

**Susitna-Watana Hydroelectric Project
(FERC No. 14241)**

**Fish and Aquatics Instream Flow Study
(Study 8.5)**

**Evaluation of Relationships between Fish Abundance
and Specific Microhabitat Variables
Technical Memorandum**

Prepared for

Alaska Energy Authority



Prepared by

R2 Resource Consultants, Inc.

September 2014

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
ADF&G	Alaska Department of Fish and Game
AEA	Alaska Energy Authority
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	U.S. Environmental Protection Agency
FA	Focus Area
FDA	Fish Distribution and Abundance
FERC	Federal Energy Regulatory Commission
HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Index
ICPMS	Inductively Coupled Plasma-Mass Spectrometry
IFS	Instream Flow Study
ISR	Initial Study Report
LR	Lower River
LWD	Large Woody Debris
MR	Middle River
N	Nitrogen
NMFS	NOAA National Marine Fisheries Service
P	Phosphorus
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project, FERC Project No. 14241
QAIC	Version of Akaike's Information Criteria (AIC) for overdispersed count data where quasi-likelihood and sample size adjustments are made.
RSP	Revised Study Plan
SPD	Study Plan Determination
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TWG	Technical Workgroup
UR	Upper River
USR	Updated Study Report
VHG	Vertical Hydraulic-head Gradient
WQ	Water Quality

1. INTRODUCTION

On April 1, 2013 the Federal Energy Regulatory Commission (FERC) issued its Study Plan Determination (SPD) for 14 of the 58 proposed individual studies in the Alaska Energy Authority's (AEA) Revised Study Plan (RSP) for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241 (Project). When approving the Fish and Aquatics Instream Flow Study (IFS) (Study 8.5), FERC's April 1 SPD (FERC 2013) made recommendations for additional exploratory analyses to look for strong relationships between fish abundance and microhabitat variables that had not been planned for comparison to assess Project impacts. Responding to agency requests, the FERC SPD made specific recommendations on additional microhabitat variables that should be evaluated for possible inclusion in the HSC analyses (see Pages B-84-B-86 of April 1, 2013 SPD; excerpts provided below):

Microhabitat Types, HSC and HSI Development

NMFS requests that the following microhabitat variables be collected: depth, velocity, surface flow and groundwater exchange fluxes, upwelling/downwelling (determined by vertical hydraulic gradient-head or VHG), substrate type, cover, woody debris, turbidity, dissolved oxygen (intragravel and surface water), macronutrients (N, P), temperature (intragravel and surface water), pH, dissolved organic carbon (DOC), alkalinity, invertebrate drift density, benthic organic matter, algal biomass, and Chlorophyll-a.

FWS states that VHG, intragravel water quality, and groundwater are particularly important microhabitats that are omitted from the assessment and should be included in HSC/HSI development.

EPA states that relationships between the hierarchical habitat classifications proposed by AEA and microscale habitat variables that are statistically relevant to fish use, have not been tested and that the abundance and spatial distribution of microhabitat may not necessarily depend on the spatial distribution of larger-scale aspects of channel planform. EPA suggests that possible spatial relationship(s) between suitable microhabitat conditions (e.g., substrate, depth, velocity, temperature, etc.) and channel planform should be treated as hypotheses that require testing.

Discussion and Staff Recommendation

As noted above, AEA proposes to develop site-specific HSC by collecting microhabitat data for depth, velocity, substrate, proximity to cover (including LWD), upwelling, and turbidity for specific locations where target species and lifestages are observed. Therefore, AEA is already addressing seven of the 18 microhabitat variables recommended by the agencies for detailed analysis and preparation of HSC curves for this study, and its proposed approach for developing HSC curves for these seven variables is consistent with accepted practices for implementing an instream flow study within the context of a hydroelectric licensing case (section 5.9(b)(6)).

In regard to three of the 11 microhabitat variables recommended by the agencies (i.e., invertebrate drift density, benthic organic matter, and algal biomass), HSC would be developed for these resources as part of Study 9.8 (river productivity), in addition to supplementary measures of Chlorophyll-a.

In regard to the remaining eight of the 11 microhabitat variables recommended by the agencies for detailed analysis, there is insufficient information in the project record at

this time to make a determination on whether to require AEA to develop preference curves for these eight variables: surface flow and groundwater exchange fluxes, dissolved oxygen (intragravel and surface water), macronutrients (i.e., nitrogen and phosphorus), temperature (intragravel and surface water), pH, dissolved organic carbon, alkalinity, and Chlorophyll-a. Additional information on fish distribution within the project area would need to be obtained and compared to field measurements of these parameters prior to making a determination on whether there is a need to develop preference curves for the various target fish species and lifestages to be included in the instream flow study, as part of the required analysis of project effects (section 5.9(b)(5)). However, we envision that the initial analysis of any potential fish-habitat associations for these parameters would be relatively low-cost (section 5.9(b)(7)) because AEA is already proposing an intensive data collection effort within Middle River focus areas for fish distribution as part of Study 9.6 (middle and lower river fish distribution) and water quality sampling for these parameters as part of Study 5.5 (baseline water quality) and Study 7.5 (groundwater). Therefore, AEA could conduct the evaluation by relying on the extensive data collection already proposed in the RSP.

We recommend that AEA file with the Initial Study Report, a detailed evaluation of the comparison of fish abundance measures (e.g., number of individuals by species and age class) with specific microhabitat variable measurements where sampling overlaps, to determine whether a relationship between a specific microhabitat variable and fish abundance is evident. We expect the majority of locations where fish sampling and the eight additional microhabitat variable sampling efforts would overlap at a scale where they could be related would occur in focus areas where these sampling efforts are concentrated. If results from these initial comparisons indicate strong relationships may exist between a specific microhabitat parameter and fish abundance for a target species and life stage, expanded sampling may be necessary in 2014 to investigate these microhabitat relationships further. Accordingly, we recommend that AEA include in the evaluation to be filed with the Initial Study Report, any proposals to develop HSC curves for any of the 8 additional parameters as part of the 2014 study season.

This Technical Memorandum is in response to the FERC request, and first discusses the relevancy of the eight microhabitat variables (surface flow and groundwater exchange fluxes, dissolved oxygen (intergravel and surface water), macronutrients (i.e., nitrogen and phosphorus), temperature (intergravel and surface water), pH, dissolved organic carbon, alkalinity, and Chlorophyll-a) in the context of instream flow modeling, then presents the data that are available for testing of the variables, and finally describes the subset of data that are synoptic with fish presence or abundance measurements. In cases where statistical evaluation of the relationships between biological data and these microhabitat variables is appropriate, these analyses are provided. Finally, there is a summary discussion of the results and recommendations on whether to include any of the variables in future HSC curve development.

1.1. Relevancy of the Microhabitat Variables to Instream Flow Modeling

As background to this analysis, AEA lists the Susitna River licensing studies that are considering the 18 microhabitat variables requested by NMFS (as noted by FERC in SPD excerpt above) in Table 1.1-1.

The FERC noted in the SPD that AEA was already considering seven of the 18 parameters as part of the ongoing IFS HSC/HSI data collection and modeling efforts. In addition, AEA notes

that the IFS HSC analysis will also be evaluating surface water temperature and dissolved oxygen concentrations. Intergravel temperature and DO are being studied as part of the IFS Winter Studies for possible inclusion in the HSC and effective spawning habitat analyses. Thus, the IFS analysis is actually incorporating nine of the 18 parameters.

The FERC noted that the River Productivity Study (Study 9.8) was addressing three other variables (invertebrate drift density, benthic organic matter, and algal biomass). In addition, AEA again notes that the River Productivity Study is also evaluating chlorophyll-a, which brings the total number of variables being addressed by IFS and River Productivity up to 13.

Although the remaining five variables are not explicitly considered or integrated into HSC/HSI functions within the IFS modeling framework, they are being evaluated and/or modeled as part of other studies (Table 1.1-1). The results of these evaluations will be part of the overall effects analysis on fish and aquatic habitats.

AEA agrees that the eight microhabitat variables listed by FERC for further consideration have some biological relevance to fish, although some are more direct and pronounced than others (e.g., pH versus chlorophyll-a). From an HSC/HSI and modeling perspective, one of the key considerations is whether the microhabitat variables are directly flow dependent, and would or could be modified due to Project operations such that the changes would have a direct influence on the suitability of specific fish habitats. Only habitat variables meeting these criteria would factor into the development of flow versus habitat relationships that are central to the IFS modeling. The nine factors that AEA has incorporated directly into the IFS modeling are in fact those that are flow dependent and that may have a direct influence on fish and fish habitats. The remaining factors are those that would have more of an indirect effect and would not be expected to impart an immediate response to a direct change in flow.

Nevertheless, AEA proceeded with an exploratory analysis of the eight variables specified in the SPD. As stated by FERC, the overall objective of the analysis was to provide a comparison of fish abundance measures with additional microhabitat variables where sampling efforts overlap spatially and temporally. To achieve this, AEA applied appropriate statistical analysis to determine whether “strong” direct relationships were evident between fish abundance and any of the eight variables recommended by the FERC. Identification of such relationships may support further sampling and evaluation, and possibly inclusion of one or more of the parameters within the HSC/HSI model framework in 2015.

That one or more of the eight variables noted either singly or in combination with other variables is related to fish abundance is to be expected. Most salmonids have a well-defined range of parameter values within which they can function successfully. For many of the parameters, certain threshold values have been defined, and these may be considered for inclusion as part of the IFS modeling as either habitat indices or thresholds by which habitat quantities can be adjusted.

1.2. Biological Relevance of the Eight Microhabitat Parameters

The suitability of habitat is defined as the degree to which habitat has the right characteristics to support a target fish species during one or more life-history stages. Habitat suitability can be affected directly, for example by changes in water depth or temperature, or influenced indirectly, for example by changes in food availability due to changes in chlorophyll-a concentrations. Ecological communities are shaped by a complex array of direct and indirect interactions or

relationships. These interactions are spatially and temporally dynamic and can be challenging to distinguish. In defining the relationship between fish abundance and the FERC variables, a direct effect is defined as the direct impact of one individual variable on habitat selection that is not influenced or mediated by another variable. An indirect effect is a general term referring to an impact that can occur through several trophic levels or chains of interactions among species, such as influences on food availability, predation or interference competition. It is much more difficult to specify an indirect relationship between an environmental variable and habitat selection or use, since that relationship is influenced by other unstable factors.

A brief review of each of the eight candidate variables and their potential influencing effect on fish and fish habitat is provided below. This provides important context from which to formulate hypotheses regarding Project operational effects on these variables and serves as a precursor to the quantitative analysis that follows.

1.2.1. Surface Flow and Groundwater Exchange Fluxes

The exchange of groundwater and surface water is part of the natural process in most river systems, and in the Susitna River it is quite pronounced, as evidenced by the number of clearwater sloughs and side channels. The surface-groundwater exchange (i.e., upwelling and downwelling) alters thermal and chemical regimes in aquatic habitats, which in turn affect aquatic organisms (Soulsby et al. 2000, Ward and Tockner 2001; Malcolm et al. 2003). Within a river system, the chemical characteristics of the source (either ground- or surface) can alter the chemical characteristics in the recipient aquatic environment. Temperature regimes of ground- and surface-sourced waters are also generally distinct. Groundwater is buffered from surficial influences whereas surface water is often heavily influenced by annual climate regimes and daily air temperatures. Therefore, thermal regimes in upwelling zones usually display less variability in annual temperatures than those without upwelling.

Ambient water temperature affects physiological processes in fish (Carter 2005). The presence of surface-groundwater exchange often provides cool (or warm depending on the season) water refuge, influencing fish habitat use and distribution (Ebersole et al. 2001). Furthermore, development and survival of intergravel eggs and embryos is dependent on intergravel thermal and chemical regimes, which are controlled by ground-surface water exchange (Geist and Dauble 1998, Baxter and Hauer 2000, Quinn 2005, Geist et al. 2006, Burrell et al. 2010). However, because groundwater chemical composition can vary significantly over space at a fine scale, the presence of upwelling, by itself, does not always indicate that a site is appropriate for incubation (Malcolm et al. 2009).

1.2.2. Dissolved Oxygen (Intergravel and Surface Water)

Dissolved oxygen (DO) is oxygen that is dissolved into water by diffusion from the surrounding air, through hydrologic turbulence or as a waste product of photosynthesis by aquatic plants. The gas-absorption capacity of water increases to saturation as water temperature decreases; therefore, DO concentration can be limited by water temperature (Welch et al. 1998).

DO is essential to the survival of all aerobic aquatic organisms, and has a direct effect on habitat suitability (Beschta et al. 1987), habitat use (Matthews and Berg 1997), physiology (Bjornn and Reiser 1991), and survival (Heard 1991) of fishes and other aquatic organisms. Minimum DO concentrations are required to satisfy metabolic needs of fish during all phases of the freshwater

life cycle; therefore, fish abundance could be affected by extremely low levels of ambient DO. For example, during the juvenile stage, salmonids may avoid habitats with low DO when concentrations fell below 4.5 mg/L (Carter 2005). The State of Alaska recommends that water column (surface) DO concentrations be maintained at a minimum of 7.0 mg/L, and that intergravel (i.e., depth of 20 cm in the gravel) DO concentrations remain above 5.0 mg/L (DEC 2012).

