  

STREAM TEMPERATURE MONITORING NETWORK FOR COOK INLET SALMON STREAMS 2011 DATA

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Prepared by

COOK INLETKEEPER

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EXECUTIVE SUMMARY

The Cook Inlet basin in Southcentral Alaska encompasses 47,000 square miles and contains high quality freshwater and marine salmon habitat, some of which is at risk due to climate and land-use change. High stream temperatures stress fish making them increasingly vulnerable to pollution, predation and disease. Yet despite the links between warm water temperatures and reduced salmonid survivorship in other regions, there is little consistent, long-term temperature data for salmon streams in Alaska. Through this multi-year project, we are implementing a Stream Temperature Monitoring Network to identify thermal impacts in coastal salmon habitat. Beginning in the summer of 2008, continuous water and air temperatures have been taken in 48 non-glacial salmon streams during open-water periods. This report presents the fourth year of data (2011) from this five year collaborative project.

In 2011, stream temperatures exceeded Alaska's water temperature criteria of 13°C at 42 sites, 15°C at 36 sites, and 20°C at 11 sites. Maximum stream temperatures varied broadly among sites: 11.6 – 22.5°C, with average summer temperatures ranging from 7.5 – 17.3°C. In 2011, weekly air and water temperatures continued to have a stronger relationship than daily temperatures; average air and water temperatures have a stronger relationship than maximum temperatures. In preparation for the 5-year data synthesis and regional analysis, watershed and site characteristics have been identified which will be assessed for their potential to buffer salmon habitat from climate and land-use impacts. This project will play an important role in helping state and federal resource managers prioritize streams for research, restoration and protection efforts to ensure Alaska wild salmon endure as thermal change continues.

Background

Water temperature plays a critical role in all phases of the salmonid lifecycle, especially in freshwater systems. Stream temperature affects survivorship of eggs and fry, rate of respiration and metabolism, timing of migration, and availability of oxygen and nutrients. High water temperatures have been shown to induce physiological stress in salmon, which makes them more vulnerable to secondary stressors such as pollution, predation and disease.[1] However, water temperature can vary greatly across watersheds or even among tributaries within the same watershed, due to climatic drivers as well as structural factors like stream morphology, land cover, and groundwater influence.[2]

Due to the critical role that water temperature plays in the function of aquatic ecosystems and because human activities may impact temperature, the Alaska Department of Environmental Conservation has adopted maximum water temperature criteria under Alaska's Water Quality Standards (18 AAC 70) to meet the federal Clean Water Act's fishable and swimmable goals.[3] (See box to the right for Alaska's numeric water temperature criteria for the growth and propagation of freshwater fish, shellfish, other aquatic life and wildlife.)

ALASKA'S
WATER TEMPERATURE CRITERIA

The following maximum temperatures shall not be exceeded, where applicable:

egg & fry incubation = 13°C
spawning areas = 13°C
migration routes = 15°C
rearing areas = 15°C

and may not exceed 20°C at any time.

In 2002, monitoring by the Homer Soil and Water Conservation District and Cook Inletkeeper revealed that wetland-dominated salmon streams on the lower Kenai Peninsula exceeded Alaska's water temperature criteria for egg and fry incubation (13°C) on more than 50 days in the summer. By 2005, exceedances were happening on more than 80 days with maximum temperatures above 20°C.[4] Other studies in upper Cook Inlet salmon streams show maximum temperatures in Montana Creek[5], a clear water tributary to the Susitna River, and Cottonwood Creek[6], a lake-dominated system, also above state water temperature criteria.

As salmon populations continue to decline in the southern part of their range, numerous synthesis papers have come out in an attempt to determine the maximum temperature limits for Pacific salmon.[7, 8] Based on a multi-agency workgroup in 2001, thermal conditions known to support different life stages of salmon were summarized (see Table 1).[9] More recent work highlights the complexity of ensuring salmonid survival due to the need to consider climate change, the evolution of historic population structure, spatio-temporal variability, and the need for rigorous monitoring programs.[10]

Despite the links between warm water temperatures and reduced salmonid survivorship in other regions[11], there is little consistent, long-term temperature data for salmon streams in Alaska. Given Alaska's extreme size, preponderance of water bodies, and small population base, implementing a Stream Temperature Monitoring Network on a large basin scale, such as the Cook Inlet basin, is prudent and an effective use of financial and human resources.

Table 1. Estimates of thermal conditions known to support life stages and biological functions of anadromous salmon. These numbers do not represent rigid thresholds, but rather represent temperatures above which adverse effects are more likely to occur.

Consideration	Condition	Temperature
Temperature of common summer habitat use		10-17°C
Lethal temperatures (one week exposure)	Adults:	> 21-22°C
	Juveniles:	>23-24°C
Adult migration	Blocked:	>21-22°C
Swimming speed	Reduced:	>20°C
	Optimal:	15-19°C
Gamete viability during holding	Reduced:	>13-16°C
Disease rates	Severe:	>18-20°C
	Elevated:	14-17°C
	Minimized:	<12-13°C
Spawning	Initiated:	7-14°C
Egg incubation	Optimal:	6-10°C
Optimal growth	Unlimited food:	13-19°C
	Limited food:	10-16°C
Smoltification	Suppressed:	>11-15°C

The Cook Inlet basin encompasses 47,000 square miles and contains high quality freshwater and marine salmon habitat, some of which is at risk due to climate and land-use change. Alaska is thought to be experiencing the greatest regional warming of any state in the U.S. and warming patterns are expected to continue at least into the next century. In addition, the Cook Inlet watershed is the most populated and fastest-growing region in Alaska.[12]

All five species of wild Pacific salmon return to Alaska's Cook Inlet basin to spawn.

PROJECT GOALS AND OBJECTIVES

The goal of the Stream Temperature Monitoring Network for Cook Inlet Salmon Streams is to identify thermal impacts in coastal salmon habitat. Stream temperature data will be used to identify watershed characteristics that buffer stream temperatures, thus making them less susceptible to climate and land-use changes. The main objectives are to: 1) collect comparable temperature data for 48 non-glacial salmon streams; 2) generate GIS maps to illustrate temperature patterns, temperature exceedances, and potential thermal refugia; and 3) generate maps of future scenarios of air temperature and precipitation conditions derived from climate projection data for the Cook Inlet basin. This report presents the fourth year of data (2011) from this five year collaborative project.

METHODS

The Stream Temperature Monitoring Network is the result of protocol development and monitoring design work which began in 2007. A technical advisory committee made up of state, federal, and private resource managers and scientists worked together to develop a standardized protocol for monitoring water temperature. This protocol[13] contains a detailed description of methods, equipment needed, how to deploy data loggers in the field, how to program and download data, and how to perform maintenance and quality assurance measures. Using these protocols, Cook Inletkeeper coordinated with project partners, resource agencies, and community-based groups to collect temperature data in 48 salmon streams. Cook Inletkeeper worked with Kenai Watershed Forum to compile these data, with Aquatic Restoration and Research Institute during preliminary data analysis, and with The Nature Conservancy of Alaska to generate GIS maps to illustrate temperature patterns across the Cook Inlet basin.

