Fishery Data Series No. 14-52

Salmonid Use of Nearshore Marine and Estuarine Habitats of the Taku River and Inlet, 2010–2011

by

Kercia Schroeder,

Patricia Hansen,

Kathy Smikrud,

and

Jeff Nichols

December 2014

Alaska Department of Fish and Game | Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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by
Kercia Schroeder, Kathy Smikrud, Jeff Nichols
Alaska Department of Fish and Game, Division of Sport Fish, Douglas

and

Patricia Hansen
Alaska Department of Fish and Game, Division of Sport Fish, Anchorage

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

December 2014

This investigation was partially financed by the State Wildlife Grant under grant segments T-10-3, and T-10-4, project P-06.

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Kercia Schroeder[1], Kathy Smikrud, Jeff Nichols
Alaska Department of Fish and Game, Division of Sport Fish,
PO Box 110024, Juneau, AK 99811-0024, USA

Patricia Hansen,
Alaska Department of Fish and Game, Division of Sport Fish
333 Raspberry Rd., Anchorage, AK 99518-1565, USA

[1]Author to whom all correspondence should be addressed: kercia.schroeder@alaska.gov

This document should be cited as:
Schroeder, K., P. Hansen, K. Smikrud, and J. Nichols. 2014. Salmonid use of nearshore marine and estuarine habitats of the Taku River and Inlet, 2010–2011. Alaska Department of Fish and Game, Fishery Data Series No. 14-52, Anchorage.

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ABSTRACT

Habitats utilized during estuarine residence and early-ocean entry are critical to the survival of many juvenile anadromous and forage fish species. However, only limited information exists on fish habitat use during these critical periods in Southeast Alaska. In 2008, the Alaska Department of Fish and Game, Division of Sport Fish initiated a 2-phase project to investigate spatial and temporal fish habitat use patterns in Taku Inlet and the Taku River estuary in Southeast Alaska. The first phase of the project included surveys conducted in 2008 and 2009 in nearshore areas of the estuary and inlet. The second phase of the project, which is presented in this report, focused on sampling offshore/neritic habitats throughout the study area in 2010 and 2011. Data collection occurred once a month from May to August 2010 and from April to August 2011. In Taku Inlet, fish were captured using a Kodiak pair trawl; in the estuary, a pole seine and a modified otter trawl were used. Biotic and abiotic environmental parameters were also collected at sampling locations and were individually analyzed to determine which habitat variables had significant association with the presence of juvenile Pacific salmon. During the 2010 and 2011 surveys, 33,606 fish were captured, including 555 salmon *Oncorhynchus*. All five species of Pacific salmon were captured, with sockeye salmon *O. nerka* being the most abundant species captured both years. Examination of habitat variables indicated that turbidity had a significant effect on the presence of juvenile Pacific salmon in both the inlet and estuary, and the distance to the mouth of Taku Inlet only had a significant effect in the estuary. Prey availability was only assessed in the inlet and results showed it also had a significant effect on the presence of salmon.

Key words: juvenile Pacific salmon, anadromous fish, marine fish, fish survey, habitat survey, estuary, offshore, neritic, nearshore, plankton, turbidity, Southeast Alaska, Taku Inlet, Taku River estuary.

INTRODUCTION

Limited information exists on fish habitat use in nearshore marine and estuarine waters in Southeast Alaska (SEAK). However, it is clear that habitats utilized during estuarine residence and early-ocean entry are critical to the survival of many juvenile anadromous and forage fish species (Abookire et al. 2000; Benaka 1999; Mortensen et al. 2000; Moulton 1997; Murphy et al. 1988; Orsi et al. 2000; Robards et al. 1999). Estuaries and nearshore marine habitats are known to provide a myriad of important ecological functions to salmon and other marine fish species, including: refuge and rearing habitat for juvenile salmonids, forage fish, and groundfish; food production for juvenile and adult fish; conditions suitable for the physiological transition from a freshwater to marine habitat; migration corridors for juvenile fish from a freshwater to marine system; migration corridors for adult fish returning to natal spawning grounds; and spawning habitat for forage fish, groundfish, and salmonids (Abookire et al. 2000; Brennan et al. 2004; Lorenz and Schroeder 2010; MacDonald et al. 1987; Simenstad et al. 1982; Williams and Thom 2001).

In 2007, the Alaska Department of Fish and Game, Division of Sport Fish (ADF&G-SF) participated in a collaborative project (funded through the Pacific Salmon Commission-Northern Fund) with the National Oceanic and Atmospheric Administration-National Marine Fisheries Service (NOAA-NMFS) entitled *Assessment of critical salmon habitat in a transboundary river estuary*. The purpose of the project was to investigate spatial and temporal patterns of salmon distribution in the Taku River estuary relative to the different habitats available (Lorenz and Schroeder 2010). The collaborative project ended in 2007, but provided relevant information and momentum from which the current project was developed.

In 2008 and 2009, ADF&G-SF initiated surveys to investigate the patterns of spatial and temporal fish use in nearshore habitats of the Taku River estuary and associated Taku Inlet (Schroeder et al. 2013, hereafter referred to as the Taku nearshore project). A concurrent and complementary ADF&G-SF project, supported through a separate funding source (Alaska

Sustainable Salmon Fund, or AKSSF), was conducted in the Taku River watershed from 2009 to 2011 (Nichols et al. *in prep*, hereafter referred to as the Taku River habitats project); and used similar methodologies to those used in the Taku nearshore project to explore fish habitat associations across the floodplain of the Taku River. The two projects used a combination of remote-sensed and field verified habitat identification methods and strategic fish sampling to identify temporally and spatially specific fish habitat associations within the U.S. portion of the Taku River, the adjoining estuary, and nearshore habitats of Taku Inlet.

In 2010, ADF&G-SF developed a sampling protocol and initiated surveys for the second phase of the Taku nearshore project, described in this report. The second phase of the project built upon the projects identified above, by expanding the investigation of spatial and temporal fish use patterns into offshore/neritic habitats in the Taku River estuary and Taku Inlet. Collectively, the two phases of the Taku nearshore project (i.e., nearshore/estuary in 2008–2009 (phase I) and offshore/neritic in 2010–2011 (phase II)) and the Taku River habitat project provide much needed information on how fish populations distribute themselves in the U.S. portion of the Taku River watershed and marine waters of Taku Inlet, and which habitats are most important. These baseline data are available to assist managers in making informed resource management decisions.

OBJECTIVES

The overall goal of this project was to identify, quantify, and characterize estuarine, nearshore, and offshore/neritic habitats in Taku Inlet and the Taku River estuary, with respect to fish distribution patterns.

Specific objectives for 2010 and 2011 (phase II of the project) were to:

1. Identify and map the spatial distribution of fish species that utilize surface waters of offshore/neritic areas in Taku Inlet.
2. Identify and map the spatial distribution of fish species that utilize offshore areas in the Taku River estuary.
3. Measure and map a selection of biotic and abiotic parameters throughout the offshore/neritic areas of Taku Inlet and the Taku River estuary thought to be important for determining juvenile Pacific salmon *Oncorhynchus* distribution. Biotic and abiotic parameters include: water quality (temperature, specific conductivity, salinity, dissolved oxygen, pH, and turbidity); water depth; tide elevation and stage; Taku River discharge level; distance to nearest shoreline; distance to the mouth of Taku Inlet; and prey availability.
4. Identify those biotic and abiotic characteristics (Objective 3) associated with the presence of juvenile Pacific salmon.

STUDY AREA

The Taku River watershed is a large, glacial mainland river system that originates in the Stikine Plateau of northwestern British Columbia, Canada, and empties into the head of Taku Inlet, approximately 20 km southeast of Juneau, Alaska (Figure 1). The watershed is host to 5 species of Pacific salmon, and is one of the largest producers of Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in the region (Der Hovanisian and Geiger 2005). The Taku watershed also produces significant numbers of sockeye (*O. nerka*) and chum salmon (*O. keta*) relative to other stream systems in SEAK, and has documented use by eulachon (*Thaleichthys pacificus*), capelin (*Mallotus villosus*), and Pacific sand lance (*Ammodytes hexapterus*) for spawning in the lower reaches near the estuary (Johnson and Daigneault 2013). Data collected under a separate project, conducted in 2007 (Lorenz and Schroeder 2010), and results from the first phase of this project indicate that the estuarine environment at the mouth of the river may also provide habitats important to emigrant juvenile salmon.

The study area encompasses approximately 108 km^2. The upper and lower extents of the study area remain consistent with the study area originally identified for phase I of this project. However, for phase II, the study area was divided into 2 different sampling areas: (1) Taku Inlet; and (2) the Taku River estuary (Figure 2). This change was due to the different sampling designs that were required to capture fish in offshore habitats in the Taku River estuary compared to the offshore/neritic habitats in Taku Inlet. The boundary line used to separate Taku Inlet from the Taku River estuary was consistent with the northern boundary line established for the Taku Inlet commercial gillnet fishery. The northern boundary line, which was established by the Alaska Department of Fish and Game, Division of Commercial Fisheries (ADF&G-CF), separates the shallow waters in the estuary from the deeper waters in the Inlet.

Taku Inlet

Taku Inlet is a large, steep fjord that functions as a migratory corridor between the Taku River and marine waters that ultimately empty into the Gulf of Alaska. The inlet is 3–6 km wide and reaches depths of over 200 m. The lower extent of the study area is a line that identifies approximately where Taku Inlet empties into Stephens Passage (Figure 2).

Taku River Estuary

The Taku River estuary is considered to be large in comparison to others across SEAK. The upper extent of the study area (Figure 2) remains consistent with regard to the upper extent of the estuary work conducted in the 2007 ADF&G-SF collaborative project with NOAA-NMFS (Lorenz and Schroeder 2010). For the purposes of the collaborative project and defining the study area in the present context, the Taku River estuary is defined as the area between the extreme high water mark and a depth of 20 m in areas where bottom sediments are derived predominately from fluvial sources. This definition was used to help determine the upper and lower extents of the estuary section of the study area.

The estuary is a dynamic area characterized by continually changing conditions due to tide levels, river discharge levels, sediment transport, etc. During low tide, extensive mud flats and sand bars are exposed throughout the estuary. Locations of the sand bars tend to change frequently due to the dynamic and converging influences of the fresh and marine waters in the estuary.

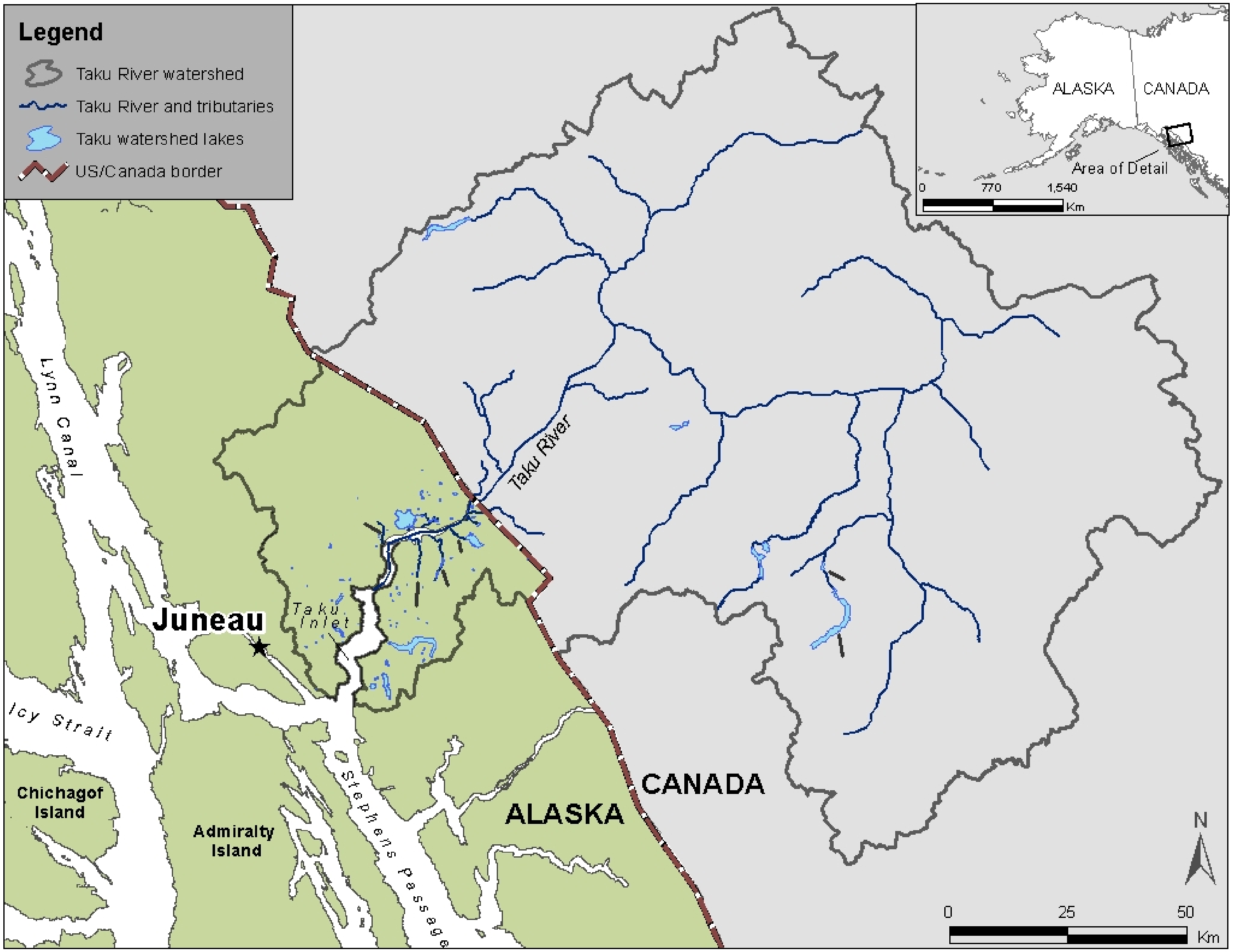

Figure 1.–Location of the Taku River watershed in Southeast Alaska.

