are the impacts of existing structures to fish and habitat use in Knik Arm?
• What is the impact on salmon and other aquatic organisms from point and non-point discharges of pollutants entering Knik Arm? For example: wastewater, storm drains and airport deicing.

6.1. Synopsis

Two anthropogenic factors were identified by the September 2009 advisory panel as issues of concern relating to development in Knik Arm. The first concern is that existing and proposed structures such as vertical bulkheads, piers and riprap may have measurable impacts on the life history of salmon in the Knik Arm estuary. The second issue relates to the impact that point and non-point discharges of pollutants entering the Arm may have on salmon. This project description is presented in concept only due to the limited scope of the USFWS contract.

6.2. Goal:

To understand and describe how salmon and other organisms are affected by anthropogenic pressures, including man-made structures and contaminants.

6.3. Objectives

1. Observe/document fish abundance and behavior around bulkheads, riprap, and natural shorelines
2. Establish water quality baseline levels
3. Identify key potential pollutants of concern in the Arm

6.4. Methods

Imaging sonar (DIDSON) surveys would be conducted around bulkheads, riprapped shores, and natural shorelines (see CS-3). The DIDSON data will be processed with Echo View software and a database of fish targets will be generated that contains positional information for the target (x, y, z coordinates), transect ID, date and time. The primary advantage of the DIDSON is the high resolution visual representation of fish movement and behavior. Investigations will examine how fish behavior is affected by man-made structures.

Fish capture methods using traps and net gear as described in CS-3 would be employed along bulkheads, riprap, etc. for acoustic target species composition.

Conduct a literature review to assess potential sensitivities of salmonids to key potential pollutants of concern.

Begin a water quality baseline sampling program at various locations in the Arm to identify key potential pollutants of concern. Monitor water quality to detect seasonal changes and annual trends.

Conduct in situ, caged fish studies is areas of suspected concentrations of pollutants and compare to control sites.

Conduct controlled laboratory studies to assess response thresholds and dose-response curves for salmonids to key potential pollutants of concern in the Arm.

6.5. Schedule

Field investigations for fish behaviour near man-made structures should take place in May and June when juvenile salmon are most abundant. Field sampling for water quality should occur throughout the year. Controlled laboratory studies could take place at any time.

6.6. Budget

No estimate of cost has been completed for this project.

6.7. Deliverables

- Completion report
- Manuscript

7. References

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APPENDIX A. *Abbreviations and Acronyms*

The following abbreviations and acronyms are used in this document.