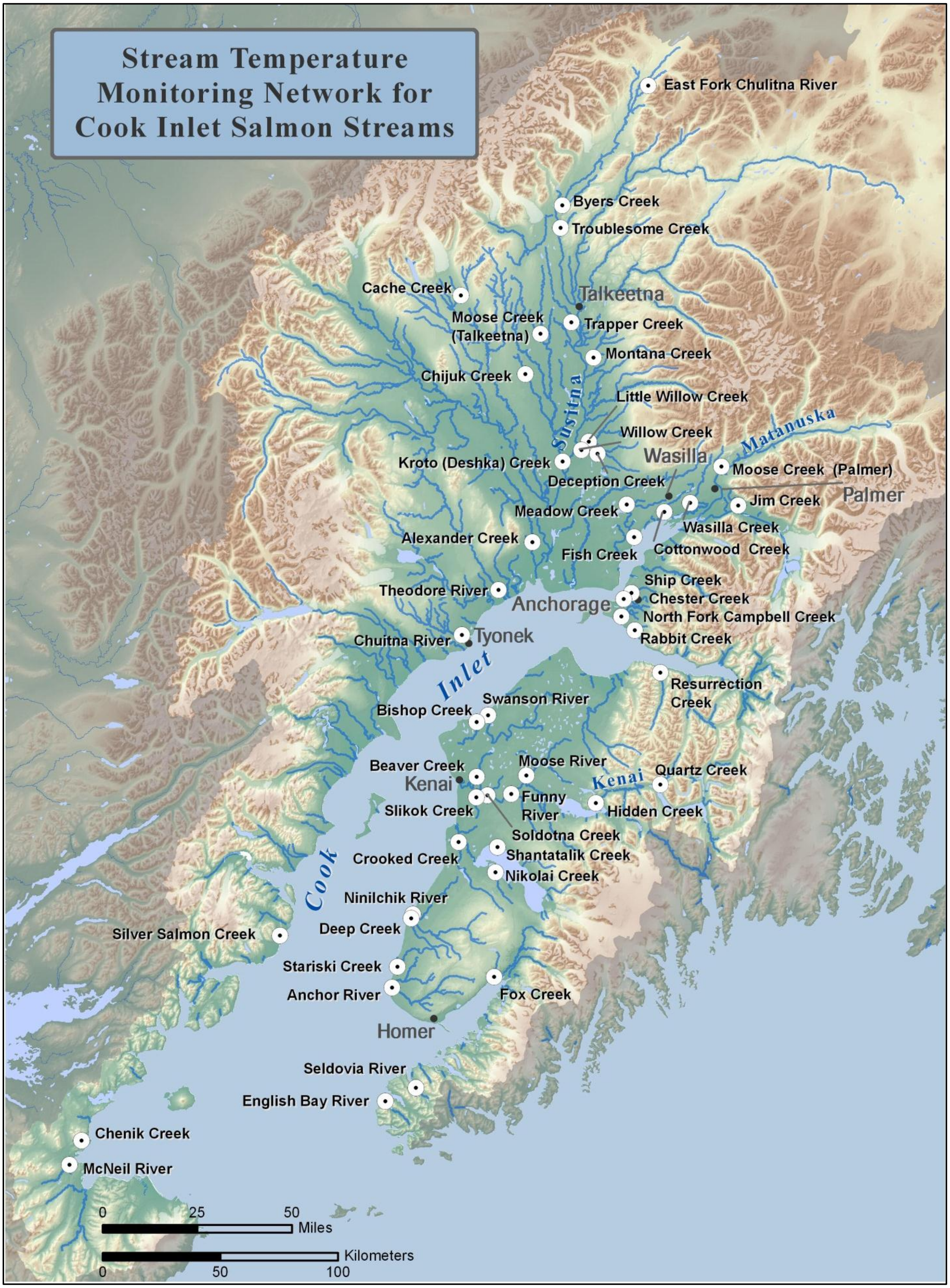
The Cook Inlet sampling design includes 48 non-glacial salmon streams which represent both large and small watersheds; and clear water and brown water systems (Table 2, Map 1). Streams were selected because of existing stream gages, fish weirs, ease of access and the availability of partners to perform maintenance and quality assurance checks. The streams selected represent a range of urban development but all of them are considered reference streams (i.e. benchmarks) for the goal of establishing a baseline relationship between air and water temperature in a variety of stream types. We selected specific sampling locations as far downstream in the watershed as possible, where the stream water is flowing and well mixed and not likely to be dewatered during low flows, and with no tidal influence. Side channels, backwaters, or areas below tributary inputs were avoided. We used a hand-held thermometer to ensure that the water was well mixed and that temperatures are consistent (within 0.3°C) both vertically and horizontally.

Prior to deployment, we checked data logger accuracy against a National Institute of Science and Technology (NIST)-certified thermometer. Data loggers (StowAway TidbiT, TidbiT v2, and HOBO Water Temp Pro v2) were programmed for a recording interval of 15 minutes. We secured water loggers in stream using one of two methods: 1) the logger was cable tied inside a protective case or PVC housing, which was attached by a cable to a rebar stake. A stake pounder was used to sink the rebar 3 feet into the stream bottom near a large rock or other landmark; or 2) the logger was attached to trees or other stationary objects on the stream bank using plastic coated cable. The cable was attached to the logger with clamps and a loop was made at the opposite end of the cable using similar clamps. The cable was wrapped around the stationary object on the bank and the logger passed through the loop and placed within the stream. The cable was buried under the grass to avoid detection and to keep it from catching on passing wildlife. A large rock or weight was placed on the cable in the stream approximately 6 inches above the logger, securing the logger in place.

Water data logger is inside PVC housing and secured by cable to rebar.

Table 2. Cook Inlet Stream Temperature Monitoring Network data logger locations.

