IDENTIFICATION AND CHARACTERIZATION OF INCONNU SPAWNING

HABITAT IN THE SULUKNA RIVER, ALASKA

By

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A

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Abstract

Inconnu *Stenodus leucichthys* are present throughout much of the Yukon River drainage in Alaska, but only five spawning areas have been identified. Spawning habitat requirements are therefore thought to be very specific; however, the physical qualities of these habitats have only been characterized in general terms. The Sulukna River is one of five identified inconnu spawning areas within the Yukon River drainage. A systematic sampling design was used in September and October of 2007-2008 to define Sulukna River spawning locations. Presence of inconnu was identified using hook and line sampling methods and spawning was verified by catching broadcast eggs in plankton nets. Small-scale, large-scale, and chemical habitat variables were sampled at transects located every 1.8 river kilometer (rkm). Project results indicate that spawning habitat was confined to a narrow reach of approximately 20 rkm. Spawning habitat occurred significantly more often in transects characterized with substrate between 6 and 12 cm, a width to depth ratio between 15 - 36, and water conductivity between 266 - 298 μS/cm. Similar studies on other known spawning habitats would reveal whether these qualities are common to all inconnu spawning populations or unique to the Sulukna River.

Table of Contents

List of Figures

Page

List of Tables

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1.1 General introduction

1.1 Background

Inconnu *Stenodus leucichthys* is the largest member of the whitefish sub-family Coregoninae. They are a northern latitude fish, occurring in Arctic and sub-Arctic drainages in North America and northern Asia (Scott and Crossman 1973). Within Alaska their distribution includes the Yukon, Kuskokwim, Selawik, and Kobuk River drainages (Morrow 1980), and within Canada, the Anderson, upper Yukon, and Mackenzie River drainages, including the Great Slave Lake (Scott and Crossman 1973). Northern Asian populations range from Siberia to the White Sea and south to Kamchatka (Morrow 1980), and a sub-species of inconnu is present in Caspian Sea drainages. Although inconnu are geographically widespread and inhabit some of the largest northern drainages, there is a dearth of knowledge regarding their life history biology.

Habitat management requires an understanding of the features that make it essential. Essential habitats are defined as geographically or physically distinct areas that one or more species requires for its survival at some phase in its life history. Defining these habitats requires sufficient information to evaluate all major phases in their life history (Langton et al. 1996). How inconnu and spawning habitat are related within Alaska is not well understood because the spawning habitat features are poorly defined. Management of inconnu populations within Alaska has typically been conducted despite this lack of information, and although these populations appear healthy, existing information cannot support or refute that claim. Inconnu are an important resource for subsistence users within Alaska (Brown et al. 2005; Andersen 2007) because of their availability year-round and are caught in sport fisheries.

Within the Yukon River, five inconnu spawning populations have been identified (Figure 1.1): two populations in the upper Koyukuk River (Alt 1969), one population in the mainstem of the Yukon River upstream from the Porcupine River mouth (Brown 2000), one population in the Chatanika River (Alt 1969), a tributary of the Tanana River, and one population in the Sulukna River, a tributary of the Nowitna River (Alt 1985). The first three populations are considered to be amphidromous while the latter two represent a potamodromous form (Alt 1988).

Inconnu spawning areas are generally located in remote areas making direct sampling expensive and difficult. The increasing availability and sophistication in handling spatial data may enable the development of a system capable of rapidly and accurately delineating the extent of fish-bearing streams for large drainage networks with accuracy comparable to on-ground surveys (Fransen et al. 2006). Geographic information systems (GIS) (ESRI 2003) technology offers the spatial and analytical ability to derive this type of information. The use of a GIS to perform spatial analysis of habitat feature definition and distribution has been successfully used in other fish populations to quantify fish and habitat relationships (Begout Anras et al. 1999; Toepfer et al. 2000; Fransen et al. 2006). However, there are potential drawbacks associated with spatial data in Alaska regarding the available data resolution that could affect accuracy of the spatial models (Tanner 2008). If sufficient accuracy cannot be achieved then identifying areas most likely not to

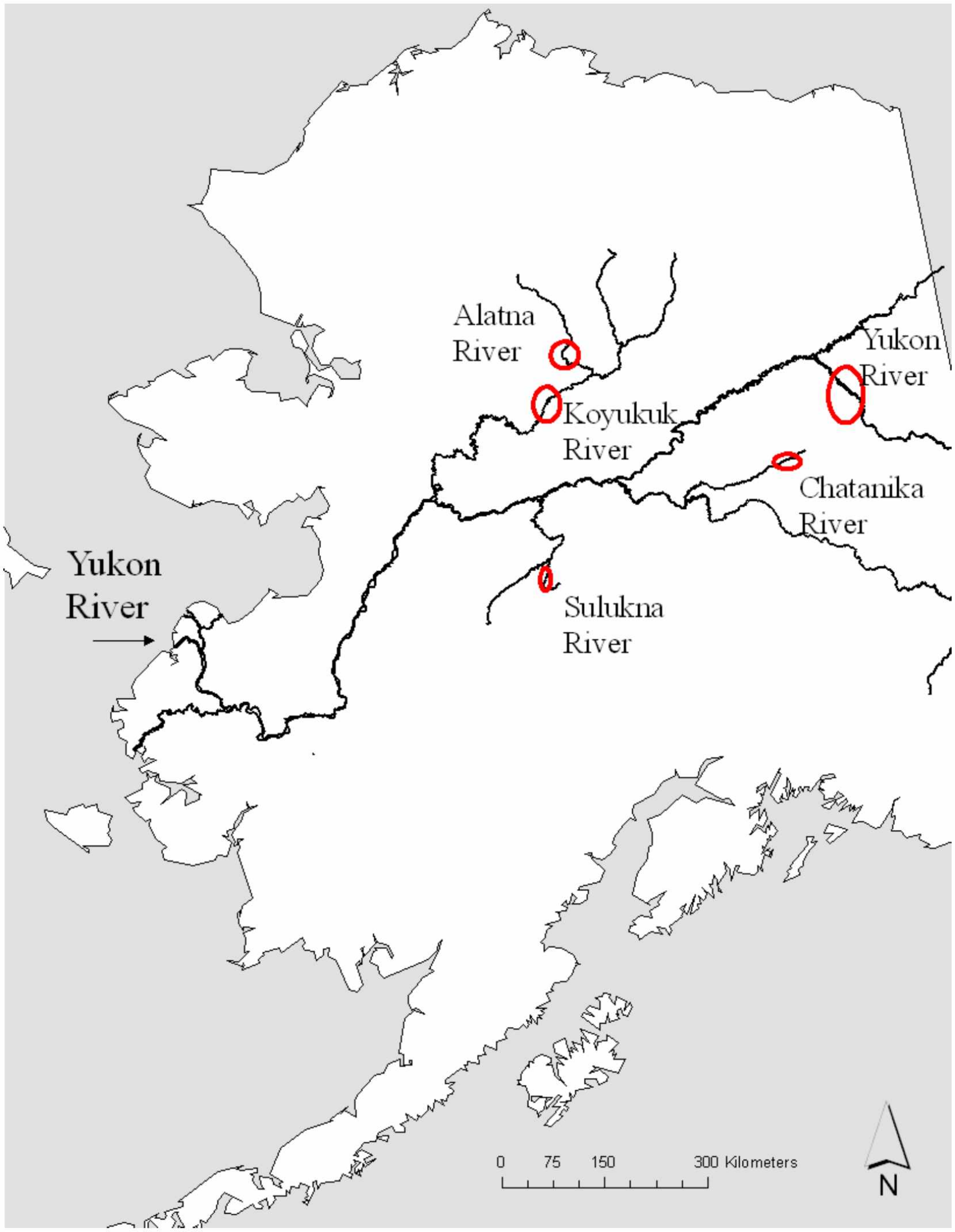

Figure 1.1 Location of identified inconnu spawning areas within the Yukon River drainage, Alaska.

contain spawning populations could benefit management decision making (Fransen et al. 2006).

1.2 Study area

The Sulukna River, originating in the Sischu Mountains, is a clearwater river flowing north, approximately 180 rkm in length. Its confluence is located at rkm 280 upstream on the Nowitna River (Figure 1.2). The Sulukna River drains a 1,772 km^2 (684 $mile^2$) watershed (Latitude 64°07'50" N, Longitude 154°02'46" W; Township 16S, Range 25E, Section 1, SW 1/4, Kateel River Meridian) and is a low gradient system with headwaters originating at 500 m above sea level. The Sulukna River is relatively unaltered by human influence which has likely preserved the natural behavior of inconnu. There is no active mining occurring within the drainage and only one historical report indicating placer mining for gold and tin in 1918 (Eakin 1918). Permitting for hunting and trapping has been small. One permit has been issued for trapping within United States Fish and Wildlife Service (USFWS) lands, and hunting, primarily for moose, generally occurs on the Nowitna River because of easier boat access (G. Beyersdorf, BLM, personal communication). Land status for the Sulukna River is shared between the USFWS Nowitna National Wildlife Refuge, approximately the lower 10 rkm of the river, and the Bureau of Land Management (BLM) managing the remaining portion. Spawning grounds are located within BLM managed lands; therefore, the BLM has designated their lands an area of critical ecological concern (ACEC).

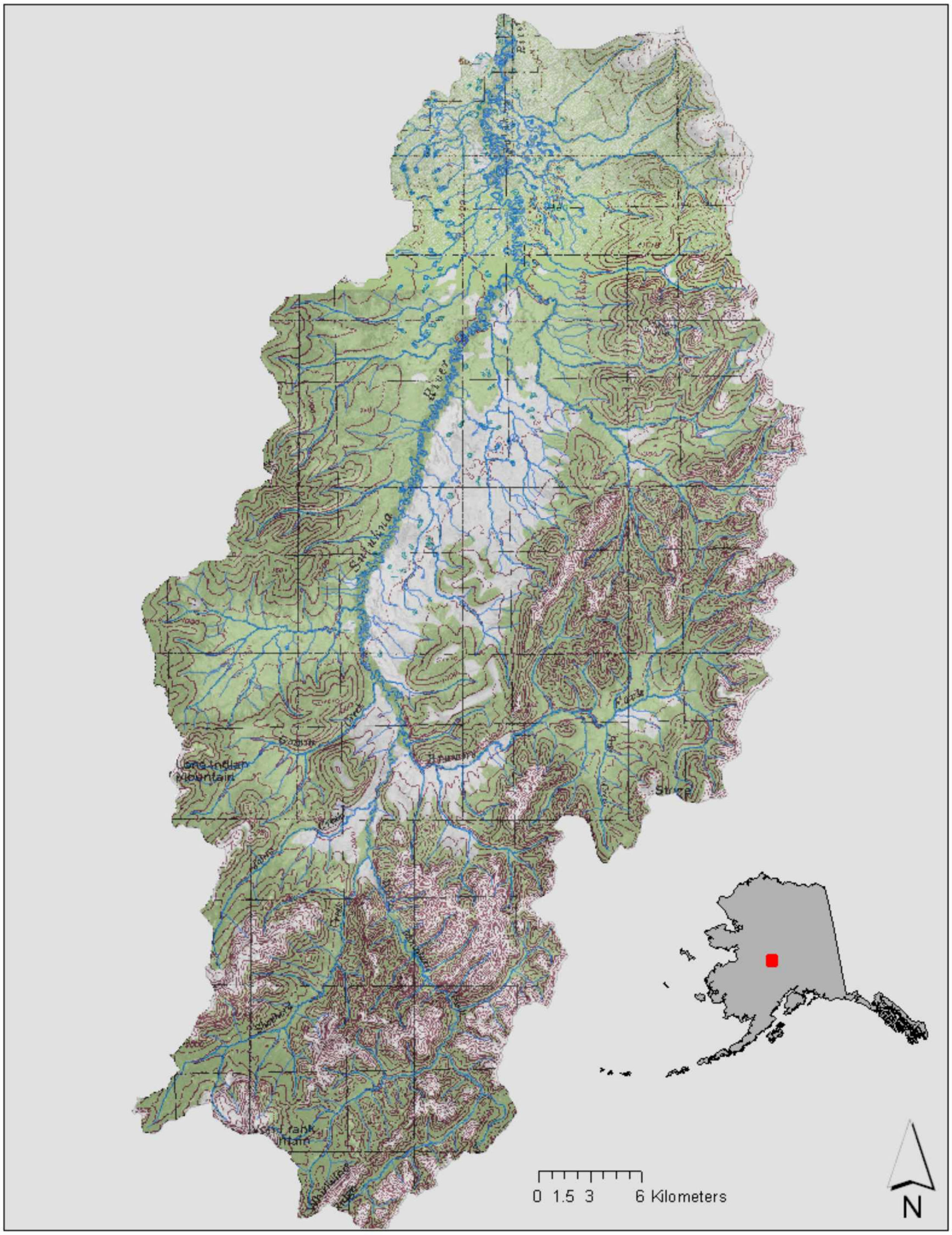

Figure 1.2 The Sulukna River, Alaska.

1.3 Life history

Inconnu are primarily amphidromous, making freshwater to saltwater migrations; however, some populations are potamodromous, remaining in freshwater throughout their life (Alt 1988, Howland et al. 2001). Migrations are related to feeding, spawning, and overwintering, with amphidromous inconnu undertaking the longest migrations (Alt 1988). Upstream migrations from feeding areas to spawning areas occur in late summer and fall with maximum distances up to 1,700 km in the Yukon River (Brown 2000) and 1,800 km in the Mackenzie River (Stephenson et al. 2005). These different types of migration and the migratory periodicity over long distances indicate that inconnu are present in river systems throughout the year (Alt 1969; Howland 1997).

Inconnu are iteroparous broadcast spawners. Spawning occurs in late September and early October (Alt 1988). Spawning habitat has been typified as containing a current of 2 m/s, water depth of 2 m, and substrate of differentially sized gravels (Alt 1985). Inconnu broadcast spawn, releasing eggs and milt into the water column. Alt (1988) describes spawning behavior wherein females often move perpendicular to the current, on or slightly below the water surface while expelling eggs. Large females can contain as many as 400,000 eggs and may require more than one pass to extrude all eggs (Morrow 1980). Fertilized eggs hatch from late February to April, and larvae are approximately 7 mm in length (Morrow 1980). Sturm (1994) indicated that egg hatching occurred in hatchery grown inconnu eggs approximately 91 days after fertilization at 4^{o}C.