Intergravel DO affects development of fish eggs and embryos. Reiser and Bjornn (1979) reported that low DO concentrations during egg incubation may delay hatching, increase anomalous development, premature hatching, and result in smaller size at emergence. Overall survival of pre-emergent salmonids was significantly reduced when average intergravel DO concentrations fell below approximately 8 milligrams per liter (Davis 1975). However, development rate and growth performance of intergravel embryos does not necessarily relate to proximate fish abundance during non-intergravel development stages.

1.2.3. Macronutrients (i.e., Nitrogen and Phosphorus)

Macronutrients, such as nitrogen (N) and phosphorus (P), are important in stream habitats because both play a significant role in limiting the amount of photosynthesis and overall productivity (Welch et al. 1998).

Most concern over macronutrient concentrations in streams relates to land use and development, where large volumes of point-source nutrient enrichment from agricultural and stormwater runoff can increase algal blooms, reduce fish habitat (Evans et al. 1996), and violate water quality (WQ) standards. In stream environments less vulnerable to point-source enrichment, concern over macronutrients often relates to nutrient cycling, the process during which macronutrients, such as P and N, are assimilated into the aquatic environment and provide a nutritional base for lower trophic organisms (e.g., periphyton and macroinvertebrates) (Chaloner and Wipfli 2002).

The concentration of N and P at one location in a stream or river is unlikely to relate directly to fish abundance at that same location, because N and P must first be assimilated into the food chain by macroinvertebrates. Although fish will eventually be impacted, this assimilation generally occurs along productivity gradients that vary broadly over space and time (Nakano and Murakami 2001, Meyer et al. 2007).

1.2.4. Temperature (Surface Water and Intergravel)

Most fish are capable of inhabiting a broad range of water temperatures that naturally occur in northern latitude river systems. Water temperature controls metabolic demands, waste costs, and influences growth and development in freshwater fishes, so seemingly small incremental changes in water temperature, both surface and intergravel, can have a significant effect on physiological performance during each life stage (Hanson et al. 1997), and consequently could affect distribution and abundance of fish communities (Lantz 1970, Power et al. 1988, Eliason et al. 2011). However, the detection of a surface water temperature effect on fish is sensitive to the spatio-temporal scale at which the investigation is carried out (Jackson et al. 2000, Nakano and Murakami 2001). Considering spatio-temporal constraints of sampling in the Susitna River basin, presence or absence (not necessarily abundance) of thermally sensitive species (i.e., those with a narrow range of 'optimal' temperatures) might be a more informative response variable to

correlate with maximum or minimum temperature. Regardless, in the Susitna River basin, water temperature could have significant influence on fish abundance because macrohabitat-associated temperature regimes could vary widely.

Not only is surface water temperature important to fish, but intergravel water temperature as well. Intergravel water temperature is a critical variable controlling the development and survival of salmonid embryos and alevins (Crisp, 1988, 1990). Warm water temperatures play an important role in providing potential sanctuary for incubating eggs from lower surface water temperatures and freezing substrate as well as accelerating the developmental rate of embryos and increasing egg-to-smolt survival (Wangaard and Burger, 1983). Like intergravel DO, intergravel temperature does not necessarily relate to proximate fish abundance during non-intergravel development stages.

1.2.5. pH

The pH (acidity) of water directly affects physiology of fish (Herrmann et al. 1993, Marschall and Crowder 1996), and is measured on a scale between 1 and 14, with 1 being extremely acidic, 7 neutral, and 14 extremely basic. Generally, an acceptable range of pH for viability of aquatic life, particularly fish, depends on numerous factors, including acid neutralizing capacity (i.e., alkalinity, pH accumulation, water temperature, and dissolved oxygen levels (Wagner et al. 1997). Salmonids generally prefer a pH between 6.5 (slightly acidic) and 9 (slightly basic) (USEPA 1986, 1999). The State of Alaska has set a water quality standard for pH of 6.5-8.5 for growth and propagation of fish (DEC 2012).

1.2.6. Dissolved Organic Carbon

Dissolved organic carbon (DOC) is a term used to describe organic matter that is broken down finely (0.2-0.5 μ m) by microbes and other biotic and physical processes, and is then made available for assimilation into higher levels of the trophic food web in streams, such as macroinvertebrates (Suberkropp 1998). While DOC is critical to productivity in streams, effects of DOC concentration on fish abundance is unlikely to be evident in the Susitna River because DOC tends to be stored in upstream habitats, then transported to downstream habitats where it can be assimilated into higher trophic organisms (Bisson and Bilby 1998). Thus, spatial and temporal variability in microbial processes and DOC would presumably confound the ability to detect relationships between DOC and fish abundance (McGuire et al. 2014).

1.2.7. Alkalinity

Alkalinity is the name given to the quantitative capacity of an aqueous solution to neutralize an acid. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of a waterbody to acid inputs. In most stream-fish populations, alkalinity of stream water alone is not known to have a significant, direct effect on fish. However, as noted above, elevated acidity of water (pH) directly hinders reproduction, development, growth, and survival of fish (Herrmann et al. 1993, Marschall and Crowder 1996). Therefore, fish abundance could be lower where water is acidic and alkalinity is low. Though alkalinity has few if any direct impacts on fish of the Susitna River, a weakly buffered system is predisposed to fluctuations in pH.

1.2.8. Chlorophyll-a

Chlorophyll-a is a biomolecule critical to photosynthesis, and is often measured in streams to estimate algal production (e.g., Hynes 1970). While a valuable indicator of overall water quality and productivity, chlorophyll-a concentration is unlikely to predict abundance of most fish species in the Susitna River basin. However, chlorophyll-a concentrations could correlate with abundance of some omnivorous fishes (e.g., longnose sucker) that feed extensively on algae.

1.3. Data Sources

Fish habitat use and abundance data for the Susitna River have been collected as part of the IFS HSC Study (Study 8.5) and Fish Distribution and Abundance (FDA) Study (Studies 9.5 and 9.6). If synoptic data for named microhabitat parameters are not available from these studies, then habitat data from other studies have been considered if they were collected within the same macrohabitat unit, and within two weeks of (frequency of Focus Area [FA] water quality sampling), relevant fish abundance data. These other sources were the Water Quality Study (Study 5.5), the River Productivity Study (Study 9.8), the Groundwater Study (Study 7.5), and the IFS Winter Study (Study 8.5).

As part of the Baseline Water Quality Study, there were two types of monitoring programs used to characterize surface water conditions: Baseline Water Quality Monitoring and Focus Area Monitoring. These programs were distinguished by the frequency of water quality sampling and the density of sampling efforts in a localized area (AEA 2012; RSP Section 5.5.4.4). Although similar water quality variables were collected during each monitoring effort, water quality data collected under the baseline monitoring occurred monthly from June-September 2013 at mainstem transects spaced at approximate 5-mile intervals. In contrast, the Focus Area monitoring included off-channel habitats, and had a higher frequency (every two weeks) and density of sampling locations. The locations were coordinated with the IFS study to provide some overlap with HSC and FDA sampling efforts (AEA 2014, Study 8.5 Section 4.4.2).

The River Productivity Study (AEA 2014; Study 9.8) also collected some relevant microhabitat parameters at point sampling locations in selected macrohabitat units in Focus Areas.

The IFS and Groundwater Winter Studies collected data on several named microhabitat variables in the same macrohabitat units where the FDA Winter Study (AEA 2014; Study 9.6) sampled for fish abundance during the 2013-2014 winter period. However, the number of sampling locations and overlapping time periods did not result in enough samples to evaluate relationships.

A summary of the fish habitat use and abundance and water quality data considered for this analysis are presented in Table 1.3-1 and discussed briefly below.

1.3.1. Fish Habitat Suitability Data

The IFS HSC Study was designed to compare habitats in the Susitna River according to their suitability for target species and life stages of fish. Suitability criteria for in-stream flow studies typically use depth, velocity, substrate and/or cover for comparing suitable habitat because these variables can be directly impacted by dam operations and impacts can be predicted by well-established models (Bovee and Milhous 1978, Milhous et al. 1984, Bovee 1986, Bovee et al. 1998). In the Susitna River system, groundwater upwelling is also expected to have an influence

on the selection of habitat by fish, and may be impacted by Project operations. The HSC study is in the process of developing HSC curves that consider water depth, velocity, substrate, cover, and groundwater upwelling, as well as surface water temperature, dissolved oxygen concentration, and conductivity. These variables were measured during 210 sampling events in the Middle River below Devils Canyon in 2013 (AEA 2014; Study 8.5). HSC field sampling is ongoing to resample some 2013 locations as well as additional locations in the Lower River and in the Middle River above Devils Canyon. At each site, habitat measurements have been taken where fish were observed and at random transect locations to represent unused habitats. These data are being used to estimate the probability that fish will use habitat units as a function of the measured habitat variables. Because the study was designed for this purpose, the HSC Study is more relevant for studying fish habitat preference than other data collection efforts. Because it is clear from the FERC recommendation that FERC agrees with this characterization, habitat data collected as part of the HSC study will be considered primary. Therefore, if data are available from the HSC Study for any of the FERC recommended microhabitat variable, no additional analyses are made here.

1.3.2. Fish Abundance Data

The FDA Study was designed to estimate spatial distribution and relative abundance of juvenile anadromous salmonids and non-salmonid anadromous and resident fishes of the entire Susitna River and some tributaries. FDA surveys were seasonal events during the ice-free seasons, with various sampling methods chosen based on target species, life stage, and water conditions. Snorkeling and electrofishing were preferred methods for juvenile fishes in clearwater areas where velocities were safe. Minnow traps, beach seines, set nets, and fyke nets were employed as alternatives in deeper waters and in habitats with limited access, low visibility, or high velocities. Fish counts from baited minnow traps and fyke nets were not used as part of analysis because these capture methods may not reflect selected habitat, but instead represent migrating fish or fish drawn to an artificial food source.

Although microhabitat parameters were not an integral part of the FDA Study, some water quality data was collected synoptic with fish surveys. Because these data are synoptic in space and time, the microhabitat data collected as part of the FDA sampling will be used as a secondary source of data for this study. In other words, if data for a FERC requested microhabitat variable was not available from HSC sampling, but was available from FDA sampling, the FDA data was used for the comparisons in this report.

1.3.3. Surface Flow and Groundwater Exchange Fluxes

As described in the ISR (AEA 2014; Study 8.5), micro-piezometers have been used as part of the HSC study to locate areas of upwelling and downwelling in sample reaches (i.e., vertical hydraulic-head gradient [VHG]). The use of micro-piezometers during HSC surveys have been effective in detecting points of upwelling and downwelling within sample reaches, and have therefore been used to characterize upwelling in macrohabitat units. However, these data are not appropriate for estimating quantitative exchange flux (i.e., volume of groundwater exchange), which is highly spatially variable based on substrate and flow. Native surface-groundwater exchange is being studied at selected sites in the Susitna River (Groundwater Study 7.5); however, these evaluations are being recorded at a spatio-temporal scale that cannot currently be compared to HSC or fish distribution and abundance data.

Although the presence of groundwater upwelling and downwelling are being incorporated into the HSC curve development process (AEA 2014, Study 8.5 Appendix M), there are no surface flow and groundwater exchange flux data available and so no analysis of this variable has been completed.

1.3.4. Dissolved Oxygen (Intergavel and Surface Water)

Surface water DO has been collected as part of the HSC Study, the FDA Study, and the Water Quality Study. The HSC data are most relevant (synoptic with fish data), and are already being analyzed as part of the HSC study (AEA 2014; Study 8.5 Appendix M). The preliminary results of this ongoing analysis are summarized in this Technical Memorandum.

There were no inchannel, intergavel (i.e., approximately 20-cm deep within the gravel) dissolved oxygen data collected during the open-water period in 2013. Both the Water Quality Study and the Groundwater Study collected groundwater dissolved oxygen concentrations in floodplain wells, but these data would not be relevant for intergavel concentrations in the river. Intergavel dissolved oxygen concentrations were recorded as part of the IFS Winter study at two sites during September 2013 – April 2014. Although one fish sampling event occurred in proximity to each dissolved oxygen monitoring site, these data are inadequate for describing potential correlations between intergavel dissolved oxygen and fish utilization. Consequently, no evaluation of the relationship between intergavel DO and fish abundance has been completed. Intergavel DO thresholds will be developed (literature based) and used as part of the effective spawning habitat analysis. This analysis will be used to determine potential impacts of Project operations during the egg incubation period when intergavel conditions (DO and temperature) are most critical to young salmonids.

1.3.5. Macronutrients (i.e., Nitrogen and Phosphorus)

Macronutrient concentrations were collected in 2013 as part of the Baseline and Focus Area Water Quality Characterizations in 2013 (AEA 2014; Study 5.5). However, review of 2013 water quality results analyzed by the laboratory indicated overestimates for Total Phosphorus (TP) concentrations and for Total Kjeldahl Nitrogen (TKN) concentrations. High turbidity levels in the river water have a tendency to interfere with detection of specific nutrient particles using ICPMS (Inductively Coupled Plasma-Mass Spectrometry) instrumentation and are difficult to distinguish from the target analytes (e.g., TP and TKN). The 2013 results for these water quality parameters are being re-sampled in 2014 and a correction factor identified to enable use of the 2013 data. As such, no analysis of potential relationships between macronutrients and fish abundance measures could be completed.