LOCATION	REGION	DESCRIPTION	Latitude	Longitude
Alexander Creek	Mat-Su	approx. 2 miles upstream from Susitna River	61.44000	-150.59600
Anchor River	Kenai	immediately downstream of weir	59.77300	-151.83400
Beaver Creek	Kenai	Togiak Road access	60.56100	-151.12300
Bishop Creek	Kenai	Silvertip Road access	60.76800	-151.10300
Byers Creek	Mat-Su	upstream from Park's Highway	62.71158	-150.20407
Cache Creek	Mat-Su	1/2 mile downstream from east end of landing	62.38900	-151.08100
Chenik Creek	West Inlet	incorporated into stream gage set up	59.20900	-154.19000
Chester Creek	Anchorage	downstream of Arctic Blvd	61.20500	-149.89600
Chijuk Creek	Mat-Su	Oilwell Road Crossing	62.07963	-150.58314
Chuitna River	West Inlet	1/4 mile upstream of Beluga Highway bridge	61.10100	-151.19000
Cottonwood Creek	Mat-Su	upstream from Surrey Road	61.52500	-149.52700
Crooked Creek	Kenai	lower site below hwy, Cohoe King Road access	60.31600	-151.28400
Deception Creek	Mat-Su	upstream from Willow-Fishook Road	61.76200	-150.03400
Deep Creek	Kenai	1/4 mile upstream from highway bridge	60.03300	-151.67100
East Fork Chulitna River	Mat-Su	downstream from Park's Highway	63.14500	-149.42100
English Bay River	Kenai	20 feet upstream of weir	59.34300	-151.91200
Fish Creek	Mat-Su	below Knik-Goose Bay Road	61.43800	-149.78100
Fox Creek	Kenai	public access trail above private land at m	59.79900	-151.05600
Funny River	Kenai	upstream of Funny River Road bridge	60.49000	-150.86000
Hidden Creek	Kenai	1000 feet upstream of Kenai River confluence	60.43900	-150.20800
Jim Creek	Mat-Su	1 mile upstream of Jim Creek Flats	61.52900	-148.93300
Kroto (Deshka) Creek	Mat-Su	1.0 miles upstream from Susitna River	61.74000	-150.32000
Little Willow Creek	Mat-Su	0.25 miles downstream from Parks Highway	61.81000	-150.09900
McNeil River	West Inlet	incorporated into stream gage set up above	59.11700	-154.27900
Meadow Creek	Mat-Su	Beaver Lakes Road Crossing	61.56300	-149.82400
Montana Creek	Mat-Su	end of Access Road South of Helena	62.12800	-150.01900
Moose Creek, (Palmer)	Mat-Su	150 yards downstream of Glenn Hwy bridge	61.68200	-149.04300
Moose Creek (Talkeetna)	Mat-Su	Oilwell Road Crossing	62.22900	-150.44100
Moose River	Kenai	1 mile up, Otter Trail Rd.	60.55700	-150.73500
NF Campbell Creek	Anchorage	upstream of Diamond Blvd. and Campbell Lake	61.14000	-149.92300
Nikolai Creek	Kenai	boat to mouth, 75 feet downstream of weir	60.19500	-151.00900
Ninilchik River	Kenai	immediately downstream of highway bridge	60.04900	-151.65600
Quartz Creek	Kenai	1.5 miles upstream along highway corridor	60.49300	-149.70000
Rabbit Creek	Anchorage	upstream of Old Seward Hwy crossing	61.08500	-149.82300
Resurrection Creek	Kenai	1/4 mile upstream from highway bridge	60.91800	-149.64300
Seldovia River	Kenai	3/4 mile upstream of mouth	59.38900	-151.68000
Shantatalik Creek	Kenai	boat to mouth, 75 feet upstream of weir	60.29100	-150.98500
Ship Creek	Anchorage	downstream of Reeve Blvd.	61.22700	-149.83100
Silver Salmon Creek	West Inlet	1/2 mile upstream from Ranger station	59.98184	-152.67859
Slikok Creek	Kenai	Chugach Rd access	60.48300	-151.13100
Soldotna Creek	Kenai	upstream of East Redoubt Rd. crossing	60.48900	-151.04400
Stariski Creek	Kenai	1/4 mile upstream from highway bridge	59.85100	-151.78700
Swanson River	Kenai	North Kenai Road crossing	60.79200	-151.01200
Theodore River	Mat-Su	500 yards upstream from Beluga Hwy bridge	61.26600	-150.88400
Trapper Creek	Mat-Su	Bradley Road Crossing	62.26600	-150.18400
Troublesome Creek	Mat-Su	downstream from Park's Highway	62.62700	-150.22700
Wasilla Creek	Mat-Su	Nelson Road access	61.55300	-149.31400
Willow Creek	Mat-Su	0.25 miles upstream from Susitna River	61.78000	-150.16100



Map 1. Cook Inlet Stream Temperature Monitoring Network data logger locations.

In addition, we collected air temperature data at each monitoring location. Air temperature loggers were secured within a solar radiation shield. The solar shield and logger were secured to a post or suspended from vegetation in the area at least 6 feet off of the ground. The air temperature logger was placed 25 - 100 feet from the stream in an effort to prevent water temperature from influencing local air temperature data. Supplemental site and reach information was also collected including latitude and longitude location, elevation, channel width and depth, extent to which vegetation shades logger, channel flow status, and stream habitat type.

We deployed loggers from mid-May to mid-June as conditions allowed. Data-collecting partners periodically checked on loggers to ensure that they were still in place and operating. At the end of the field season (after October 1), the loggers were retrieved and the data downloaded on a data shuttle or base station. Data loggers were checked a second time for sufficient battery power, and temperature accuracy at approximately 0 and 20°C using a NIST thermometer. For more details, the Quality Assurance Project Plan is available from Inletkeeper upon request.

Temperature statistics were calculated for each site and include overall maximum temperature; daily, weekly and seasonal average, maximum, and minimum temperature; monthly cumulative degree days (sum of average daily temperatures); maximum 7-day rolling average (MWAT), maximum 7-day rolling maximum temperature (MWMT); and maximum daily fluctuation. Water temperature data were also compared to Alaska's numeric water temperature criteria.

We use regression equations to determine the relationship between daily and weekly average and maximum water temperatures and air temperatures. Air temperatures from each site were compared with water temperatures. Linear regressions provide a measure of the strength of the relationship through the R^2 value; R^2 values closest to 1.0 represent the strongest relationship. Regression coefficients (slope of the linear relationship) quantify the correlation of water temperature to air temperature.

2011 Results

We deployed data loggers at 48 sites and retrieved 47 air temperature datasets (missing Cottonwood Creek) and 47 water temperature datasets (missing Rabbit Creek), which is a 97.9% retrieval rate. Water loggers at Moose Creek (Talkeetna), NF Campbell Creek and Quartz Creek had to be reset after the original loggers were lost. The East Fork Chulitna water logger had to be reset after it was found out of the water. The water logger at Trapper Creek did not start collecting data until July apparently due to a faulty launch procedure. Water temperature datasets from Alexander Creek and Kroto (Deshka) Creek had to be truncated due to questionable data. These loggers may have become buried deep in soft sediments causing the temperature profiles to be dampened (i.e. reduced diurnal variability). Datasets for McNeil River and Chenik Creek are of short duration due to limited ADF&G staff presence at these sites.