Larvae and juvenile studies specific to inconnu are lacking, although insight can be gained by reviewing information from Coregonid relatives. Nasje et al. (1986)

hypothesized that mechanical disturbances, such as spring freshet, initiated larval emergence of cisco *Coregonus albula* and whitefish *C. larvaretus* larvae in Norway, and noted that peak drift was concurrent with the start of spring freshet. Similarly, Reist and Bond (1988) suggested that newly emerged young are displaced downstream by spring floods in the Mackenzie River. However, Bogdanov et al. (1992) noted hatching in the Ob River of larval whitefish *Coregoninae* spp. occurs under the ice and continues until several days after the river is free of ice. Downstream migration rates of larval inconnu are unknown, although otolith microchemistry (Brown 2000) indicated that some larvae reach saltwater within their first year of life. Inconnu larvae begin feeding on plankton initially, transition to insects and small fish during their first year, and become piscivorous by their second year (Alt 1973).

Inconnu are long-lived and slow growing. Females typically have a longer life span than males and they reach sexual maturity at an older age (Howland 1997; Brown 2000). Spawning may occur at intervals of one or more years throughout life, which may extend to 30 years or more.

1.4 Study objectives

This thesis describes an inconnu spawning habitat study conducted during 2007 and 2008. The study characterized the prevalent habitat features of the Sulukna River where inconnu were found spawning in September and October of 2007 and 2008. The main objectives of the study were to: (1) quantify and model habitat characteristics of inconnu spawning habitat in the Sulukna River; and (2) construct a spatial model for inconnu spawning habitat in a GIS and apply the model to other drainages where inconnu are known to spawn. A variety of sampling protocols was used to quantify the small-scale, large-scale, and chemical habitat features of inconnu spawning areas. This thesis is organized into chapters that describe each component of the study. Each component has individual background information, methods, results, and discussion section. A summary of conclusion combines the results of all chapters.

2.1 Identification and characterization of inconnu spawning habitat

2.1 Introduction

Identifying and quantifying inconnu spawning habitat are predicated on locating fish while spawning. Alt (1973, 1975) documented initial movements of inconnu into the Nowitna River through a tag and recovery program conducted at the river mouth between 1972 and 1974. Pre-spawning inconnu were captured at the mouth of the Sulukna River and in lower portions of the Sulukna River in 1974. Surveys documenting spawning location were conducted by boat in 1984 (Alt 1985), but no spawning area was identified. The USFWS, Alaska Department of Fish and Game (ADF&G), BLM, and Tanana Chiefs Conference began a radio telemetry project tagging inconnu within the Nowitna River drainage beginning in 2003 and continuing in 2005 through 2009. Continuation of tagging occurred in 2005 through 2008. Aerial tracking occurred throughout September and October in all years consistent with inconnu spawning timing. Results of this project indicated that the radio tagged inconnu in the Sulukna River were distributed between rkm 25 and 92, but the largest aggregate of radio tagged inconnu was located between rkm 72 and 92 (Figure 2.1; R. Brown, USFWS, personal communication). Intensive descriptions of inconnu spawning habitat features have not been conducted. Alt (1985) located the largest concentrations of inconnu in mid-September in deep eddy-type holding areas where the stream bottom was composed of different-size gravel swept clean of algae and silt by a moderate current.

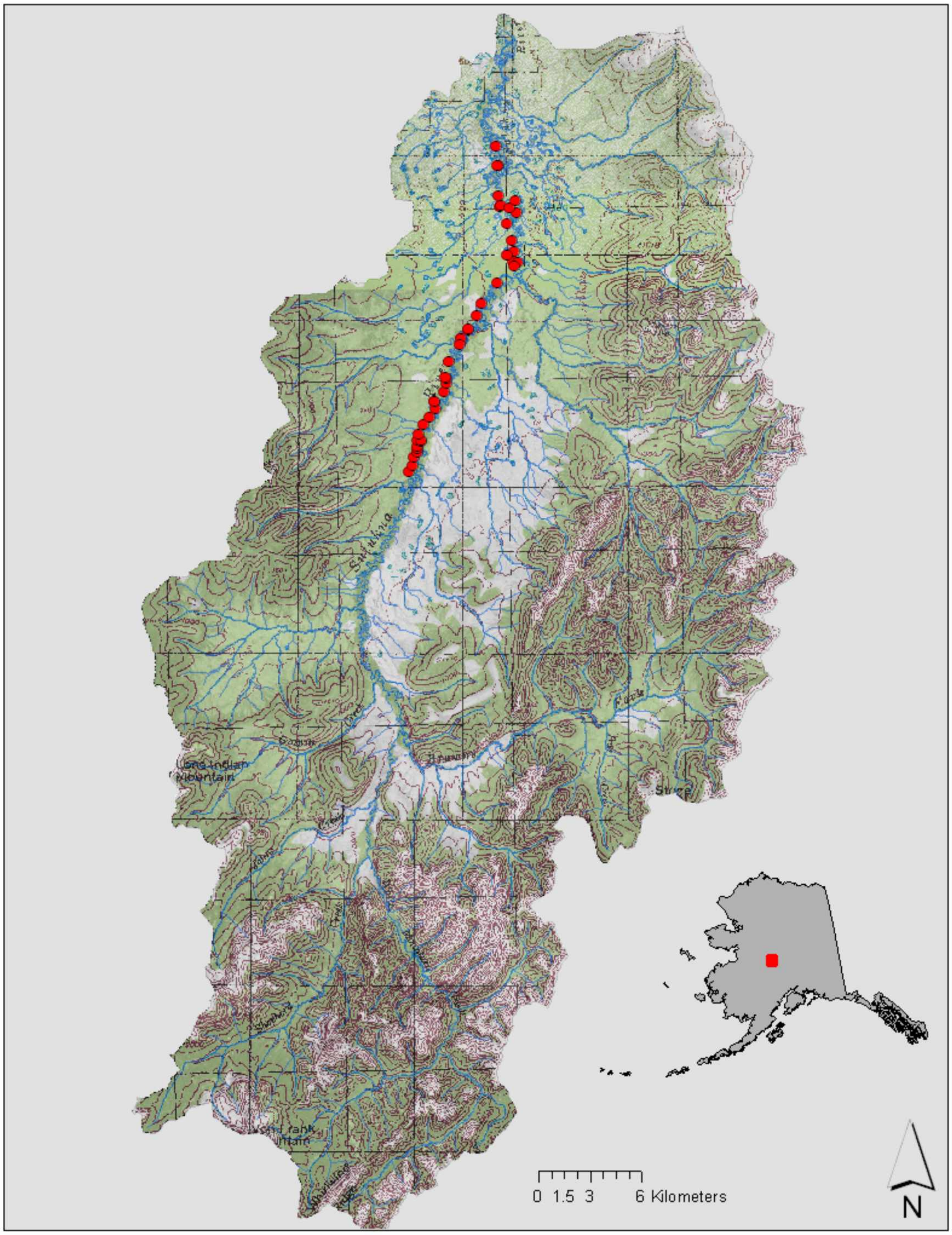

Figure 2.1 Location of radio tagged inconnu in 2003, 2005-2008 (USFWS, unpublished data).

Chemical characteristics are important in homing of migratory fish (Hasler and Wisby 1951) and important in embryo survival and development (Shumway et al. 1963, Scarnecchia and Bergersen 1987). Mueller et al. (1996) measured water quality (defined as the chemical characteristics of water) on the Sulukna River and noted higher values for pH, conductivity, total hardness, and alkalinity when compared to other tributaries in the Nowitna River and other Yukon River drainages (Table 2.1). Brabets et al. (2000) described water quality in surface water on 11 tributaries located throughout the Yukon River drainage. Mean values for conductivity and alkalinity in these tributaries were lower than those on the Sulukna River (Table 2.2). Water quality characteristics of surface water and ground water are strongly affected by surficial and bedrock geology (Brabets 2000). Sulukna River geology is composed of limestone, dolomite, and sandstone. This combination is common to other known inconnu spawning areas; i.e. the Alatna, Selawik, and Kobuk Rivers (Beikman 1980).

This component of the study describes the presence and absence of spawning inconnu, sampling methods, and quantification of habitat characteristics. Objective one was to identify the prevalent physical and chemical characteristics of inconnu spawning habitat. Objective two was to describe captured inconnu according to length distribution and sex ratio. Objective three was to describe the water temperature of areas with inconnu spawning presence and absence and to gather additional thermal information specific to onset of spawning and spring ice breakup.

Table 2.1 Water quality measurements at Koyukuk, Northern Unit of Innok, and Nowitna National Wildlife Refuges, Alaska, 1991 (Source: Mueller et al. 1996).

River	Collection date	pH	Conductivity (µS/cm)	Total hardness (mg/L)	Total alkalinity (mg/L)
Clear Creek	18-Jun	7.1	30	3	13
Hogatza River	17-Jun	7.1	24	0	17
Lower Camp Ck.	13-Jun	7.0	66	21	24
Eddy Creek	14-Jun	7.2	78	36	32
Sulatna River	19-Jun	7.3	120	71	62
Sulukna River	11-Jun	8.3	218	125	119

Table 2.2 Water quality data of select Yukon River tributaries. Each numeric value represents the mean of multiple samples.

River	No. of analyses	Conductivity (μS/cm)	Total alkalinty (mg/L)	Source
Sulukna River	174	294	142	Current study - 2008
	76	233	109	Current study - 2007
		218	119	Mueller 1996
Teslin River	124	127	59	Brabets et al. 2000
Pelly River	274	274	99	Brabets et al. 2000
Stewart River	306	306	100	Brabets et al. 2000
Klondike River	253	253	82	Brabets et al. 2000
Fortymile River	145	145	50	Brabets et al. 2000
Porcupine River	262	262	98	Brabets et al. 2000
Chandalar River	221	221	107	Brabets et al. 2000
Tanana River	243	243	96	Brabets et al. 2000
Melozitna River	86	86	36	Brabets et al. 2000
Koyukuk River	213	213	86	Brabets et al. 2000
Innoko River	101	101	41	Brabets et al. 2000

2.2 Methods

2.2.1 Pilot study

Due to the limitation of available data on the distribution of spawning inconnu used within the Sulukna River, a pilot study was implemented in the 2007 project year to assess project feasibility. The pilot study used available Sulukna River background information to draw assumptions needed to implement field data collection. All hook and line sampling occurred between September 15 and October 5. Inconnu were found in pools located between rkm 56 and 92, but fish observed with loose eggs or milt were found between rkm 71 and 92. Pools were greater than 1.5 m deep and contained a mix of small cobble (6 – 12 cm length) and gravel (1 – 6 cm length) substrate. The pilot study provided insight on the location and timing of spawning inconnu within the Sulukna River. Upstream travel by canoe was found to be sufficient for transportation of field gear and personnel. A barrier of large woody debris encountered at rkm 101 prohibited passage farther upstream.

2.2.2 Sampling design

Sampling transects were located between rkm 0 (confluence of the Sulukna River and Nowitna River) and rkm 101, representing approximately 60% of the river length. A random starting point was selected by stratifying the first river km into ten 100 m segments. Each segment was assigned a number between one and ten. A random number generator was used to select the first 100 m section which represented the first transect. Transects were located every 1.8 rkm throughout the Sulukna River waterway (Figure 2.2). The measure of 1.8 rkm was chosen to assure a minimum transect sample size of $n = 50$.

Physical location of each transect was determined in July 2008. A transect became permanent if it was located within a pool habitat type with a minimum of 1.5 m depth. If a transect location did not meet this criterion, it was moved to the next pool downstream with appropriate depth. This qualification was based on the 2007 pilot study and descriptions by Alt (1985) indicating the most likely habitat to contain inconnu.

Transects were sampled moving downstream beginning at the uppermost transect at rkm 101 mark in September and October of 2008. Presence of inconnu was verified using hook and line sampling. Three people fished for 30 minutes at each transect to determine presence or absence of inconnu. Prior to sampling, a 20-minute buffer was used to allow inconnu to return to their preferred location within the waterway in case they were disturbed due to the noise from outboard motors. Captured inconnu were sampled for sex, based on external morphology (male, female, undetermined), spawning readiness based on loose milt or eggs during handling (ripe) or not loose (not ripe), and length (tip of nose to fork of tail measured in mm). Spawning was verified in all transects by assessing the presence of milt or eggs in captured inconnu by rubbing the belly of the fish to produce roe or milt out of the vent. Plankton nets (31 cm x 31 cm, 1 mm mesh) were placed in the thalweg of the upper transects anchored to the substrate with sand bags to verify the start of spawning. Nets were deployed overnight in pool or run habitats prior to spawning occurring. A run was characterized by moderately shallow water that lacked pronounced turbulence and found intermediate between pools and riffles (Bisson et al. 1982). Once spawning was verified in the uppermost transects, sampling of downstream transects was initiated. Results of the radio telemetry project indicated that all radio tagged inconnu appeared to have departed the Sulukna River by October 10 (R. Brown, USFWS, personal communication) and spawning began on September 23 in 2007 and 2008; therefore, all sampling needed to occur within the 17 day timeframe.