Figure 2.–Map showing the extent of the study area in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

METHODS

DATA COLLECTION

Data collection for this project occurred from May to August 2010, and from April to August 2011 (Table 1). There was 1 sampling trip each month, for a total of 9 sampling events.

Table 1.–Sampling dates for 2010 and 2011 field trips, Taku Inlet and the Taku River estuary, Southeast Alaska.

Month	2010 sampling dates	2011 sampling dates
April	—	04/25/11–04/30/11
May	05/12/10–05/18/10	05/21/11–05/25/11
June	06/15/10–06/21/10	06/21/11–06/25/11
July	07/07/10–07/13/10	07/20/11–07/24/11
August	08/24/10–08/30/10	08/17/11–08/21/11

The sampling design for this project was based on a systematic random selection of points generated from a grid encompassing the project area; the area of the grid included a systematic array of points with even interval spacing of 1,450 m in the Taku Inlet area (Figure 3) to 1,600 m in the Taku River estuary area (Figure 4). Consideration to logistical constraints dictated that we could sample approximately 36 individual locations across the entire project area. The differential spacing used in the two areas allowed us to accommodate for differences in size between the areas. A combination of random and systematic selection of points ensured sampling locations were not clustered within an area, and thus were more representative of the area as a whole. Ultimately, 24 locations were selected for sampling in Taku Inlet (Figure 3) and 12 locations were selected in the Taku River estuary (Figure 4). All 36 locations were sampled during each monthly field trip.

On the first trip, the first day of sampling started at the southern end of the section and moved north, crisscrossing east and west as much as possible. Sampling the locations using this approach covered as much of the study area as possible each day. For example, on the first day of the first trip, sampling began at Location 2 in Taku Inlet, followed by Location 5, Location 11, Location 12, Location 17, Location 18, Location 21, and Location 23. This approach covered the study area from south to north and east to west as much as possible during the day. The second day of sampling started at the northern end of the section and moved south, again crisscrossing east and west as much as possible. All remaining sites in Taku Inlet were sampled on the third day, starting in the center of the section and moving north, then starting in the south and moving toward the center. The same sampling order was used during the other odd numbered trips; the sampling order was reversed on trips 2 and 4. The same approach was used to determine the sampling order for the Taku River estuary and Taku Inlet.

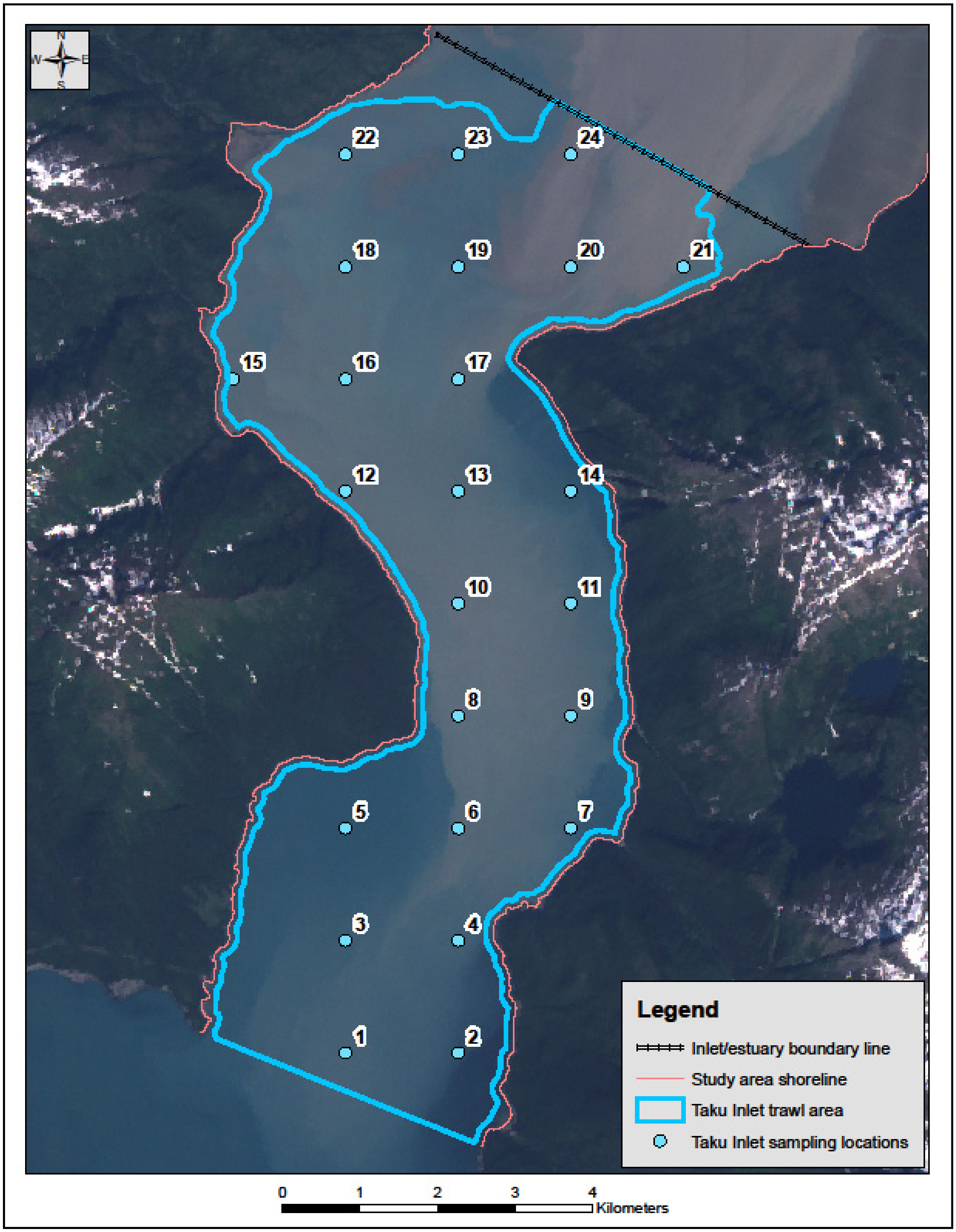

Figure 3.–Map identifying the 24 locations sampled in Taku Inlet in 2010 and 2011, Southeast Alaska.

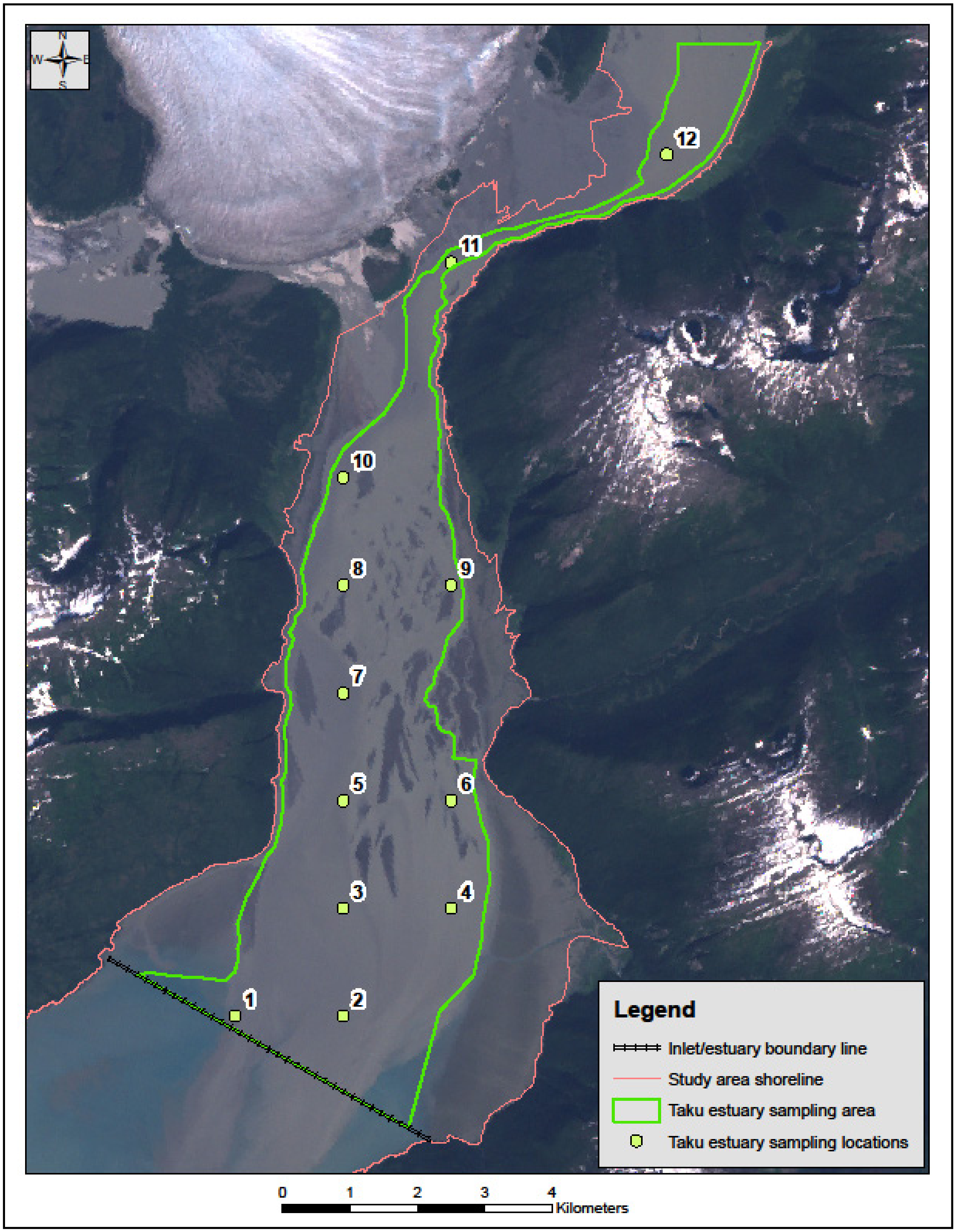

Figure 4.–Map identifying the 12 locations sampled in the Taku River estuary in 2010 and 2011, Southeast Alaska.

All sampling took place during relatively slack tidal conditions (±2 hours from high tide and low tide). At each location, captured fish were retained in a tote on the boat. All fish were counted and identified to the lowest taxon possible. For fish that could not be identified to the species level, comments were recorded describing physical characteristics of the fish and photos were taken to assist with identification upon return to field camp where observers were able to reference detailed field guides. In addition to identifying and counting all fish captured, length measurements were recorded (to the nearest mm FL) for all salmonids captured. Fish were released after processing.