1.3.6. Temperature (Intergavel and Surface Water)

Surface water temperature has been measured as part of the HSC Study, the FDA Study, and the Water Quality Study. The HSC data are most relevant as they were synoptic and are already being analyzed as part of the HSC study; preliminary results of that analysis are discussed here.

Intergavel water temperature data have been collected in the Middle River in association with Groundwater and IFS winter studies programs, most broadly during winter 2013-2014 and to a lesser extent during open water 2014. Although approximately 30 intergavel temperature sites were maintained during 2013-2014, only two sites are co-located with fish sampling sites and

have data records concurrent with fish sampling. There were multiple sampling events at one of the two sites such that a total of five samples from two macrohabitats could be compared. This is insufficient replication to evaluate evidence of a relationship between intergravel temperature and fish presence. The available data are further constrained to the winter time period when relatively small fluctuations in temperature occur. Similar to intergravel DO, intergravel temperature thresholds will be developed as part of the effective spawning habitat analysis.

1.3.7. pH

The HSC Study collected and recorded pH only sporadically, so these data were not considered for the analysis in this report. Although the collection of pH was not part of the sampling protocol for FDA sampling, the multiparameter water quality meters used for sampling temperature and dissolved oxygen concentrations automatically recorded pH. Therefore, the numerous surface water pH measurements included in the FDA database (Table 1.3-2) have been used for this analysis.

1.3.8. Dissolved Organic Carbon

Dissolved organic carbon was collected during the Water Quality Study as part of the Baseline and Focus Area Water Quality Characterizations in 2013 (AEA 2014; Study 5.5). Laboratory analyzed data were not reported in the ISR, but QC3 data are now available and have been used for this analysis. Fish samples collected by FDA within the same macrohabitat unit within 2 weeks of the water quality samples were used for the comparisons in this Technical Memorandum (Table 1.3-2, see example in Figure 1.3-1).

1.3.9. Alkalinity

Alkalinity was collected by the Water Quality Study as part of the Baseline Water Quality Characterization in 2013, but not for the Focus Area Water Quality Characterization. Fish samples collected by FDA within the same macrohabitat unit within 2 weeks of the water quality samples were used for the comparisons in this Technical Memorandum (Table 1.3-2, see example in Figure 1.3-1).

1.3.10. Chlorophyll-a

Chlorophyll-a in the water column was analyzed as part of the Water Quality Study for the Baseline and Focus Area Water Quality Characterizations in 2013. The River Productivity Study collected composite benthic algae samples from rock substrate at each benthic invertebrate site location sampled in the Susitna River in 2013 (AEA 2014, Study 9.8). The River Productivity and Water Quality chlorophyll-a samples could not be combined because the samples were collected from different sources (substrate particle – River Productivity Study; mid-water column – Water Quality Study) so they are analyzed separately in this report. Fish samples collected by FDA within the same macrohabitat unit within 2 weeks of the River Productivity or Water Quality samples were used for the comparisons in this report (Table 1.3-2, see example in Figure 1.3-1).

2. METHODS

Although the data for microhabitat variables come from multiple sources, the fish data that are being correlated to the microhabitat variables come from only two main sources – HSC and FDA Studies. A description of the methods used to compare microhabitat variables to each fish data source are presented below.

2.1. HSC Analysis – Surface Water Dissolved Oxygen and Temperature

As mentioned by FERC in the SPD, the HSC study is collecting a suite of habitat metrics (water velocity, depth, temperature, DO, conductivity, turbidity, substrate composition, cover, and presence of groundwater) that are being evaluated for development of HSC which can be used to relate Project operations to changes in fish habitat. These data are collected with the objective of determining the relationship between the habitat variables and fish habitat preference. For each of the HSC variables, analyses are being conducted using logistic regressions with random effects for sites, which allow the overall probability of fish presence to vary by site after accounting for measured habitat variables. Using availability and utilization data, the HSC regressions predict the probability of fish presence as a function of a set of habitat variables, which include two of the additional variables (surface water dissolved oxygen and temperature) requested by FERC. These models were compared based on weight of evidence using Akaike's Information Criteria (AIC). A description of these analyses and preliminary results are described in the ISR (AEA 2014; Study 8.5, Appendix M), and are not further described here.

2.2. FDA Analysis

Most of the analyses presented in this report involve comparisons between habitat data collected by various studies and fish abundance data collected by the FDA study. Fish abundance data collected at random sites in the Upper, Middle, and Lower Rivers using electrofishing, seining, and snorkeling were used for these comparisons. Survey locations within tributary mouths and tributaries above the mouth were included, but results with and without these samples outside of the Susitna River were compared to ensure that tributary conditions were not biasing results. Subsets of this main dataset were used where synoptic data were available for each microhabitat parameter.

To increase the number of samples with observed fish and to avoid conflicting results for multiple species, fish counts were summed by species/life stage groups for the analyses, as follows:

- 1) Anadromous salmon fry (Chinook [*Oncorhynchus. tshawytscha*], chum [*O. keta*], coho [*O. kisutch*], sockeye [*O. nerka*])
- 2) Anadromous salmon juvenile fish (Chinook, coho, sockeye)
- 3) Resident salmonids (juvenile or adult; round whitefish [*Prosopium cylindraceum*], Arctic grayling [*Thymallus arcticus*], rainbow trout [*Oncorhynchus mykiss*], Dolly Varden [*Salvelinus malma*])
- 4) Resident non-salmonids (juvenile or adult; burbot [*Lota lota*], longnose sucker [*Catostomus catostomus*])

Adult anadromous species were not included because they were not targeted by FDA sampling, and some sampling methods (i.e., electrofishing) were interrupted when anadromous adults were encountered.

Total abundance for each of the fish groups varies longitudinally in the Susitna River, particularly for the anadromous salmon groups. Because anadromous fish were not observed during FDA sampling using the selected gear types in the mainstem Susitna River above Devils Canyon, these zero count results are not included in the analysis for the anadromous categories, as they would likely bias the results. To account for other longitudinal differences not related to water quality, a fixed effect describing longitudinal location in the river was included as a candidate predictor in the models when possible.

The fish abundance data, like most count data, are highly skewed, with many zero counts (no fish captured or observed) and few large counts. Simple linear correlation or regression techniques are generally not appropriate for data which are not approximately normally distributed. For regression, log-transformed counts can be modeled using Poisson distribution, but when there are excessive zero counts these models can fit poorly due to overdispersion (extra variance). For the FDA data comparisons, a set of nested Poisson regression models are fit and compared using Akaike Information Criteria corrected for overdispersion and sample size (QAICc; Burnham and Anderson, 2002). The model with lowest QAICc is considered the “best fit” model. Models with QAICc greater than the null model (i.e., the model with no predictors) are considered to have “no evidence” of predictive capability, models with QAICc lower than but within 2 units of the null model to have “weak evidence” of predictive strength, and models with QAICc more than 2 units better (lower) than the null model to have “evidence” of predictive strength. Akaike weights (Burnham and Anderson, 2002) are then used to evaluate the weight of evidence for the best fit model over the null model when relevant.

2.2.1. pH Collected for FDA Study

In 2013, there were 220 pH measurements taken by FDA crews in the Middle River, ranging from pH = 6.1 to pH = 9.6, and 102 measurements taken in the Lower River, ranging from pH = 5.5 to pH = 12.7 (Table 1.3-2). A total of 34 of the MR and LR pH observations are in tributary mouths or in tributaries just above the mouth, and may be less relevant for habitat preferences in the Susitna River. Therefore, results with and without these tributary samples are compared.

For pH analysis, anadromous salmon fry and juveniles were combined because there were few locations where pH was sampled and anadromous fish were found (35 positive fry counts with corresponding pH and 19 positive juvenile counts).

There are 14 pH observations outside the general preferred range of pH for fish (6.5-9), with 4 of these samples corresponding to positive fish observations. One of these samples had an anadromous fry and juvenile count greater than 300 fish observed. This point was very influential in model fitting and generally caused nonsensical pH – abundance modeled relationships. In addition, there were three observations with pH > 10.5 that may be considered extreme. Although there is no clear indication that these pH measurements were caused by equipment error, individual data points should not be allowed to greatly change regression coefficients. Results with and without these observations were compared to measure the influence of these high pH points.

A longitudinal fixed effect was included to account for spatial differences in fish abundance that may not be due to microhabitat variables. For pH models, geomorphic reaches were used, although some had to be combined because of low sample sizes. The factor levels used were: UR (all reaches combined), MR-1 and 2, MR-5 and 6, MR-7, MR-8, and LR (all reaches combined).

The following models with Poisson errors were considered and compared for each of the three fish groupings using QAICc:

1) Null Model

$\text{Log}(\text{Abundance}) = \text{intercept}$,

where *intercept* = the theoretical fish abundance value when $pH = 0$. This is a flat line at the mean abundance; pH has no influence.

2) Reach Model

$\text{Log}(\text{Abundance}) = \text{reach}$,

where *reach* = a fixed 6-level factor describing longitudinal location on the Susitna River. This is the null model within each longitudinal location in the river; pH has no influence.

3) Preference pH models

$\text{Log}(\text{Abundance}) = \text{intercept} + a \cdot pH + b \cdot pH^2$

$\text{Log}(\text{Abundance}) = \text{reach} + a \cdot pH + b \cdot pH^2$,

where *a* and *b* are estimated regression coefficients.

As discussed previously, if fish were to select habitat based on pH, there would be higher fish abundance in the mid-range of pH, and fewer fish in the extremes. This would be a quadratic model that is convex down ($b < 0$) with a maximum value between pH of 6 and pH of 9.

Observed relationships contrary to this hypothesized shape are assumed to be extraneous and likely due to variables other than pH.

Each of the three models described above were fit to 1) the entire pH dataset, 2) the dataset without the tributaries, and 3) with and without outliers for comparison.

2.2.2. Parameters Collected as Part of the Water Quality Study

There were only four transects from the Baseline Water Quality Study, and 12 transects and 7 point sample locations from the Focus Area Water Quality Study that overlapped with at least one FDA site within a two week time period. Average water quality concentrations (i.e., average of six points along transect) for main channel transects were used to compare to overlapping main channel FDA sites. If the overlapping FDA site was a plume or tributary mouth sample on one bank of the river, the transect point samples closest to the overlapping FDA site (i.e., a subset of the points along the transect) were averaged. A total of 26 FDA locations were matched with the Water Quality samples in seven macrohabitat types, but most were main channel sites with low numbers of fish observed. In some cases there were two water quality samples within two weeks of an FDA survey event; in this case the closest sampling date was used. When there were two fish observations within two weeks of a single water quality measurement, both fish observations were used. With multiple dates and some Water Quality

sites that were matched with multiple FDA sites, there were a total of 67 data points for comparison (Table 1.3-2, see example in Figure 1.3-1).

Out of 67 data points, 56 had 0 observations of anadromous fry, 52 had 0 observations of anadromous juveniles, 35 had 0 observations of resident salmonids, and 36 had 0 observations of resident non-salmonids. Anadromous fry and juveniles were combined for the comparisons because of the low capture rates. For alkalinity, which was only sampled as part of the Baseline Water Quality Study, there were only 19 matched data points for comparison.

Because there were only three paired samples above Devils Canyon, these samples cannot be used for any longitudinal groupings. Below Devils Canyon, the longitudinal factor had two levels: MR-5 and 6 versus MR-7 and 8. If there were no differences between these two groups, then the MR-2 data were included (for non-anadromous fish groups only). For alkalinity, there was no longitudinal factor because of the small sample sizes.

For each habitat variable, the following models with Poisson errors were considered and compared for each of the fish abundance groups using QAICc:

1) Null Model

$\text{Log}(\text{Abundance}) = \text{intercept},$

where *intercept* = the theoretical fish abundance value when the water quality parameter = 0. This is a flat line at the mean abundance with no influence of the water quality parameter.

2) Habitat Model

$\text{Log}(\text{Abundance}) = \text{reach},$

where *reach* = a fixed factor describing longitudinal location on the Susitna River. This is the null model within each reach with no influence of the water quality parameter.

3) Preference water quality models

$\text{Log}(\text{Abundance}) = \text{intercept} + a*X$

$\text{Log}(\text{Abundance}) = \text{reach} + a*X,$

where *a* is the estimated regression coefficient for X, the water quality parameter.

Dissolved organic carbon samples matched with FDA survey sites did not vary widely among macrohabitats except for samples in MR-8 side sloughs (4 matched samples) that ranged from 1.5 to 10.5 mg/L, while the maximum of all other habitats was 3.7 mg/L (Figure 2.2-1). Results with and without this high concentration value were compared.

The chlorophyll-a concentrations in the water column matched with FDA sites also did not vary widely among macrohabitats, except for samples within backwaters (5 matched samples) that ranged from 0 to 3.2 ug/L, while the maximum of all other habitats was 1.3 ug/L (Figure 2.2-2). Results with and without this high concentration value were compared.