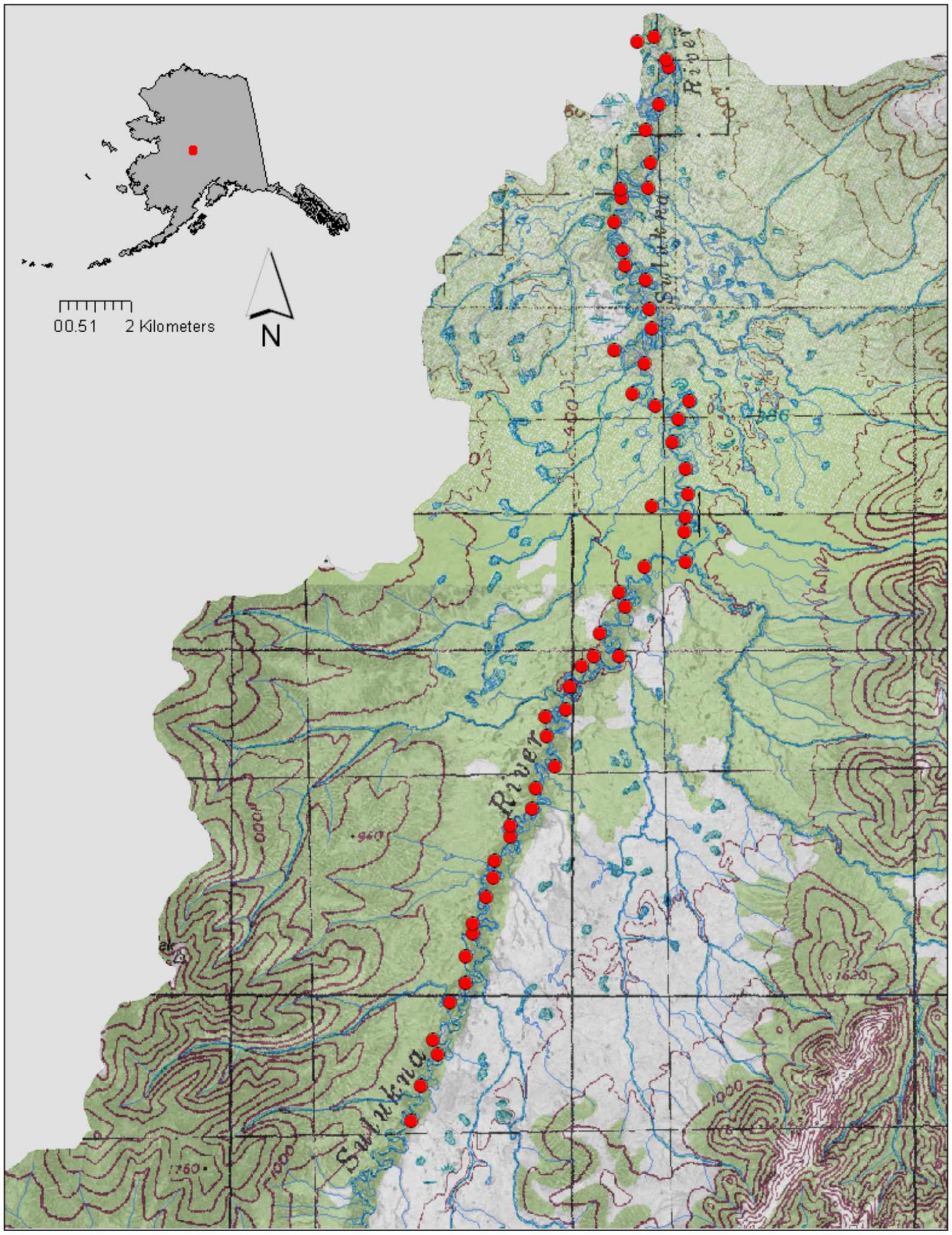

Figure 2.2 Expanded view of the Sulukna River, Alaska highlighting transect locations with circles.

After completing hook and line sampling, 17 habitat parameters were measured at each transect (Table 2.3). Variables included elevation, drainage basin area, bankfull width, bankfull mean depth, bankfull max depth, slope, wetted width, dominant and subdominant substrate, presence of a riffle, width to depth ratio, maximum and mean water velocity, water temperature, pH, conductivity, and alkalinity. Slope was measured using a level and stadia rod. An acoustic Doppler current profiler (ADCP) was used to measure water depth and water velocity. A Hach HQ40d pH/Conductivity/LDO Dual-Input Meter configured multimeter was used to measure water temperature, alkalinity, conductivity, and pH. Substrate was defined using the Wentworth classification (McCave and Syvitski 1991). The presence of a riffle was defined as being the next habitat type immediately downstream of a transect using the description outlined by Bisson et al. (1982), a channel profile having turbulent choppy surface water, and was a qualitative criterion used to describe the channel configuration (Rosgen 1996). Four variables were calculated outside of the field setting: width to depth ratio, elevation, sinuosity, and drainage basin area using a GIS.

Radio telemetry project information for the years of 2003 and 2005 - 2006 was used to partition the Sulukna River into three zones based on where radio tagged fish were found. The length of the Sulukna River between rkm 0 and 23 was considered to be the portion of river below the spawning area, rkm 23 and 92 was considered the portion of the river where spawning was occurring, and rkm 92 and 101 was considered the portion of the river above the spawning area. Ten Onset Hobo v2 temperature loggers were

Table 2.3 Variables determined or measured at each transect during inconnu presence-absence surveys on the Sulukna River, Alaska.

Variable	Method	Definition
		Large-scale variables
Elevation	GIS	Site elevation (±15m) as determined from Digital Elevation Map
Drainage basin area	GIS	Total area (±1 m^2) from which the water drains into the stream upstream of the survey site
		Small-scale variables
Bankfull width	Field	Mean width of (±0.1m) of the bankfull channel (defined by the presence of permanent rooted vegetation or waterline mark)
Bankfull mean depth	Field	Mean depth (± 0.1 m) from the height of the bankfull channel to the channel bottom
Bankfull max depth	Field	Max depth (± 0.1 m) from the height of the bankfull channel to the channel bottom
Slope	Field	Drop in elevation (±0.01 m) over length of stream channel surveyed, typically 100 meters, unitless measure
Wetted width	Field	Mean width of (±0.1m) of the wetted width of the stream
Dominant substrate	Field	The most prevalent substrate, individual pieces will be measured (± 1 cm) at the widest part
Sub-dominant	Field	The second most prevalent substrate, individual pieces will be measured (± 1 cm) at the widest part
Presence of a riffle	Field	Indicates a riffle being the next habitat type immediately downstream of the sampled transect
Width to depth ratio	Field	Ratio of bankfull width/mean bankfull depth (± 1.0m)
Max velocity	Field	Maximum downstream velocity (± 1 m^3/s) of water within the surveyed stream channel
Mean velocity	Field	Mean downstream velocity (± 1 m^3/s) of water within the surveyed stream channel
		Chemical variables
Water temperature	Field	Temperature (± 1 degree Celsius) of water within the water column
pH	Field	Measure of acidity within the water column
Conductivity	Field	Measure (± 1 µs/cm) of ionic material dissolved within the water column
Alkalinity	Field	Measure (± 1 mg/L) of the capacity of water to neutralize acid.

placed within the Sulukna River to evaluate differences in water temperature between zones over a one year time period, identify the water temperature when spawning began, and determine when breakup occurred, and develop a daily temperature profile of the Sulukna River. Temperature loggers were anchored by duckbill anchors fixed to the river bottom touching the substrate. Location of the logger was marked using a GPS.

2.2.3 Statistical analyses

The association between presence of inconnu and measured habitat variables was tested using logistic regression. The objective was to identify those variables that distinguished between transects with and without spawning inconnu. Logistic regression was used to identify important explanatory variables used in inconnu spawning habitat. The use of presence and absence models has been used to predict fish presence at smaller scales (Guay et al. 2000) as well as at a landscape or large scale. These models are primarily based on logistic regression (Watson and Hillman 1997; Porter et al. 2000; Harig and Fausch 2002). Logistic regression generates an equation predicting the probability (from 0 to 1) of presence as a function of any suite of environmental variables, which need not be normally distributed. Logistic regression models can be used to identify the environmental variables that can exert the strongest influence on the presence or absence of species (Rosenfield 2003).

2.2.4 Habitat characteristics

To test the hypothesis that habitat variables differed between transects with and without inconnu, data were pooled across all transects. Descriptive statistics (i.e., mean, range, standard deviation, and 95% confidence limits) were calculated for each continuous variable. Percentage of occurrence in transects with and without inconnu was calculated for discrete variables. Before testing the statistical hypothesis, all data were standardized and screened for normality and patterns of missing values, presence of outliers, and variance. Model selection was conducted following the methods of Hosmer and Lemeshow (2000). Data analysis was performed using Statistical Analysis Software (SAS) (SAS Institute 1988). Bivariate plots were used to test linearity of untransformed and $\log_e [x + 1]$ transformed variables. Transformation did not improve linearity of the variables. Univariate analysis was conducted for each variable by fitting the univariable logistic regression model to obtain the estimated coefficient, the estimated standard error, the likelihood ratio test for the significance of the coefficient, and the univariable Wald statistic. Any variable whose univariable test had a P-value < 0.25 was included in the correlation matrices (Hosmer and Lemeshow 2000). Pearson rank correlation matrices were used to test for multicollinearity among variables to select independent variables for use in the multivariable model. Examination of variables occurred if correlation between variables was $r \geq 0.70$ (Berry and Felman 1985). If this occurred, then the variable with the larger P-value (poorer relationship) in univariable analysis was removed. Multiple logistic regression was used to select the model with the lowest Akaike's Information

Criteria (AIC) value to assess the relationships between transects with and without inconnu. Smaller AIC values indicate better models (Burnham and Anderson 1998). The same AIC value was found when all of the parameters entered the model. To minimize the number of variables in the model, a stepping procedure of removing the variable with the highest P-value was used. This procedure reduced the number of explanatory variables in the model while preserving the statistical significance.

To assess model performance, the final model was evaluated according to its ability to correctly classify presence and absence for the observed data. Transects with a probability rating of ≥ 0.5 were likely to have inconnu present.

2.2.5 Length distribution and sex ratio

The difference among length-frequency distributions of male and female inconnu was tested using the Kolmogorov-Smirnov (K-S) two sample test. The sex of sampled inconnu were plotted against their length to illustrate the difference in length distributions between female and male inconnu.

2.2.6 Thermal regime

Onset Hobo v2 temperature loggers were used to collect water temperature data every hour beginning in September 2007 to September 2008. Daily mean temperatures were used to calculate the number of degree days from spawning to ice breakup. The number of degree days was calculated by adding the average temperature for each day above 0^{o}C. This accumulation was added over the period of time the temperature logger collected information. In this study, the onset of ice breakup was identified by an increase in water temperature from 0 to 1 degree Celsius.

2.3 Results

2.3.1 Habitat characteristics

Spawning inconnu were found during September and October of 2008 in 11 of the 58 transects between rkm 71 – 91 (Figure 2.3). Values for mean and maximum water velocity were missing on 13 transects. SAS PROC LOGISTIC excludes an input dataline if a value for a predicator value is missing. As a result, the number of transects was reduced from 58 to 45 in this analysis. Inconnu caught with hook and line were not ripe prior to September 23 in both project years. During the 2008 project year, plankton nets caught inconnu eggs within the water column beginning September 23. Only nets placed in run habitats during the night caught eggs, indicating that inconnu were spawning during the night in or above run habitats. Spawning movements included inconnu breaking the surface and making rapid movements to expel eggs and milt. Hook and line sampling was conducted in run habitats during the day, but no fish were caught. Fish were caught in pool habitats during the day, suggesting that fish moved from pool habitats into run habitats to spawn.

Inconnu were observed in areas with discreet habitat characteristics, where wetted channel width ranged from 19 – 29 m, bankfull width ranged from 26 – 43 m, width to

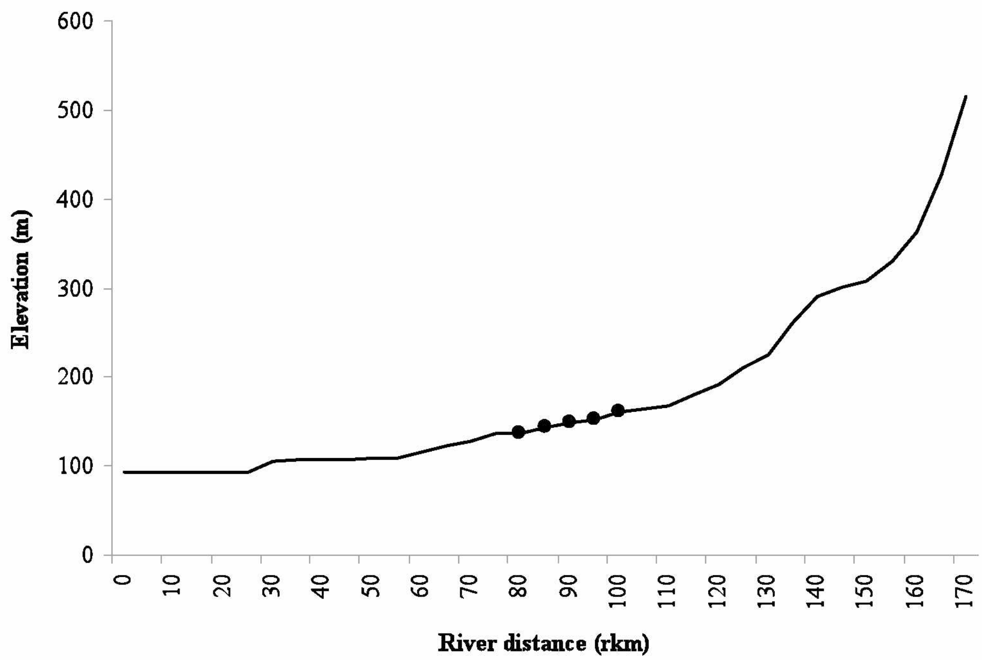

Figure 2.3 Longitudinal profile of the Sulukna River, Alaska. Circles indicate location of transects where spawning inconnu were present.

depth ratio ranged 25 – 30, drainage area ranged from 956 – 1004 km^2, and elevation ranged from 128 – 148 m. Water quality measurements of alkalinity and conductivity significantly ($p < 0.05$) differed between transects with and without inconnu presence. Conductivity, drainage area, and elevation were significantly different between transects with inconnu presence and absence ($p < 0.0001$) (Table 2.4). Analysis indicated that inconnu were most frequently found on sites with small cobble (6 – 12 cm) as the dominant substrate (Figure 2.4) and gravel (3 – 6 cm) as the subdominant dominant

Table 2.4 Descriptive statistics of continous variables measured in stream transects with and without inconnu spawning. Probability values of univariable logistic regression are given.

