Southeast Alaska Freshwater Monitoring Network Implementation Plan

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Prepared by Rebecca Bellmore and Michael Winfree
with support from the Network Steering Committee and Working Group.

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Contents

Background

Water temperature is a key environmental variable that is both driver and indicator of river ecosystem function (Caissie 2006). Temperature affects the health, growth, and behavior of aquatic biota (Webb *et al* 2008). In turn, temperature is controlled by climate, watershed characteristics, and stream morphology (Leppi *et al* 2014, Mauger *et al* 2017, Johnson 2004, Lisi *et al* 2015, Winfree *et al* 2018). Climate change and development have the potential to alter stream and lake temperatures in Southeast Alaska, which will have implications for important aquatic resources (Bryant 2009, Shanley *et al* 2015; Kovach *et al* 2013; Kovach *et al* 2015). Although water temperature is currently being monitored at over 60 sites in the region (Geist *et al* 2014), the lack of a coherent sampling plan and limited data sharing across entities make it difficult to assess the current thermal status of the region's streams. Additionally, the lack of long-term data (greater than 20 years) makes trends difficult to discern. The Southeast Alaska Freshwater Temperature Monitoring Network aims to address these gaps by supporting strategic, long-term freshwater temperature monitoring and facilitating data sharing among partners and with the public.

The economy and culture in Southeast Alaska are tied to abundant aquatic resources, particularly salmon, that are supported by freshwater ecosystems (TWC Economics 2010). Salmon fisheries directly support 1 in 10 jobs in the region and result in nearly a billion dollars of economic output each year, including $189 million in personal income (based on 2007 data; TWC Economics 2010). Salmon are not just an economic driver; they are a deep part of the cultural identity of the region. Indigenous people have relied on salmon for thousands of years, and residents continue to depend on salmon, with an estimated 90% of rural households in Southeast Alaska utilizing salmon (USFS 2015).

Southeast Alaska is characterized by abundant, high quality freshwater habitat that supports salmon through their freshwater life history stages. Changing water temperatures have the potential to impact salmon productivity through a variety of mechanisms. Thermal conditions regulate metabolic rates and energy needs of salmon across life history stages and have important implications for growth and development during the egg incubation and juvenile rearing life history stages (Beacham and Murray 1990). Furthermore, adult and juvenile migration timing and stress during migration are also affected by water temperature (Kovach *et al* 2013, 2015, Taylor 2008). In addition to direct impacts on salmon physiology and behavior, stream temperature affects critical environmental conditions such as food availability and dissolved oxygen concentrations (Fukushima and Smoker 1997; Fellman *et al* 2017; Sergeant *et al* 2017; Fellman *et al* 2019). Importantly, stream temperature variability influences egg development at different time-scales (e.g. seasonal and daily: Steel *et al* 2012), and spatial variability of thermal conditions within a stream can provide important refugia during rearing and migration (Armstrong *et al* 2013, Armstrong and Schindler 2013).

Stream temperatures are controlled by numerous factors, including climate conditions, watershed topography, and stream discharge (Caissie 2006). Climate change has the potential to impact stream temperatures through changes in air temperature and incoming short- and long-wave radiation. The sensitivity of stream temperature to air temperature has been found to be mediated by watershed characteristics that affect water residence time and exposure to radiative inputs, including watershed size, slope, shading, and the area of standing water in lakes and wetlands (Johnson 2004, Mauger *et al* 2017, Winfree *et al* 2018). Additionally, stream temperature is affected by the source of stream flow (e.g. rainwater, snowmelt, glacier melt) (Fellman *et al* 2014, Hood and Berner 2009, Lisi *et al* 2015), and is related to watershed elevation and latitude in Southeast Alaska (Moore 2006, Winfree *et al* 2018).