Alkalinity concentrations for 19 matched WQ-FDA samples ranged from 25 to 54 mg/L, with most of the variability seen in MR-5 (Figure 2.2-3). Because of the small sample sizes, longitudinal location in the river could not be included in the models for alkalinity.

2.2.3. Benthic Chlorophyll-a Collected for River Productivity Study

The River Productivity Study collected composite benthic algae samples from wetted channel substrate at each benthic invertebrate site location for a total of 309 composited algae samples in the Susitna River in 2013 (AEA 2014, Study 9.8). There were seven River Productivity sampling sites within three Focus Areas (FA-104 [Whiskers Slough], FA-173 [Stephan Lake Complex], and FA-184 [Watana Dam]) that were sampled for benthic algae within two weeks of an FDA survey and within the same macrohabitat. At each site there were two sampling times that were concurrent with FDA samples. Most of these 14 sampling events could be closely associated with multiple FDA samples taken from nearby mesohabitats within the same macrohabitat unit. In total, there were 23 FDA samples matched with River Productivity benthic chlorophyll-a estimates (Table 1.3-2, see example in Figure 1.3-1). The benthic chlorophyll-a concentrations, taken from main channel, side channel, side slough, and tributary mouth habitats, ranged from 0.042 to 66 mg/m².

The River Productivity samples that could be matched with FDA samples were collected between August 10 and September 27, 2013. There were no anadromous salmon fry, and a total of 4 anadromous juvenile salmon captured at the matched sites during this time period. Therefore, no comparisons for these fish groups were possible. There were a total of 94 resident salmonids captured during 15 of the 23 matched sampling events, and a total of 24 resident non-salmonids captured during 7 of the 23 matched sampling events.

The models shown for comparisons with Water Quality data in the previous section were also used for the River Productivity benthic chlorophyll-a comparisons, with the following difference for the *reach* (longitudinal fixed factor) variable.

The best candidate for a longitudinal fixed effect for the River Productivity chlorophyll-a models would be comparing FA-104 (Whiskers Slough) to the Focus Areas above Devils Canyon (FA-173 [Stephan Lake Complex] and FA-184 [Watana Dam]). However, there are no matched side slough samples above Devils Canyon, and all FA-104 (Whiskers Slough) samples were from side sloughs. Both the chlorophyll-a concentrations and the fish counts were highly variable across macrohabitat types (Figure 2.2-4). Therefore it was most reasonable to combine the longitudinal consideration with macrohabitat. A categorical factor with three groups was used: 1) side sloughs in FA-104 (Whiskers Slough); 2) side channels in FA-173 (Stephan Lake Complex) and FA-184 (Watana Dam); and 3) main channel or tributary mouth in FA-173 (Stephan Lake Complex) and FA-184 (Watana Dam).

3. RESULTS

3.1. HSC Analysis

Preliminary HSC analysis results for chum salmon spawning and coho salmon fry are thoroughly described in the Initial Study Report (AEA 2014, Study 8.5, Appendix M), and are only briefly summarized here.

3.1.1. Surface Water Dissolved Oxygen

In the initial analyses of 2013 HSC data, there was no evidence of a predictive relationship between surface water DO and chum salmon spawning. For coho salmon fry, the data indicated a *negative* relationship between dissolved oxygen and the presence of fish, which was unlikely due to dissolved oxygen concentrations. Analysis for other target fish species/life stages will be presented in the Updated Study Report (USR).

3.1.2. Surface Water Temperature

In the initial analyses of 2013 HSC data, there was no evidence of a predictive relationship between water temperature and chum salmon spawning. However, there was strong evidence of a predictive relationship between water temperature and coho fry presence. The fitted relationship indicates that coho salmon fry prefer cooler water temperatures during the open water period. This relationship and others will continue to be explored as part of the HSC analysis in the USR.

3.2. FDA Analysis

3.2.1. pH collected for FDA Study

The pH model results for the three fish groups are summarized in Table 3.2-1. With the influential point (single sample point with pH = 9.64 and 374 fish observed) removed, there is evidence of a quadratic relationship between pH and log-transformed anadromous juvenile counts. Anadromous fry and juvenile counts with the fitted pH preference models are displayed in Figure 3.2-1. The pH preference models displayed in Figure 3.2-1 do not include the influential point. Without this point, there is evidence that anadromous fry and juvenile abundance is higher in locations with pH near 6.7 (6.5 when tributary sites are included). The displayed model including a quadratic effect of pH on non-tributary samples has weight of evidence more than 10 times the null model based on Akaike weights (Table 3.2-1). The influential data point that was not included in this model contradicts this relationship – with this data point included, the relationship dissolves completely. The remaining observations with pH > 10 do not influence the model parameters or results.

For resident salmonids, there is strong evidence of a quadratic effect of pH, with preferred pH near 7 (Figure 3.2-2). The observations with pH > 10 are plotted in red, but they do not influence the model parameters or results. The model without tributary samples is nearly identical to the model including tributary samples. The model including a quadratic effect of pH on non-tributary samples has weight of evidence more than 20 times the null model based on Akaike weights (Table 3.2-1).

For resident non-salmonids, there is no evidence of a relationship between pH and fish abundance (Figure 3.2-3). The extreme observations with pH > 10 are plotted in red, but they do not influence the model parameters or results. There are significant differences in abundances of resident species among reaches, but adding pH to the model with a fixed reach effect did not improve the model fit.

3.2.2. Parameters collected for Water Quality Study

Model results for Water Quality parameters compared to abundance of species/life stage groups are summarized in Table 3.2-2.

There is no evidence of a relationship between dissolved organic carbon and fish abundance. For anadromous fry and juveniles (Figure 3.2-4), the null model has the lowest QAICc, both with and without the samples with DO > 10 mg/L. There are differences among reaches for resident salmonids but no relationship with DO (Figure 3.2-5), as the reach model has the lowest QAICc both with and without the highest DO values included. The null model has the lowest QAICc for resident non-salmonids, again indicating no relationship with DO (Figure 3.2-6).

For chlorophyll-a in the water column, the model fit to all data shows weak evidence of a relationship with anadromous fry and juvenile fish (QAICc is 0.67 units less than QAICc for the null model.) However, this relationship is driven by the extreme chlorophyll-a concentration, and disappears when this value is excluded (i.e., the null model is the best fit; Figure 3.2-7). The null model has the lowest QAICc for resident salmonids, indicating no evidence of a relationship (Figure 3.2-8). However, there is a strong evidence (QAICc 3.6 – 9.9) of an increasing relationship between chlorophyll-a in the water column and the presence of resident non-salmonids (Figure 3.2-9). The chlorophyll-a model has weight of evidence 6 times that of the null model based on Akaike weights. Without the single high chlorophyll-a concentration, the weight of evidence ratio for the regression is increased to 142.

Although the alkalinity dataset is small (n=19), there is evidence of an increasing relationship between alkalinity and counts of resident fish. For resident salmonids (Figures 3.2-10), the weight of evidence for the alkalinity model is 7 times the weight of evidence for the null model. For resident non-salmonids (Figure 3.2-11), the weight of evidence ratio is 8.

3.2.3. Benthic Chlorophyll-a Collected for River Productivity Study

Model results for benthic chlorophyll-a compared to abundance of species/life stage groups are summarized in Table 3.2-3. Benthic chlorophyll-a concentrations have mixed results as a predictor of fish abundance with little to no relationship for anadromous fry and juvenile and resident salmonids, but strong evidence for a relationship for resident non-salmonids (Figure 3.2-12 and Figure 3.2-13).

4. DISCUSSION AND RECOMMENDATIONS

Habitat suitability criteria curves and habitat suitability index (HSI) models have been utilized by natural resources scientists for over two decades to assess the effects of habitat changes on biota. HSC/HSI curves are designed to quantify changes in habitat under various flow regimes (Bovee et al. 1998). HSC curves describe the instream suitability of habitat variables (typically depth, velocity, substrate and cover) related to stream hydraulics and channel structure. HSC curves can also be developed for other variables influenced by flow including water quality (temperature, dissolved oxygen, turbidity, pH) and presence of groundwater upwelling or downwelling. It is the goal of the HSC Study to develop the best predictive models possible for habitat suitability of the target species and life stages (AEA 2014, Study 8.5). As previously stated, water depth, velocity, groundwater upwelling/downwelling, substrate type, cover

(including woody debris), turbidity, DO, temperature, and specific conductance are already included in HSC curve development. The final HSC curves will be used with the hydraulic and habitat models (AEA 2014, Study 8.5) to estimate the effects (habitat gain or loss) of alternative operational scenarios at the Focus Area scale.

At the request of FERC, a detailed evaluation of fish abundance measures and eight additional habitat variables (surface flow and groundwater exchange flux, surface and intergravel DO and temperature, macronutrients, pH, DOC, alkalinity, and chlorophyll-a) was completed to determine whether relationships were evident and if additional HSC curve development was warranted.

There are three crucial requirements to be met for habitat variables to be included in HSC development. The first is that there is a predictive and direct relationship between the habitat variable and fish presence; second, that changes to the habitat variable as a function of flow can be spatially and quantitatively predicted at the Focus Area scale; and third, that predicted changes in the variable are observable at a temporal scale (hours to days) similar to changes in flow conditions in response to Project operations. If any of these criteria cannot be met, then AEA recommends that the individual variable not be included as part of site-specific HSC curve development.

Of the eight variables requested by FERC for further investigation, three (VHG as a surrogate for surface and groundwater exchange flux, surface water DO and temperature) will continue to be collected in ongoing HSC sampling events, and analyzed as part of the HSC suitability curve development process in the USR. Intergravel DO and temperature will also continue to be collected, but this data will be used to develop threshold (highs and lows) that can be applied as part of the effective spawning habitat analysis. Although not specifically requested by FERC, specific conductance will continue to be collected and included as part HSC curve development. For four of the remaining five variables (pH, DOC, alkalinity, and chlorophyll-a), statistical analysis has been completed to estimate the probability that these variables are “strong” predictors of habitat use by the target species and life stages. The remaining variable, macronutrients, had no data from 2013 that could be used to compare to fish abundance measures. A description of the predictive value of each of these five variables is presented below along with a recommendation regarding inclusion in future HSC development activities (Table 4.1-1).

4.1. Macronutrients

Review of surface water quality samples collected in middle Susitna River Focus Areas in 2013 indicated that the concentrations of Total Phosphorus and Total Nitrogen were overestimated and will need to be re-sampled in 2014. As such, no analysis of potential relationships between macronutrients and fish abundance measures could be completed as part of this effort. Although no site-specific macronutrient data was available, it is widely believed that the concentration of N and P does not relate directly to fish abundance because it must first be assimilated into the food web before utilized by fish (Nakano and Murakami 2001, Meyer et al. 2007). Furthermore, the rate of P and N assimilation varies over space and time making it unrealistic to believe that the water quality model can predict changes to total N and P concentrations within all macrohabitat types of a Focus Area on an hourly or daily time-step in response to changes in Project operations. Considering these facts, it is AEA’s recommendation that macronutrients are

not added as a variable to predict fish habitat use as part of the HSC curve development process, and that no additional data collection efforts are required.

4.2. pH

The pH of water can directly affect not only the habitat selection of fish but fish health as well. The degree to which pH affects fish depends on numerous factors, including acid neutralizing capacity (i.e., alkalinity, prior pH accumulation, water temperature, and dissolved oxygen levels (Wagner et al. 1997). Although pH was not collected as part of the HSC surveys, it was largely collected as part of FDA surveys (AEA 2014, Study 9.5 and 9.6). Results of this assessment show no clear evidence of a relationship between pH and abundance of resident, non-salmonid fish in the Susitna River. However, there is strong evidence that salmonids (resident and anadromous fry and juvenile) are found most commonly in areas with pH near 7 in the Middle and Lower River segments of the Susitna River. This result is not surprising given that salmonids generally prefer a pH between 6.5 and 9 (USEPA 1999).

It is anticipated that Focus Area water quality modeling will estimate pH levels throughout the Susitna River resulting from different flow release scenarios (AEA 2014, Study 5.5). The data used in this Technical Memorandum show that 90-100% of salmonids are selecting habitats in the range of 6.2-8.7, which is very similar to the USEPA determined preference range (USEPA 1999). Therefore, AEA recommends that a pH range of 6.5-9 is used as a threshold by which to evaluate the loss or gain in habitat area. Utilizing threshold values for pH would satisfy the request by the agencies that pH be considered for suitable habitat, without requiring additional data collection or modeling to develop predictive fish-habitat relationships.

4.3. Dissolved Organic Carbon

There is no evidence that DOC can be used as a predictor of fish abundance or habitat use in the Susitna River. Dissolved organic carbon was collected during the Water Quality Study as part of both the Baseline and Focus Area Water Quality Characterizations in 2013 (Study 5.5). Levels of DOC can show considerable spatial and temporal variability depending on sample location and assimilation into the trophic food web. A more meaningful indicator of the influence of DOC on fish abundance might be macroinvertebrate productivity (relative abundance) and species richness (AEA 2014, Study 9.8). As such, AEA recommends DOC not be added as a variable to predict fish habitat use as part of the HSC curve development process.