Variables	Transects with spawning		Transects without spawning		Likelihood ratio
	Mean	Range	Mean	Range	
Wetted width (m)	23	19 - 29	26	15 - 38	0.0647*
Bankfull width (m)	32	26 - 43	36	22 - 71	0.0767*
Slope (unitless measure)	0.0011	0.0001 - 0.0029	0.0021	0.0002 - 0.0165	0.3392
Max depth (m)	5.67	2.89 - 8.16	5.00	3.07 - 7.56	0.2489*
Mean depth (m)	4.51	2.41 - 5.92	4.11	2.61 - 6.17	0.242*
Max velocity (ft/s)	2.55	1.71 - 3.85	2.47	1.74 - 4.39	0.815
Mean velocity (ft/s)	1.24	0.71 - 2.46	1.38	0.60 - 2.80	0.2863
Width to depth ratio (index)	4.34	2.94 - 8.65	5.43	2.45 - 9.14	0.0713*
Sinuosity (index)	3.02	2.38 - 4.55	2.27	1.19 - 3.57	0.5973
Drainage (km^2)	1018	956 - 1462	1310	946 - 1659	0.0001*
Elevation (m)	137	107 - 148	111	93 - 148	0.0002*
Total alkalinity (mg/L)	134	114 - 164	144	122 - 173	0.0078*
pH	8.26	7.98 - 8.65	8.30	7.88 - 8.85	0.4529
Conductivity (μS/cm)	283	266 - 307	297	192 - 315	0.0547*

* Model inclusion pvalue < 0.25

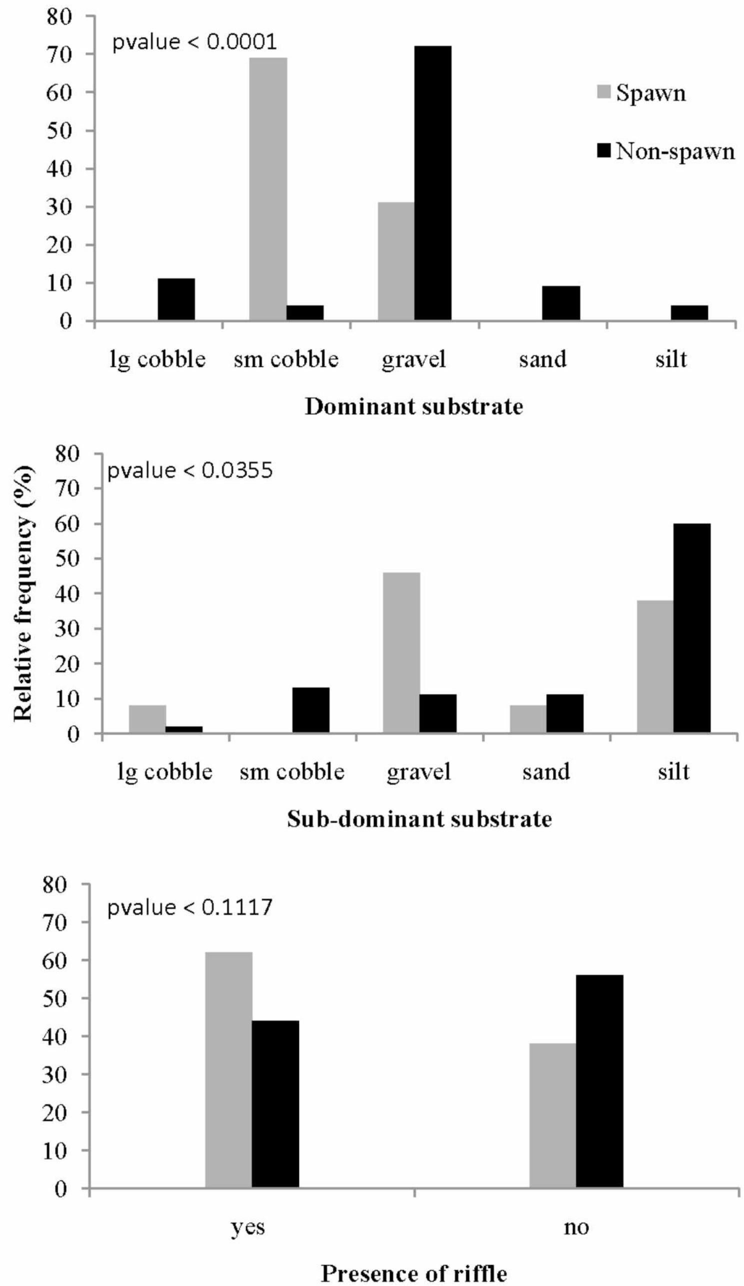

Figure 2.4 Relative frequency of dominant substrate, subdominant substrate, and presence of a riffle in transects with and without spawning inconnu on the Sulukna River, Alaska. Univariable logistic analysis assessed differences between sites with and without spawning inconnu.

substrate, and as having a riffle downstream of the transect. The presence of a riffle downstream of a transect was consistent with the smaller width to depth ratio observed on transects with inconnu, indicating that the channel was narrower and deeper, had a higher slope, and was therefore more likely to contain a riffle.

Multiple logistic regression identified three predictor variables – dominant substrate, width to depth ratio, and conductivity – that explained 68% of the variation in inconnu presence among transects (Table 2.5). The analysis indicated an inverse relationship with inconnu presence and width to depth ratio and conductivity. Five types of substrate were compared to the inconnu presence. Inconnu presence was inversely related to the dominant substrate not being small cobble; alternately stated, inconnu presence was more likely if small cobble was the dominant substrate (Table 2.6). Application of the final model to the observed data resulted in an 84% correct classification rate, with 75% sensitivity indicating the percent classification of presence transects and 88% specificity indicating the percent classification of absence transects.

2.3.2 Length distribution and sex ratio

Of the 174 inconnu sampled in September and October of 2007 and 2008, 33% were female ranging from 715 – 985 mm in length and 67% were male ranging from 620 – 840 mm in length (Figure 2.5). Length frequency distributions between sampled female and male inconnu were significantly different (K-S two sample test, $P < 0.0001$).

Table 2.5 Summary of variables that entered multiple logistic regression. Arrows next to variables indicate the relationship between the variable and the presence of inconnu; an up arrow indicates a direct relationship, a down arrow an inverse relationship.

	Model selection		
Variables	Univariable analysis	Multicollinearity	Best model
Wetted width (m)	dominant substrate	dominant substrate	dominant substrate
Bankfull width (m)	↓not small cobble	↓not small cobble	↓not small cobble
Slope	subdominant substrate	subdominant substrate	↓width to depth ratio
Max depth (m)	↑gravel	↑gravel	↓conductivity
Mean depth (m)	↑large cobble	↑large cobble	
Max velocity (ft/s)	↓sand	↓sand	
Mean velocity (ft/s)	↑silt	↑silt	
Width to depth ratio (index)	↓bankfull width	↓bankfull width	
Sinuosity (index)	↓wetted width	↓wetted width	
Drainage (km^2)	↓width to depth ratio	↓width to depth ratio	
Elevation (m)	↓conductivity	↓conductivity	
Total alkalinity (mg/L)	↓total alkalinity	↑elevation	
pH	↓drainage		
Conductivity (μS/cm)	↑elevation		
Dominant substrate			
Subdominant substrate			
Presence of riffle			

Table 2.6 Results of multiple logistic regression that assessed relationships between presence of inconnu and habitat features.

Variable	Coefficient	SE	pvalue
Intercept	-0.9966	0.6301	0.1137
Dominant substrate			
not small cobble	-2.1593	0.5947	0.0003
Conductivity	-0.5397	0.4432	0.2233
Width to depth ratio	-0.8517	0.6648	0.2001

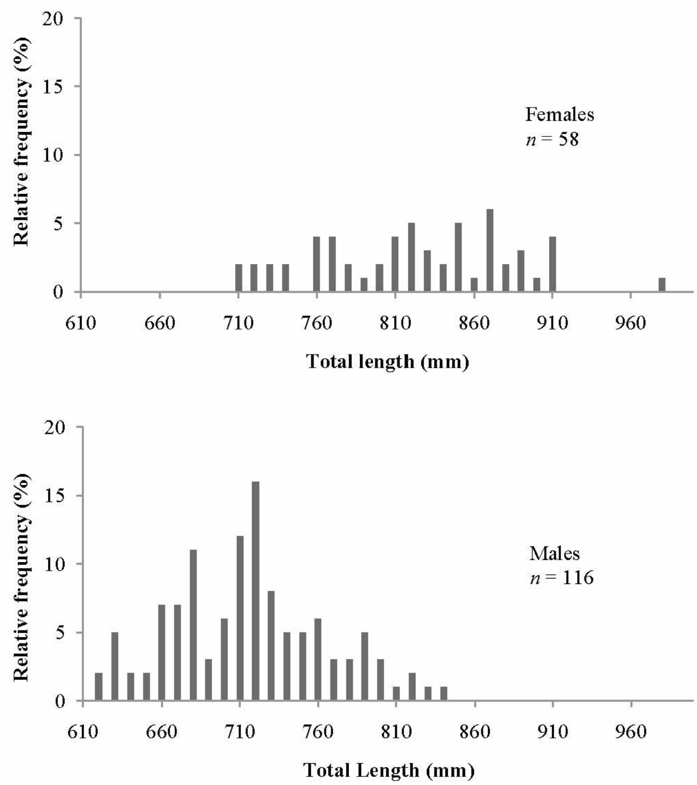

Figure 2.5 Relative length frequency of inconnu sampled in transects on the Sulukna River, Alaska. Kolmogorov-Smirnov two-sample test assessed the difference between length of male and female inconnu frequency distributions (p < 0.0001).

2.3.3 Thermal regime

Of the ten temperature loggers deployed in September 2007, four were recovered in September 2008. Review of the collected information indicated that all but one temperature logger froze during the winter. Spawning within the Sulukna River began on September 23 in both years of the project, when the mean average water temperature was 4.47°C. The water temperature profile indicated that the temperature was lowest on October 12, 2007 at 0°C and highest on July 5, 2008 at 13°C (Figure 2.6). Spring ice breakup, based on my temperature criteria, began on May 8, 2008 when the mean water temperature increased from 0 to 1°C. The calculated number of degree days (based on the one temperature profile) between spawning and ice breakup was 82.

2.4 Discussion

In this study I described the relationship between the presence of spawning inconnu and habitat variables in the Sulukna River watershed. No previous investigations have described the spawning habitat of inconnu using these methods. Therefore, no information exists to make comparisons or draw conclusions to other watersheds or systems. Spawning inconnu appeared to use a relatively small portion of the Sulukna River, as a result, spawning inconnu were found in few transects.

2.4.1 Habitat characteristics

Variation in velocity and depth exists between stream habitats (Bisson et al. 1988). Inconnu were observed spawning in areas of channel morphology typified as runs.

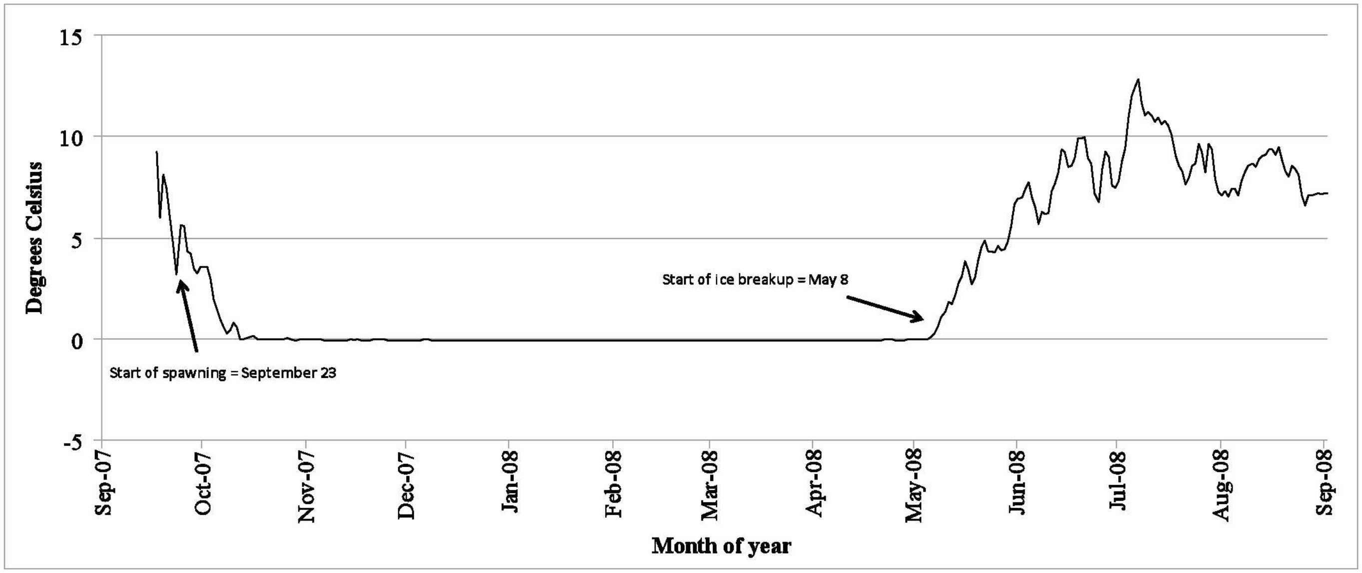

Figure 2.6 Annual water temperature profile of the Sulukna River, Alaska from September 2007 to September 2008.

Although transects were not specifically located on runs, transects with spawning inconnu presence predominantly had riffles as the next habitat type downriver and were typically located in sections of the river where channel morphology was defined with pool, riffle, and run combinations. This observation is indicative of inconnu selecting specific areas within the river, based on geomorphology and habitat features. Inconnu presence was significantly related to substrate, width to depth ratio, and conductivity. These features are the result of geomorphic forms that exert influence on sedimentology and channel morphology, in turn affecting spawning site selection. The presence of small cobble within the spawning area was the best predictor of spawning area location within the Sulukna River. Generalized movement of bedload (substrate) particles requires a specific degree of force for substrate transport to persist (Petit 1994). Force is provided by the amount of water within a channel moved over a specific gradient, which results in differing substrate sizes located within specific areas of the river. The distribution of energy within a channel is characterized by the width to depth ratio, which is a measure of the channel's ability to move sediment at various discharge rates. In transects where channel width to depth ratios were lower, large cobble or boulder sediment supply was more prevalent. Conversely, where this ratio was higher, the channel was wider and shallower, and sand and silt substrate was predominant (Rosgen 1996).

The relationship between spawning substrate and the degree of width to depth ratio can be explained by the lateral confinement of the channel. Cobble and gravel supply and transport capacity are stronger in incised mountain valleys and develop actively shifting meanders wherever valley width allows (Coulombe-Pontbriand and Lapointe

2004). As confinement of the channel by steeper slopes and higher shear stress is dissipated, the normal development of a river is allowed to meander. In this study, the measure of meander was defined as sinuosity (Rosgen 1996), which increased in transects moving downstream.

Conductivity values increased in transects moving downstream. Mueller et al. (1996) noted that conductivity was greatest within the Sulukna River as compared to other neighboring tributaries, but progressive increases in conductivity values at transects located downstream were unexpected in this study. Conductivity has been related to increases in hyporheic water (Malcolm et al. 2009) driven by channel morphology and sinuosity (Triska et al. 1993). The intensity of hyporheic exchange is a function of the substrate permeability, controlled by substrate sedimentology, but equally of the hydraulic head controlled by local channel and bedform morphology (Geist and Dauble 1998; Geist 2000). Calles et al. (2007) found that conductivity in hyporheic water within stream reaches would increase where fine substrate dominated, due to a prolonged retention time of groundwater within the substrate and would increase conductivity values within the surface water. However changes in the water quality of surface water beyond specific reaches known to have hyporheic upwelling have not been substantiated. Differences in water quality between neighboring tributaries of the Nowitna River drainage as compared to the Sulukna River were thought to stem from differences in geology, but the geology appears to be uniform throughout the Nowitna River drainage and not unique to the Sulukna River (Brabets et al. 2000).