Range of Variability

Maximum stream temperatures varied broadly among sites: 11.6 – 22.5^{o}C, with average summer temperatures ranging from 7.5 – 17.3^{o}C (Table 3). Average temperatures across all sites were 8.6 – 17.8^{o}C in July and 7.2 – 14.2^{o}C in August; July and August cumulative degree days ranged from 268 - 535 and 223 - 441, respectively. The maximum daily fluctuation was greatest at Fox Creek at 10.3^{o}C and smallest at English Bay River at 3.0^{o}C.

Temperature Exceedances

In the summer of 2011, we recorded water temperatures above 13^{o}C at 42 sites and above 15^{o}C at 36 sites, with temperatures exceeding 20^{o}C at 11 sites (Map 2, Table 4). The number of days of exceedances at sites with shorter deployment dates may be under reported. Twenty-nine sites had a maximum 7-day rolling maximum above 15^{o}C (Map 3). Fourteen sites had a maximum 7-day (or weekly) rolling average (MWAT) above 15^{o}C (Map 4).

Relationship to Air Temperature

In 2011, average summer air temperatures measured at each site ranged from 9.6^{o}C (East Fork Chulitna River) to 13.2^{o}C (Alexander Creek) with 68% of the sites between 10.0 - 11.9^{o}C. July air temperatures ranged from 11.0 - 14.9^{o}C and were colder than in 2009 but warmer than 2008 and 2010 (Chart 1, Map 5).

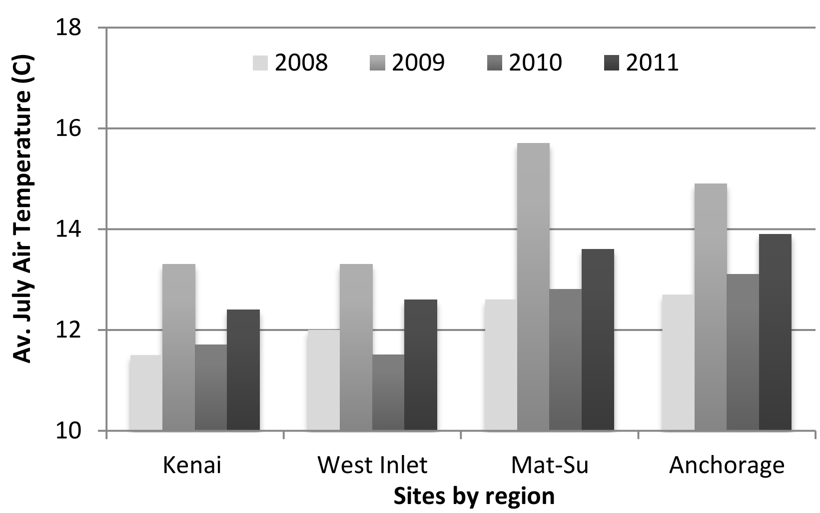
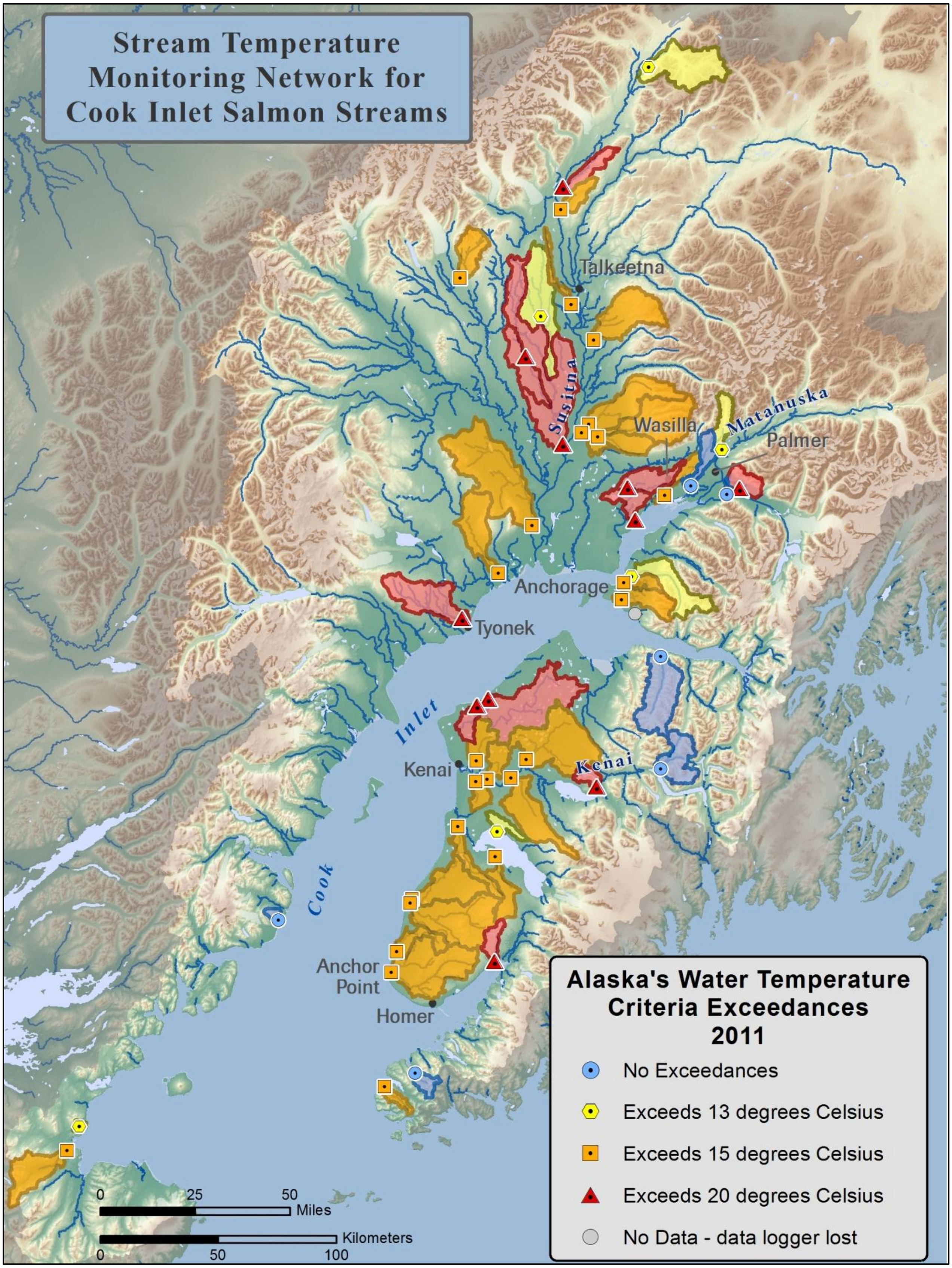


Chart 1. Average July air temperatures by region.

Table 3: Summary of water temperature statistics for May/June through September, 2011. All values are in degrees Celsius (C).