Spatial Distribution of Fish in Taku Inlet

Offshore/neritic habitats in Taku Inlet were sampled using a Kodiak pair trawl. Sampling methods used for this trawl were slightly modified from the standard sampling methods identified for this type of net in Orsi et al. (2004). For the safety of the charter vessel, sampling gear, and personnel, all sampling locations were established ≥100 m from the shoreline and at water depths ≥20 m.

The trawl was 15 m long, 6 m wide, and 3 m deep, with 3 mm cod-end mesh. The trawl was towed at the surface between 2 vessels; the net was spread open horizontally and was held open vertically by 2, 3 m long rigid metal pipes. Floats were attached to each wingtip to ensure that the trawl headrope remained on the surface. This type of trawl could be fished over relatively shallow depths, but could not effectively fish in seas with wave height >1 m. The trawl was towed at approximately 2 knots for 10 minutes, traveling parallel to the shoreline when conditions allowed. At each location, the current, swells, and wind conditions were assessed to determine the direction in which the trawl was set and towed. Deployment and retrieval of the pair trawl took place on the larger of the two vessels, with the assistance of a hydraulic winch.

Spatial Distribution of Fish in the Taku River Estuary

Two different types of sampling equipment were used to catch fish at sampling locations in the estuary. Sampling was conducted out of an open skiff and required a crew of 4. Methods used to capture fish were as follows:

- At low tide, shallow, wadeable areas along the edges of sandbars were sampled with a pole seine. The seine (7.5 m long, 2 m deep) consisted of 13 mm stretch mesh and had a pole attached to each end of the net. The net was fished by pulling it into the current, parallel to the sandbar bank, for 50 m.
- Deeper, unwadeable areas in the estuary were sampled with an otter trawl (3 m wide, 1 m deep) that was towed behind the skiff with a bridle scope of approximately 20 m. Floats were attached to each wingtip at the top of the net to allow the net to fish surface waters. One trawl door was attached to each side of the net to spread the trawl open. When conditions allowed, the trawl was towed into the current, parallel to the nearest shoreline, at a speed of approximately 2 knots for 10 minutes. At each location, the current, swells, and wind conditions were assessed to determine the direction in which the trawl was set and towed.

Environmental Characterization

Physical, biological, and chemical parameters that were measured were selected from important estuarine and marine habitat characteristics identified in supporting literature (Abookire et al.

2000; Benaka 1999; Bi et al. 2007; De Robertis et al. 2005; Emmett et al. 2004; Emmett et al. 2006; MacDonald et al. 1987; Morgan et al. 2005; Morsell et al. 1983; Mortensen et al. 2000; Moulton 1997; Orsi et al. 2000; Robards et al. 1999; Schabetsberger et al. 2003; St. John et al. 1992). This information was obtained for each scheduled sampling location; most of the environmental parameters were collected at the time of sampling and others were identified upon return to the office using ArcGIS®[1], or online resources.

Water Quality

Physiochemical conditions were assessed immediately before and after sampling at each location. A Quanta Hydrolab® multi-sensor was used to collect water quality information for: temperature, specific conductivity, salinity, dissolved oxygen, pH, and turbidity. A vertical profile was obtained by taking measurements in 1 m increments from the surface to a depth of 4 m (where possible).

Water Depth

Water depths in Taku Inlet were identified at the same time physiochemical conditions were measured, both at the start and end points of sampling at each location. All water depth data were collected using the charter boat's sonar depth finder.

Tide Level

Tide levels were identified at the same time that physiochemical conditions were measured. The tide elevation was obtained by utilizing the tide page on the geographic positioning system (GPS) unit and by ensuring that the "nearest tide station" had been selected. Observers also noted whether the tide was high or low and whether it was incoming (flooding) or outgoing (ebbing).

Taku River Discharge

Taku River discharge levels were identified, upon return to the office, via the U.S. Geological Survey website (http://waterdata.usgs.gov/ak/nwis/current/?type=flow) that features real-time streamflow data for Alaska (USGS 2013).

Distance to Nearest Shoreline

The straight line distance to the nearest shoreline (based on mean high tide levels) was derived using a geographic information system (GIS) upon return to the office. A distance measurement was identified for each point where physiochemical conditions were measured.

Distance to Mouth of Inlet

The straight line distance to the mouth of Taku Inlet was derived using a GIS, upon return to the office. This distance measurement was identified for each point where physiochemical conditions were measured.

Prey Availability

At the same time physiochemical conditions were being measured, 1 shallow, 20 m vertical, plankton tow was done to assess prey availability at sampling locations in Taku Inlet. The plankton haul was conducted using a conical North Pacific Standard (NORPAC) ring net (50 cm

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[1] Product names in this document are included for a complete description of the process and do not constitute product endorsement.

diameter frame, 333 µm mesh). A weight was attached to the net to ensure a depth of 20 m was achieved. The net was pulled upward at a steady rate of approximately 1.0 m/s. Once the net reached the surface, a hose was used to rinse the net from the top end downward so that all plankton were collected in the cod-end. Plankton samples were then emptied into a pre-labeled sample bottle that contained a 5% buffered formalin solution. The bottle was labeled with the date, time, location, and GPS waypoint.

In the laboratory, the volume of plankton caught in each tow was determined using the displacement volume method. This method consisted of pouring the catch into a cone-shaped filter and allowing excess water to drip from the catch. The catch was then added to a known volume of water and the additional volume registered was a measure of the displacement volume of the zooplankton (Frolander 1957).

DATA ANALYSIS

Spatial Distribution of Fish in Taku Inlet and the Taku River Estuary

For each location, the number of juvenile salmon captured was classified into 1 of 3 ordinal categories (catch scores; Table 2). Fish distribution and catch scores were mapped for each sampling event in ArcGIS®. Variables mapped include:

1. number of fish captured
2. number of juvenile salmon captured

Table 2.–Ordinal categories (catch scores) used to analyze the catch data for surveys, Taku Inlet and Taku River estuary, Southeast Alaska, 2010 and 2011.

Number of juvenile salmon caught	Catch score
0	1
1–5	2
>5	3

Environmental Characterization

Environmental data for each sampling location and sampling event was also mapped in ArcGIS®. Measurements taken at the start and end of each fish tow were averaged and considered the value for that location. The point data was interpolated to a surface using the *spatial analyst extension* in ArcGIS®; ordinary kriging was the interpolation method used because it produced a surface with the lowest mean square error (MSE). Classification breaks were identified by using all values collected during each sampling year, and individual classes were defined by using a modified equal interval classification. Ten classes were demarcated—the first and last classes corresponded to the 5^{th} and 95^{th} percentiles, and the remaining eight classes were defined by equal interval breaks. Values were rounded to the nearest 10^{th} of a decimal.

Environmental Characteristics Associated with Juvenile Salmon

An analysis of variance (ANOVA) was used to determine which environmental variables had a significant effect on the presence of juvenile salmon in both Taku Inlet and the Taku River estuary. The ANOVA was done for each environmental variable separately. The dependent variable was the individual environmental metric and the independent variable was the ordinal value of the number of juvenile salmon caught. If the environmental variable was not normally distributed, then a rank transformation was used (Kruskal-Wallis nonparametric ANOVA).

RESULTS

DATA COLLECTION

From May to August 2010, a total of 149 locations were sampled. In 2011, a total of 175 locations were sampled from April to August. Of the 324 locations sampled during the study, juvenile salmon were caught at 36% (n = 116) of them (Table 3). Figure 5 identifies the distribution of juvenile salmon catch scores in surveys conducted during 2010 and 2011.

Table 3.–Total number and percent of sampled locations associated with the three ordinal catch score categories, Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Catch Score	Number of juvenile salmon caught	Number of sampled locations	Percent of sampled locations
1	0	208	64
2	1–5	93	29
3	>5	23	7
		324	100

A total of 15,458 fish were captured in 2010 and 18,148 were captured in 2011 (Table 4). Smelt larvae (Family Osmeridae) were the most abundant fish captured both years. Of the fish captured, Pacific salmon accounted for approximately 2.1% (n = 320) of the total catch in 2010 and 1.3% (n = 235) in 2011; sockeye salmon were the most abundant salmon species captured in both years (Table 4).

Annual and seasonal ranges of observed water quality conditions are identified in Table 5. Dissolved oxygen data were not collected in July 2010 due to a malfunctioning sensor.

DATA ANALYSIS

Biotic and abiotic environmental parameters were individually analyzed with respect to catch scores (Table 6; Figures 6 and 7). Note that the water quality sensor used in this project derived salinity values from conductivity measurements, therefore conductivity and salinity measurements are correlated and not independent. Water quality parameters (temperature, specific conductivity, salinity, turbidity, dissolved oxygen, and pH), tide elevation and stage, Taku River discharge level (Appendix B), distance to nearest shoreline, and distance to the mouth of Taku Inlet were measured for all locations throughout the study area. Water depth and prey availability were only measured at inlet locations.

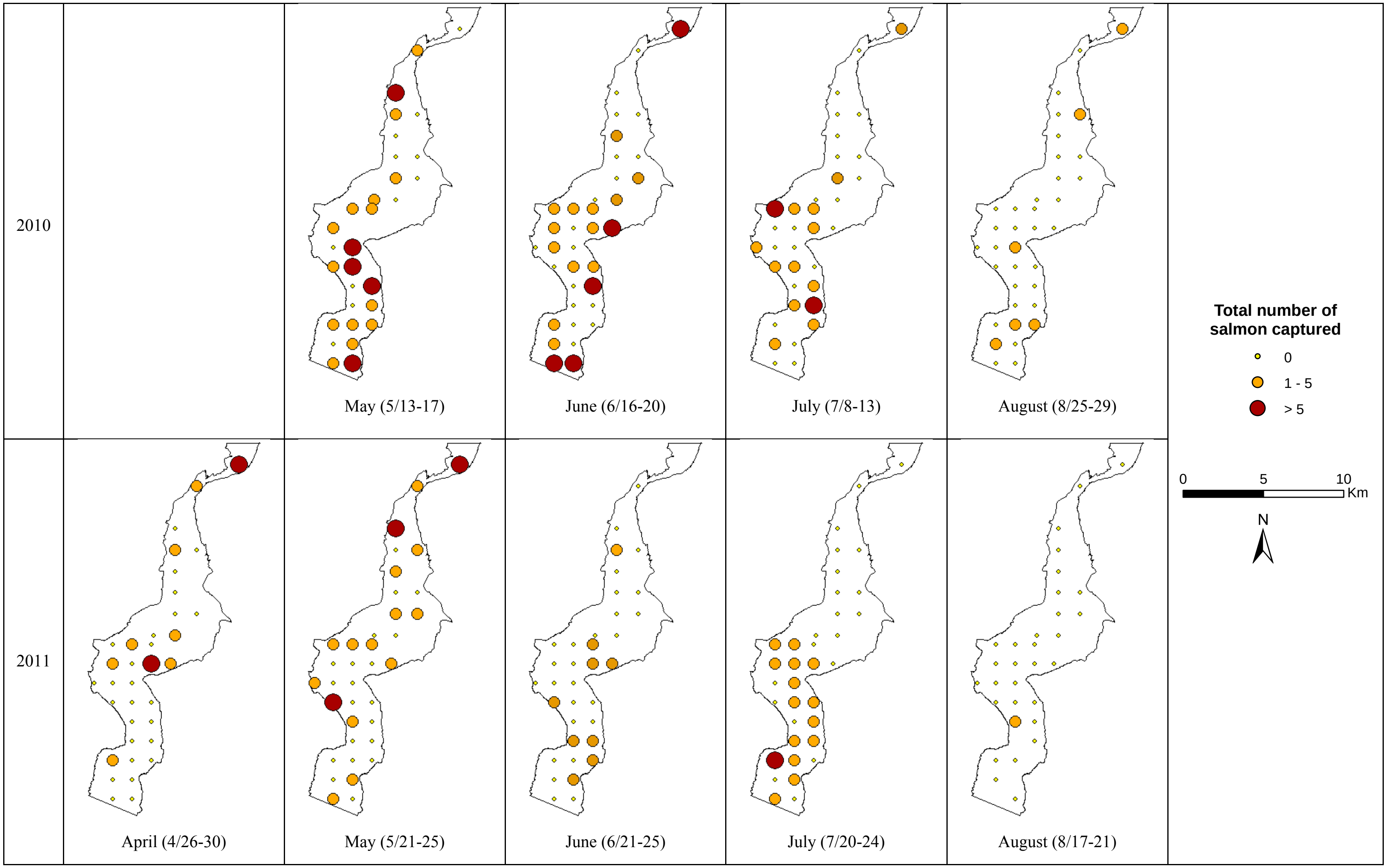

Figure 5.–Maps showing juvenile salmon catch results throughout the study area (by year and sampling period) in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Table 4.–Fish catch composition by taxa, year, and sampling period for Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