4.4. Alkalinity

Alkalinity samples were not collected within middle Susitna River Focus Areas during the 2013 Water Quality Characterization Study (ISR Study 5.5). As a result, there were only 19 samples (where FDA and alkalinity sampling overlapped) from which to evaluate a relationship between alkalinity and fish abundance. Although in most stream-fish populations, alkalinity of stream water alone is not known to have a significant, direct effect on fish, results of the statistical analysis did show a weak relationship between alkalinity levels and both resident and non-resident salmonids abundance. Since alkalinity levels are not being collected or modeled on a Focus Area scale and the generally weak relationship between alkalinity and fish abundance, AEA recommends alkalinity not be added as a variable to predict fish habitat use as part of the HSC curve development process.

4.5. Chlorophyll-a

In 2013, chlorophyll-a samples were collected by both the Water Quality Study (5.5) and River Productivity Study (9.8). Unfortunately, the samples were collected from two different sources (mid-water column and river substrate) and could not be combined as part of this analysis. Similar to DOC, chlorophyll-a levels are generally not considered a direct indicator of fish abundance (particularly for salmonids) or habitat use, but rather an indicator of overall water quality and productivity. That said, statistical modeling did show a strong relationship between chlorophyll-a levels and resident, non-salmonid fish species. This result is not entirely surprising since most of the non-salmonid species that are included in this group consume algae.

Chlorophyll-a data are being collected as part of the River Productivity Study (AEA 2014, Study 9.8) to evaluate and model benthic macroinvertebrates and algal communities. Since both macroinvertebrates and algae are direct food sources for several of the target fish species and life stages, it is AEA's recommendation to use the HSC curves developed from the River Productivity Study for benthic macroinvertebrates and algae. To reduce duplication of effort, it is AEA's recommendation to not add chlorophyll-a in development of HSC curves for the IFS Study.

5. REFERENCES

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6. TABLES

Table 1.1-1. Microhabitat variables requested for inclusion by NMFS in the FERC SPD (FERC 2013), noting Susitna River studies considering these variables.

NMFS Requested Microhabitat Variable	Variable Currently Included and/or Considered in IFS Modeling	Variable Included, Considered or Modeled by Other Resource Study
Water depth	Yes	Fluvial Geomorphology (Study 6.6)
Water velocity	Yes	Water Quality (Study 5.5)
Surface flow and groundwater flux		Groundwater Study (Study 7.5)
Upwelling/downwelling (via VHG)	Yes	Groundwater Study (Study 7.5)
Substrate type	Yes	Fluvial Geomorphology (Study 6.6)
Cover	Yes	Geomorphology (LWD; Study 6.5)
Woody Debris	Yes	Geomorphology (Study 6.5)
Turbidity	Yes	River Productivity Study (TSS; Study 9.8); Water Quality Modeling (Study 5.6)
Dissolved Oxygen (intergravel and surface)	Yes	Water Quality Modeling (Study 5.6) Groundwater Study (Study 7.5) Effective Spawning Analysis (Study 8.5)
Macronutrients (N,P)		Water Quality Modeling (Study 5.6)
Temperature (intergravel and surface)	Yes	Water Quality Modeling (surface; Study 5.6) Groundwater Study (Study 7.5) Effective Spawning Analysis (Study 8.5)
pH		Water Quality (Study 5.5)
Dissolved Organic Carbon (DOC)		Water Quality (Study 5.5)
Alkalinity		Water Quality (Study 5.5)
Invertebrate drift density		River Productivity Study (Study 9.8)
Benthic Organic Matter		River Productivity Study (Study 9.8)
Algal biomass		River Productivity Study (Study 9.8); Water Quality Modeling (Study 5.6)
Chlorophyll-a		River Productivity Study (Study 9.8); Water Quality Modeling (Study 5.6)

Table 1.3-1. Potential data sources for evaluation of relationships between microhabitat variables and fish abundance measures.

Study	Named Variable(s) Measured	Collection Area	Collection Period	Sample Frequency	Sampling Intensity
Water Quality Monitoring – Baseline (5.5)	Surface Water Temperature, DO, pH, Alkalinity, Total Phosphorus, Total Nitrogen, Chlorophyll-a, Dissolved Organic Carbon	Mainstem from PRM 29.9-235.2	June-September, 2013	Monthly	Approximately every 5-miles
Water Quality Monitoring – Focus Area (5.5)	Surface Water Temperature, DO, pH, Total Phosphorus, Total Nitrogen, Chlorophyll-a, Dissolved Organic Carbon	FA-104, 113, 115, 128, 138, 141, and 144	Late July-Early September, 2013	Every 2-weeks	3-4 stations per FA
Groundwater Study (7.5)	Surface flow and groundwater exchange fluxes?	FA-104, FA-113, FA-115, FA-128, FA-138	August - December, 2013	Continuous	1-7 stations per FA
Instream Flow Study – HSC (8.5)	Surface Water Temperature, DO	FA-104, 113, 115, 128, 138, 141, and 144	June-September, 2013	Every 2-weeks	6-12 sample sites per FA
Instream Flow Study – Winter (8.5)	Surface Water Temperature, DO	FA-104 & 128	February-April, 2013	Monthly	6-12 sample sites per FA
Groundwater Study – Winter (7.5)	Water Temperature, DO	FA-104 & 128	March & April, 2013	Continuous	1-intergravel D.O. site per FA, 9-intergravel temp. sites in FA 104
Fish Distribution and Abundance (9.5 & 9.6)	Surface Water Temperature, DO, pH	Entire Susitna River	July-October, 2013	Three seasonal events	Varies
River Productivity Study (9.8)	Chlorophyll-a (benthic)	4 Focus Areas, 1 LR Site	June-September, 2013	Three seasonal events	3-5 Stations per Site

Table 1.3-2. Summary of relevant study sources and data used for the analyses of FERC recommended variables.

Variable(s) Analyzed	Most Relevant Study/Source	Total Number of Samples Available	Number of Samples Matched to Fish Data
Surface flow and groundwater exchange fluxes	Groundwater Study (7.5)	Temporally Continuous Data at Limited Number of Stations; Not designed to measure flux	n/a
Dissolved Oxygen (Surface)	Instream Flow Study – HSC (8.5)	Chum Spawning (n=960); Coho Fry (n=669)	Chum Spawning (n=960); Coho Fry (n=669)
Dissolved Oxygen (Intergravel)	Instream Flow Study – Winter (8.5)	Multiple samples at two sites	2 total (not used)
Macronutrients: Total Phosphorus, Total Nitrogen	Water Quality Monitoring – Baseline and Focus Area (5.5)	Samples rejected for Quality Control issues	n/a
Water Temperature (Surface)	Instream Flow Study – HSC (8.5)	Chum Spawning (n=992); Coho Fry (n=833)	Chum Spawning (n=992); Coho Fry (n=833)
Water Temperature (Intergravel)	Instream Flow Study – Winter (8.5) and Groundwater Study – Winter (7.5)	Multiple samples at 30 stations	5 total (not used)
pH	Fish Distribution and Abundance (9.5 & 9.6)	322	322
Dissolved Organic Carbon	Water Quality Monitoring – Baseline and Focus Areas (5.5)	Multiple samples at 45 sites	67
Alkalinity	Water Quality Monitoring – Baseline (5.5)	Multiple samples at 18 sites	19
Chlorophyll-a (Water)	Water Quality Monitoring – Baseline and Focus Areas (5.5)	Multiple samples at 45 sites	67
Chlorophyll-a (benthic)	River Productivity Study (9.8)	Multiple samples at 25 sites	23

Table 3.2-1. Summary of pH model results

Species/Lifestage	Dataset	Best Fit Model	Delta (Null or Reach Model – Best Fit Model)	Ratio of Akaike Weights (Best Fit/Null or Reach Model)
Anadromous Fry + Juv	All Samples	Null	0	1
	Remove Influential Point	Reach and Quadratic Effect of pH	21	33000
	pH< 9.5	Reach and Quadratic Effect of pH	20	27000
	No Trib Samples	Null	0	1
	No Trib Samples; Remove Influential Point	Quadratic Effect of pH	5	11
	No Trib Samples; pH<9.5	Quadratic Effect of pH	5	9.8
Resident Salmonids	All Samples	Reach and Quadratic Effect of pH	10	150
	pH< 10	Reach and Quadratic Effect of pH	9.5	110
	No Trib Samples	Reach and Quadratic Effect of pH	6.2	22
	No Trib Samples; pH<10	Reach and Quadratic Effect of pH	5.9	19
Resident Non-Salmonids	All Samples	Reach	0	n/a
	pH< 10	Reach	0	n/a
	No Trib Samples	Reach	0	n/a
	No Trib Samples; pH<10	Reach	0	n/a

Table 3.2-2. Summary of Water Quality model results

Parameter	Species/Lifestage	Dataset	Best Fit Model	Delta (Null or Reach Model – Best Fit Model)	Ratio of Akaike Weights (Best Fit/Null or Reach Model)
DOC	Anadromous Fry+Juv	All data	Null	0	n/a
		without high DOC value	Null	0	n/a
	Resident Salmonids	All data	Reach Model	0	n/a
		without high DOC value	Reach Model	0	n/a
	Resident Non-Salmonids	All data	Null	0	n/a
		without high DOC value	Null	0	n/a
Chlorophyll-a	Anadromous Fry+Juv	All data	Chlorophyll-a	0.67	1.4
		without high chlorophyll value	Null	0	n/a
	Resident Salmonids	All data	Reach Model	0	n/a
		without high chlorophyll value	Reach Model	0	n/a
	Resident Non-Salmonids	All data	Chlorophyll-a	3.6	6.2
		without high chlorophyll value	Chlorophyll-a	9.9	142
Alkalinity	Resident Salmonids	All data	Alkalinity	3.9	7
	Resident Non-Salmonids	All data	Alkalinity	4.2	8.1

Table 3.2-3. Summary of benthic chlorophyll-a model results.

Species/Lifestage	Dataset	Best Fit Model	Delta (Null or Reach Model – Best Fit Model)	Ratio of Akaike Weights (Best Fit/Null or Reach Model)
Resident Salmonids	All Samples	Habitat and Linear Effect of Benthic Chlorophyll-a	33	1.7E+07
Resident Non-Salmonids	All Samples	Habitat and Linear Effect of Benthic Chlorophyll-a	21	3.2E+04

Table 4.1-1. Evaluation of FERC requested variables and recommendations for inclusion in future HSC curve development.

Variable	Relationship with Fish Abundance Measures (Strong, Weak, None)	Direct Link to Fish Habitat Use	Modeled at Focus Area Scale	Recommended for Future HSC Analysis
Macronutrients: Total Phosphorus, Total Nitrogen	Insufficient Data	Unknown	No	No
pH	Strong	Yes	Yes	Yes
Dissolved Organic Carbon	None	No	Yes	No
Alkalinity	Weak	No	No	No
Chlorophyll-a	Strong	No	Yes	No

7. FIGURES

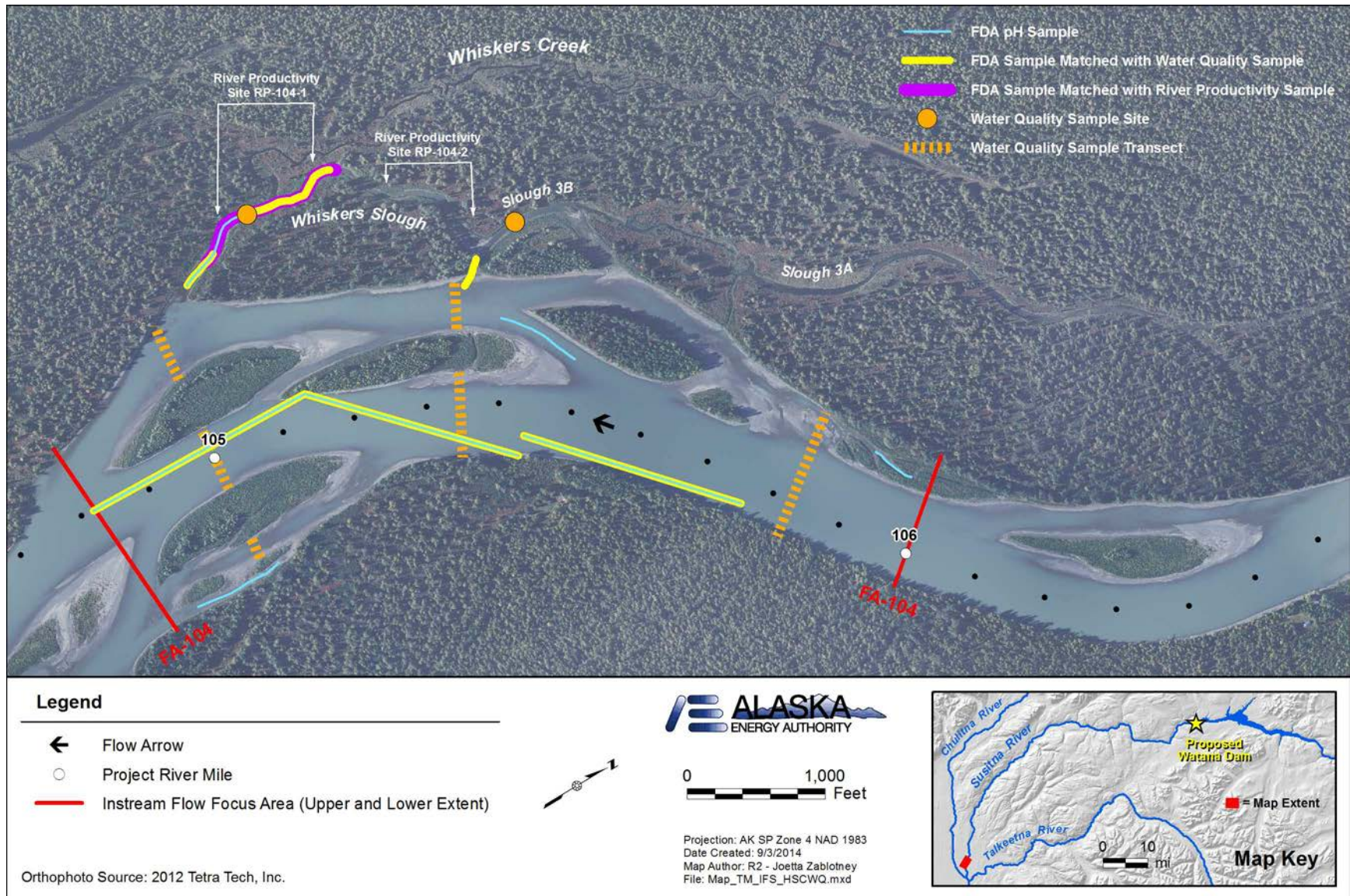


Figure 1.3-1. Map of FA-104 (Whiskers Slough) showing example of fish abundance and water quality samples from multiple sources that were combined to compare fish abundance with habitat variables.