The upwelling of groundwater into potential spawning areas provides physical and chemical characteristics to the water column (Geist et al. 2002). Hyporheic water exchange has been shown to be an important variable in spawning site selection in salmonids (Baxter and McPhail 1999; Mueller and Geist 1999; Geist et al. 2002) but has not been linked to spawning habitat in inconnu or other whitefish species. A more comprehensive water quality study would have to be undertaken before the relationship between water quality and inconnu spawning habitat could be shown. Alt (1973) suggested that chemical and biological factors in association with physical limiting factors, such as barriers to migration, probably act to limit inconnu presence. These project results would support this notion as all variables (physical and chemical) included in the model indicate a discreet preference for a specific area within the river.

2.4.2 Length distribution and sex ratio

Brown (2000) showed that increases in the gonadosomatic index trend were apparent in inconnu as they migrate to spawning grounds. Females appear gravid, distention of the belly, allowing for sex determination using external examination. Sexual dimorphism, with females displaying a greater length has been documented by Taube (1996), Brown (2000), and Hander et al. (2008) for spawning populations in Alaska. Study results are similar to length frequency distributions found in inconnu sampled in the mainstem of the Yukon River (Brown 2000). Males were caught more often than females using hook/line sampling. Male inconnu mature earlier than females (Alt 1969; Brown 2000) and have been noted to be more prevalent on spawning grounds (Hander et al. 2008).

2.4.3 Thermal regime

Conclusions for thermal regime were derived from information collected on one temperature logger. The estimate of degree days from spawning to ice breakup in the project was much smaller (82 degree days) than those noted by Howland et al. (2002) for inconnu egg hatching. John and Hasler (1956) hypothesized that hatching was initiated by mechanical stress associated with ice breakup. Ice breakup in the Sulukna River occurred in early May. However, Howland et al. (2002) indicated that two brood stocks of inconnu from the Mackenzie River incubated within a laboratory setting hatched between 258 to 603.7 degree days at a mean temperature of 8.5°C over a period of approximately four weeks and noted extensive variability in hatch dates. These results were consistent with estimates from the Clear Creek Fish Hatchery located in Andersen, Alaska of 315 – 400 degree days at 2.5 – 8.7°C (J. Fish, ADF&G, personal communication), and Teletchea et al. (2009) noted that 365 degree days for incubation at 3.5°C were needed for inconnu egg hatching. Estimating hatching times of wild inconnu based on laboratory results has difficulties; however, errors in estimating the number of degree days on the Sulukna River are likely due to the limited number of temperature loggers available to analyze information. Additionally, I made no attempt to locate eggs within the substrate; thus temperature regime information was likely not located where incubating eggs were present in the substrate. This information should be used as a first attempt to collect temperature regime information on inconnu in a natural environment, most importantly as an indication of inconnu spawning timing and water temperature on the Sulukna River. No juvenile inconnu life history relating thermal regime with hatching in a natural environment was available in Alaska during the duration of this project and more intensive studies should be conducted.

3.1 Spatial analysis in drainages containing spawning inconnu

3.1 Introduction

Conservation of aquatic systems requires the ability to identify species' historical, current, and potential distributions (Argent et al. 2003). The ability to objectively characterize fish habitat throughout a species distribution at large spatial scales is becoming more common due to the use of geographical information system (GIS) (Torgersen and Close 2004; Wall et al. 2004; Fransen et al. 2006; Neeson et al. 2008). GIS technology presents an opportunity to expand field-measured, physical habitat criteria to empirically derive watershed scale models that have the capability to rapidly and consistently delineate the extent of fish bearing streams (Fransen et al. 2006). Watershed level assessment is particularly useful for aquatic studies because watersheds span large land areas, encompass a connected range of stream sizes, integrate natural and altered properties of a drainage area (Imhof et al. 1996), represent subdivisions of a specie's overall distribution, and incorporate differences in regional distribution (Argent et al. 2003).

An initial attempt to characterize the inconnu spawning habitat on the Selawik River drainage using large scale spatial data yielded mixed results due to spatial data providing insufficient detail, primarily from the lack of resolution in the digital elevation model (DEM) (Tanner 2008). Therefore, the nature and magnitude of potential error derived from the source data must be fully considered (Priestnall and Aplin 2006). To address these uncertainties, Tanner (2008) recommended verification through ground-truthing as predicted values may differ substantially from observed field values, a result consistent with other studies (Montgomery et al. 1999; Massong and Montgomery 2000). To some extent, these problems cannot be addressed fully within Alaska because the available spatial source data are limited. However, generalized inferences can be made to determine likely fish presence on a watershed level. While not a substitute for actual stream location, an appropriate artificial stream network can be used to extract hydrological attributes (Tanner 2008) such as stream linkages, stream orders, and drainage areas (Fisher and Rahel 2004), which improve information used in management actions.

Limited information exists regarding inconnu populations within Alaska. The majority of collected information has been centered on identifying the location of spawning populations throughout the state. This lack of information is primarily a result of the populations being located in remote areas, the short temporal use within these drainages, and the low numbers of drainages being used. Design and use of fish-habitat models in a GIS gives researchers the ability to mediate the difficult problems associated with inconnu field investigations. Fransen et al. (2006) used a GIS approach to determine the upstream extent of fish within a drainage and suggested that models with relatively few factors are most successful. Descriptions of spawning habitat for inconnu were described in previous chapters and indicate three variables were prevalent: dominant substrate, width to depth ratio, and conductivity in the water column.

In this component of the study, I sought to identify potential inconnu spawning habitat in other drainages using a spatial model. The development of the spatial model was composed of three steps: (1) develop a spatial model using field measured values of spawning habitat characteristics to define a criterion for identifying potential spawning areas, (2) apply the spatial model to the Alatna, Kobuk, and Selawik River drainages, where spawning areas have been previously identified, using a GIS, and (3) assess the accuracy of spatial model predictions.

3.2 Study area

The Sulukna River, originating in the Sischu Mountains (Figure 3.1), is a clearwater river located approximately 175 miles up the Nowitna River. It flows north to the Nowitna River, draining a 1,772 km^2 watershed. Length of the Sulukna River is approximately 180 rkm. The Sulukna River is a low gradient system with headwaters originating 500 m above sea level. Area geology is composed of Cretaceous and lower Paleozoic geology consisting of sandstone, limestone, and dolomite (Beikman 1980). Land status for the Sulukna River is shared between the United States Fish and Wildlife Service (USFWS) Nowitna National Wildlife Refuge, approximately the lower 10 rkm of the river, and the Bureau of Land Management (BLM) managing the remaining portion. Spawning grounds are located within BLM managed lands between resulting in a designation of an area of critical ecological concern (ACEC). This project identified the inconnu spawning area between rkm 71 and 91.

The Alatna River is designated a wild and scenic river within the boundaries of Gates of the Arctic National Park. The Alatna River originates in the Endicott Mountains, flowing for approximately 300 rkm in a southeast direction to its confluence with the Koyukuk River. Geology of the Alatna River is Cretaceous and Paleozoic geology

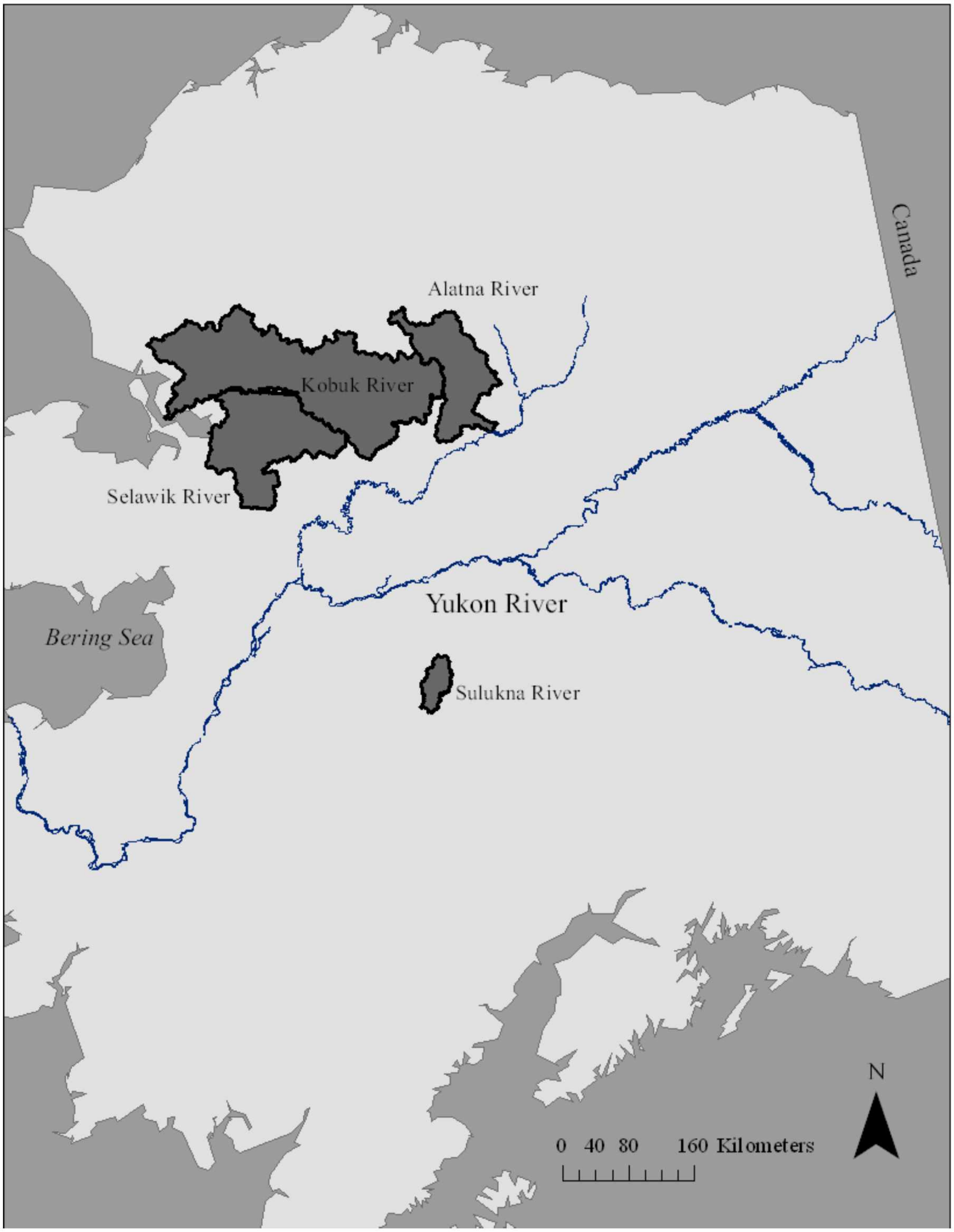

Figure 3.1 Location of the Alatna, Kobuk, Selawik, and Sulukna River drainages in Alaska.

consisting of sandstone, limestone, and dolomite (Beikman 1980). The inconnu spawning area is thought to be located upstream of Siruk Creek confluence at rkm 80 to rkm 120 (Brown 2009).

The Selawik River is located within the Selawik National Wildlife Refuge in northwestern Alaska and is designated a wild and scenic river. The Selawik River originates within the Percell Mountains and flows west, draining into Selawik Lake, and has an approximate drainage area of 11,700 km^2. Length of the Selawik River is approximately 205 rkm. The Selawik River delta is underlain by continuous permafrost. Area soils are composed of stratified alluvial deposits, silty and sandy, as well as volcanic ash and loess (McNab and Avers 1994) and Cretaceous geology consisting of sandstone and limestone (Beikman 1980). Headwaters contain several hot springs and the drainage includes numerous lakes, tributaries, and tundra slopes (Tanner 2008). Location of the inconnu spawning areas is a 12 rkm in the vicinity of the Ingruksugruk Creek confluence located near the 230 rkm distance (Underwood et al. 1998).

The Kobuk River drainage is approximately 31,850 km^2 and is located in northwestern Alaska. The river originates in the Brooks Range and flows westward for approximately 480 rkm into the Hotham Inlet. Land in the drainage is managed primarily by the National Park Service, Gates of the Arctic National Park and Preserve, the USFWS, and native corporations. Much of the Kobuk River is underlain by permafrost and Cretaceous and Paleozoic geology consisting of sandstone, limestone, and dolomite (Beikman 1980). The drainage contains several large lakes, and trees approach their northern limit; forest and tundra meet, creating a mosaic of forest and open tundra

(Brabets 2001). The location of the inconnu spawning area is upstream of Mauneluk Creek confluence (375 rkm) and downstream of the Beaver River confluence (460 rkm) (Taube 1996).

3.3 Methods

The multivariate logistic model used in chapter two indicates that dominant substrate ranging from 6 – 12 cm in length along the B-axis, width to depth ratios from 25 – 30, and conductivity values in the water column ranging from 266 – 298 μS/cm accounted for the largest amount of variability in explaining inconnu spawning habitat on the Sulukna River. I have attempted to use these variables in a GIS to make inferences about three watersheds known to contain spawning inconnu by applying each variable as a criterion to an artificial stream network within each drainage. Criteria were used to eliminate individual stream segments within each artificial stream network, based on field measured values within the Sulukna River. Prior to analysis artificial stream networks were defined in terms of scale and each criterion was defined.

Deriving an artificial stream network for the Selawik River, Kobuk River, and Alatna River drainage was based on the methods of Neeson et al. (2008). Stream networks were calculated using a 2 second DEM that was downloaded and projected to 30-m pixels in the Alaska Albers NAD 83 coordinate system. This DEM resolution has a minimum detectable elevation change of 0.3 m between adjacent cells. Digital line graphs or stream shapefiles were from the Alaska Department of Fish and Game anadromous waters catalog fish distribution database in Albers projection (NAD 83). All analysis below was completed using NAD 83 UTM projections. Prior to analysis, all artificial stream networks were screened using the ArcMap tool STREAMORDER. This tool classified segments within a DEM based on the Strahler method (Strahler 1964). Inconnu typically spawn within mainstem reaches of rivers, therefore analysis was limited to segments with stream orders greater than or equal to four in the Sulukna River and six in the Alatna, Selawik, and Kobuk Rivers.