	2010					2011					
Species[a]	May	June	July	August	Total	April	May	June	July	August	Total
Pacific sand lance	0	0	2	3	5	0	0	0	2	0	2
Crested sculpin	0	0	0	1	1	0	0	0	0	0	0
Pacific herring	3	3	21	8	35	0	23	29	10	137	197
Pacific spiny lumpsucker	0	0	1	0	1	0	0	0	0	0	0
Threespine stickleback	0	0	18	20	38	6	8	3	49	53	119
American river lamprey	0	19	17	0	36	0	1	47	28	6	82
Pacific staghorn sculpin	0	0	0	0	0	0	6	0	0	0	6
Snake prickleback	1	0	0	1	2	0	1	0	0	0	1
Capelin	69	14	54	3	140	4,504	1,541	12	45	50	6,142
Pink salmon	67	0	0	0	67	71	7	0	2	0	80
Chum salmon	0	0	0	0	0	0	4	0	0	0	4
Coho salmon	5	1	0	5	11	0	8	0	3	0	11
Sockeye salmon	4	105	73	1	183	0	7	53	29	1	90
Chinook salmon	6	29	17	7	59	5	32	11	2	0	50
Starry flounder	3	22	13	0	38	3	25	12	3	0	43
Round whitefish	0	6	0	0	6	0	0	0	0	0	0
Dolly Varden	1	4	0	0	5	0	3	0	2	0	5
Eulachon	219	1	186	3	409	46	232	1	68	3	350
Pacific sandfish	1	8	7	44	60	0	2	5	2	115	124
Class Osteichthyes	0	0	2	0	2	72	2	0	1	0	75
Order Pleuronectiformes	0	9	0	6	15	0	0	0	0	0	0
Family Cottidae	1	7	8	1	17	3	3	0	2	0	8
Family Gadidae	0	0	3	0	3	0	0	0	0	0	0
Family Liparidae	0	3	1	0	4	2	6	1	1	0	10
Family Myctophidae	0	0	4	0	4	0	1	0	2	0	3
Family Osmeridae	517	3,242	5,967	4,572	14,298	43	944	1,885	3,097	4,797	10,746
Family Stichaeidae	0	0	17	0	17	0	0	0	0	0	0
Family Trichodontidae	0	1	0	0	1	0	0	0	0	0	0
Subfamily Coregoninae	0	1	0	0	1	0	0	0	0	0	0
Total	897	3,475	6,411	4,675	15,458	4,755	2,856	2,059	3,348	5,162	18,148

[a] Latin names (*genus species*) for all individual species identified above are provided in Appendix A.

Table 5.–Seasonal and annual ranges of water quality parameters collected on the surface in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

	2010				2011				
Surface water parameter	May	June	July	August	April	May	June	July	August
Temperature (°C)									
Min	6.66	6.64	5.63	1.47	4.71	5.78	6.04	0.87	3.79
Max	12.65	13.40	11.94	9.59	10.47	10.39	12.61	14.33	8.82
Specific conductivity (mS/cm)									
Min	0.16	0.11	0.06	0.03	0.22	0.10	0.10	0.05	0.06
Max	41.93	34.41	30.17	33.73	46.01	26.59	26.30	25.18	29.49
Salinity (PSS)									
Min	0.08	0.05	0.02	0.01	0.10	0.04	0.05	0.02	0.03
Max	26.09	21.97	19.14	20.45	28.94	15.01	15.67	12.53	17.66
Turbidity (NTU)									
Min	5	8	12	13	2	3	13	17	10
Max	712	>1000	>1000	708	684	738	934	>1000	>1000
Dissolved oxygen (mg/L)									
Min	11.43	16.16	ND	12.32	11.93	10.57	10.03	8.61	4.06
Max	26.29	32.42	ND	38.52	33.61	14.21	16.08	16.26	18.36
pH									
Min	8.43	7.57	7.23	7.44	8.13	7.99	7.61	8.12	8.23
Max	9.18	8.72	8.71	9.02	9.11	8.87	8.17	9.99	9.43

Table 6.–Summary of data analysis testing the effect of catch score and area (inlet and estuary) on various dependent variables, Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

			Independent variables	
Sampling area	Dependent variables	Data ranked?	Area	Catch score
Both inlet and estuary				
	Water temperature	No	P < 0.01	P = 0.14
	Salinity	Yes	P < 0.01	P = 0.43
	Turbidity	Yes	P < 0.01	P = 0.04
	Dissolved oxygen	Yes	P < 0.01	P = 0.15
	pH	No	P = 0.11	P = 0.35
	Distance to shore	No	P = 0.06	P = 0.08
	Discharge	Yes	P = 0.09	P = 0.63
	Tide elevation	Yes	P = 0.50	P = 0.57
Inlet only				
	Available prey	Yes		P < 0.01
	Distance to inlet	No		P = 0.37
	Depth	No		P = 0.53
Estuary only				
	Distance to inlet	No		P < 0.01

Water temperature, salinity, and dissolved oxygen were all significantly different between areas (all $P < 0.01$). Water temperature and salinity were significantly higher in the inlet, and dissolved oxygen was significantly greater in the estuary. However, within an area, the comparison among sites with different catch scores showed no significant difference for any of these variables (Table 6; Figure 6). Surface plots for water quality parameters not significantly associated with the presence of juvenile Pacific salmon are included in Appendix C.

There was a significant difference in turbidity between areas and among sites with different catch scores. Turbidity was higher in the estuary than the inlet ($P < 0.01$) and catch scores were higher at locations with lower turbidity ($P = 0.04$; Table 6; Figures 6 and 8).

Plankton displacement volumes were used to determine prey availability in the inlet only. Juvenile salmon catch scores were significantly higher at locations with higher available prey ($P < 0.01$; Table 6; Figures 7 and 9).

Distance to the mouth of Taku Inlet was only significant for sites within the estuary ($P < 0.01$). Catch scores in the estuary were higher at locations that were farther from the inlet ($P < 0.01$; Table 6; Figure 7 and 10).

There were no significant differences between areas or among sites with different catch scores for pH, distance to shore, discharge, or tide elevation (Table 6).

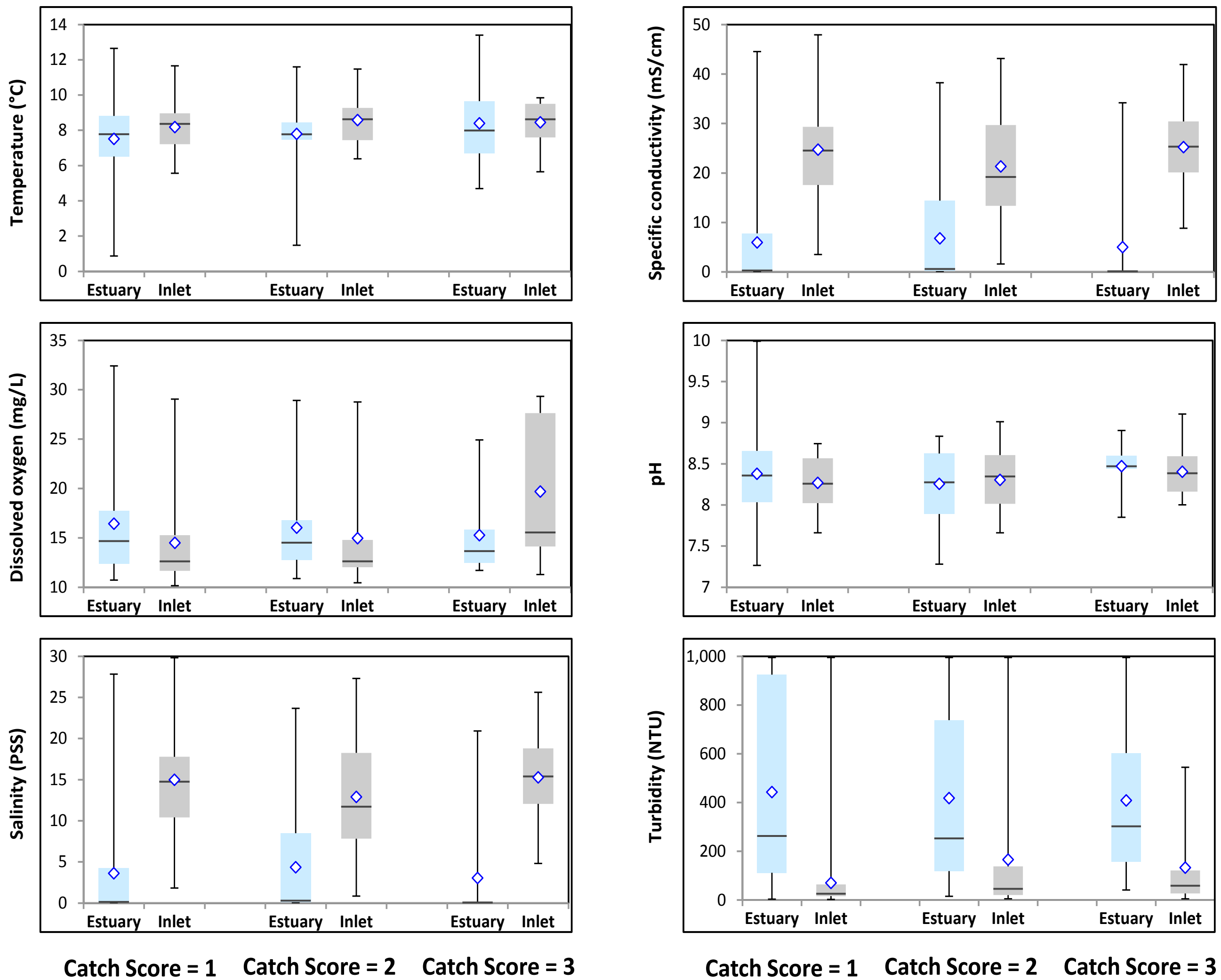

Figure 6.–Box plots displaying catch scores of juvenile Pacific salmon, relative to different water quality parameters, at sampled locations in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Note. Results for inlet locations are identified by dark boxes and estuary locations are identified by light boxes; mean and median catch score values are identified by diamonds and solid horizontal lines, respectively, within box plots.