Stream Name	Highest temperature in dataset	Average summer temperature	June average temperature	July average temperature	August average temperature	September average temperature	June degree days	July degree days	August degree days	September degree days	Maximum 7-day rolling average temperature	Maximum 7-day rolling maximum temperature	Maximum Daily Difference
Alexander Creek	19.58	14.58		15.89	13.51			492.56	418.73		16.33	17.59	3.97
Anchor River	19.63	11.42	10.60	13.36	11.23	7.76	318.14	414.15	348.00	232.86	14.19	17.33	8.02
Beaver Creek	16.32	11.68	11.04	13.04	11.84	8.21	331.17	404.31	367.05	246.17	13.53	15.20	5.09
Bishop Creek	20.53	14.14	14.69	16.31	14.00	9.47	440.58	505.59	433.92	284.08	16.82	18.94	5.25
Byers Creek	20.03	13.25	11.91	15.50	12.66	9.60	357.27	480.55	392.51	287.86	16.02	18.47	7.72
Cache Creek	16.37	9.40	8.44	11.09	8.69	6.74	253.06	343.77	269.26	202.28	11.81	14.74	8.81
Chenik Creek	14.43	10.13		10.55				327.09			12.38	13.48	4.22
Chester Creek	16.13	11.94	11.49	13.35	12.03	9.04	344.66	413.79	372.94	271.29	13.78	15.39	5.56
Chijuk Creek	20.87	13.18	14.40	15.56	12.42	8.68	432.01	482.43	385.15	260.38	16.73	18.77	7.58
Chuitna River	21.96	12.52	9.99	15.08	12.16	8.12	299.61	467.55	376.81	243.45	16.21	19.41	7.19
Cottonwood Creek	19.18	13.66	14.35	15.52	13.61	9.40	430.63	481.06	421.92	281.94	15.94	17.67	6.17
Crooked Creek	17.70	11.02	11.03	12.92	10.80	7.31	330.88	400.41	334.70	219.42	13.73	16.55	6.22
Deception Creek	16.15	10.16	10.44	12.20	9.57	6.80	313.27	378.18	296.64	204.04	12.60	14.52	5.97
Deep Creek	19.22	11.37	10.40	13.18	11.44	7.71	311.86	408.62	354.71	231.39	14.27	17.59	7.85
East Fork Chulitna River	13.59	7.49			7.19	5.33			222.75	159.93	9.71	11.74	6.58
English Bay River	16.94	13.20		14.01	14.13	10.65		434.44	437.92	319.61	15.09	15.91	2.96
Fish Creek	20.37	14.13	15.11	16.28	13.94	9.26	453.32	504.74	432.00	277.66	16.81	18.68	5.77
Fox Creek	20.46	12.01	11.54	13.72	11.96	8.42	346.21	425.37	370.88	252.49	14.37	18.37	10.34
Funny River	16.09	9.68	9.25	11.41	9.61	6.27	277.48	353.63	298.05	188.06	12.35	14.59	5.57
Hidden Creek	21.44	13.91	11.89	15.67	14.07	10.71	356.56	485.71	436.28	321.16	16.87	19.55	7.81
Jim Creek	22.32	14.97		17.82	14.24	9.77		552.31	441.37	293.13	19.22	20.77	4.12
Kroto (Deshka) Creek	22.49	17.33	15.47	17.24			464.13	534.57			18.64	20.35	5.76
Little Willow Creek	16.42	10.39	9.74	12.22	10.00	7.28	292.05	378.80	309.87	218.46	12.55	14.26	4.48

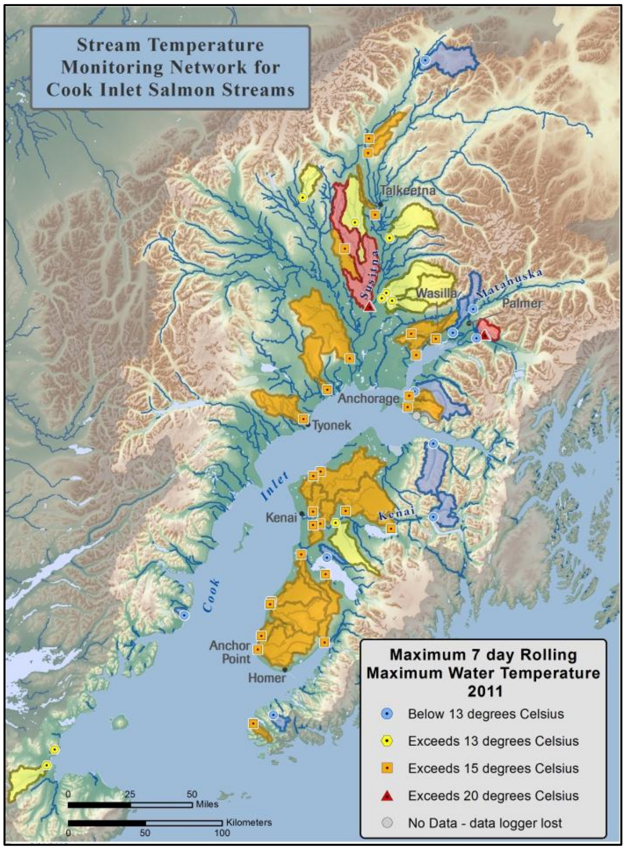
Stream Name	Highest temperature in dataset	Average summer temperature	June average temperature	July average temperature	August average temperature	September average temperature	June degree days	July degree days	August degree days	September degree days	Maximum 7-day rolling average temperature	Maximum 7-day rolling maximum temperature	Maximum Daily Difference
McNeil River	15.53	9.76		9.88				306.40			12.03	13.89	7.08
Meadow Creek	20.15	12.80	13.91	15.15	12.32	8.23	417.38	469.78	381.97	246.88	15.64	18.20	7.92
Montana Creek	16.65	10.80	10.04	12.33	10.62	7.86	301.06	382.29	329.09	235.66	12.73	14.82	6.57
Moose Creek (Palmer)	13.28	8.00	7.40	9.23	7.62	6.13	221.95	286.07	236.24	183.86	9.53	11.39	7.72
Moose Creek (Talkeetna)	14.58	10.72			11.94	8.41			334.21	252.45	12.55	13.60	3.38
Moose River	17.48	12.25	11.92	14.05	12.27	8.31	357.50	435.55	380.23	249.38	14.90	16.07	5.62
NF Campbell Creek	16.44	10.48		12.61	10.23	7.27		390.83	317.11	218.18	13.23	15.33	5.14
Nikolai Creek	17.56	9.52	9.09	11.07	9.57	6.35	263.64	343.08	296.74	190.61	12.25	15.74	8.26
Ninilchik River	18.96	11.61	11.34	13.68	11.41	7.71	340.27	423.99	353.61	231.29	14.54	17.56	7.13
Quartz Creek	11.56	8.16			8.77	6.94			245.61	208.24	9.17	10.68	4.33
Rabbit Creek													
Resurrection Creek	12.73	7.98	6.95	8.85	8.11	6.01	208.42	274.38	251.36	180.21	9.48	11.09	5.59
Seldovia River	12.53	9.07		9.32	9.95	7.61		289.06	308.58	228.28	10.94	11.85	3.81
Shantatalik Creek	13.69	9.57	9.15	10.79	9.58	6.85	265.48	334.42	296.85	205.58	11.19	12.79	4.61
Ship Creek	13.88	9.16	8.25	10.44	9.10	6.75	247.38	323.52	282.22	202.57	10.88	12.81	5.74
Silver Salmon Creek	11.90	8.15	7.19	8.64	8.40	6.92	215.81	267.94	260.25	207.60	9.47	11.18	3.85
Slikok Creek	16.79	10.31	9.96	11.59	10.24	7.34	298.66	359.38	317.32	220.33	12.26	15.49	7.51
Soldotna Creek	17.69	11.63	11.09	12.94	11.76	8.25	332.62	401.02	364.56	247.63	13.54	16.19	7.15
Stariski Creek	18.44	11.34	10.68	13.27	11.14	7.66	320.44	411.38	345.29	229.74	14.07	16.62	6.38
Swanson River	20.37	13.71	13.97	15.87	13.59	9.08	419.14	492.03	421.44	272.32	16.53	18.68	5.79
Theodore Creek	16.20	10.31		11.61	9.39	7.80		359.94	291.03	233.98	13.56	15.40	5.42
Trapper Creek	19.96	12.85			12.84	8.74			397.98	262.17	16.10	17.60	4.23
Troublesome Creek	18.44	11.03	10.51	13.24	10.28	7.44	315.30	410.49	318.64	223.28	13.69	16.53	8.28
Wasilla Creek	12.63	9.24	9.49	10.28	9.25	6.70	284.76	318.64	286.66	201.09	10.79	11.71	4.18
Willow Creek	16.30	10.26	9.17	12.01	9.90	7.46	275.24	372.27	306.80	223.88	12.45	13.95	4.65