The scale of analysis in all watersheds was defined based on the river distance of 10 rkm. Neeson et al. (2008) noted greater accuracy of GIS calculated slope over longer reaches, >200m, because the vertical resolution of a DEM imposed limits on deriving the slope. Inconnu spawning habitat in the Sulukna River, specific to this study, was confined to 20 rkm; therefore, an initial option was to calculate slope every 1 rkm to maximize the ability of the model to identify inconnu spawning habitat criterion. However, because DEMs have an inherent inaccuracy to overestimate field slope (Isaak et al. 1999; Neeson et al. 2008) and mimic stream sinuosity with the artificial stream network (Isaak et al. 1999), a 1 rkm scale would not contribute additional insight. Therefore, stream reach endpoints were distributed every 10 rkm throughout the streamline to determine slope in an effort to minimize the limits of the DEM and artificial stream network but still allow the use of spawning habitat criterion.

To test accuracy of GIS derived values for each criterion, a two-sample unequal variance t-test was used to make comparisons to values of Sulukna River field measured values. To evaluate whether there was a significant difference between GIS derived criterion values of the spawning area and non-spawning area, additional unequal variance t-tests were used to compare three sections of the Sulukna River. Section one was located between rkm 0 and rkm 70, indicative of the area below the inconnu spawning area. Section two was located between rkm 70 and rkm 90, indicative of the inconnu spawning area. Section three was located between rkm 90 and rkm 93, indicative of the area above the inconnu spawning area.

3.3.1 Definition of dominant substrate

Substrate within a river channel will move when the shear stress acting on it is greater than the resistance of the particle to movement. Shields (1936) calculated median substrate size as a product of stream slope and bankfull depth.

$$D_{50} = \frac{\tau}{(\rho_s - \rho) g t_{*_c}} = \frac{\rho h S}{(\rho_s - \rho) t_{*_c}}$$

Where τ is the total bankfull shear stress, ρ_s is the density of sediment, ρ is fluid density, g is gravitational acceleration, h is bankfull depth, S is channel slope, and τ_{*c} is the critical Shield's stress for movement of D_{50} (Shields 1936). Sulukna River field measurements indicate that dominant substrate ranged in size from 6 – 12 cm where inconnu spawning habitat was present.

3.3.2 Definition of slope using GIS

Slope was derived using a DEM for elevation values and a stream shapefile representing the centerline of the streamline to calculate reach length. Elevation values were taken from the DEM at each stream reach endpoint located every 10 rkm. Slope was calculated as the quotient of the difference between elevation values at two reach endpoints and the length of the reach, 10 rkm. To test the accuracy of field measured values and GIS-derived slopes an unequal variance t-test was used to compare values from three sections of the river: below spawning, within spawning, and above spawning. The scale at which slope results were compared was different. Field measured slopes, on average were calculated over 100 m sections, while GIS derived slopes were calculated at 10 rkm sections. It was not feasible to derive GIS slopes at this 100 m scale because of inaccuracies in the DEM and the error attached to the GPS system, approximately 10 – 30 m. Neeson et al. (2008) indicated that reaches shorter than 200 m with slopes lower than the minimum elevation change of the DEM (0.3 m), would likely have significant problems. All field measured values for slope were below the minimum elevation change of the DEM. The smallest value for field measured slopes located within the Sulukna River spawning area was 0.0001. To accurately calculate this slope in the GIS, a channel length of 10,000 m (0.3/10,000 = 0.00003) was needed. Therefore GIS derived slopes were calculated at a channel length of 10,000 m to avoid inaccuracies.

3.3.3 Error correction in GIS-derived slopes

Processing of GIS slope calculations had large errors due to positional inaccuracy of the DEM derived channel and the stream shapefile. These errors were most apparent in locations where the change in slope was less than a meter over a 10 rkm reach. Conversely, Neeson et al. (2008) noted similar discrepancies in locations with large slopes. To create hydrologically accurate DEMs, the ArcMap tool FOCALFLOW was used. FOCALFLOW determines the flow of the values in a DEM within each cell's immediate neighborhood (ESRI 2003). Larger FOCALFLOW values were screened and a channel was created. All reach endpoints were adjusted to intersect the FOCALFLOW channel, resulting in reach endpoints with elevation values that were hydrologically "correct" in the sense that they decreased in elevation from upriver to downriver.

3.3.4 Definition of bankfull depth

Bankfull depth is defined as the depth of the channel under bankfull discharge conditions. Bankfull depth was determined by using a regression equation of field-measured bankfull depths (cm) on the Sulukna River as a function of drainage area (km^2) (Stillwater Sciences 2007). This regression was used to predict the bankfull depths at each reach endpoint in other drainages.

3.3.5 Definition of drainage area using GIS

Area was calculated in km^2 by using the ArcMap tool WATERSHED (ESRI 2003). The WATERSHED tool determines the contributing area above a user determined set of cells in a DEM. Drainage area was calculated at each reach endpoint.

3.3.6 Definition of width to depth ratio

Width to depth ratio is an index value which indicates the shape of the channel cross-section (ratio of bankfull width/mean bankfull depth) (Rosgen 1996). Width to depth ratio defines the ability of the channel to discharge energy. Channels with higher width to depth ratios have shallower and wider channels, typically occurring where less channel containment and less energy is present. Width to depth ratios were estimated using a linear relationship of field measured width to depth ratios on the Sulukna River and drainage area.

3.3.7 Definition of conductivity and sinuosity using a GIS

Conductivity within the water column cannot be depicted spatially in a GIS because it is a physical quality of the water column. Conductivity has been related to hyporheic flow (Malcolm et al. 2009), which is influenced by geomorphological characteristics of the waterway (Triska et al. 1993; Geist and Dauble 1998; Kasahara and Wondzell 2003; Coulombre-Pontbriand and Lapointe 2004), in particular sinuosity. Specific to the analysis below, I used the measure of sinuosity, as a proxy for conductivity in the water column. Sinuosity is defined as channel length divided by valley length (Rosgen 1996). Sinuosity is indicative of the channel's ability to meander. Sinuosity was measured between reach endpoints located every 10 rkm on the river channel. Valley length is the valley distance between each reach endpoint.

3.3.8 Criteria application

Dominant substrate, width to depth ratio, and sinuosity criteria was used to eliminate stream segments within the artificial stream networks of the Alatna, Selawik, and Kobuk Rivers. Each criterion had a threshold value used to evaluate if the stream segment was suitable for spawning. The threshold value was the mean of GIS derived values from the Sulukna River inconnu spawning area calculated continuously moving from the upper-most transect downstream. When the mean value of each criterion in the Alatna, Selawik, and Kobuk Rivers exceeded the threshold value the result was indicative of the upstream extent.

3.4 Results

3.4.1 Application of dominant substrate

Inaccuracies in the predictions of dominant substrate were a result of the parameters mean bankfull depth and drainage area having no relationship or having a small range of data. In all drainages predicted median substrate sizes were underestimated: Sulukna River (Table 3.1), Alatna River (Table 3.2), Selawik River (Table 3.3), and Kobuk River (Table 3.4). The minimum drainage area value for field measured transects on the Sulukna River was 954 km^2. In reach endpoints, where the value was 954 km^2 or less, negative values for median substrate size were observed. This phenomenon was indicative of field measured data having a limited range of data.

3.4.2 Application of slope

Field measured water surface slopes compared to GIS derived slopes located above the Sulukna River inconnu spawning area were not significantly different (*t*-test: $P > 0.05$), located within the inconnu spawning area were not significantly different (*t*-test: $P > 0.05$), and located below the inconnu spawning area were significantly different (*t*-test: $P < 0.05$) (Table 3.5). GIS derived slopes were typically greater than field measured slopes. Comparison of GIS derived slopes between sections on the river indicated no significant difference (*t*-test: $P > 0.05$) existed between the inconnu spawning area and below spawning area sections, but a significant difference (*t*-test: $P < 0.05$) between the inconnu spawning area and the above spawning area sections. Therefore, deriving slope using a GIS can identify the upper boundary of that area.

Table 3.1 GIS derived metrics for the Sulukna River and predicted bankfull depth and median substrate size.

rkm	Drainage area (km^2)	Slope	Bankfull depth (cm)	Substrate size (cm)
0	1,649	0.0002	927	2
10	1,636	0.0002	912	2
20	1,507	0.0012	762	12
30	1,490	0.0002	743	2
40	1,463	0.0002	711	2
50	1,172	0.0008	373	4
60	1,094	0.0012	282	4
70	1,004	0.0009	177	2
80	967	0.0011	134	2
90	956	0.0012	122	2
100	930	0.0008	91	1
110	905	0.0024	63	2
120	881	0.0033	35	2
130	857	0.0066	6	1
140	833	0.0017	-22	-1
150	809	0.0055	-50	-4
160	785	0.0153	-78	-15
170	760	0.0153	-106	-21

Table 3.2 GIS derived metrics for the Alatna River and predicted bankfull depth and median substrate size.

rkm	Drainage area (km^2)	Slope	Bankfull depth (cm)	Substrate size (cm)
0	4,818	0.0006	4,613	8
10	4,816	0.0008	4,610	11
20	4,727	0.0029	4,507	37
30	4,437	0.0005	4,170	6
40	4,357	0.0009	4,077	10
50	3,969	0.0005	3,625	6
60	3,800	0.0007	3,429	7
70	3,620	0.0012	3,219	11
80	3,424	0.0009	2,992	8
90	2,994	0.0009	2,491	6
100	2,765	0.0013	2,225	8
110	944	0.0005	108	0
120	880	0.0004	33	0
130	785	0.0002	-77	0
140	536	0.0014	-367	-1
150	361	0.0002	-570	0
160	208	0.0002	-748	0
170	16	0.0002	-972	-1

Table 3.3 GIS derived metrics for the Selawik River and predicted bankfull depth and median substrate size.

rkm	Drainage area (km^2)	Slope	Bankfull depth (cm)	Substrate size (cm)
		Selawik River mainstem		
0	11,379	0.0001	12,242	5
10	11,379	0.0001	12,242	5
20	11,375	0.0001	12,238	5
30	10,717	0.0001	11,473	4
40	10,586	0.0001	11,320	3
50	10,358	0.0001	11,055	3
60	3,749	0.0001	3,369	1
70	3,717	0.0001	3,332	1
80	3,500	0.0001	3,080	1
90	3,063	0.0001	2,572	1

Table 3.3 continued.

100	2,885	0.0007	2,365	5
110	2,448	0.0002	1,857	1
120	2,064	0.0005	1,410	2
130	1,917	0.0012	1,239	4
140	1,776	0.0010	1,075	3
150	1,326	0.0022	552	4
160	1,057	0.0032	239	2
170	853	0.0015	2	0
180	564	0.0017	-334	-2
		Tagagawik River		
80	3,076	0.0001	2,587	1
90	3,070	0.0001	2,580	1
100	2,958	0.0001	2,450	1
110	2,933	0.0001	2,421	1
120	2,878	0.0002	2,357	1
130	2,482	0.0002	1,896	1
140	2,107	0.0007	1,460	3
150	2,032	0.0007	1,373	3
160	1,873	0.0020	1,188	7
170	1,829	0.0003	1,137	1
180	1,120	0.0013	312	1
190	408	0.0001	-516	0
		Kugarak River		
80	2,826	0.0001	2,296	1
90	2,254	0.0001	1,631	1
100	1,719	0.0002	1,009	1
110	1,346	0.0002	575	0
120	973	0.0002	141	0
130	599	0.0002	-294	0
140	599	0.0007	-294	-1

Table 3.4 GIS derived metrics for the Kobuk River and predicted bankfull depth and median substrate size.

rkm	Drainage area (km^2)	Slope	Bankfull depth (cm)	Substrate size (cm)
		Kobuk River mainstem		
0	26,731	0.00006	30,095	5
10	26,702	0.00006	30,062	5
20	26,580	0.00006	29,920	5
30	26,175	0.00006	29,449	5
40	25,993	0.00006	29,237	5
50	25,963	0.00006	29,202	5
60	25,930	0.00006	29,164	5
70	25,715	0.00006	28,914	5
80	25,567	0.00006	28,742	5
90	25,309	0.00006	28,442	5
100	25,183	0.00006	28,295	5
110	21,473	0.00006	23,981	4
120	21,381	0.00006	23,874	4
130	21,249	0.00006	23,720	4
140	21,117	0.00006	23,567	4
150	21,077	0.00006	23,520	4
160	19,476	0.00006	21,658	4
170	18,945	0.00006	21,041	4
180	18,040	0.00006	19,989	3
190	17,539	0.00006	19,406	3
200	17,491	0.00006	19,350	3
210	17,259	0.00006	19,080	3
220	17,026	0.00006	18,809	3
230	15,161	0.00006	16,641	3
240	15,076	0.00006	16,542	3
250	14,938	0.00020	16,381	9
260	14,650	0.00020	16,046	9
270	14,598	0.00040	15,986	18
280	14,444	0.00020	15,807	9
290	12,034	0.00060	13,004	22
300	10,865	0.00002	11,645	1
310	10,787	0.00032	11,554	11
320	10,464	0.00032	11,178	10

Table 3.4 continued.

330	9,925	0.00032	10,552	10
340	9,385	0.00032	9,924	9
350	9,126	0.00010	9,622	3
360	9,082	0.00010	9,571	3
370	7,789	0.00010	8,068	2
380	5,866	0.00060	5,831	10
390	5,720	0.00180	5,662	29
400	3,757	0.00070	3,379	7
410	3,229	0.00010	2,765	1
420	3,092	0.00150	2,605	11
430	2,775	0.00150	2,237	10
440	2,527	0.00050	1,948	3
450	1,714	0.00120	1,003	3
460	731	0.00170	-140	-1
470	467	0.00340	-447	-4
480	411	0.00050	-512	-1
490	139	0.00270	-829	-6
500	12	0.00010	-976	0
		Squirrel River		
110	3,590	0.00100	3,185	9
120	3,384	0.00010	2,945	1
130	2,510	0.00010	1,929	1
140	2,466	0.00020	1,877	1
150	1,459	0.00170	706	3
160	1,162	0.00010	361	0
170	512	0.00110	-395	-1
180	226	0.00030	-727	-1
190	34	0.00100	-951	-3
200	34	0.00220	-951	-6
		Salmon River		
160	974	0.00110	142	1
170	934	0.00110	96	0
180	655	0.00080	-229	-1
190	608	0.00140	-283	-1
200	569	0.00180	-329	-2
210	379	0.00400	-550	-6
220	111	0.00160	-861	-4
230	75	0.00320	-903	-8
		Ambler River		
290	2,002	0.00010	1,338	0

Table 3.4 continued.