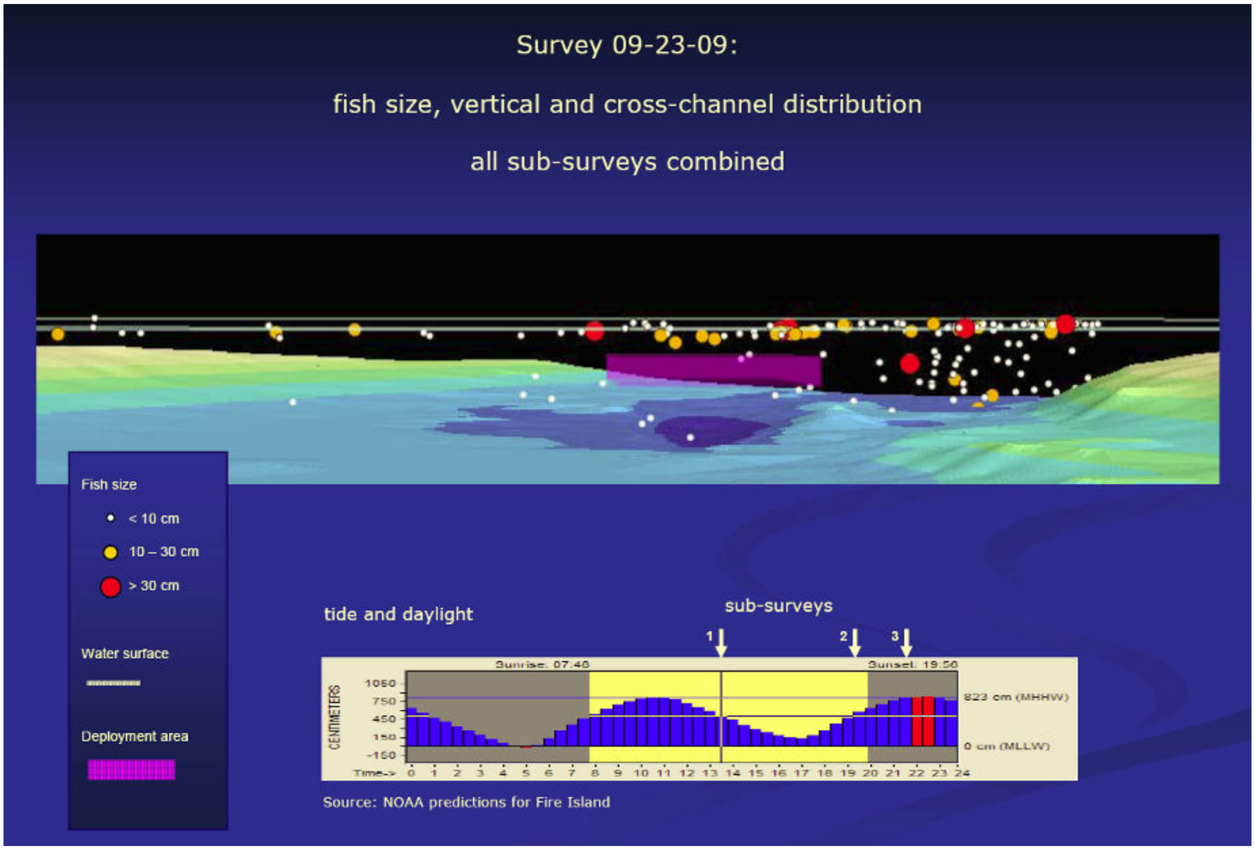
ADF&G	Alaska Department of Fish and Game
AFWA	Association of Fish and Wildlife Agencies
AKSSF	Alaska Sustainable Salmon Fund
ALOS	Advanced Land Observing Satellite
ANOVA	analysis of variance
ARLIS	Alaska Resources Library and Information Services
ASF	Alaska Satellite Facility, located at UAF Geophysical Institute
CMECS	Coastal and Marine Ecological Classification Standard
CPUE	Catch Per Unit Effort
CS	Component Study
DIDSON	duel frequency identification sonar
EFH	Essential Fish Habitat
ft	foot (measure)
GIS	Geographical Information System
GPS	Global Positioning System
hr	hour
IRI	Index of Relative Importance
KABATA	Knik Arm Bridge and Toll Authority
kHz	kilohertz
km	kilometer
LTK	Local traditional knowledge
m	Meter
max	maximum
min	minimum
MLLW	Mean Low Low Water
NEPA	National Environmental Policy Act
NFHAP	National Fish Habitat Action Plan
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPRB	North Pacific Research Board
NVE	Native Village of Eklutna
PALSAR	Phased Array L-Band Synthetic Aperture Radar
PCE	Primary constituent element
pH	hydrogen ion activity (negative log of)
POA	Port of Anchorage
PSI	Percent Similarity Index
SAR	Synthetic Aperture Radar
SPSS	Statistical Package for Social Sciences
TEK	Traditional ecological knowledge
UAF	University of Alaska, Fairbanks
USFWS	United States Fish and Wildlife Service

APPENDIX B.

Inventory of current and future development projects with potential impacts to the Knik Arm estuary.
Knik Arm Bridge Crossing (KABATA) – fill, bulkheads, piers & construction noise
Port of Anchorage Expansion – fill, bulkheads, noise, vessel traffic
Port Mackenzie – fill, bulkheads, noise & vessel traffic
Proposed Tidal Power Station at Cairn Point – turbine operation, noise, transmission lines
Proposed Tidal Power Station at Fire Island – turbine operation, noise, transmission lines
City of Anchorage – wastewater and storm water discharge
Mat-Su Communities – wastewater and storm water discharge
Anchorage Airports – aircraft/tarmac deicing
Oil and Gas Industry – ballast water and produced water
Fort Richardson- Eagle River Flats bombing range
Anchorage Hatchery – Chinook and coho salmon releases
Army Corps of Engineers – dredging for shipping channels
Alaska Rail Road – storm water
Knik River Hydropower – flow changes
Ship Creek Point small boat launch - fill
Mat-Su Borough – Matanuska River flood control – gravel mining
Fire Island Wind Farm –subsurface power transmission lines
Knik Arm Ferry – shoreline modifications
Global Climate Change – glacial recession, hydrology and sediment transport changes

APPENDIX C.