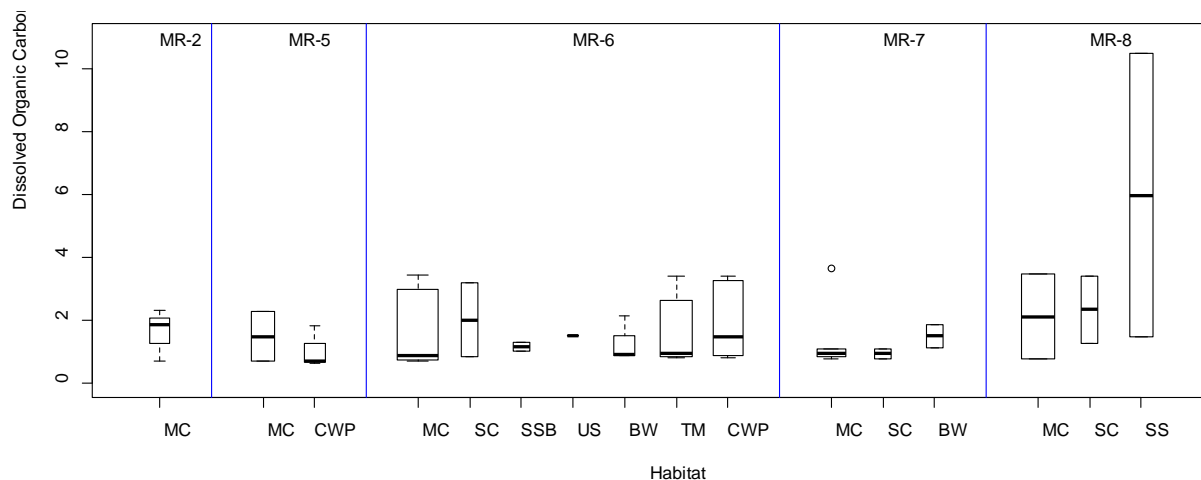


Figure 2.2-1. Box plots of dissolved organic carbon concentrations for FDA-matched Water Quality samples by Geomorphic Reach and macrohabitat type.

Notes:

MC = main channel, CWP = clearwater plume, SC = side channel, SSB = side slough beaver, US = upland slough, BW = backwater, TM = tributary mouth, SS = side slough.

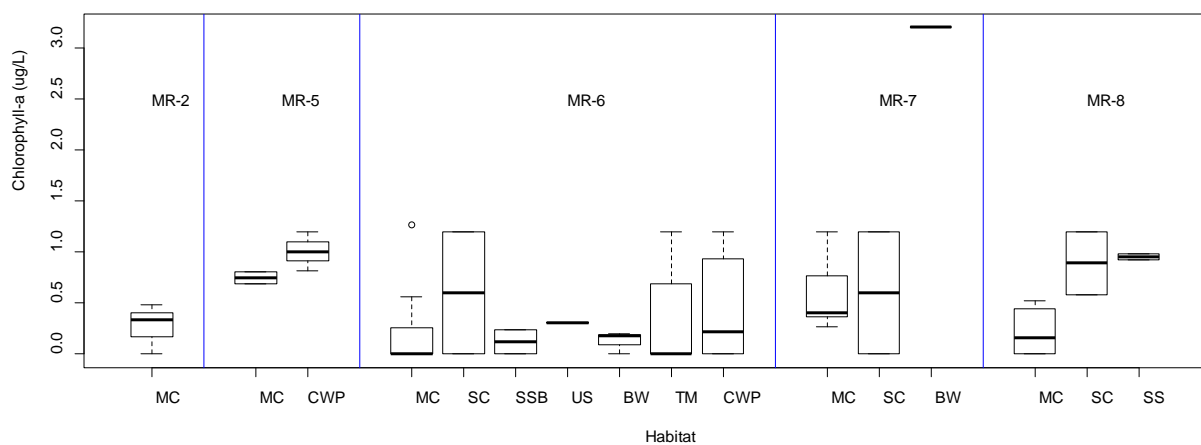


Figure 2.2-2. Box plots of chlorophyll-a concentrations for FDA-matched Water Quality samples by Geomorphic Reach and macrohabitat type.

Notes:

MC = main channel, CWP = clearwater plume, SC = side channel, SSB = side slough beaver, US = upland slough, BW = backwater, TM = tributary mouth, SS = side slough.

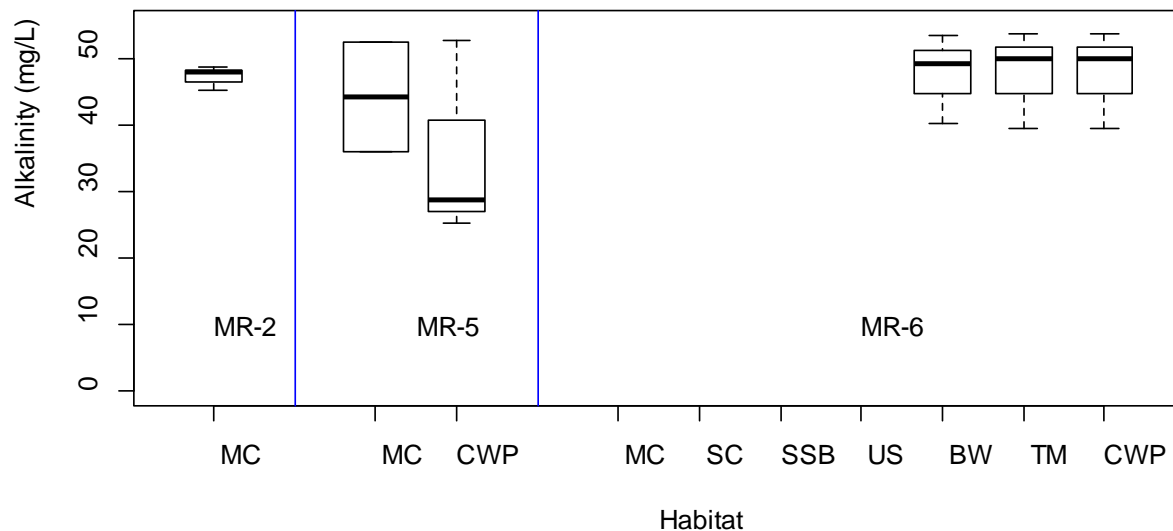


Figure 2.2-3. Box plots of alkalinity for FDA-matched Water Quality samples by Geomorphic Reach and macrohabitat type.

Notes:

MC = main channel, CWP = clearwater plume, SC = side channel, SSB = side slough beaver, US = upland slough, BW = backwater, TM = tributary mouth, SS = side slough.

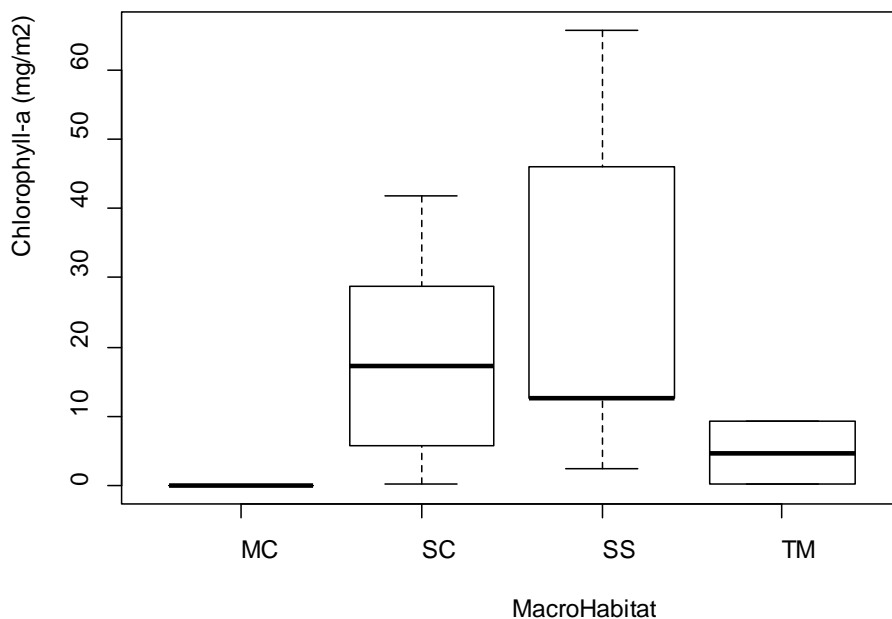


Figure 2.2-4. Box plot of River Productivity benthic chlorophyll-a samples by macrohabitat type.

Notes:

MC = main channel, CWP = clearwater plume, SC = side channel, SSB = side slough beaver, US = upland slough, BW = backwater, TM = tributary mouth, SS = side slough.

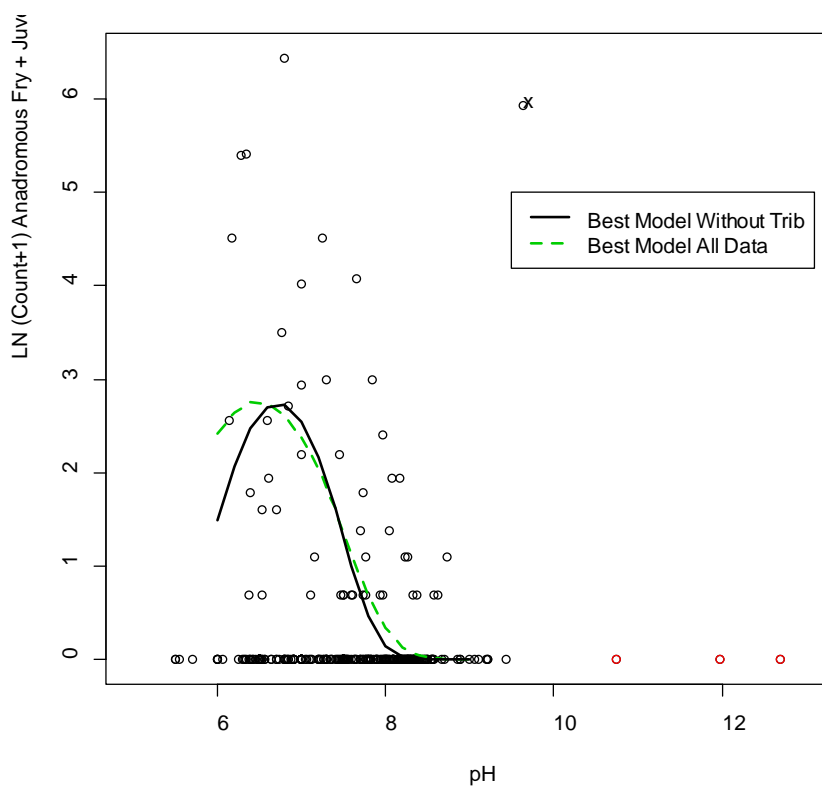


Figure 3.2-1. Scatterplot with fitted models showing relationship between pH and log-transformed (+1) counts for anadromous fry and juveniles.

Symbol “x” is over point that is removed from analysis for undue influence. Points displayed with red circles do not influence fitted parameters.