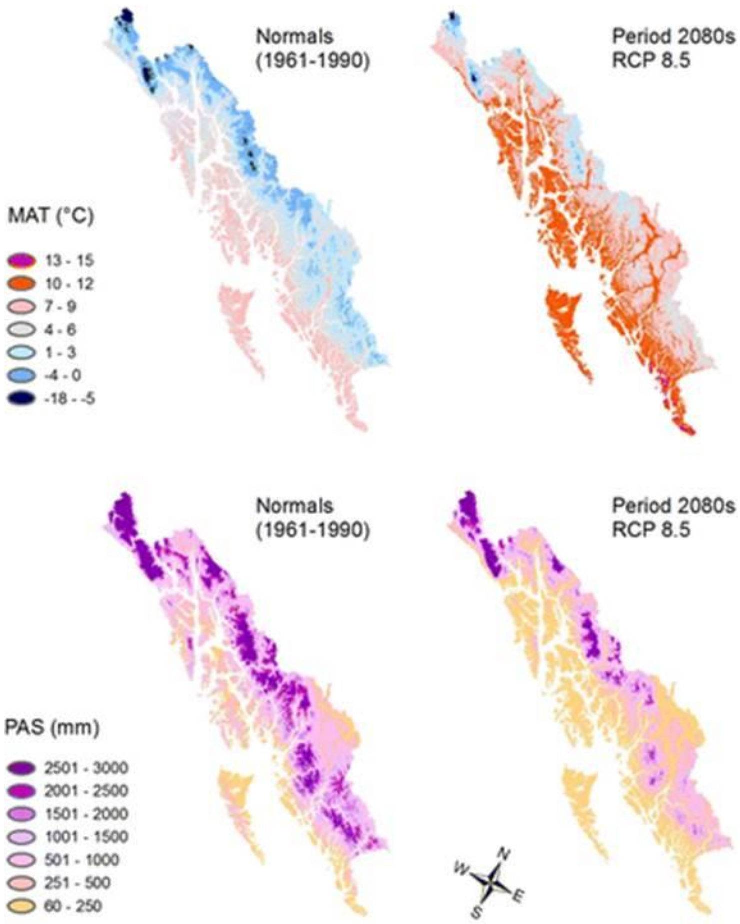

Figure 1. Current mean annual temperature (MAT) and percent of precipitation as snow (as water equivalent) (PAS) compared to projections for the 2080's under a high-range emission scenario (RCP 8.5). (Adapted from Shanley *et al* 2015.)

Climate change is anticipated to lead to significant warming and hydrologic changes in Southeast Alaska. Annual average air temperature for Southeast Alaska is projected to increase by 2.7-5.5 °C by the 2080's, with the largest magnitude increases during the winter, based on mid- and high-range emissions scenarios (RCP 4.5 and RCP 8.5) (EcoAdapt 2014; Shanley *et al* 2015). These increasing temperatures are projected to lead to less precipitation falling as snow and more falling as rain, especially in areas that have winter temperatures currently near freezing (Fig. 1) (Shanley *et al* 2015, Shanley and Albert 2014). Shifting from snowmelt to rain-fed stream flow patterns will have implications for stream temperature, particularly during late spring and summer when snowmelt runoff has disappeared (Edwards *et al* 2013).

Characterizing and understanding trends in stream temperatures across the region will be critical for understanding how stream thermal regimes and aquatic biota are responding to climate change. The importance of a temperature monitoring network was identified during the 2016 Climate Workshop, hosted by the Southeast Alaska Fish Habitat Partnership in Juneau, AK (SEAKFHP 2018). Participants noted that the lack of public data or a coordinated sampling approach, combined with the prospect of climate change, meant that the region was poorly positioned to understand or prepare for future changes. Additionally, participants at the 2016 Southeast Alaska Climate Adaptation Summit, which brought together representatives of Tribal organizations to review and plan monitoring, mitigation, and adaptation strategies to address climate change, identified coordinated water temperature monitoring as a high priority (Holen 2017). In response, funding was sought and granted from the North Pacific Landscape Conservation Cooperative to begin the process of coordinating partners, preserving historical data, identifying means of sharing future data, developing a strategic sampling plan, and laying the groundwork for sustained support of the monitoring network.