Example 3D depiction of acoustic fish targets looking through a study site in Cook Inlet.



Preliminary data from; Worthington 2009 and HDR 2010 *in prep.*

APPENDIX D.

Contributors to the Knik Arm Salmon Ecology Integrated Research Plan

James Brady, Senior Fisheries Scientist, HDR Alaska. James was the project manager for the USFWS contract to develop this plan. James has over 30 years of experience with Alaska's fisheries. He was with ADF&G for 23 years where he oversaw fisheries research and management programs including supervision of two research vessels, and a broad variety of stock assessment programs in Cook Inlet, Prince William Sound, Bristol Bay and the Yukon River drainage. He has developed research grant proposals for the PCSRF, NPRB, and the USFWS and is currently a co-investigator on NPRB project 2008-823. He served on the audit team for the Alaska salmon certification by the Marine Stewardship Council and advises the Bristol Bay Regional Seafood Development Association of research priorities.

Amanda Prevel-Ramos, Fisheries Biologist, HDR Alaska. Amanda has 7 years experience as a research biologist in Alaska, 5 of which were spent studying fisheries and marine mammals in Cook Inlet. Amanda managed the intertidal portion of baseline studies of marine fish and mammals in Upper Cook Inlet for LGL Alaska Research Associates, Inc. (LGL) in 2006 (Nemeth et al. 2007) and 2007 (Prevel-Ramos et al. 2007). Additionally, she conducted baseline studies of beluga whale habitat use of Knik Arm for LGL (Funk et al. 2005 and Prevel-Ramos et al. 2006). Amanda was the principal author for the Knik Arm Anadromous Fish Study Designs Literature Review under the USFWS contract.

Jon Houghton, Ph.D., **Hart Crowser/Pentec.** Dr. Houghton is a senior biologist with more than 38 years of research and consulting experience in Alaska and the Pacific Northwest. He is an expert in the ecology of anadromous salmonids in nearshore waters of Lower and Upper Cook Inlet and in the effects of perturbations, especially habitat alterations, on coldwater fish populations. He has directed seminal fish assessment studies in these waters in 1983 and 2004 through 2009 (e.g., Pentec 2005a, b; Houghton et al. 2006).

Don Degan, Aquacoustics, Inc. —Don has over 35 years experience in fisheries, 24 years experience using hydroacoustics to sample fish populations with 11 years in Alaska. Prior to founding Aquacoustics, Inc. in 1996, Don was a fisheries scientist with Duke Energy, and a District Fisheries Biologist in Iowa. He has designed and implemented hydroacoustic sampling programs for state fisheries agencies, universities, environmental consulting firms, and federal agencies, including ongoing hydroacoustic work in upper Cook Inlet.

Brian Bue, Biometrician, Bue Consulting LLC. Brian has over 30 years of experience in Alaskan fisheries. Formally a biometrican for ADF&G, he has collaborated with government agencies and private firms on a number of population assessment projects. Brian has authored more than 70 reports in the professional and agency literature.

Phil Brna, Fish and Wildlife Biologist, US Fish and Wildlife Service. Phil has over 33 years experience working on design review and permitting of large-scale development projects in Alaska including oil and gas pipelines, utility and transmission lines, hydropower projects, boat harbors, roads, subdivisions, placer mines, and large metal and coal mines. The majority of Phil's experience (21 years) was working for the ADF&G, Habitat Division, first as a southcentral Alaska habitat biologist and then as the ADF&G Pipeline Surveillance Supervisor. Phil has most recently worked as a fish and wildlife biologist for USFWS for 7 years. Phil's career has focused on evaluating effects of development projects on fish and wildlife populations and habitat, and in mitigating those impacts.