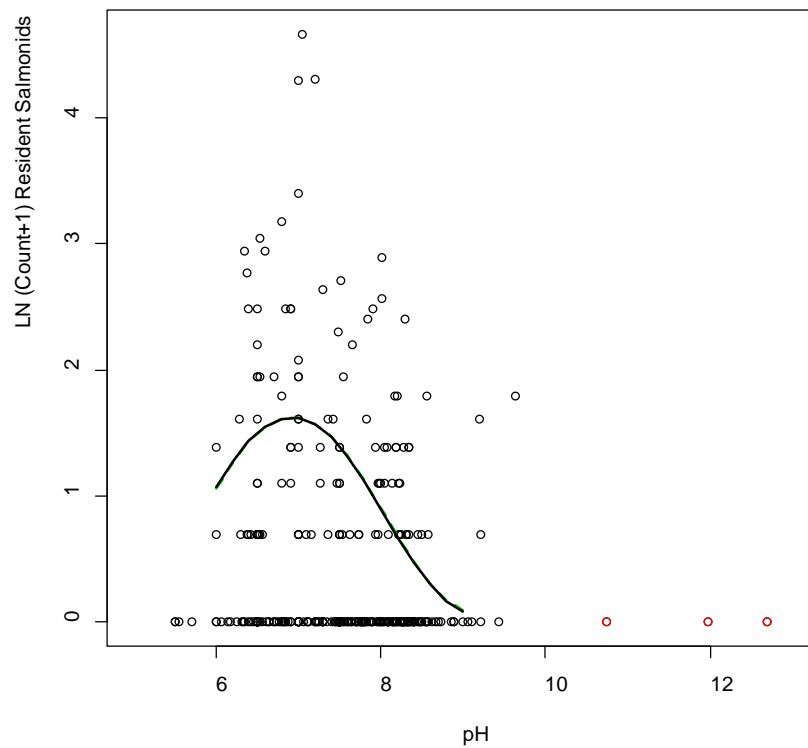


Figure 3.2-2. Scatterplot with fitted model showing relationship between pH and log-transformed (+1) counts for resident salmonids.

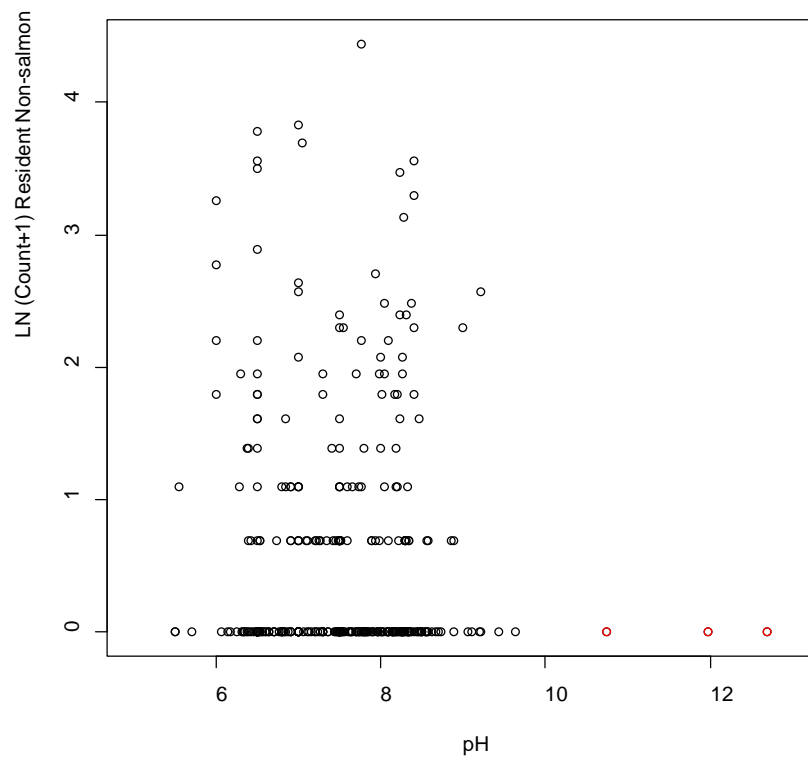


Figure 3.2-3. Scatterplot showing relationship between pH and log-transformed (+1) counts for resident non-salmonid fish.

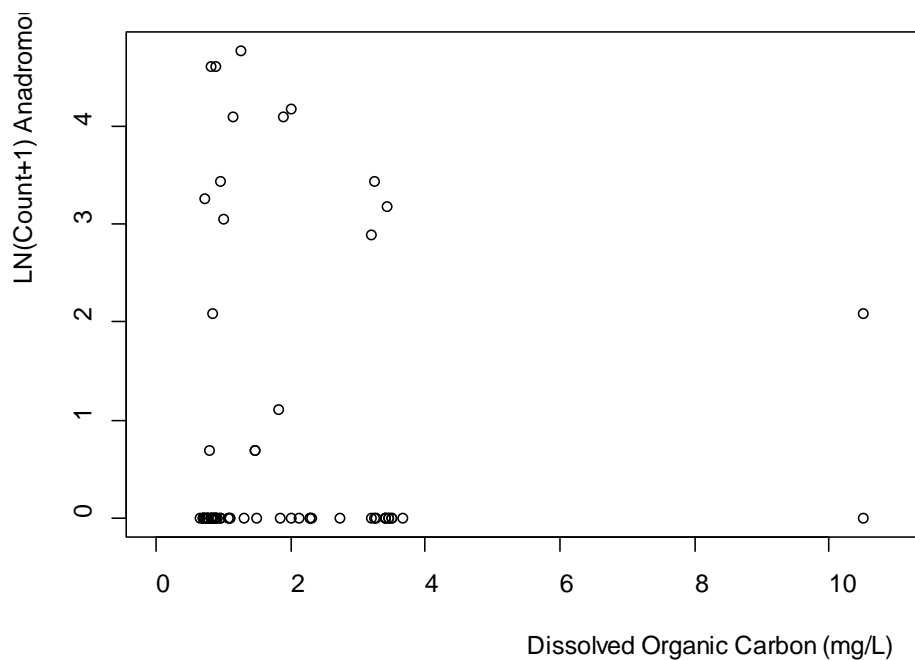


Figure 3.2-4. Scatterplot with anadromous juvenile salmonid counts plotted against dissolved organic carbon from WQ sampling.

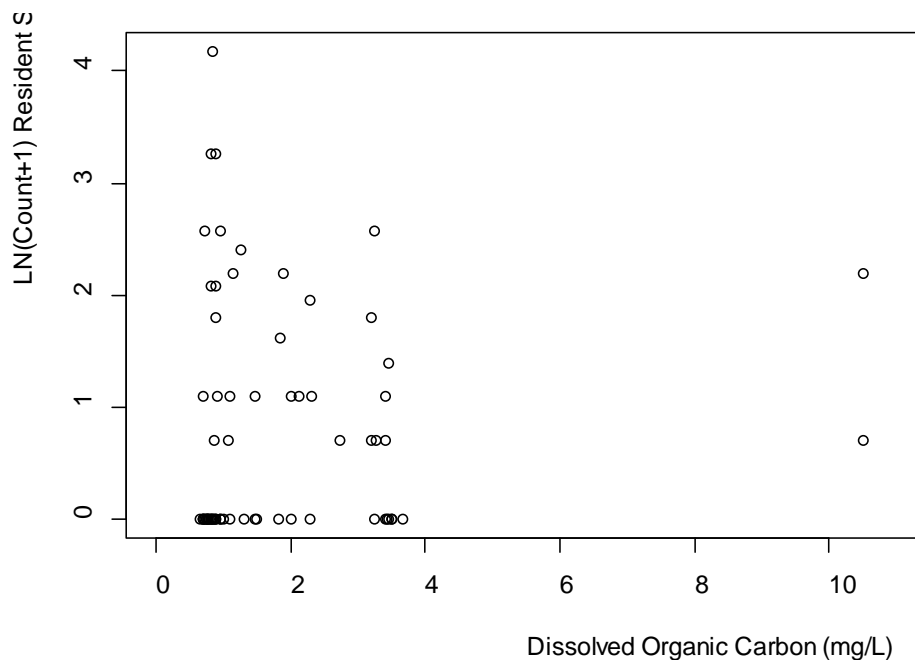


Figure 3.2-5. Scatterplot with resident salmonid counts plotted against dissolved organic carbon from WQ sampling.

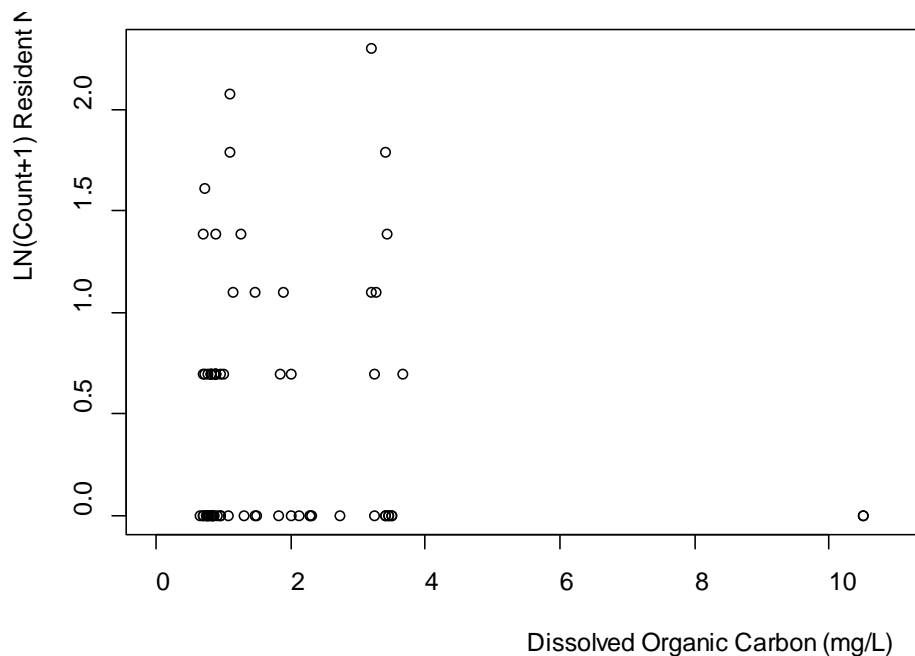


Figure 3.2-6. Scatterplot with resident non-salmonid counts plotted against dissolved organic carbon from WQ sampling.

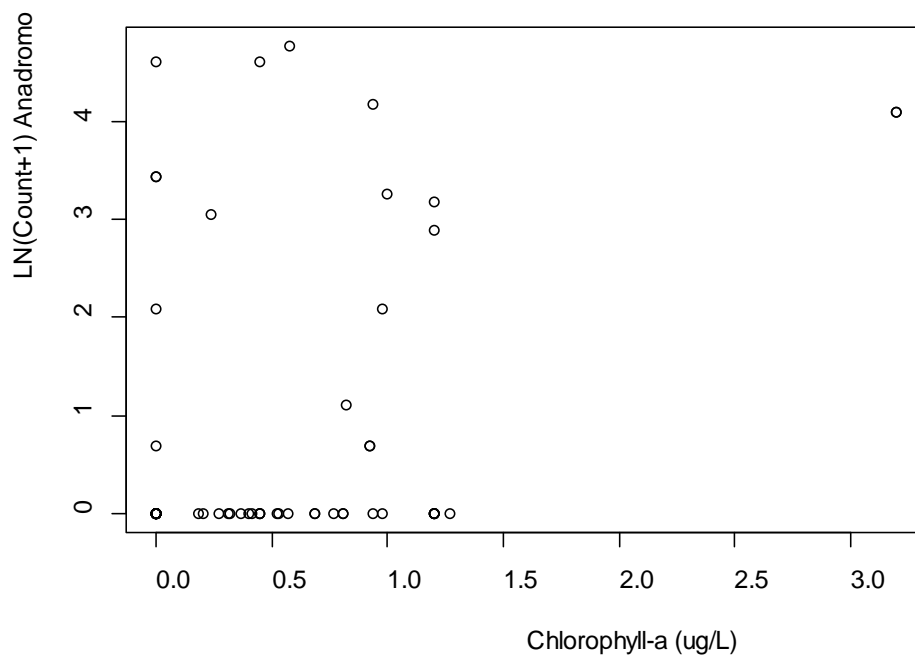


Figure 3.2-7. Scatterplot with anadromous juvenile salmonid counts plotted against chlorophyll-a from WQ sampling.