300	1,459	0.00010	706	0
310	1,072	0.00150	256	1
320	803	0.00020	-57	0
330	687	0.00120	-191	-1
340	571	0.00150	-326	-1
350	494	0.00310	-416	-4
360	389	0.00310	-538	-5
		Mauneluk River		
380	1,559	0.00140	823	3
390	1,487	0.00140	739	3
400	1,378	0.00140	612	2
410	995	0.00120	167	1
		Pah River		
400	1,864	0.00060	1,177	2
410	1,752	0.00060	1,047	2
420	1,108	0.00030	298	0
430	1,039	0.00060	218	0
		Beaver Creek		
460	888	0.00150	42	0
470	821	0.00150	-36	0
480	783	0.00270	-80	-1
490	604	0.00270	-288	-2

Table 3.5 Correlation between field measured slope and GIS measured slope values at select areas on the Sulukna River. Location defined by river distance, above (>90 rkm), within (90 - 70 rkm), and below (70 - 0 rkm) the spawning aggregate.

Location	Field measured	GIS derived mean	*P*-value
Above spawning	0.004	0.005	0.73
Spawning area	0.001	0.001	0.73
Below spawning	0.002	0.0006	0.003

3.4.3 Application of bankfull depth

A linear regression of bankfull depth versus drainage area for all transects (*n* = 45) indicated no significant correlation ($r^2 = 0.00$), (Figure 3.2). However, when data were limited to transects where inconnu were present, (*n* = 11) a weak, positive correlation was identified ($r^2 = 0.32$), (Figure 3.3). However, the range of values decreased substantially hindering inferences in other drainages.

3.4.4 Application of width to depth ratio

A linear regression of width to depth ratio versus drainage area for all transects, *n* = 45 indicated a weak positive correlation ($r^2 = 0.16$), (Figure 3.4). A weak positive correlation was identified ($r^2 = 0.22$).when data were limited to transects where spawning inconnu were present (*n* = 11). However, the result was contrary to expectations, indicating a negative relationship (Figure 3.5). Rosgen (1996) indicated that width to depth ratios should increase from upstream to downstream, a positive relationship.

3.4.5 Application of sinuosity

Sinuosity indexes for 10 rkm reaches in the Sulukna River ranged from 1.19 to 4.55. Overall, indices increased in reaches moving downstream. Sinuosity values in the above spawning area were significantly different than those in the within spawning area (*t*-test: $P < 0.05$) and sinuosity values in the below spawning area were not significantly different than those in the within spawning area (*t*-test: $P > 0.05$) (Table 3.6). Therefore, sinuosity indexes derived in a GIS appear to be useful for defining the upper boundary of inconnu spawning habitat.

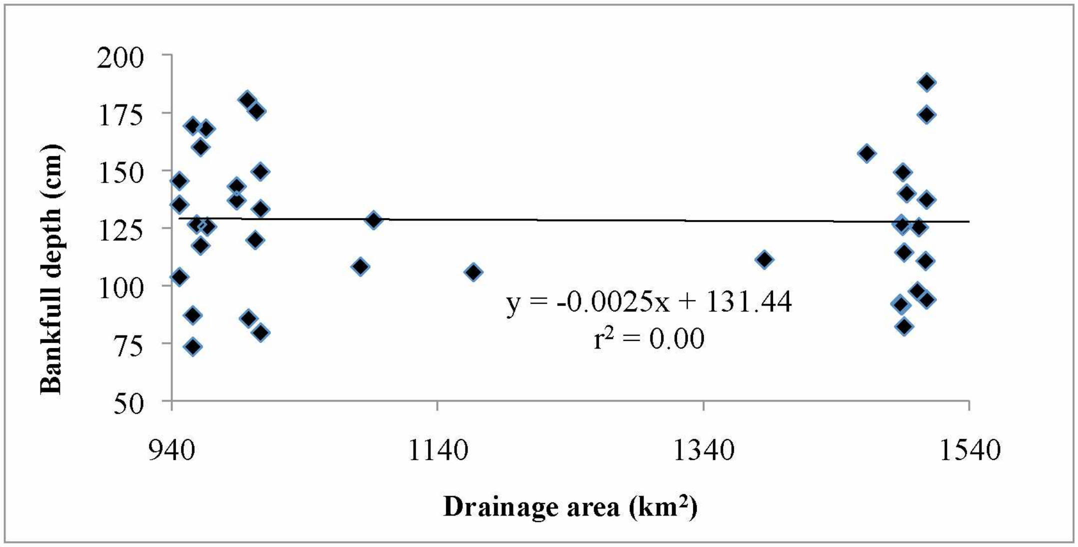

Figure 3.2 The relationship between drainage area and observed bankfull depth within the inconnu spawning area, using data from all Sulukna River transects, *n* = 45.

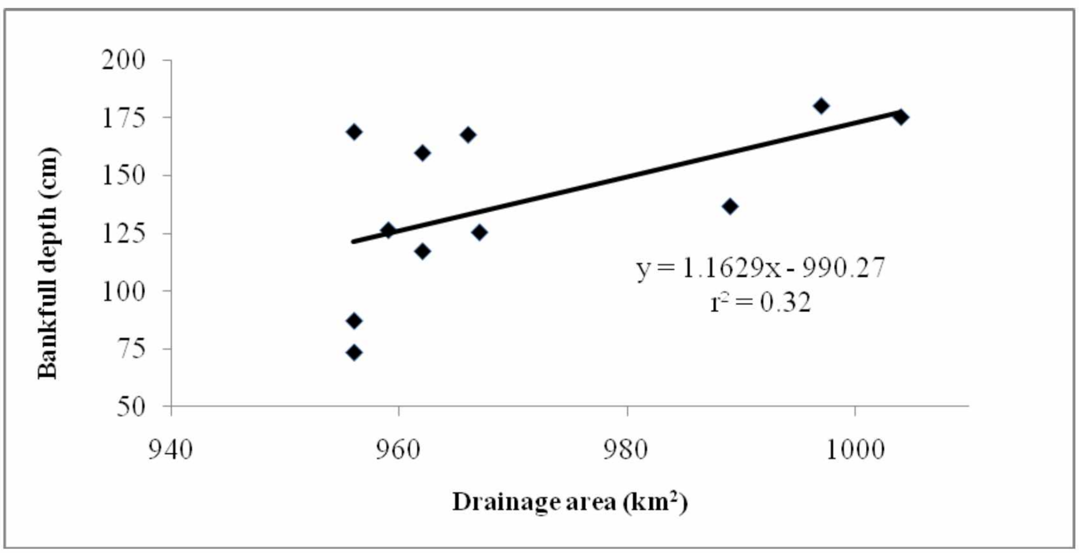

Figure 3.3 The relationship between drainage area and observed bankfull depth within the inconnu spawning area, using data from Sulukna River spawning transects, *n* = 11.

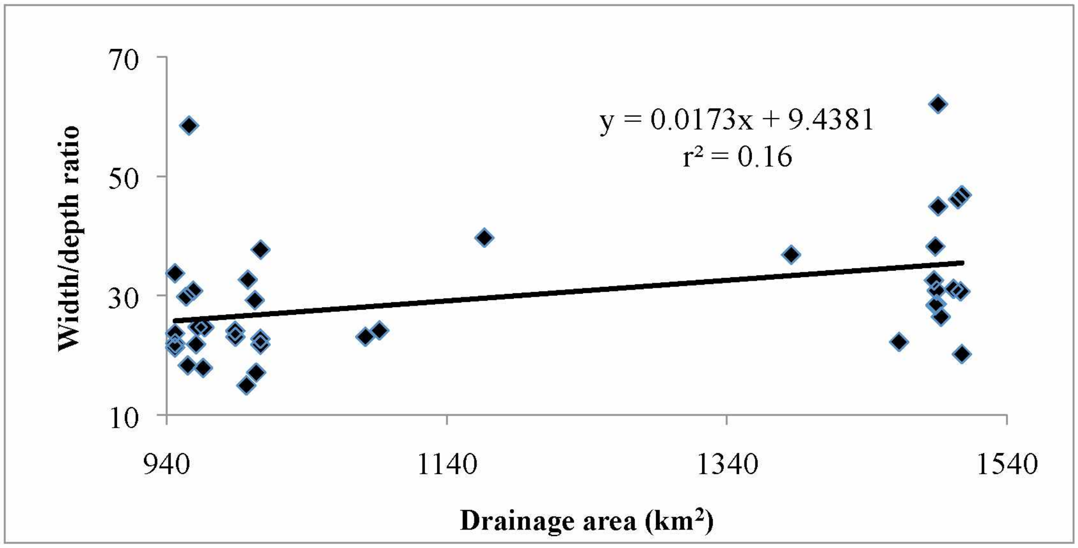

Figure 3.4 The relationship between elevation and observed width to depth ratio within the inconnu spawning area, using data from all Sulukna River transects, *n* = 45.

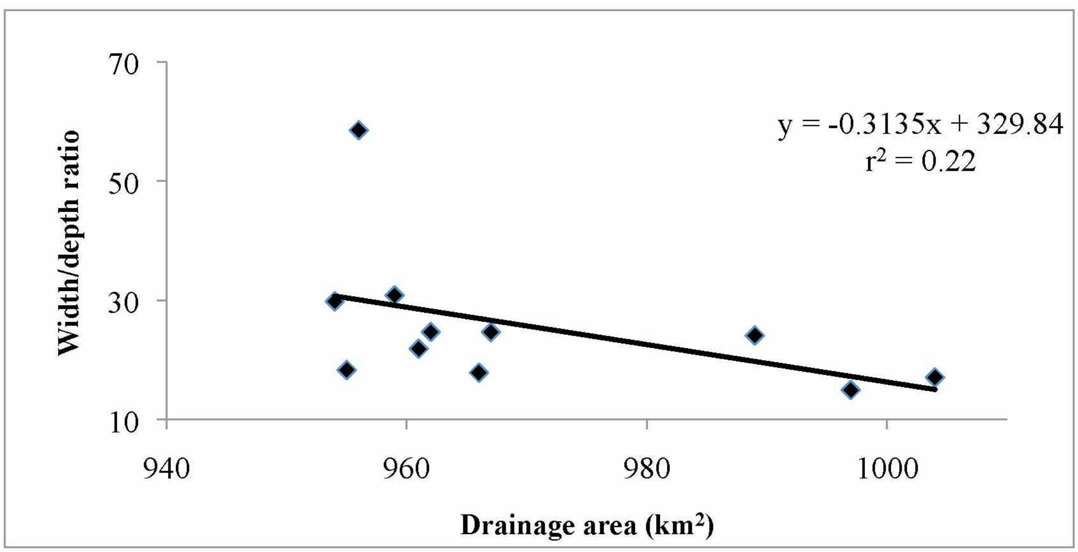

Figure 3.5 The relationship between elevation and observed width to depth ratio within the inconnu spawning area, using data from Sulukna River spawning transects, *n* = 11.

Table 3.6 GIS measured mean sinuosity measures on the Sulukna River at 10 rkm channel length distances on the Sulukna River. *P*-value indicates correlation between spawning area.

Channel length	Area	Mean	*P*-value
10 rkm	Above spawning	2.16	0.048
	Within spawning area	3.07	
	Below spawning area	3.13	0.857

3.4.6 Criterion elimination

Dominant substrate and width to depth ratio analysis did not provide usable results and were not used as criteria for stream network segment elimination. Both sinuosity and slope criteria were used to predict the upper boundary of potential inconnu spawning areas. The mean value of sinuosity in the above spawning area was 2.16. This value was used as a threshold value to identify the upstream extent of potential spawning areas in other drainages. The threshold value was computed by calculating the mean sinuosity value moving from the most upstream extent downstream. Using these threshold values for sinuosity, the upstream extent of inconnu spawning area in the Alatna River would be located at 150 rkm (Figure 3.6), in the Selawik River at 210 rkm (Figure 3.7), and in the Kobuk River at 540 rkm (Figure 3.8). Additionally, there was a significant difference between GIS derived slope on the Sulukna River between the spawning area and the above spawning area. The mean value of slope in the above spawning area was 0.005. However, the slope criterion did not contribute additional information. Values for GIS derived slope on the Sulukna River were greater than the Alatna, Selawik, and Kobuk Rivers. In no instance was the threshold value reached. Using the sinuosity criterion, the predicted upstream extent was upstream of the known spawning areas limit on the Alatna and Kobuk Rivers, but downstream of the known spawning area limit on the Selawik River (Table 3.7).