Current Status of Monitoring Sites

Stream temperature is currently being monitored year-round in 60 sites throughout Southeast Alaska. Seasonal data is being collected at an additional 5 sites (Fig. 2, Appendix B). Responsible parties include state and federal agencies, the University of Alaska Southeast, non-profit organizations and Tribal organizations. Metadata associated with some of these sites is being shared with the Alaska Online Aquatic Temperature Site (AKOATS), and data for some sites has been submitted to the Southeast Alaska GIS Library (University of Alaska Southeast) and/or the Knowledge Network for Biocomplexity, an open access data repository. Other organizations host data on their own websites or internally (e.g. National Park Service, Forest Service, US Geological Survey).

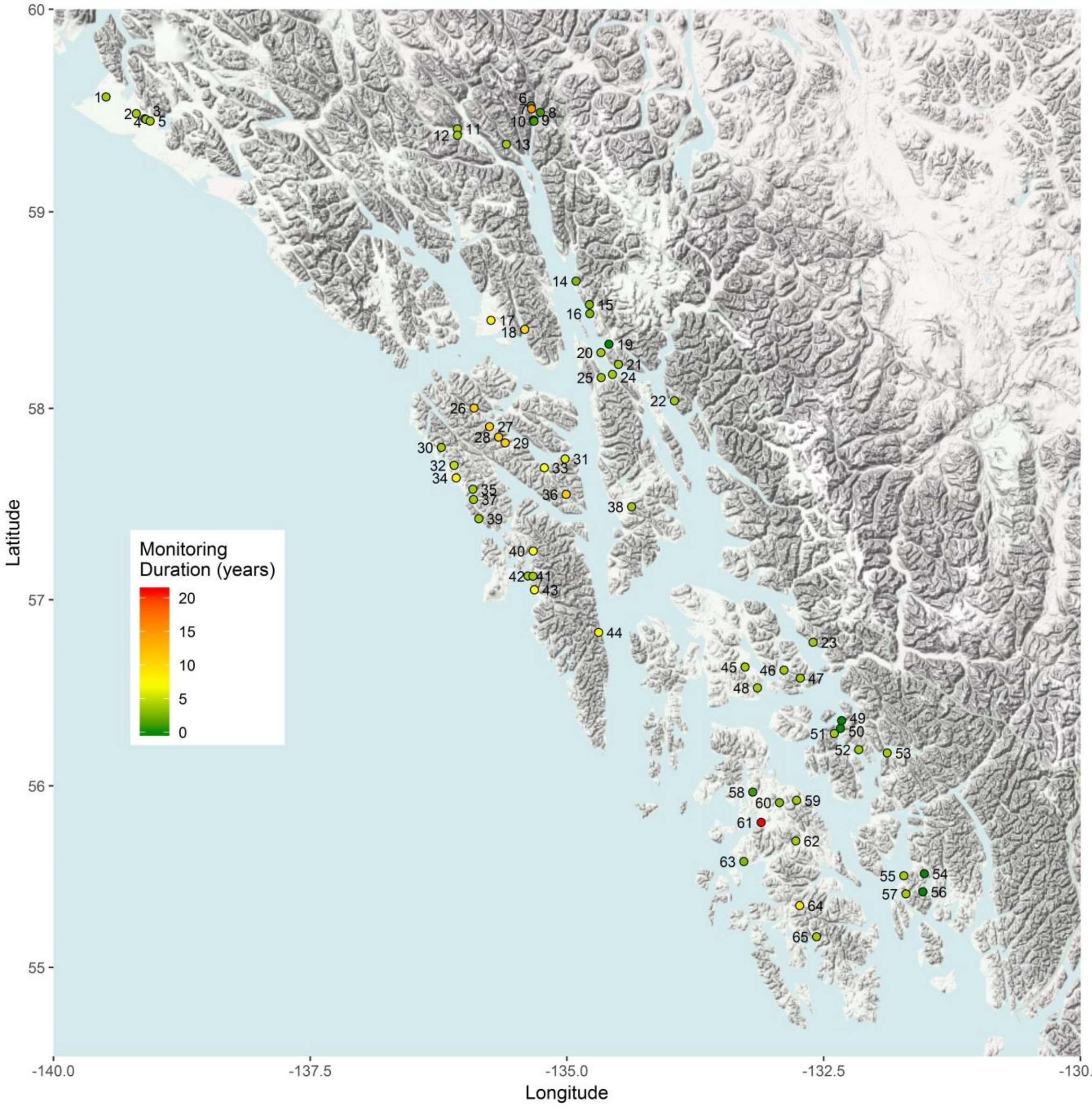

Figure 2. Existing stream temperature monitoring network. The numbers used to label each point correspond with the watershed number column in Appendix B.

Goals

The goal of the Southeast Alaska Freshwater Temperature Monitoring Network is to collect stream temperature data that meet the information needs of individual cooperators while simultaneously generating data that contributes to an understanding of regional stream temperature patterns and trends.

The Network's short-term (3-5 year) objectives are to:

- increase data collection capacity in Southeast Alaska;
- institute the use of minimum data collection standards to produce data useful for the analysis of local and regional trends in water temperature;
- prioritize resources to initiate and maintain monitoring sites that:
    - yield long-term data
    - fill critical information gaps about relationships between geomorphic characteristics and temperature patterns
    - have a range of sensitivities to climate change
- update and submit site-specific metadata annually to the Alaska Online Aquatic Temperature Site project (a statewide metadata clearinghouse) and metadata and data to the Southeast Alaska GIS Library (a regional clearinghouse for spatial data);
- provide public access to water temperature data;
- complement and leverage other monitoring efforts, such as water quality and discharge monitoring and salmon monitoring programs.

The Network's longer term (5-20 year) objectives are to:

- identify and/or develop a data repository to house all cooperator data for the long term;
- describe current temperature regimes across a range of stream types;