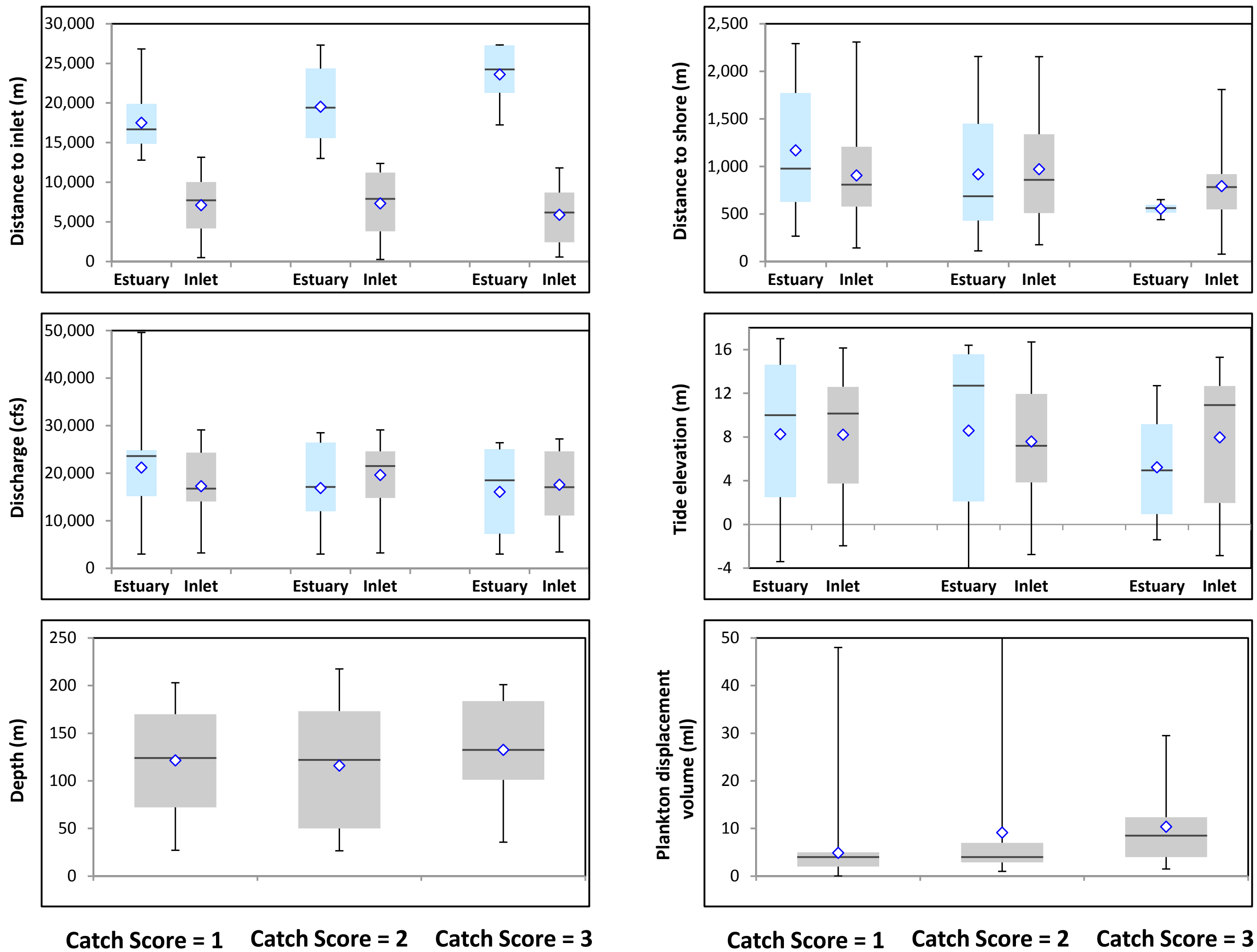

Figure 7.–Box plots displaying catch scores of juvenile Pacific salmon, relative to measured environmental parameters, at sampled locations in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Note. Depth and plankton displacement volumes were only measured at locations in the inlet. Results for inlet locations are identified by dark boxes and estuary locations are identified by light boxes; mean and median catch score values are identified by diamonds and solid horizontal lines, respectively, within box plots.

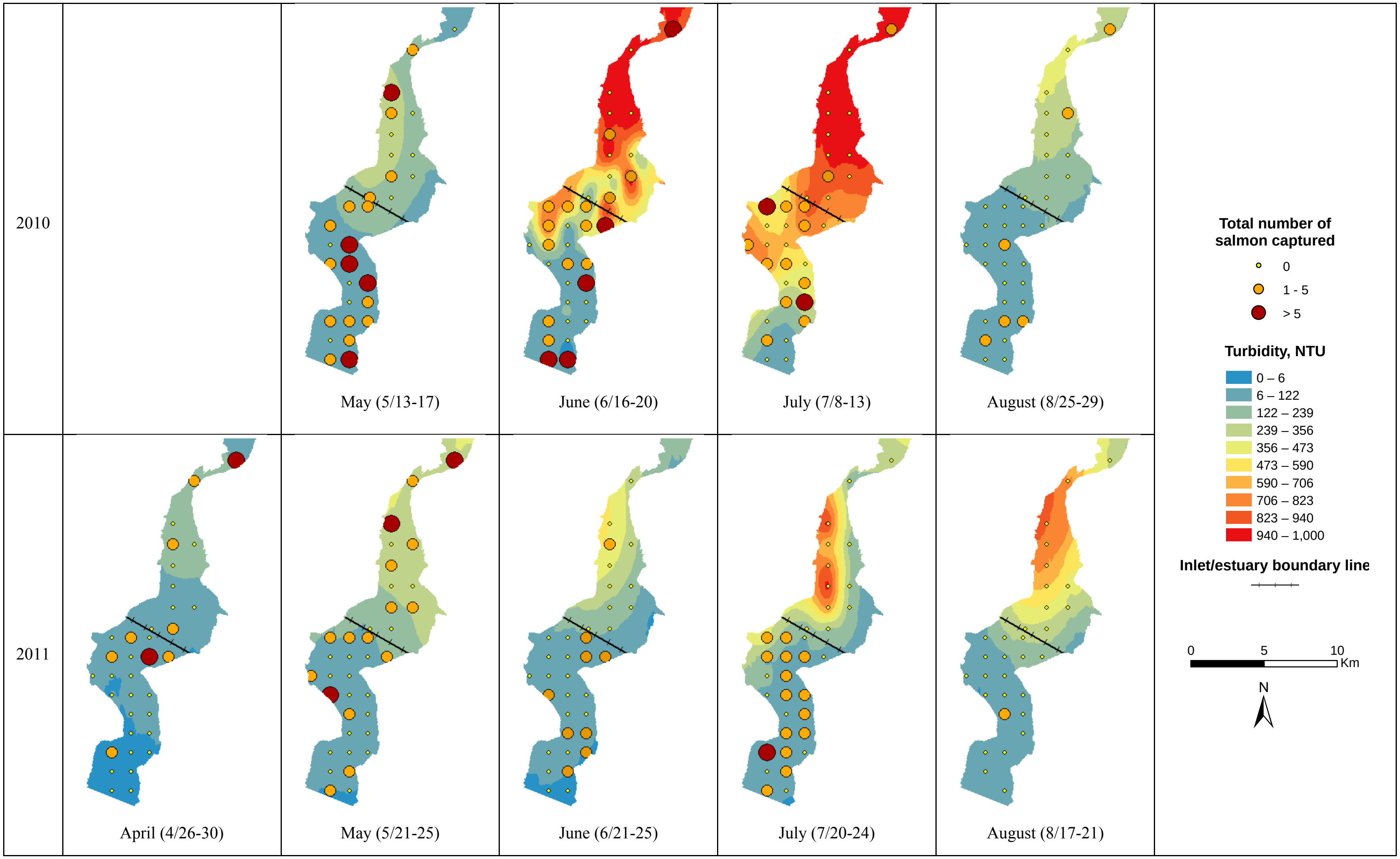

Figure 8.–Surface plots of interpolated turbidity values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

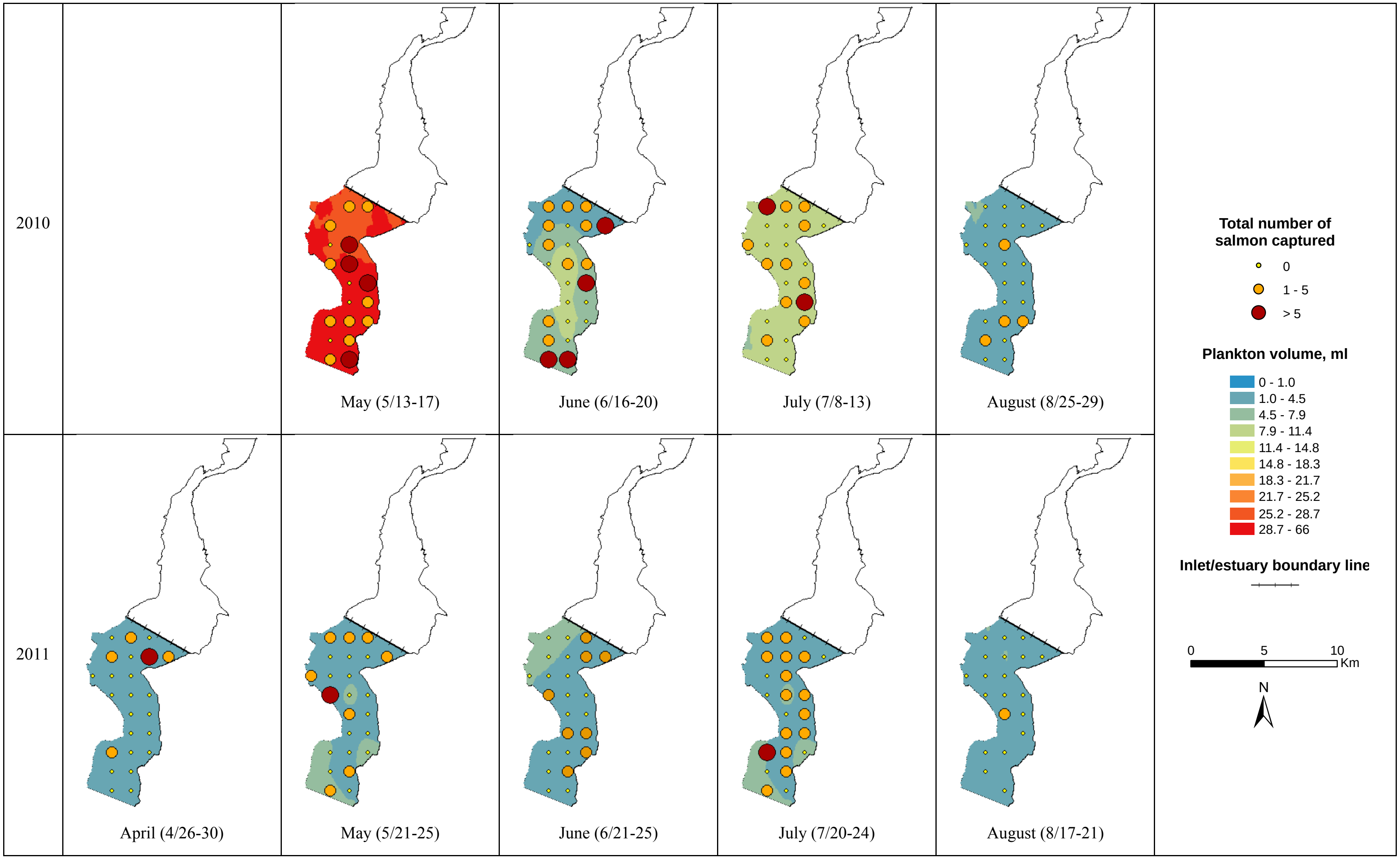

Figure 9.–Surface plots of interpolated plankton volumes and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet, Southeast Alaska, 2010 and 2011.

Note. Plankton sampling occurred in Taku Inlet only.

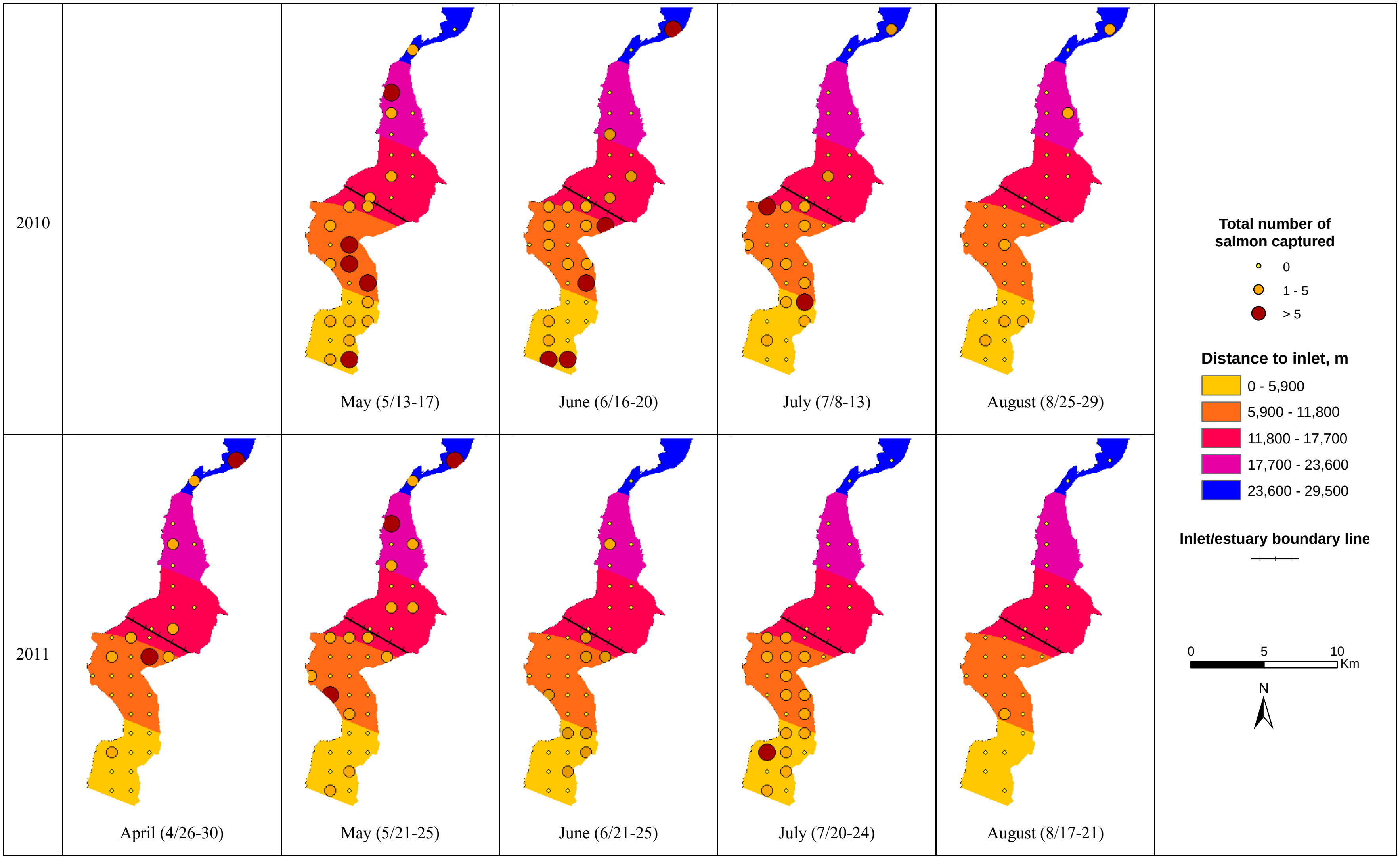

Figure 10.–Surface plots of straight line distances to the mouth of Taku Inlet and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet, Southeast Alaska, 2010 and 2011.