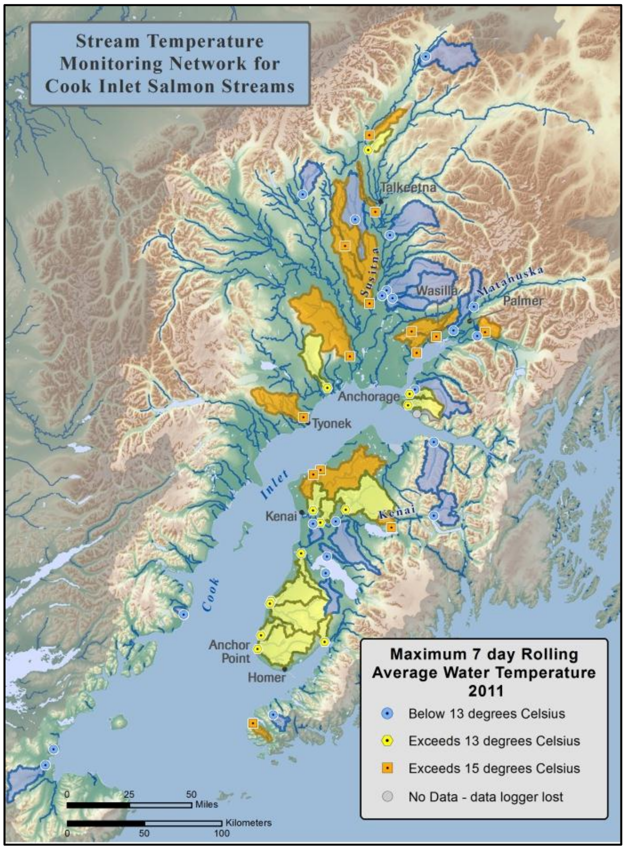


Map 2. Summer temperatures exceeded Alaska's Water Temperature Criteria of 13°C at 42 sites, 15°C at 36 sites, and 20°C at 11 sites in 2011. Temperature logger sites and their contributing watersheds are color-coded by the highest exceedance value.

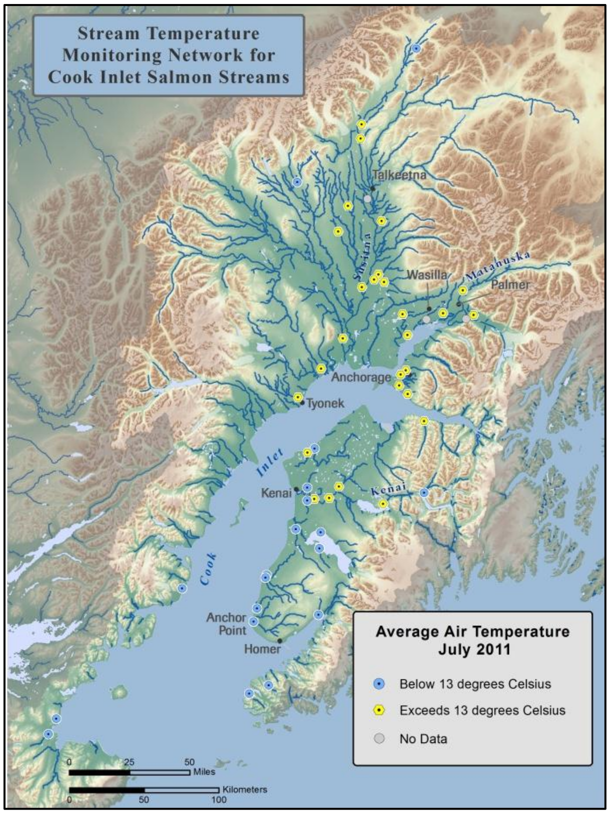
Table 4. Temperature exceedances for the summer season (June 21- September 22, 94 days total) and dates of logger deployment in 2011. At a minimum, loggers were deployed by 6/21 and pulled out after 9/22 unless otherwise noted with an asterisk.