- identify geomorphic controls on thermal profiles;
- refine projected water temperature trends under different climate scenarios;
- understand stream temperature impacts on salmon and other species of regional significance;
- provide reliable temperature data to support development of proactive approaches to managing salmon stocks in response to climate change.

Strategic Sampling Plan

The sampling plan is a prioritization approach that network cooperators can use to guide site selection and resource allocation for continuing maintenance. We recognize that the network is currently composed of cooperators with short funding horizons, which makes it difficult to guarantee the maintenance of existing and new sites into the future. Furthermore, the region is vast and the terrain is complex, thus the majority of watersheds are logistically difficult to access. Taking these challenges into consideration, we propose using a strategic sampling approach based on the watershed selection criteria listed below. Selection criteria are listed in order of priority to meet the primary goal of collecting long-term data, and, secondarily, to monitor a suite of watersheds that reflects the range of existing geomorphic and geographic characteristics and climate change sensitivity in the region.

1. Maintain existing monitoring sites that have multiple years of data.
2. Initiate and/or maintain sites that are important for traditional or subsistence use, or are of long-term interest for other reasons. Within these sites, prioritize those that are most accessible and/or have long-term funding sources.
3. Maintain and/or initiate sites that fill critical climate sensitivity, geographic, or geomorphic information gaps. Within these sites, prioritize those that are most accessible and/or have long-term funding sources.

To address criterion 3, we applied a systematic approach to identify the types of watersheds that are missing from the current suite of monitored watersheds and thus constitute priority candidates for future monitoring. This "gap analysis" is described in more detail below and in Appendix C. For criteria 2 and 3, we suggest that an "accessibility filter" should be applied to further prioritize sites. Sites should be accessed 1 to 2 times per year for maintenance, so travel to remote sites may be cost prohibitive over the long term. Therefore, new or existing sites that are accessible and/or have dedicated long-term funding to ensure regular access should be prioritized for monitoring.