DISCUSSION

This project evaluated temporal and spatial ecological patterns of juvenile salmonids as they transitioned from a large mainland river system into estuarine and early marine habitats, similar to research conducted by others in Alaska and the Pacific Northwest (Abookire et al. 2000; Brennan et al. 2004; De Robertis et al. 2005; Fresh 2006; Heifetz et al. 1989; Hillgruber and Zimmerman 2009; Lorenz and Schroeder 2010; MacDonald et al. 1987; Moulton 1997; Murphy et al. 1988; Orsi et al. 2000; Reese et al. 2009; Schroeder et al. 2013). For this project, all activities took place in Taku River estuary and associated marine waters of Taku Inlet. Of interest was investigation of the temporal and spatial use of offshore habitats as juvenile salmon occupied or migrated through the estuary and inlet, with additional focus on quantifying abiotic parameters associated with water quality (physiochemical conditions), quantity (river discharge), proximity to geographic features, and a biotic measure of prey availability.

To begin to understand juvenile salmonid distribution patterns, including a measure of their relative abundance, it is helpful to contrast the two sampling areas used to partition the overall study area. All sampling occurred offshore during this phase of the project, as opposed to the focus on nearshore sampling that occurred in the previous phase. Sampling was conducted in the relatively shallow waters of the estuary, as well as the deeper neritic waters of the inlet. The average depth of the estuary area was <15 m, most of which was dominated by shifting channels and sand bars that emerged during low tides. The inlet area was characterized by open water, with an average depth of >50 m and depths ranging from 10 m to nearly 200 m throughout the inlet.

Significant differences were observed in several physiochemical properties between the two areas. Although seasonal differences were evident across all years, the estuary was more turbid, colder, had lower salinity levels, and higher levels of dissolved oxygen compared to the inlet; the other abiotic parameters measured across the two areas were not significantly different. Higher turbidity levels and the generally colder surface temperatures in the estuary were related to direct inputs from the glacially-dominated Taku River discharge and meltwater from Taku and Norris glaciers (Figure 2). Less tidal influence and shallower water depths reduced mixing in the estuary, which also contributed to higher turbidity levels in that area. Inlet waters were moderated by more significant marine influence, resulting in lower turbidity levels and generally higher surface temperatures. For the same reason, salinity levels also exhibited a gradual decrease from the stable marine dominated waters of Taku Inlet to the freshwater dominated Taku River estuary. The higher dissolved oxygen levels observed in the estuary were likely the result of the capacity of cold freshwater to hold more dissolved oxygen than warm saltwater (Cole 1979).

Juvenile salmon catch scores (i.e., measure of relative abundance) were found to be statistically unaffected by observed differences in water temperature, salinity, dissolved oxygen, and pH across the two areas. Turbidity levels, which were significantly different between estuary and inlet areas, had a negative influence on catch scores such that fewer juvenile salmon were caught at locations with higher turbidity. The distance to shore measurement showed a moderate ($P = 0.08$) effect on catch scores, although this metric was found to be slightly different between the areas ($P = 0.06$; Table 6). In the estuary, catch scores were generally higher closer to shore, whereas catch scores in the inlet were similar regardless of proximity to shore.

Several parameters and their influence on catch scores were examined individually by area (Table 6; Figures 6 and 7). The reasoning for such analyses was related to sampling design and difficulties imposed by the study area. For example, the metric 'distance to inlet' (a geographical proximity measure) was analyzed individually for the inlet and estuary because this measure was so strongly correlated with the project sampling design (i.e., inlet and estuary sampling locations were split out). Depth measurements were not collected at sampling locations in the estuary because the depth finder on the skiff was not functioning. Vertical plankton tows were conducted to compute a measure of prey availability (i.e., zooplankton volume) for inlet sampling locations only; the shallow waters of the estuary did not allow for sampling at the 20 m depth identified in the sampling design. Catch scores were found to be significantly higher at areas within the inlet that had higher prey availability, which is strongly supported in other evaluations of juvenile salmon distribution, abundance, and survival (Orsi et al. 2000; St. John et al. 1992; Weitkamp and Sturdevant 2008).

The distance-to-inlet metric provided no discriminatory evidence to explain higher catch scores of juvenile salmon in the inlet itself, which suggested a random or relatively consistent abundance of prey in the offshore marine areas of the inlet, at least with respect to sampling locations. In the estuary however, where no estimates of prey availability were conducted, areas that were farther from the inlet (i.e., closer to the upper extent of tidal influence and mouth of the Taku River) had consistently higher catch scores of juvenile salmonids. It is possible that catch scores were higher at the upper extent of the estuary as a result of the Taku River estuary being particularly small relative to its drainage area and the number of salmon that pass through it (Lorenz and Schroeder 2010), and that the upper extent of the estuary is the narrowest part of the entire study area, which creates a natural bottleneck (Figure 2). The upper extent of the estuary is also where emigrant juvenile salmon are initially exposed to habitats influenced by salt water that requires them to undergo physiological changes associated with osmoregulation, which also likely contributes to the bottleneck.

A comparison of results obtained from both phases of the overall project provides further clarity in understanding juvenile salmonid distribution patterns across the project area, but also raises additional questions. During phase I of this project, the study area was similarly stratified into estuary and inlet; however, sampling locations in this phase occurred only in close proximity (<20 m) to the shore and thus all sampling was considered to be 'nearshore', regardless of the stratification imposed for distinguishing estuary from inlet areas. In contrast, phase II of this project employed an 'offshore' sampling strategy where all sampling locations were >20 m from the shore, even in the narrowest portions of the study area. Cumulatively, the sampling employed in the two phases of the project elucidates juvenile salmonid distribution patterns from shoreline to shoreline and the mid-channel or neritic habitats in between, as well as along the entire longitudinal profile of the estuary through Taku Inlet.

Physiochemical parameter estimates observed in offshore sampling locations (phase II) mirrored patterns found in nearshore areas (phase I) in both the estuary and inlet for surface temperature, turbidity, and salinity. Surface temperature and salinity were both significantly higher in the inlet compared to the estuary, across both nearshore and offshore locations. Turbidity was also found to be consistently higher in both nearshore and offshore areas of the estuary compared to the inlet. Dissolved oxygen, which was found to be significantly higher in the estuary in offshore locations, was similar throughout the estuary and inlet in nearshore areas. Values for pH displayed an opposing trend: where pH was not different across estuary and inlet areas associated with offshore sampling, values were higher in the estuary compared to the inlet during the nearshore phase. Measures of distance to shore, distance to inlet, depth, river discharge, and prey availability were not examined in the nearshore (phase I) project for area (i.e., estuary vs. inlet) or catch score comparisons.

In contrast to the pattern observed in offshore sampling related to individual physiochemical parameters associated with catch scores, several variables were found to be significantly related to the relative abundance of juvenile salmonids in nearshore sampling. These included water temperature, salinity, turbidity, and pH: higher water temperatures and greater salinity values were positively correlated with catch scores of juvenile salmon; and catch scores of juvenile salmon were higher in locations with lower pH. Patterns for dissolved oxygen and turbidity and their effect on catch scores were consistent for nearshore and offshore sampling: there was no significant difference in dissolved oxygen levels among locations with different catch scores, and catch scores were higher in locations with lower turbidity. It is possible that the patterns observed during both phases of this project were related to fish size and might be different for each salmon species; for example, Heifetz et al. (1989) determined that age-0 sockeye salmon in the Situk River estuary had a size-related salinity tolerance, where a size of at least 50 mm was required for 100% survival in seawater. However, the study design for this project did not include the level of detail necessary to investigate possible size-related environmental tolerances in the Taku River estuary and Taku Inlet.

More detailed length data would have also permitted investigation of size-related distribution patterns that might exist between both nearshore and offshore/neritic habitats, as well as between the estuary and the inlet. Smaller fish tend to occupy shallow littoral areas at first, and move into deeper water as they grow (Celewycz 1989; Duffy 2003, Duffy et al. 2005; Fresh 2006; McCabe et al. 1983; MacDonald et al. 1987; Semmens 2008; Thorpe 1994); swimming ability is proportional to fish size, and therefore, larger fish are able to occupy deeper habitats farther from shore where there is little protection from water currents (Chapman and Bjornn 1969; Hillman and Griffith 1987; MacDonald et al. 1987). Juvenile Pacific salmon survival rate is lowest during their transition from fresh water to salt water and may be further influenced by differences in size (Duffy 2003, Duffy et al. 2005; Heifetz et al. 1989; Mortensen et al. 2000; Moulton 1997; Murphy et al. 1988) such that smaller fish are more vulnerable to predators (Duffy 2003, Duffy et al. 2005; Murphy et al. 1988).

This study was conducted over 4 consecutive years and sampling only occurred once a month during each field season. Sampling earlier in the spring (to capture more of the pink and chum salmon outmigration), sampling on a weekly basis during the field season, and sampling over a longer period of time (in years) would result in a more comprehensive and detailed account of spatial and temporal habitat use patterns for juvenile Pacific salmon in the Taku River estuary and Taku Inlet. More intensive sampling efforts would also provide the data required to investigate differences between habitat use by each individual salmon species, which would be useful to fisheries managers responsible for protecting and managing specific salmon species.

Results from the two phases of this project provide information on how fish populations are distributed seasonally in the Taku River estuary and marine waters of Taku Inlet, and which biotic, abiotic, and physical habitat parameters are most important. These baseline data may assist managers in making informed resource management decisions for these important habitats in one of the most significant fish producing systems in SEAK.

ACKNOWLEDGEMENTS

We are grateful to the many individuals who contributed to the completion of the second phase of this project. We would like to thank the following individuals for all of their hard work and assistance with collecting data for this project: Jeff Williams, Chris S'gro, Jason Hass, Matt Kern, David Leonard, Nathan Frost, Tony Florendo, Jäspri Sylvan, and Cecil Rich. In addition to field work, most of the aforementioned people also helped with trip preparation and clean-up, as well as data entry.

We would also like to thank Cecil Rich, Tom Brookover, John Der Hovanisian, Brian Frenette, and Dan Reed for providing valuable input through their review of the 2010 and 2011 operational plans.

This project would not have been possible without the help and expertise of John and Clayton Etheridge (captain/owner and deckhand on the F/V *Seaview*) and Aaron Woodrow and Andrew Bacom (captain/owner and deckhand on the F/V *Sundance*). We would also like to thank Southeast Float Rental LLC for the accommodations and gear storage we used throughout the project.

Funding for the work discussed in this report was provided through the State Wildlife Grant (SWG) program with a 50% match provided by Fish and Game funds.