Temperature Logger Site	# Days Exceeds 13°C	# Days Exceeds 15°C	# Days Exceeds 20°C	Deployment Dates
Alexander Creek	70	47	0	*6/22 - 9/5
Anchor River	52	33	0	5/25
Beaver Creek	53	10	0	5/24
Bishop Creek	71	54	1	5/31
Byers Creek	66	42	1	5/30
Cache Creek	24	10	0	5/21
Chenik Creek	8	0	0	*6/8 - 8/9
Chester Creek	56	16	0	5/20
Chijuk Creek	61	43	2	5/31
Chuitna River	58	43	2	6/01
Cottonwood Creek	73	51	0	5/16
Crooked Creek	47	23	0	5/31
Deception Creek	32	9	0	5/18
Deep Creek	53	35	0	5/25
East Fork Chulitna River	4	0	0	*7/09
English Bay River	64	21	0	6/10
Fish Creek	73	54	3	5/19
Fox Creek	65	44	1	5/27
Funny River	19	2	0	5/31
Hidden Creek	79	57	2	5/20
Jim Creek	73	56	14	6/13
Kroto (Deshka) Creek	41	41	15	*5/20 - 7/31
Little Willow Creek	28	5	0	5/18
McNeil River	14	2	0	*6/5 – 8/25
Meadow Creek	63	43	2	5/17
Montana Creek	36	11	0	5/31
Moose Creek (Palmer)	1	0	0	5/17
Moose Creek (Talkeetna)	8	0	0	*8/04
Moose River	55	21	0	5/20
NF Campbell Creek	26	10	0	* 7/01
Nikolai Creek	26	9	0	6/02
Ninilchik River	53	35	0	5/25
Quartz Creek	0	0	0	*8/04
Rabbit Creek	No data	No data	No data	No data
Resurrection Creek	0	0	0	5/21
Seldovia River	0	0	0	6/06
Shantatalik Creek	5	0	0	6/02
Ship Creek	6	0	0	5/20
Silver Salmon Creek	0	0	0	5/15
Slikok Creek	32	15	0	5/31
Soldotna Creek	51	22	0	5/24
Stariski Creek	49	26	0	5/26
Swanson River	71	51	1	5/24
Theodore River	25	9	0	*6/22
Trapper Creek	51	26	0	*7/06
Troublesome Creek	39	26	0	5/30
Wasilla Creek	0	0	0	5/16
Willow Creek	22	5	0	5/28





Maps 3 and 4. Maximum 7-day rolling maximums (MWMT) and maximum 7-day rolling averages (MWAT) or the maximum recorded value of daily maximum/average water temperature when averaged over 7 consecutive days.



Map 5. Average July air temperatures at each site.

R-square values of regression equations between average air temperature and water temperature at each site ranged from 0.41 - 0.94 (daily) and 0.59 – 0.99 (weekly). The weekly average air-water relationship was weakest at Cache Creek and Alexander River, and strongest at Soldotna Creek (Table 5). R-square values of regression equations between maximum air temperature and water temperature at each site ranged from 0.29 - 0.84 (daily) and 0.04 – 0.95 (weekly). In 2011, weekly air and water temperatures continue to have a stronger relationship than daily temperatures; average air and water temperatures have a stronger relationship than maximum temperatures.

Nick Logelin with ADF&G and Laura Eldred with ADEC provided transportation and field support on the Kroto (Deshka) Creek.

WATERSHED CHARACTERISTICS

A preliminary analysis of relevant watershed characteristics, including watershed size and land cover, was presented in the 2008-2010 report (http://inletkeeper.org/resources/contents/stream-temperature-report/view). Members of the analysis team met in April of 2012 to outline the additional metrics to be calculated (Table 6; Appendix A). These watershed and site characteristics will be assessed in the final synthesis report following the collection of the 5th year of data in 2012.

Table 5. Comparison of R-square values and regression coefficients (slope) of weekly average and maximum air temperature and water temperature in 2011. Cottonwood Creek and Rabbit Creek are not included as either the air or water dataset was missing.

Stream Name	R^2 average weekly	R^2 max weekly	Coefficient average weekly	Coefficient max weekly
Alexander Creek	0.64	0.34	1.01	0.64
Anchor River	0.92	0.69	1.10	1.58
Beaver Creek	0.96	0.85	1.01	1.02
Bishop Creek	0.92	0.84	1.19	1.15
Byers Creek	0.80	0.69	0.85	0.80
Cache Creek	0.59	0.40	0.64	0.47
Chenik Creek	0.74	0.09	1.67	0.54
Chester Creek	0.96	0.79	0.75	0.74
Chijuk Creek	0.97	0.84	1.06	0.85
Chuitna River	0.93	0.86	1.15	1.38
Crooked Creek	0.95	0.55	1.04	1.20
Deception Creek	0.93	0.62	0.65	0.64
Deep Creek	0.95	0.67	1.12	1.31
EF Chulitna River	0.97	0.82	0.63	0.68
English Bay River	0.91	0.91	0.94	0.78
Fish Creek	0.96	0.84	1.10	1.08
Fox Creek	0.96	0.67	1.26	1.22
Funny River	0.98	0.90	0.79	0.81
Hidden Creek	0.70	0.79	0.68	0.69
Jim Creek	0.87	0.92	1.71	1.46
Kroto (Deshka) Creek	0.74	0.04	1.27	0.15
Little Willow Creek	0.89	0.65	0.62	0.57
McNeil River	0.93	0.78	1.09	0.68
Meadow Creek	0.94	0.76	1.08	1.07
Montana Creek	0.92	0.85	0.65	0.66
Moose Creek (Palmer)	0.89	0.81	0.51	0.61
Moose Creek (Talkeetna)	0.97	0.92	0.90	0.80
Moose River	0.98	0.92	0.98	0.74
NF Campbell Creek	0.97	0.80	0.78	0.75
Nikolai Creek	0.95	0.77	0.76	0.72
Ninilchik River	0.92	0.74	1.17	1.16
Quartz Creek	0.98	0.95	0.52	0.53
Resurrection Creek	0.84	0.66	0.52	0.43
Seldovia River	0.75	0.83	0.55	0.50
Shantatalik Creek	0.95	0.67	0.76	0.70
Ship Creek	0.93	0.70	0.60	0.74
Silver Salmon Creek	0.95	0.77	0.55	0.47
Slikok Creek	0.98	0.87	0.84	0.86
Soldotna Creek	0.99	0.85	0.90	0.79
Stariski Creek	0.90	0.64	1.08	1.15
Swanson River	0.93	0.87	1.29	1.19
Theodore River	0.86	0.66	0.74	0.75
Trapper Creek	0.97	0.75	1.04	0.96
Troublesome Creek	0.89	0.66	0.89	0.82
Wasilla Creek	0.96	0.86	0.64	0.57
Willow Creek	0.85	0.61	0.60	0.50

Table 6. From the list below, watershed and site characteristics will be identified with the greatest potential to buffer salmon habitats from rising temperatures.