Betsy McCracken, Fishery Biologist, U.S. Fish and Wildlife Service. Betsy has 19 years of experience with the Alaska Department of Fish and Game (ADFG) as a fishery biologist. During her tenure with the ADFG she worked for the Sport Fish, Habitat, and Commercial Fisheries Divisions. Betsy has experience with fisheries research and management projects around the state including population estimates, stock identification, and habitat assessments. In addition, Betsy was a Habitat Division assistant area permitter for the Matanuska-Susitna Valley, Copper River Basin, and Prince William Sound. Prior to moving to the U.S. Fish and Wildlife Service (Service) she was the Coordinator for the Sport Fish Division non-game aquatic species program. In here current fishery biologist position with the Service she works for the Conservation Planning Assistance Unit.

Participants in the September 3, 2009, Knik Arm Workshop.

Phil Brna	U.S. Fish and Wildlife Service
Betsy McCracken	U.S. Fish and Wildlife Service
Barbara Mahoney	NOAA Fisheries
Brian Lance	NOAA Fisheries
Doug Limpensel	NOAA Fisheries
Marc Lamareaux	Native Village of Eklutna
Chris Zimmerman	U. S. G. S.
Andrew Munro	ADF&G Comm Fish
Bob Clark	ADF&G Sport Fish
Eric Volk	ADF&G Comm Fish
Mike Daigneault	ADF&G Habitat
Matthew LaCriox	EPA
James Brady	HDR Alaska
Jon Houghton	Pentec/Hart Crowser
Don Degan	Aquacoustics Inc.
Brian Bue	Bue Consulting LLC
Amanda Prevel-Ramos	HDR Alaska

APPRNDIX E. ***Letters of support***

NMFS – Barbara Mahoney – 12-3-2009

USFWS – Doug McBride – 12-3-2009

The Nature Conservancy – Corinne Smith – 12-3-2009

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
222 W. 7th Avenue, #43
Anchorage, Alaska 99513-7577

Dec. 03, 2009

North Pacific Research Board
1007 W. 3rd Ave., Suite 100
Anchorage, AK 99501

Dear Sir:

I am writing in support of HDR's proposal to you titled: *Estuarine Habitat Classification and Mapping of Knik Arm.* This is a foundational component of a multi-study research approach looking at information needs for Knik Arm, Cook Inlet, Alaska. Knik Arm, surrounded by Alaska's largest population center, two ports, two military bases, and two municipalities faces development pressures from numerous projects.

Not much is known about Knik Arm and the important habitats for fishery resources and marine mammals, including the endangered Cook Inlet belugas (73 FR 62919, 22 October 2008) that frequent the area. The recent proposed critical habitat designation (74 FR 63080, 2 December 2009) for beluga whales further emphasizes the need for information to better understand Knik Arm.

The significant research questions driving the Knik Arm Anadromous Fish Research Plan were developed and prioritized by a multiagency advisory panel in September 2009. To address information needs, an integrated approach was developed with five components: 1) synthesis of existing data sets; 2) estuarine habitat classification and mapping; 3) spatial and temporal assessment of fish resources by habitat class; 4) fish ecology studies (diet, energetics, genetics, etc.); and 5) evaluate anthropogenic affects.

This integrated approach addresses fish habitat research priorities identified by the NPRB as well as estuarine conservation strategies identified in the Strategic Action Plan of the Mat-Su Salmon Habitat Partnership. We support this comprehensive research effort to better understand Knik Arm and how, through an anadromous fish research plan, it may help to understand the lack of recovery for the Cook Inlet beluga.

I highly recommend funding their proposal under your grant program.

If you have any questions, please call at (907) 271-3448 or email Barbara.Mahoney@noaa.gov.

Sincerely,

Barbara A. Mahoney
Biologist, Protected Resources Division

U.S. FISH & WILDLIFE SERVICE

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Anchorage Fish & Wildlife Field Office
605 West 4th Avenue, Room G-61
Anchorage, Alaska 99501-2249

IN REPLY REFER TO:

AFWFO

DEC - 3 2009

North Pacific Research Board
1007 W. 3rd Avenue, Suite 100
Anchorage, AK 99501

Re: Knik Arm Anadromous Fish Research Plan:
Estuarine Habitat Mapping and Classification

To Whom It May Concern:

The Knik Arm Anadromous Fish Research Plan, under development by HDR for the U.S. Fish and Wildlife Service (Service) is an integrated approach to looking at critical information needs for Knik Arm, the most northerly part of the Cook Inlet estuary. Knik Arm is surrounded by Alaska's largest population center and faces pressure from numerous development projects.