Stream Temperature Monitoring Site Prioritization Criteria

1. Maintain existing monitoring sites that have multiple years of data.

The majority of existing monitoring sites in the region have less than 5 years of record, although a few sites have a decade or more of data (Fig 2, Appendix B). We suggest that, should funding levels decline so that a subset of sites must be decommissioned, the sites with the longest data sets be prioritized for maintenance. Current year-round and seasonal monitoring sites (Fig. 2, n=65) and associated start dates and watershed characteristics are listed in Appendix B.

2. Initiate/maintain sites in watersheds that are important for traditional or subsistence use, or are of long-term interest for other reasons.

To promote sustained data collection, we suggest prioritizing new sites that are of long-term interest for traditional and subsistence use or other reasons, such as proximity to a tour operator, fishing lodge, or fish hatchery. Network cooperators will likely be able to justify continuing to dedicate resources to monitoring these important sites, and the potential for coordinating with other sampling or field activities is high. Among these types of sites, those that are more easily accessible and/or have a long-term funding source should be prioritized.

3. Initiate sites that fill critical climate sensitivity, geographic, or geomorphic information gaps.

A monitoring network employing a sampling strategy that is entirely opportunistic is likely to result in multiple sites with similar characteristics, which may limit our ability to understand relationships between watershed variables and thermal regimes or regional trends through time, which are long-term goals of the network. A truly randomized sampling approach is infeasible in Southeast Alaska due to the rugged terrain and inaccessibility of many areas; however, a strategic monitoring approach can increase coverage of key environmental gradients and allow for more robust analyses (Jackson *et al* 2016). Further, we propose that the range of characteristics monitored be spatially distributed and reflect the variability within five biogeoclimatic provinces, which represent distinct intersections of climate, geographic context, and biological diversity in Southeast Alaska (Fig. 3) (Shanley *et al* 2015).

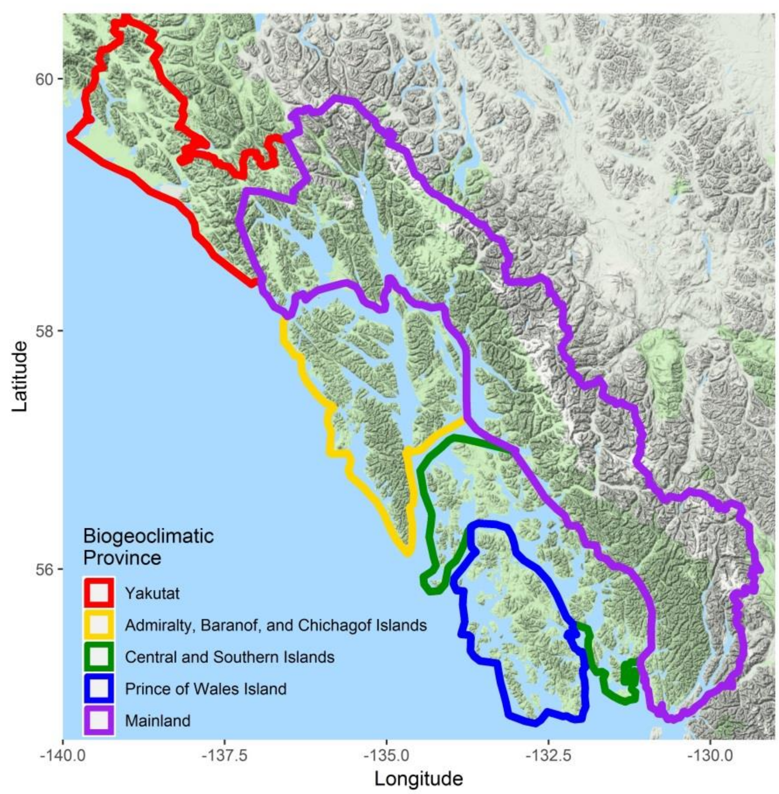

Figure 3. Biogeoclimatic provinces of Southeast Alaska's coastal temperate rainforest, adapted from Shanley *et al* 2015.