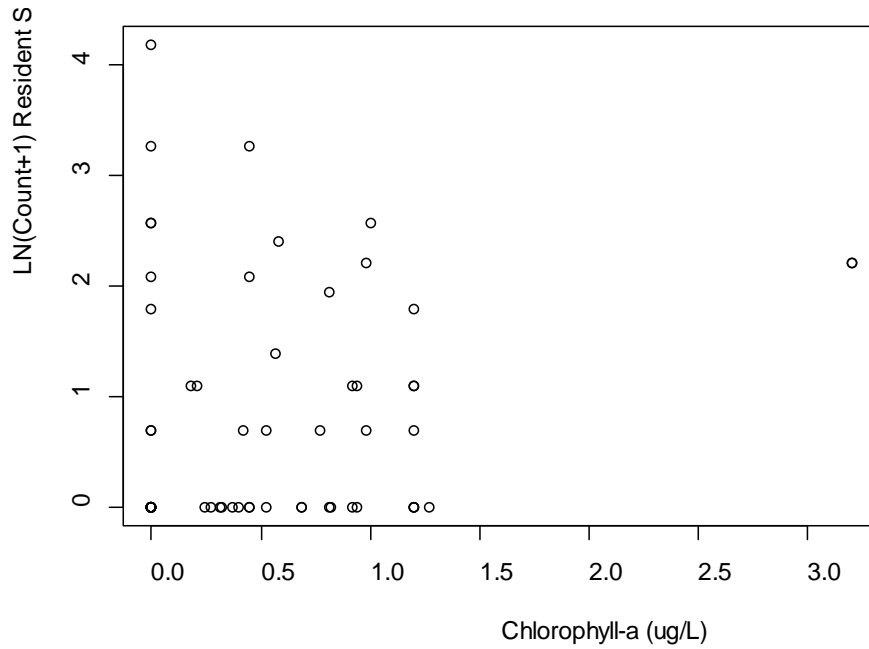


Figure 3.2-8. Scatterplot with resident salmonid counts plotted against chlorophyll-a from WQ sampling.

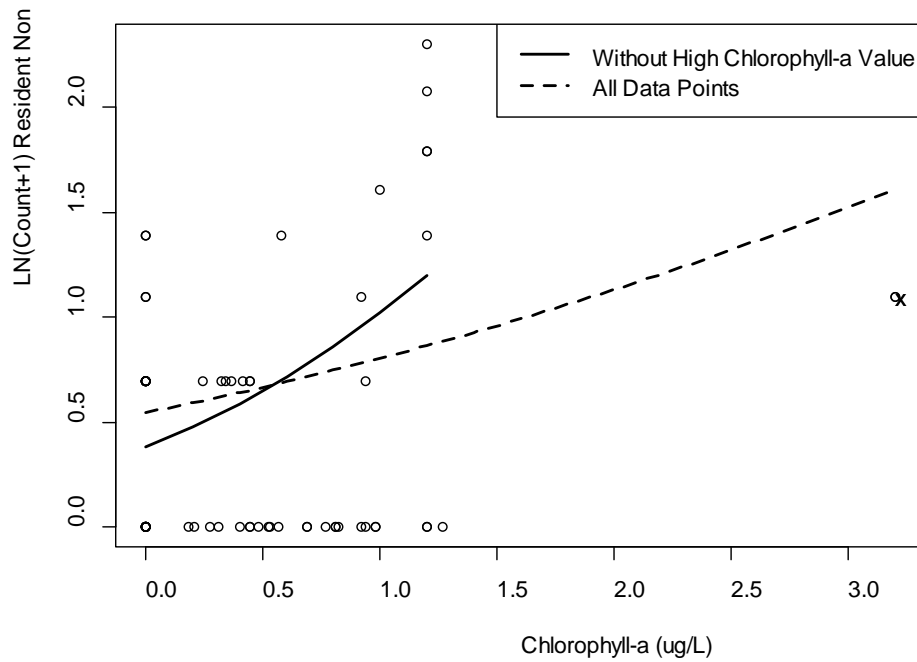


Figure 3.2-9. Scatterplot showing relationship between water column chlorophyll-a concentrations and log-transformed counts of resident non-salmonid fish.

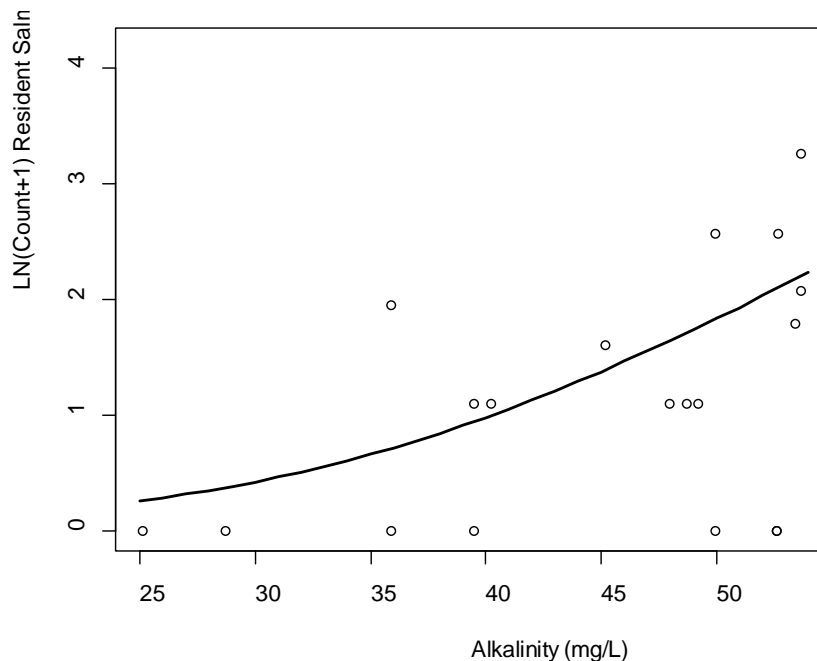


Figure 3.2-10. Scatterplot with resident salmonid counts plotted against alkalinity from WQ sampling with fitted model.

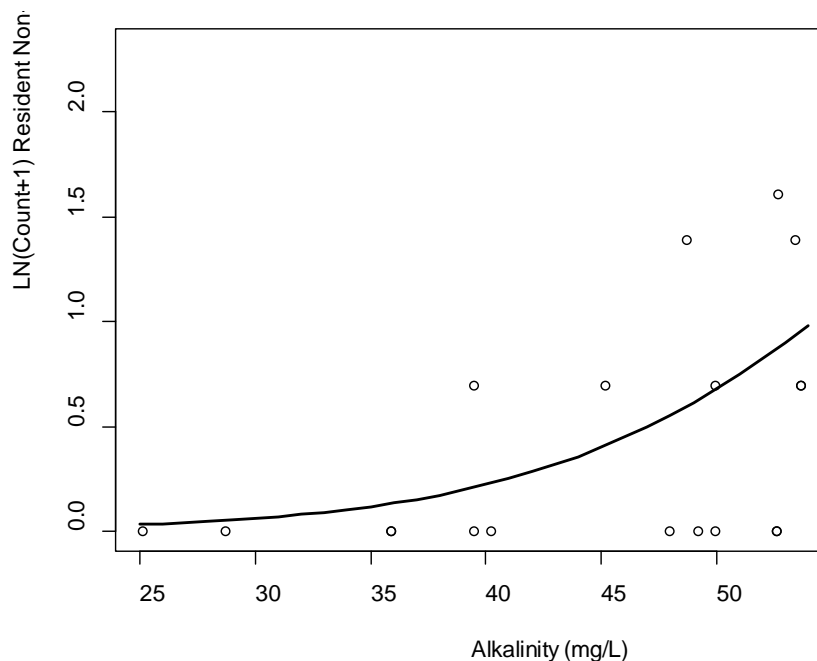


Figure 3.2-11. Scatterplot with resident non-salmonid counts plotted against alkalinity from WQ sampling with fitted model.

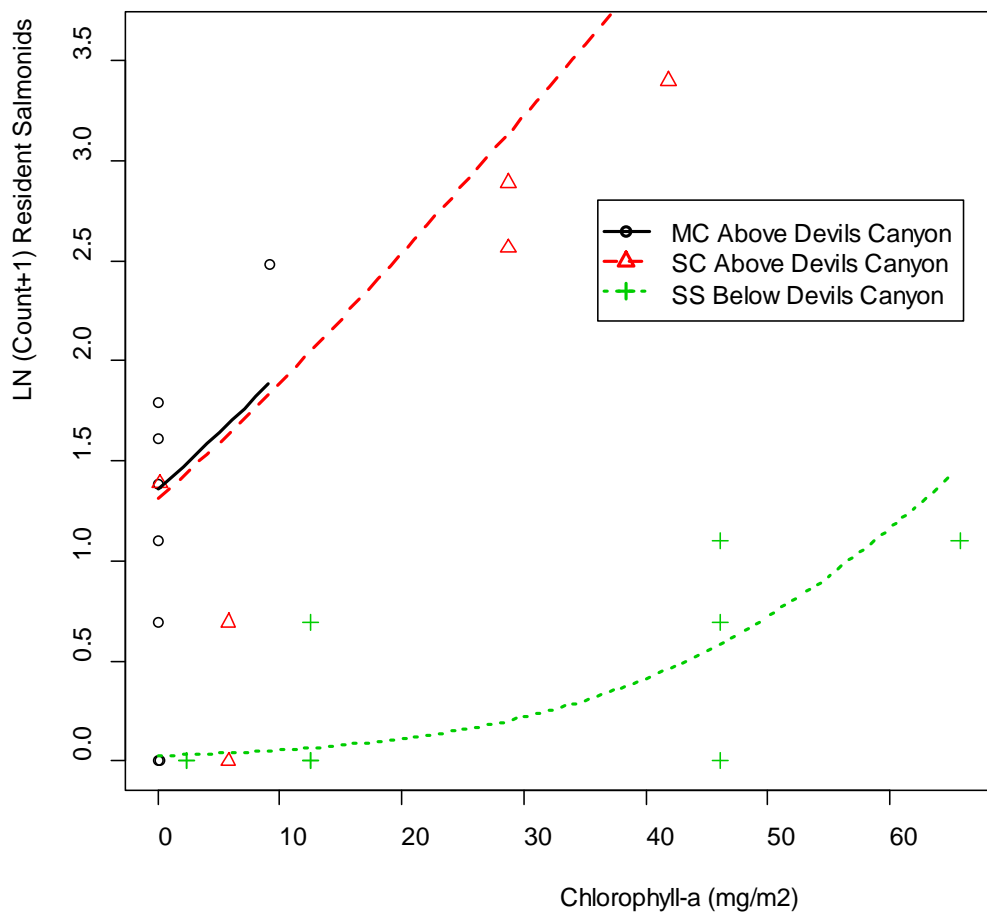


Figure 3.2-12. Scatterplot and fit models showing relationship between benthic chlorophyll-a and resident salmonid counts in three Focus Areas.

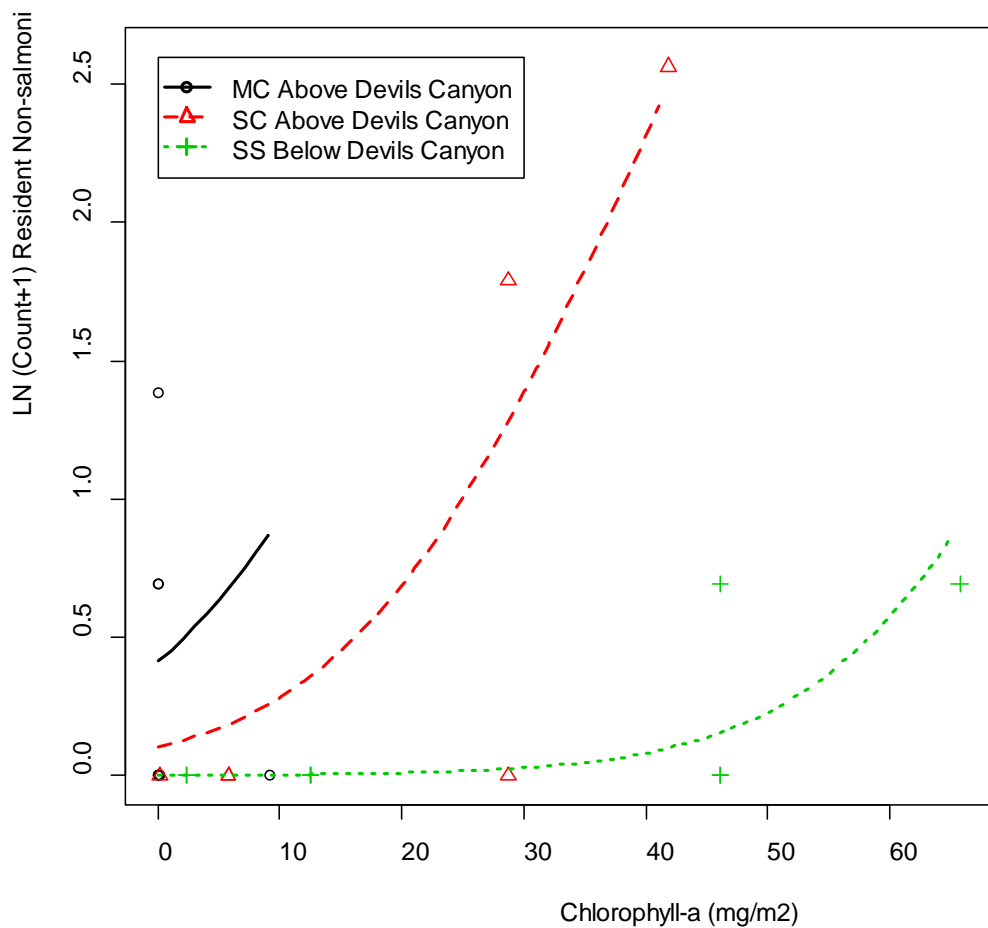


Figure 3.2-13. Scatterplot and fit models showing relationship between benthic chlorophyll-a and resident non-salmonid counts in three Focus Areas.