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APPENDIX A: FISH SPECIES

Appendix A1.–Taxonomic identification of all fish captured during this project in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Species
Pacific sand lance (*Ammodytes hexapterus*)
Crested sculpin (*Blepsias bilobus*)
Pacific herring (*Clupea pallasii*)
Pacific spiny lumpsucker *(Eumicrotremus orbis)*
Threespine stickleback *(Gasterosteus aculeatus)*
American river lamprey *(Lampetra ayresii)*
Pacific staghorn sculpin *(Leptocottus armatus)*
Snake prickleback *(Lumpenus sagitta)*
Capelin *(Mallotus villosus)*
Pink salmon *(Oncorhynchus gorbuscha)*
Chum salmon *(Oncorhynchus keta)*
Coho salmon *(Oncorhynchus kisutch)*
Sockeye salmon *(Oncorhynchus nerka)*
Chinook salmon *(Oncorhynchus tshawytscha)*
Starry flounder *(Platichthys stellatus)*
Round whitefish *(Prosopium cylindraceum)*
Dolly Varden *(Salvelinus malma)*
Eulachon *(Thaleichthys pacificus)*
Pacific sandfish *(Trichodon trichodon)*
Class Osteichthyes (bony fish; unidentified)
Order Pleuronectiformes (flatfish; unidentified)
Family Cottidae (sculpin; unidentified)
Family Gadidae (cod; unidentified)
Family Liparidae (snailfish; unidentified)
Family Myctophidae (lanternfish; unidentified)
Family Osmeridae (smelt; unidentified)
Family Stichaeidae (prickleback; unidentified)
Family Trichodontidae (sandfish; unidentified)
Subfamily Coregoninae (whitefish; unidentified)

APPENDIX B: TAKU RIVER USGS STREAM FLOW DATA

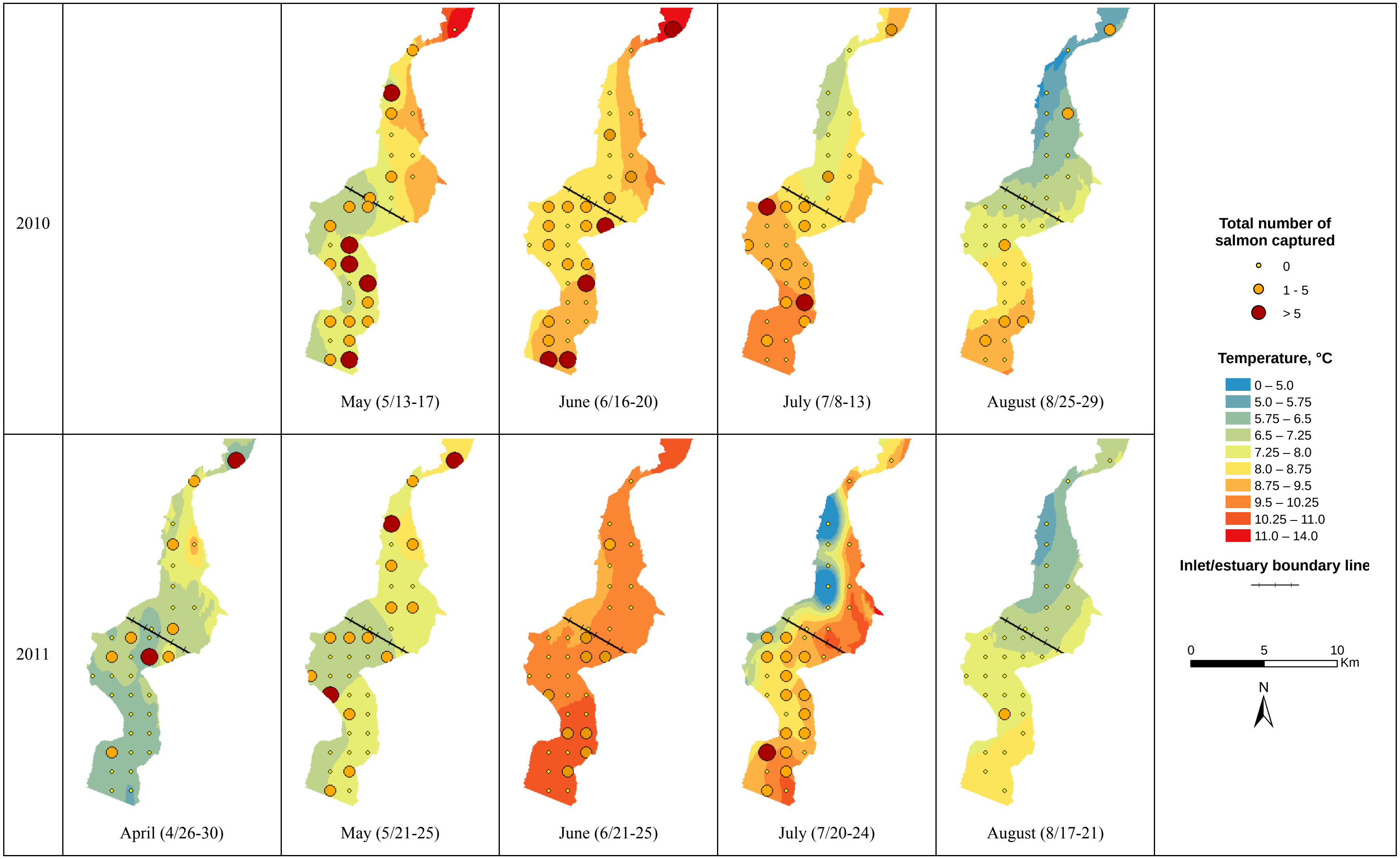
Appendix B1.–Taku River stream flow data, including the 20-year daily mean, for sampling dates in 2010.

Sampling date	Stream discharge (cfs)	20-year daily mean discharge (cfs)
05/13/2010	11,100	17,400
05/14/2010	11,000	18,900
05/15/2010	11,000	20,200
05/16/2010	11,400	20,600
05/17/2010	12,000	21,100
06/16/2010	17,100	38,000
06/17/2010	16,800	37,200
06/18/2010	16,700	36,400
06/19/2010	17,400	36,200
06/20/2010	18,500	36,200
07/08/2010	22,700	32,400
07/09/2010	24,600	30,800
07/10/2010	26,000	30,800
07/11/2010	28,500	31,200
07/12/2010	26,200	31,500
07/13/2010	21,800	32,000
08/25/2010	16,200	21,300
08/26/2010	14,800	21,600
08/27/2010	14,300	21,000
08/28/2010	13,300	21,100
08/29/2010	12,200	22,000

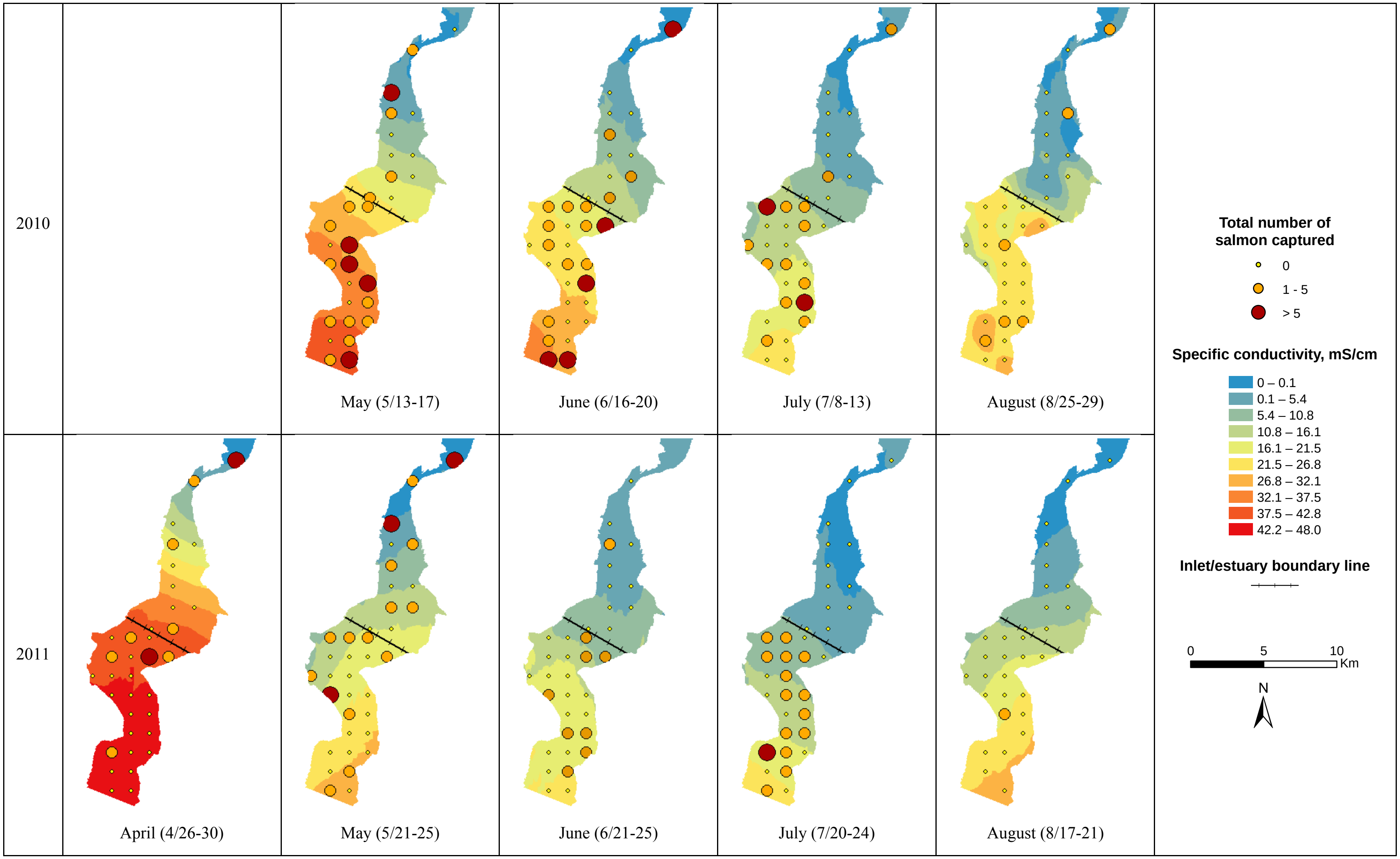
Appendix B2.–Taku River stream flow data, including the 20-year daily mean, for sampling dates in 2011.

Sampling date	Stream discharge (cfs)	20-year daily mean discharge (cfs)
04/25/2011	2,700	6,550
04/26/2011	2,980	7,200
04/27/2011	3,170	7,850
04/28/2011	3,220	8,420
04/29/2011	3,350	8,880
04/30/2011	3,420	9,420
05/21/2011	23,000	23,300
05/22/2011	26,400	24,300
05/23/2011	27,200	25,400
05/24/2011	25,900	26,600
05/25/2011	29,100	28,500
06/21/2011	23,500	33,900
06/22/2011	23,600	33,600
06/23/2011	23,500	32,700
06/24/2011	24,300	32,400
06/25/2011	27,500	34,200
07/20/2011	22,600	31,900
07/21/2011	21,400	31,900
07/22/2011	21,500	32,100
07/23/2011	23,000	32,700
07/24/2011	24,300	31,600
08/17/2011	15,300	32,300
08/18/2011	14,600	30,400
08/19/2011	14,800	31,600
08/20/2011	24,800	30,400
08/21/2011	49,600	24,400