To address the network's goal of further refining relationships among watershed geomorphic characteristics and stream temperature, we identified several key metrics that are related to stream temperature in the region and assessed how well currently monitored watersheds represent the range in these metrics (HUC12 and HUC14 scale) across the region. Gaps in coverage for individual metrics were identified, along with potential sites (easily accessible, if possible) that could be monitored in the future to fill these gaps ("gap analysis"). These watershed metrics include mean watershed elevation, mean watershed slope, percent glacier cover, and percent lake coverage (Lisi *et al* 2015, Mauger *et al* 2017, Winfree *et al* 2018, Fellman *et al* 2014).

Additional watershed variables, such as karst and aspect, can affect stream temperature, but we chose to limit the number of target variables so that the number of new strategic sites needed to fill information gaps would be manageable.

In addition to watershed geomorphic characteristics, we also did a gap analysis for a suite of metrics that will improve our understanding of how climate change is affecting streamwater thermal regimes in the region. These metrics included: summer and winter sensitivity of stream temperature to air temperature, (Winfree *et al* 2018), projected change in snow-water equivalent (snowpack) on April 1 by 2080, and projected fraction of precipitation falling as snow in 2080 (Littell *et al* 2018). As with the watershed characteristics, these variables were estimated for currently monitored watersheds and all HUC12 and HUC14 watersheds, and sites that could fill gaps were identified.

All gap analysis results, including potential sites identified for monitoring are included in Appendix C.

Roles and Responsibilities

Network Coordinator

The network coordinator is responsible for maintaining communication among network cooperators, overseeing the execution of the implementation plan, and promoting the efficient use of resources. The network coordinator will

- Engage with cooperators quarterly to assess resource needs and availability and make connections between key cooperators to promote opportunities for resource sharing.
- Provide guidance on site selection and preservation (at the watershed and regional level) to meet the goals of the sampling plan.
- Provide field methods training and guidance, including proper local site selection and sensor installation and maintenance. Ideally, the network coordinator will lead an annual field training course for cooperators.
- Facilitate data and metadata submission by connecting cooperators with data repository managers.

Additionally, the network coordinator may apply for and manage funds to support the network – including for equipment and staff time for maintenance, training, coordination etc.

Data Manager

The data manger will work with cooperators to promote data collection and sharing that meets minimum standards and promotes the goals of the network. The data manager will

- Provide guidance on data quality assurance and storage.
- Facilitate data and metadata submission through annual reminders.
- Organize an annual meeting for cooperators to report on activities and share results.
- Annually report to network cooperators on the state of the network, including active sites and the status (e.g. location) of data.

Network Cooperators

Network cooperators will sign onto the Memorandum of Understanding (Appendix A). Network cooperators' participation is entirely voluntary, and they are responsible for maintaining their own monitoring sites, including

- securing funding for equipment and staff time.
- installing and maintaining equipment, and downloading and data.
- submitting data to and updating metadata in repositories at least annually.

Cooperators are expected to follow minimum standards, described below. Cooperators are encouraged to share resources and knowledge in a manner that is consistent with their own goals and funding, and should provide quality-controlled data to the public upon request.

Data Standards

To ensure that data are of high quality and comparable across sites, and can therefore be used in regional analyses, the network has adopted a set of protocols and minimum standards for stream temperature data collection and storage. These standards and protocols, and the reasoning behind their selection are described in detail in Mauger *et al* (2014). Briefly, these include:

Minimum Standards

Data Logger	Accuracy	±0.25°C
	Measurement Range	-4 to 37°C (24 – 99°F)
Data Collection	Sampling frequency	≤ 1 hour interval
		≥ 1 calendar month
Quality Assurance and Quality Control	Accuracy checks	Water bath at two temperatures, 0°C and 20°C before and after field deployment to verify logger accuracy (< 0.25°C compared with NIST-certified thermometer)
	Site selection	Five measurements across the stream width to verify the site is well mixed (varies < 0.25°C)
	Data evaluation	Remove erroneous data from the dataset
Data Storage	File formats	CSV format in 2 locations
	Metadata	Unique site identifier; agency/organization name and contact; datum, latitude and longitude; sample frequency. To be stored with temperature data
	Sharing	Quality-controlled hourly data