Little is currently known about the relative importance of habitats in the Arm and the role that they play in the life history of anadromous fish. Key research questions driving the Knik Arm research plan were developed and prioritized by a multiagency advisory panel in September 2009. Addressing these key information needs required development of an integrated approach involving five study components. These are:

1. Synthesis of existing data sets;
2. Comprehensive classification and mapping of habitats;
3. Spatial and temporal assessment of fish resources by habitat class;
4. Fish ecology studies (diet, energetics, genetics, otolith microstructure) and;
5. Evaluation of anthropogenic affects.

This integrated approach addresses estuarine conservation strategies identified in the Strategic Action Plan of the Mat-Su Salmon Habitat Partnership. The Mat-Su Partnership operates under the National Fish Habitat Action Plan and has received significant funding and support from the Service.

The Service supports HDR's request for funding of study component 2- Knik Arm Estuarine Habitat Mapping and Classification. This research approach has potential to be a model for other estuarine areas of Alaska and will provide a framework for future Knik Arm studies and ultimately conservation of important anadromous fish habitat and populations.

If you have any questions please contact Phil Brna at 271-2440, or by email at phil_brna@fws.gov.

Sincerely,

Doug McBride for
Ann G. Rappoport
Field Supervisor

The Nature Conservancy
Protecting nature. Preserving life.™

The Nature Conservancy in Alaska
715 L Street, Suite 100
Anchorage, AK 99501

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nature.org

3 December 2009

North Pacific Research Board
1007 W. 3rd Avenue, Suite 100
Anchorage, AK 99501

SUBJECT: NPRB Proposal Knik Arm Anadromous Fish Research Plan – Study No. 2 by HDR Alaska

To Whom It May Concern:

I'm writing on behalf of The Nature Conservancy in support of HDR Alaska's proposal to institute an integrated approach to looking at anadromous fish ecology in Knik Arm of upper Cook Inlet in southcentral Alaska.

The mission of The Nature Conservancy is to preserve the plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. For over 50 years, we have pursued this mission by using best available science and a pragmatic, non-confrontational approach to achieve conservation results. In Alaska, as elsewhere, we have conducted rigorous biodiversity assessments to identify and prioritize areas that – if managed to conserve key species – will ensure that Alaska's healthy ecosystems will be passed on to future generations. One of The Nature Conservancy's main foci in Alaska is salmon habitat conservation in the Mat-Su Basin in southcentral Alaska. The waters of the basin drain into Knik Arm and upper Cook Inlet, and understanding how salmon use these marine habitats is essential for conserving these fish.

One of the Conservancy's strategies for conserving salmon habitat in an efficient and collaborative manner is to work with the Mat-Su Basin Salmon Habitat Partnership (www.fishhabitat.org), of which HDR Alaska is also a member. As a member of the steering committee for the partnership, I think this project directly targets one of its priorities for salmon conservation. Last year the Partnership completed its Strategic Action Plan. In the plan, we identified research needs in the Mat-Su Basin as a priority to enable effective conservation of salmon habitat; in particular, the plan notes the need to "understand salmon use of Cook Inlet, temporally and spatially, by lifestage in estuary, nearshore, and deep water habitats, in order to identify habitats critical to Mat-Su Basin salmon." This project directly addresses that need by classifying and delineating estuarine and intertidal habitats.

This project will also provide information at the local level that should be applicable at the regional and national level by improving knowledge about the range of habitats used and required by Pacific salmon. We still have the opportunity to protect Mat-Su Basin salmon and their habitat from the growth and development of human communities that has reduced salmon populations in the contiguous U.S. Studies like this one will help the Mat-Su Salmon Partnership to do so.

Sincerely,

Corinne Smith
Mat-Su Basin Program Director