Watershed Characteristics	
Region	Mat-Su, Kenai, Anchorage, West side
Aspect	Predominate flow direction: N, NE, E, SE, S, SW, W, NW
Size by HUC	HUC 10, multi-HUC 12, HUC 12, less than HUC 12
Size	Large, medium, small, tiny by acreage
Water color	Clear, brown/stained (reflects wetland influence)
Landcover	% wetlands, forested, open water, developed, scrub/shrub riparian landcover
Slope	Δ in elevation from headwaters to mouth/distance
Elevation	Maximum watershed elevation, average basin elevation, elevation variance, % of watershed above an elevation threshold
Permeability	Soil and bed material
Discharge	Baseflow index, drainage density
Site Characteristics	
Elevation	GPS, ± 12 meters
Reach aspect	Predominate flow direction: N, NE, E, SE, S, SW, W, NW
Channel depth	at logger
Channel width	at logger transect
Width to depth ratio	Width/depth at logger transect
Habitat type	Pool, riffle, run
Canopy cover	Shading at logger, solar radiation input

Discussion

With 4 years of this 5-year project complete, the Stream Temperature Monitoring Network has proven to be a successful collaborative regional monitoring effort to collect comparable stream temperature data across the Cook Inlet watershed. Consistently coordinated by Cook Inletkeeper, with fifteen different partners involved, the Temperature Network is a great example of how a partnership of federal and state agencies, tribal entities and community-based organizations and volunteers can accomplish more together, and more effectively, than by any group working alone.

Project Management

One of the major challenges of this project has been to fine tune the deployment of data loggers at 48 different sites. The majority of water loggers that we have lost after deployment have been due to soft sediment bottoms and highly mobile stream beds. By switching from a rebar deployment method to a bank-secured cable we have resolved this problem at specific sites. However, the majority of datasets we have had to throw out because of erroneous data have been the result of bank-secured cables getting caught up on the bank during high flows. Regular maintenance visits help reduce the loss of data although is not practical at more remote sites.

With more than 4 million data points collected to date, we have also had to fine tune our data management and analysis methods. After attempting to create a database that could do everything, we have split our needs up into 1) data storage and uploading into EPA's STORET and 2) generating temperature metrics. Kenai Watershed Forum has taken on the first task by storing and uploading data to STORET from a FileMaker Pro database. This allows the data to be stored locally but also makes it available through this national data portal. The second task of analyzing the data is now accomplished through a series of custom-made Excel macros which can be used to process a year's worth of data in less than two days.

Results

Non-glacial salmon streams in the Cook Inlet watershed consistently exceed Alaska's numeric water quality criteria set for the protection of fish, even during the relatively cool, wet summers of 2008 and 2010. The warmer summers of 2009 and 2011 provide a valuable contrast to capture a realistic range of variability in current weather conditions. Through the Stream Temperature Monitoring Network, we can use these 48 "reference" streams to establish a baseline relationship between air and water temperature in a variety of stream types. This regional perspective, incorporating spatio-temporal variability as described in Poole[14], can serve as a tool for identifying thermal impacts in a time of changing climate.

Next Steps

In the fifth year of the Stream Temperature Monitoring Network, we will use regional climate projections from Scenarios Network for Alaska Planning (SNAP) to better understand how air temperatures are likely to change in the future. These projections tell us that air temperatures and, to a lesser degree, precipitation will increase across the landscape over the next 100 years. July air temperatures may increase as much as 5^{o}C in the Susitna River valley and increasing winter air temperatures may reduce snow accumulation, especially on the lower Kenai Peninsula and west side of Cook Inlet. This combination of warmer summers and less snow to support summer base flows has the potential to create thermal conditions that are stressful or unsuitable for salmon in certain stream types and geographic locations.

Temperature loggers have been re-deployed at all sites in 2012. With continued data-collection to capture annual variation, this project will play an important role in helping state resource managers prioritize streams with the greatest potential to buffer stream temperatures for research, restoration and protection efforts to ensure Alaska wild salmon endure as thermal change continues.

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Appendix A

Stream Temperature Monitoring Network for Cook Inlet Salmon Streams
April 26, 2012 Analysis Team Notes
Sue Mauger, Dan Rinella, Jason Leppi

<u>Objectives</u>

1. Describe stream and air temperature patterns in non-glacial watersheds which represent the variation in watershed characteristics that occur across the Cook Inlet landscape.
    a. Collect water/air temperature data at 48 non-glacial streams from June 1 – October 1 for 5 years: 2008-2012. (Report Map 1, page 6)
    b. Summarize data by calculating temperature metrics ('Temperature Metrics' attachment; Report Table 3)
        i. Are these the right metrics? Are we calculating them correctly? What's missing?
        Air-water regressions – look at rising and falling limbs to see if discharge/seasonality is a significant factor
        Curvilinear vs linear relationship - do more graphing to look at patterns
        Equilibrium temperature – see Mohseni and Stefan, 1999
    c. Generate regional maps to illustrate patterns (Report Maps 2-4)
        i. Can these maps be improved?
        Maps look good – consider adding: "temperature logger site and contributing watershed" in the map label

2. Identify watershed characteristics with the greatest potential to buffer stream temperatures from climate and land-use change.
    a. Quantify watershed metrics for each site ('Watershed and Site Characteristics' attachment)
        i. Are these the right metrics? Are we calculating them correctly? What's missing?
        Improve calculation of aspect using DEM
        Improve calculation of watershed size using GIS to get actual acreage
        Add the following:
        Landcover for riparian zone
        Maximum watershed elevation
        Average basin elevation
        Elevation variance ? – fisheries paper
        % of watershed above an elevation threshold (see Battin et al, 2007)
        Soil permeability
        Baseflow index (see Kelleher et al, 2011); USGS -Janet Curran's peak flow calculations for Cook Inlet might be useful)
        Solar radiation

Drainage density (see Isaak 2010)
Surficial geology – potential for recharge, Jim Wiggington
Ratio of lake to watershed area

b. Correlate with temperature metrics (Report pages 33-35)
    i. Methods?
    Multiple linear regression models
    Mixed effects models – Jason will investigate
    Build a reach-level model to be able to discount it?

3. Use present time air-water relationships to backcast and forecast water temperatures
    a. Backcast at sites with strong airport data correlations
        i. Definition of a strong correlation
        Look into NARR data (1979- present), 30 km grid
    b. Forecast with SNAP data (Report pages 36-41; 'Backcast and Forecast' attachment)
        i. Quantifying uncertainty
        ii. Air temperature at site or integrated watershed scale?
        Look into why the A1B and A2 scenarios from SNAP don't start at the same temperature in 2009

Who else should be in the discussion?

Consider a modeler in general, Stephanie McFee (climate model support, now with USGS), Matt Rinella (modeler, USDA), Jim Wiggington (EPA hydrologist), Branden Bornemann (KWF GIS analyst), Becky Shaftel (additional GIS analysis support).

Flesh out analysis timeline.

By October 2012: Sue will work on getting the watershed metrics calculated in time for a fall meeting. Sue will look into additional funding for analysis team.

October 2012 - February 2013: Based on fall meeting discussion, final model selection will be made. Sue will complete QA checks and finalize 2012 temperature data. Jason will have provided about a month worth of time working with Sue to prep data to run models.

February – May 2013: Run models

May – July 2013: Write up comprehensive report on 2008-2012 temperature data and identify relevant watershed characteristics.

August – December 2013: Submit 1-3 papers to peer reviewed journals.