APPENDIX C: WATER QUALITY AND PLANKTON SURFACE PLOT MAPS

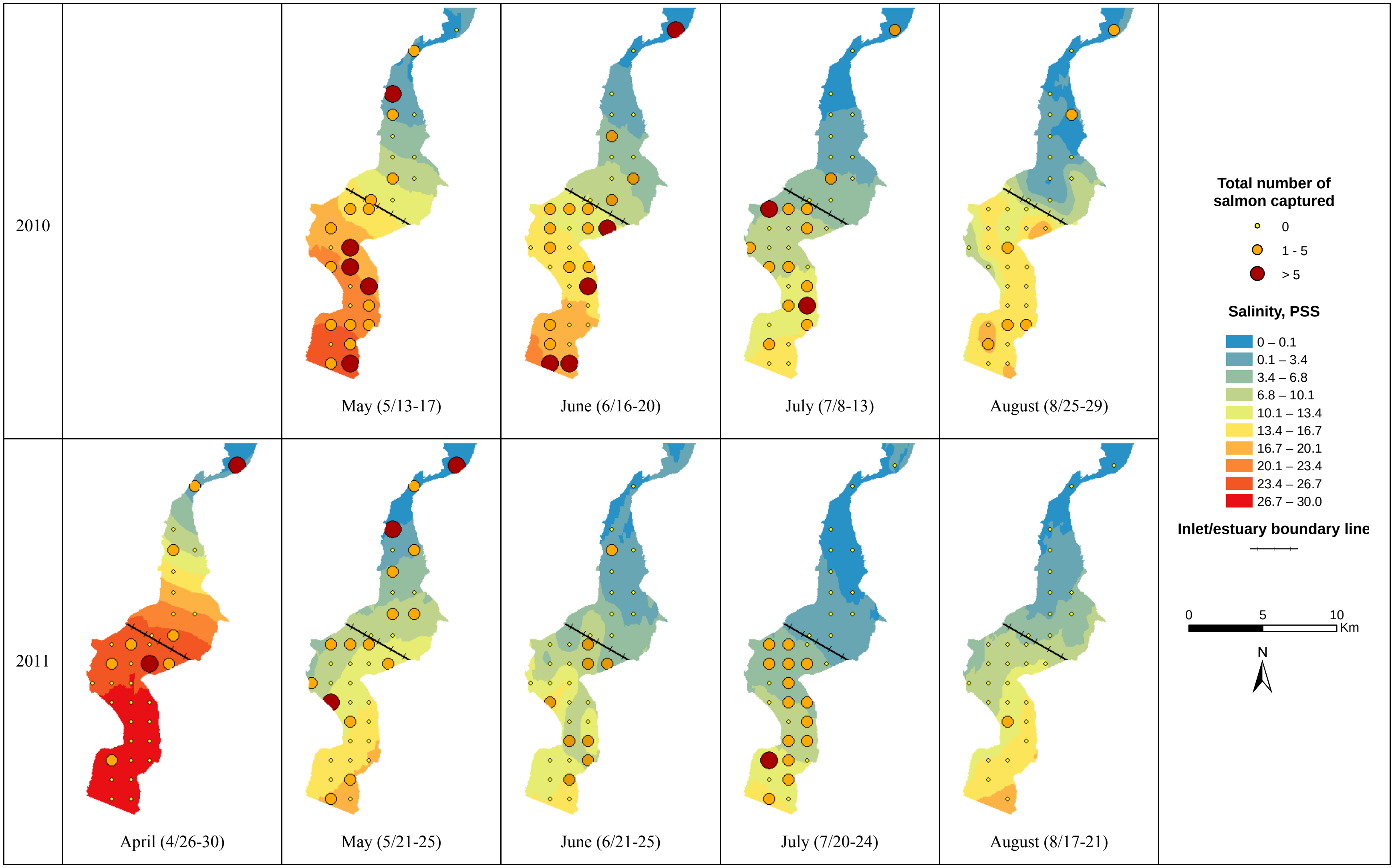


Appendix C1.–Surface plots of interpolated water temperature values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

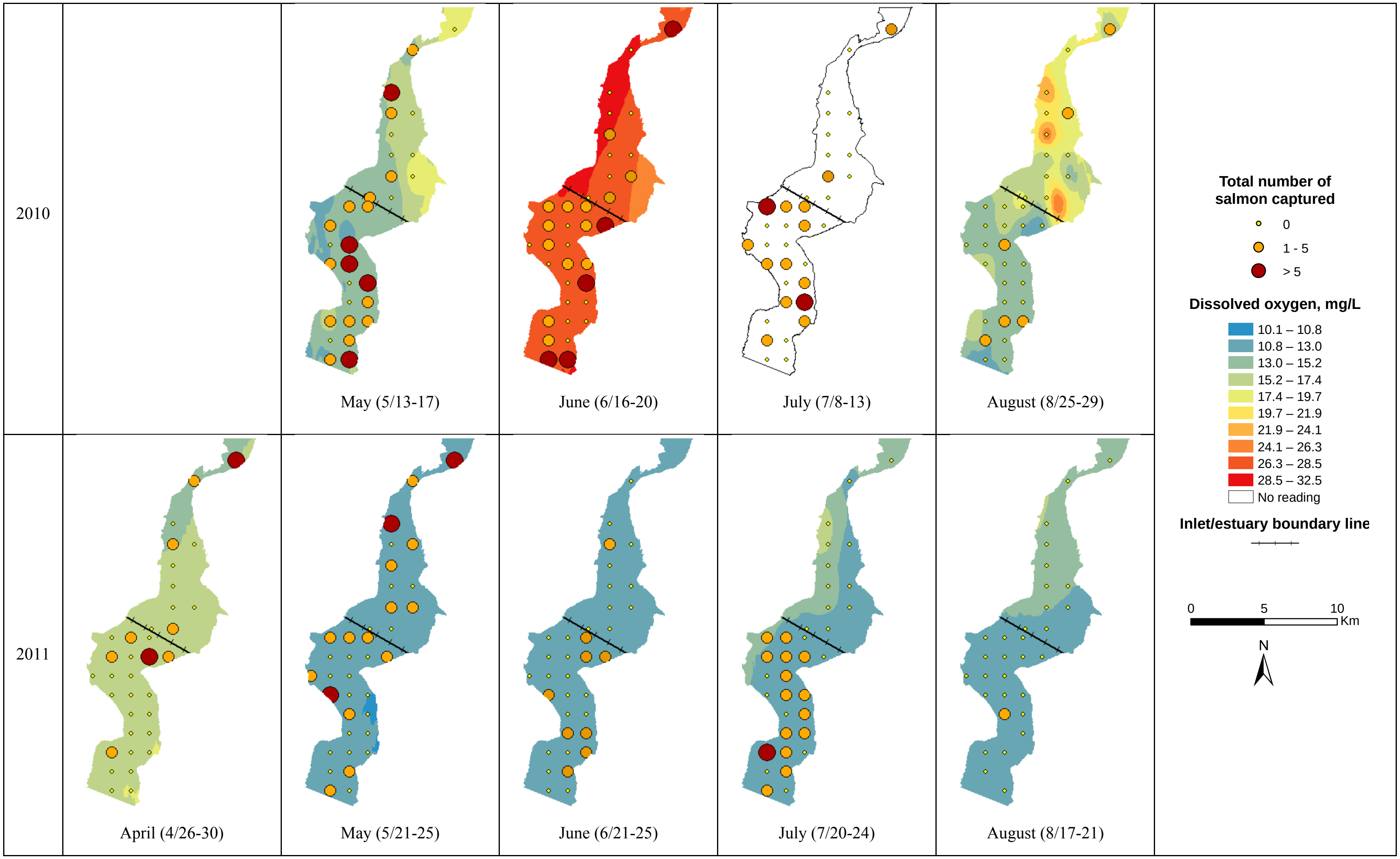


Appendix C2.–Surface plots of interpolated specific conductivity values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Note. The water quality sensor used in this project derived salinity values from conductivity measurements, therefore conductivity and salinity measurements are correlated and not independent.

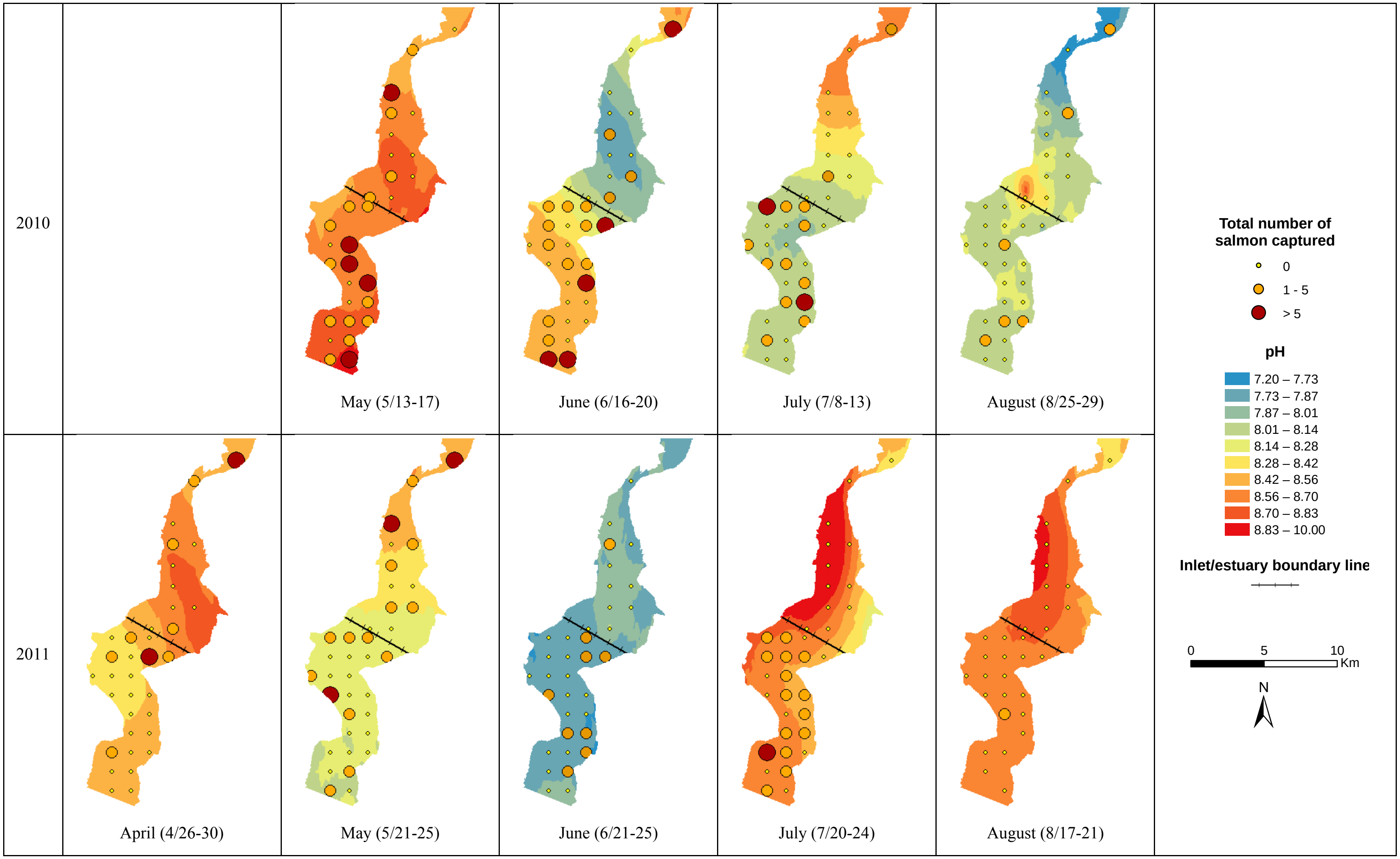


Appendix C3.–Surface plots of interpolated salinity values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.



Appendix C4.–Surface plots of interpolated dissolved oxygen values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

Note. Dissolved oxygen data was not collected in July 2010, due to a malfunctioning sensor.



Appendix C5.–Surface plots of interpolated pH values and associated salmon catch results (by year and sampling period) at locations sampled in Taku Inlet and the Taku River estuary, Southeast Alaska, 2010 and 2011.

APPENDIX D: DATA FILES

Appendix D1.–Electronic computer files submitted with this report.

File Name	Description
Taku_2010_FinalData.xls	Excel file containing all fish, water, and plankton data collected during the 2010 field season.
Taku_2011_FinalData.xls	Excel file containing all fish, water, and plankton data collected during the 2011 field season.
BoxPlots_2010-2011_FDS_Final.xls	Excel file containing all box plots and associated data produced for this report by project biometrician.
TakuRiver_Watershed_FDS.jpg	JPEG map of the Taku River watershed.
TakuInletEstuary_StudyArea_FDS.jpg	JPEG map of the project study area.
TakuInlet_SamplingLocs_2010-2011_FDS.pdf	PDF map showing project sampling locations in Taku Inlet.
TakuEstuary_SamplingLocs_2010-2011_FDS.pdf	PDF map showing project sampling locations in the Taku River estuary.
2010_FishData.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2010 fish data.
2011_FishData.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2011 fish data.
2010_Plankton.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2010 plankton data.
2011_Plankton.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2011 plankton data.
2010_WaterData.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2010 water data.
2011_WaterData.shp	GIS shapefile (State Plane, NAD83, FIPS 5001 projection) containing the 2011 water data.