3.5 Discussion

Applying information spatially over large areas can be successful using a few broad habitat variables (Argent et al. 2003). Results of this project indicate that our smaller scale habitat variables; dominant substrate and width to depth ratio did not work well, but that our broader scale habitat variables provided insight for predicting the upstream extent of inconnu spawning areas. One major difference between these variables was the scale of measurement. Argent et al. (2003) suggested increasing the number of variables that describe the entire landscape under investigation only if they have relevance to the aquatic system or serve as a surrogate for instream measures and can be measured at comparable spatial scales. Scale was defined by Torgersen and Close (2004) as small scale equal to 1 – 10 m and large scale equal to 1 – 10 km. Dominant substrate and width to depth ratio are more susceptible to change over a larger scale as compared to sinuosity and slope because they reflect a small scale more accurately. Therefore, a greater variation in results was expected because of the 10 km scale used in this analysis. Application was predicated on identifying areas in the Alatna, Selawik, and Kobuk River drainages where a mean value of sinuosity, based on field measured information in the Sulukna River, was reached. *T*-tests were useful in comparing field measured and GIS derived values of slope and in comparing different sections of the river, and provided a method demonstrating that slope can be predicted accurately using a GIS. However,

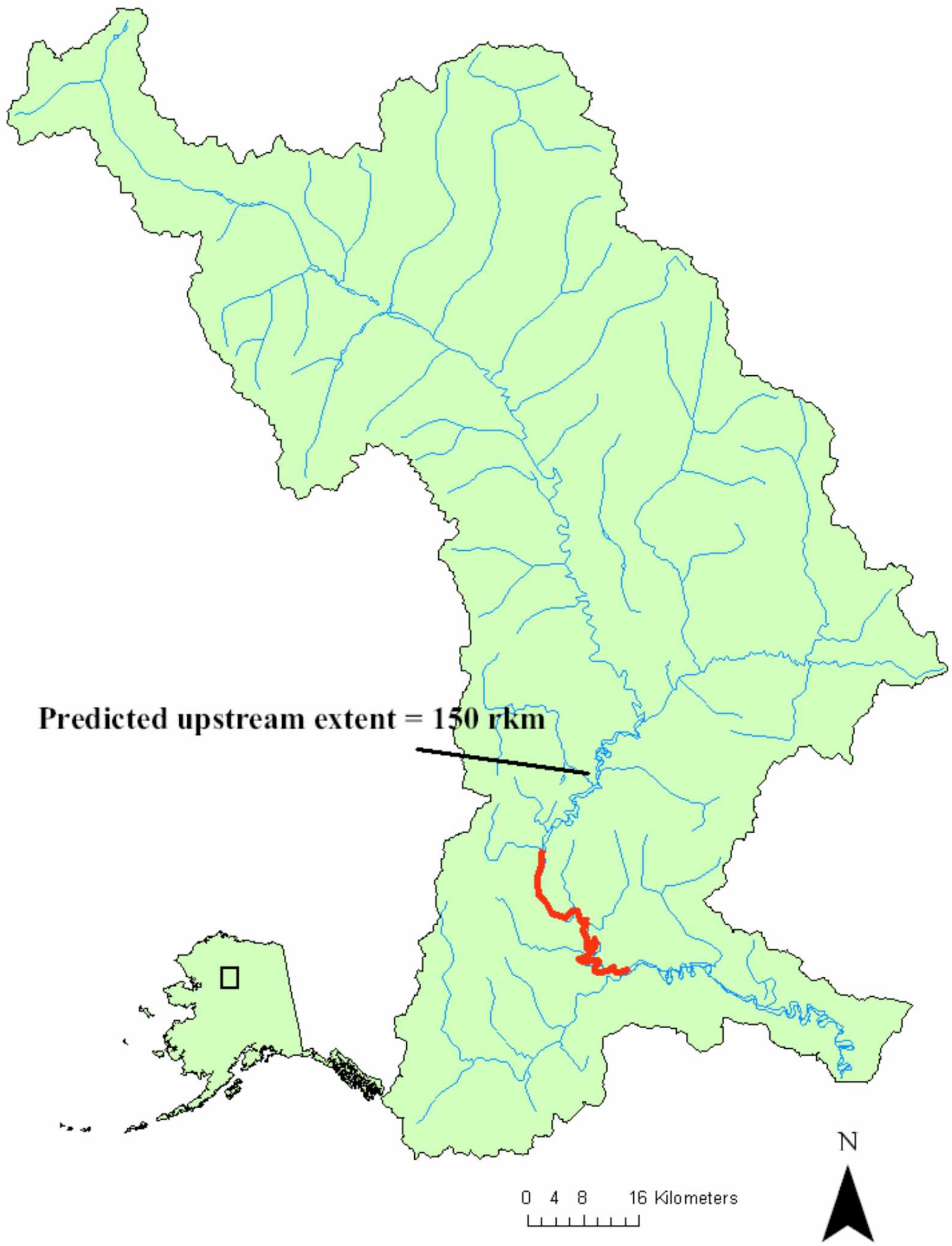

Figure 3.6 The Alatna River drainage, Alaska. Bolded lines indicate known inconnu spawning area. GIS derived upstream extent based on sinuosity criterion is indicated.

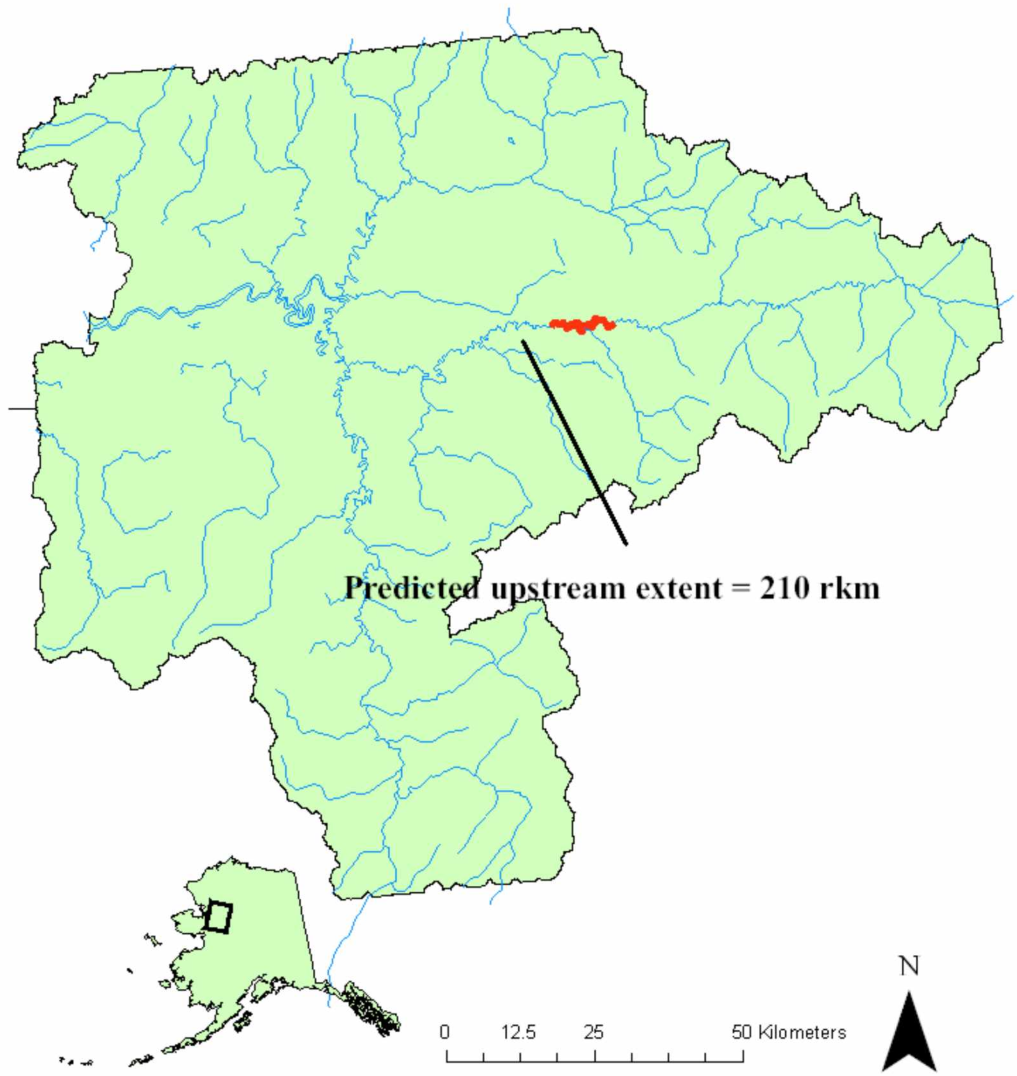

Figure 3.7 The Selawik River drainage, Alaska. Bolded lines indicate known inconnu spawning area. GIS derived upstream extent based on sinuosity criterion is indicated.

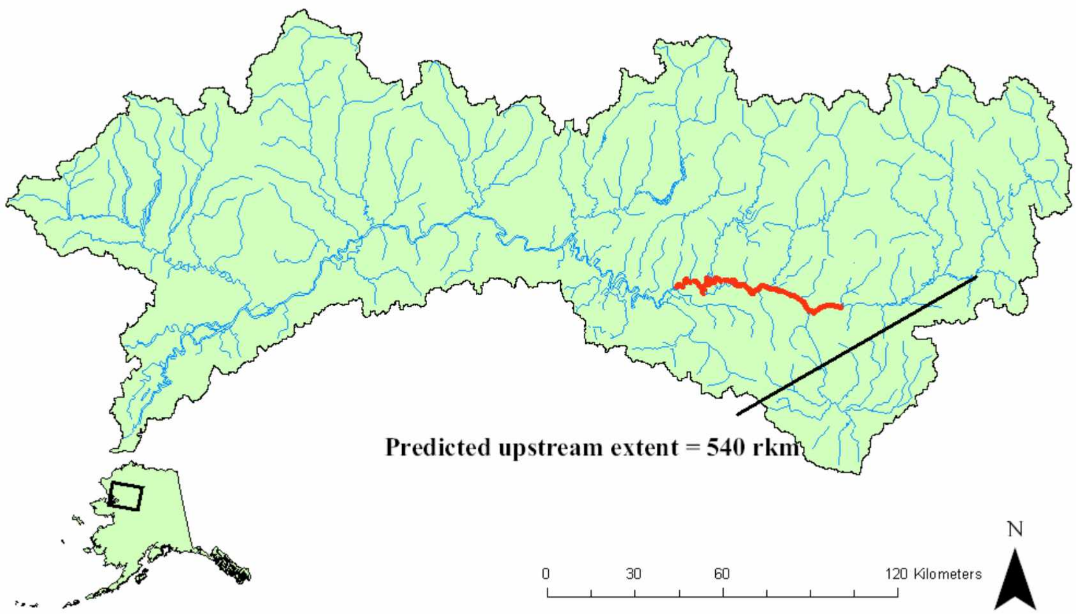

Figure 3.8 The Kobuk River drainage, Alaska. Bolded lines indicate known inconnu spawning area. GIS derived upstream extent based on sinuosity criterion is indicated.

Table 3.7 Location of GIS derived and known upstream extent of inconnu spawning habitat in the Alatna, Selawik, and Kobuk Rivers, Alaska using the sinuosity criterion.

River	Known upstream extent (rkm)	Predicted upstream extent (rkm)	Error (rkm)
Alatna River	120	150	30
Selawik River	230	210	20
Kobuk River	395	540	145

other methods are preferable for increasing accuracy and modeling capability although they require survey coverage that is evenly and widely distributed (Valavanis et al. 2008).

Errors in GIS data can explain some of the loss of accuracy in the model. Walker and Willgoose (1999) found elevation errors in a DEM up to 12m, noting that the errors may be a result of map to DEM conversion. Stream channels derived from the DEM did not imitate stream sinuosity, likely due to errors in the stream path shapefile (Isaak et. al. 1999). In general, the GIS derived stream channels became more linear because the resolution of the DEM could not adequately represent stream direction or elevation. Neeson et al. (2008) suggested using a higher DEM resolution and manually traced shapefiles to increase accuracy. Specific to the Selawik River, the GIS derived predicted upsteam extent did not accurately reflect the true upstream extent. The stream shapefile used in the analysis only extended 30 rkm past the known upstream extent. Had a more complete stream shapefile been available, the threshold value for sinuosity would have likely been met farther upstream and would have been more accurate.

The Sulukna River has some similar characteristics, i.e. geology; with the Alatna, Selawik, and Kobuk Rivers, however it differs from these drainages in size and geographic location, i.e. latitude. GIS derived predictions were based on large scale geomorphic features, and the range of information collected on the Sulukna River did not perform well when applied to larger drainages.

This analysis identified large geographic areas that have the potential to support inconnu spawning habitat, which can be used to predict likely inconnu spawning distribution. In all drainages where inconnu spawn, they use discrete areas within a waterbody. In lotic systems, this area appears to be where a specific sized substrate exists. Because substrate size is driven by the slope of the channel within a system, initial landscape level predictions of inconnu spawning habitat location should be predicated on the slope criterion. Additionally, future research should focus on collecting field measured values in other drainages and developing better datasets with higher resolution spatial data. Increasing the range of data used in analysis would increase model accuracy. Whiting et al. (1999) and Smith (2005) developed models with larger sample sizes, encompassing larger areas. The Sulukna River is the smallest river in length and drainage size and restrained the model accuracy by confining the range of data. If field measured values encompassed a larger amount of variability, then resulting models would probably be more effective at predicting spawning habitat

4.1 Discussion and recommendations

The methods presented herein represent a first attempt to quantify inconnu spawning habitat and make spatial inferences regarding potential inconnu spawning habitat in other drainages. Habitat variables included small scale, large scale, and chemical variables collected throughout the accessible portion of the Sulukna River. Although this study design was effective for initial identification and characterization of the spawning habitat, it restricted prediction using GIS application. Inconnu spawning habitat was identified with a hook and line sampling program to a 20 rkm reach (rkm 71 to 91) on the Sulukna River, which limited the model results to a small sample (n = 11). Therefore, spatial prediction of potential spawning habitat in other drainages was precluded by the small range of data used in creating spatial criteria.

The major difficulty for spatial analysis in this study was trying to make classification decisions about presence or absence of potential inconnu spawning habitat in other drainages at a large scale based on quantitative data collected at a small scale. This difficulty was further complicated because of the relatively small size of the Sulukna River in relation to other drainages. Small scale data, dominant substrate, and width to depth ratio information, could be refined by increasing the number of transects within a known spawning reach and collecting this information throughout multiple watersheds. This solution, however, is limited by the number of inconnu spawning stocks and the timing of accessibility to these stocks for data collection. Remote sensing imagery may alleviate these problems. For example, Vadas and Orth (1998) and Toepfler et al. (2000)

used photo imagery to quantify stream habitat. Although classification of dominant substrate would be difficult using this method, mapping of width to depth ratio indicative of the shape of the channel would benefit from this approach. Additionally, imagery could facilitate the classification of channel habitat units: pool, run, riffle and channel unit combinations where inconnu spawning habitat exists. Large scale variables, slope, and sinuosity provide good representation of the presence of inconnu spawning habitat, and can be used to make general inferences. One of the most important advantages of GIS is that queries and manipulations with an artificial network can be made to answer a variety of questions. Initial queries into the location of inconnu spawning habitat should begin with large scale model analysis which will provide a good indication of spawning habitat locations.

In all known inconnu spawning rivers, the length of river used for spawning is minimal and spawning sites are uncommon. Underwood (2000) estimated the population size of inconnu within the Selawik River near 5,000 fish and that spawning habitat was limited to a 12 rkm reach. Hander et al. (2008) estimated the same population to be 23,000 – 46,000 fish ten years later, with no increase in the length of spawning habitat. These changes in abundance indicate that long-term variation in population size exists and suggest that spawning habitat is not a limiting factor.

Water quality characteristics, specifically conductivity, alkalinity, calcium hardness, and pH values, are generally higher in the Sulukna River than neighboring tributaries. Scarnecchia and Bergersen (1987) noted higher production of trout was directly related to conductivity and alkalinity. Mortensen (1977) noted increases in production of brown trout and nonsalmonid fishes with high conductivities, which was in agreement with O'Connor and Power (1976) on brook trout production. Additionally, Kwak and Waters (1997) suggested that measures of ionic strength (alkalinity, conductivity, or hardness) are indices of water fertility because they generally show a positive relationship with fish production, although other proximate physical factors may account for variation in abundance. Future studies should further define this relationship for inconnu and other whitefish species.

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