Lake Standards

Currently there is no agreed-upon protocol for monitoring lake temperature. Lakes vary in size, stratification, turnover, number and influence of inlets and outlets, etc., and assessing the thermal regimes of lakes requires addressing these aspects on a case-by-case basis. However, other than the stream site selection protocol, the standards and protocols described above can be applied to lake temperature monitoring to ensure the data are accurate, quality-controlled, and stored for future use.

Data Management

A critical goal of the network is to ensure that temperature data are shared and accessible now and into the future. In addition to storing metadata and data files in the formats recommended above, network cooperators are expected to submit metadata and data to repositories so that their information will be discoverable.

As of the writing of this document, there are several efforts underway to develop and/or promote databases that can be used by entities across Alaska to submit and retrieve continuous temperature data. The existing options vary in their longevity, ease of data submission, search and retrieval functions, and use by other entities, making no single option ideal. Currently, we recommend that network cooperators annually submit:

- Metadata and data to the Southeast Alaska GIS Library through the University of Alaska Southeast
- Metadata to the Alaska Online Aquatic Temperature Site (AKOATS), run by the University of Alaska Anchorage and supported by the Western Alaska Landscape Conservation Cooperative
- Data to Knowledge Network for Biocomplexity (KNB), run by the National Center for Ecological Assessment and Synthesis (NCEAS)

The SEAK GIS library is a regional database that can house cooperators' data in one location, along with other hydrologic and geospatial data. While retrieval is not currently automated (no public interface), quality controlled data is available upon request, and multiple data sets can be retrieved in the same format simultaneously.

The AKOATS houses metadata associated with stream temperature monitoring sites statewide, so cooperators' monitoring information can be available to a wider audience. Additionally, as of the writing of this document, there are plans to link to stream temperature data in the KNB.

The KNB is a free data repository available for any researcher, and it has a public interface where users can search for and download available data. Data is retrievable on a project-by-project basis, and is not guaranteed to be quality controlled (data is available in the form it is submitted).

Current contact information for the entities are:

- SEAK GIS Library: Sanjay Pyare and Eran Hood
- AKOATS: Marcus Geist
- KNB/NCEAS: Jeanette Clark, or direct submission to KNB (https://knb.ecoinformatics.org)

Sustainability

The sustainability of the network will depend on continued funding for monitoring sites and support for coordinators. Some strategies for achieving this include:

- Develop products (papers, models, etc.) that address cooperators' interests and needs to support funding requests by highlighting the utility of the network to regional stakeholders and environmental managers.
- Incorporate temperature monitoring into other funded projects (e.g. water quality monitoring, fish projects).
- Mainstream data management and sharing into cooperators' normal monitoring and research to limit the work of the technical coordinator.
- Share/Rotate responsibility for network coordination among cooperators as funding allows.
- Maintain accurate information on current sites, responsible parties, and contact information.

Budget

Budget Item	**Cost**	**Description**
Data Manager	$21,900	Currently UAS Research Assistant, SEAK temperature database manager
Network Coordinator	$19,250	Currently SAWC Science Director
Annual sensor replacement	$5,676	Replace 1/3 of sensors per year, assuming 2 per site, $129 per logger
Site installation equipment	$396	Install/replace 1/5 of sites per year, $30 per site
Shipping costs	$200	Instruments, shuttles, NIST loggers, etc.
Cooperator staff time (typically provided by cooperating organizations)	$39,600	(estimate) Travel to sites, data management, estimated as 10 hours per site for travel and data management, twice per year, $30 per hour
Travel to sites (typically provided by cooperating organizations)	Not estimated	Highly variable across sites; ranges from a short drive to long boat rides
Estimated annual network cost:	**$87,022**	Excludes travel to sites

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Appendices

Appendix A. Memorandum of Understanding

Southeast Alaska Freshwater Temperature Monitoring Network
Memorandum of Understanding

The purpose of this Memorandum of Understanding (MOU) is to establish a framework for cost-efficient communication and coordination of a network among public and private sector organizations that have interest in the acquisition of fresh water temperature data in Southeast Alaska. Signatories of this MOU, hereafter referred to as "Cooperators" may consist of private, municipal, state, federal, and tribal entities with an interest in stream temperature data collection. Cooperators will benefit from shared resources, combined expertise, shared responsibilities, unified strategy, consistency of methods, and collective results.

Areas of Agreement

Signatories shall agree to support Goals and Objectives as outlined in "Implementation Plan: Southeast Alaska Fresh Water Temperature Monitoring Network**"** as well as to share information and resources where feasible and compatible with their policies and goals.

Furthermore, they shall agree to:

- Meet minimum standards and protocols to ensure the quality and comparability of water temperature data;
- Share metadata and data:
    - Provide metadata and data to the Southeast Alaska GIS library (a Southeast-specific library of spatial data maintained by the University of Alaska Southeast);
    - Update and submit site-specific metadata annually to the Alaska Online Aquatic Temperature Site (a statewide metadata clearinghouse) and the Southeast Alaska GIS library (a Southeast-specific library of spatial data maintained by the University of Alaska Southeast);
    - If a statewide Data Clearinghouse is established, copies of metadata and data will be provided to the organization responsible for operation of the Clearinghouse;
    - Provide copies of metadata and quality-controlled data to requesting entities and members of the public and/or direct them to the Southeast Alaska GIS library, which will make metadata and data available;
- On behalf of Cooperators, the Network Coordinator may lead development of grant applications and subsequent coordination of approved grant funds to support implementation of the network plan.

Independent Responsibilities

Each Cooperator is:

- Responsible to its own governing body;
- Responsible and accountable for its own funds, equipment, and personnel;
- Shall assume no responsibility for network-scale analysis of data or reporting of results from such analysis.

Modification and Termination

This agreement will be effective from the date of signature of at least two Cooperators. Any Cooperator may terminate their involvement via written notice to the Network Coordinator.

This MOU may be amended as necessary by mutual consent of the Cooperators by execution of a written amendment signed and dated by a majority of Cooperators.

This MOU will be reviewed every three (3) years and updated as necessary.

Contact Information

Rebecca Bellmore
Southeast Alaska Watershed Coalition
1107 W. 8th St., Ste #4
Juneau, AK 99801
Phone: (907) 205-4028
Email: ebecca@sawcak.org

Memorandum of Understanding

Southeast Alaska Freshwater Temperature Monitoring Network

Signatory Page

____
Name of Cooperator

Hereby agrees to the terms of the Memorandum of Understanding.

____
Signature Date

____
Printed Name

____
Title

____
Address

____
City/State/Zip

____
Phone and Fax numbers

____
Email address

Appendix B. Existing stream temperature monitoring sites

Description of parameters:

Elev (m)	Mean watershed elevation
Slope (deg)	Mean watershed slope
% Forest	Percent watershed cover that is forest
% Lake	Percent watershed cover that is lake
% Glacier	Percent watershed cover that is glacier
SI 2080	Projected Snow Index – fraction of winter (October – March) precipitation that is snow for the 2080's based on RCP 8.5
SWE 2080	Projected Snow Water Equivalent change (fraction) from historical to 2080's based on RCP 8.5
Summer sensitivity	Sensitivity of stream temperature to air temperature during summer months (Δ°C/1°C)
Winter sensitivity	Sensitivity of stream temperature to air temperature during winter months (Δ°C/1°C)

Location	No.	Region	Site Manager[1]	Latitude	Longitude	Area (km^2)	Elev (m)	slope (deg)	% Forest	% Lake	% Glacier	SI 2080	SWE 2080	Summer sensitivity	Winter sensitivity	Duration (y)
Old Situk	1	YAK	FS	59.571	-139.489	20.6	50.0	4	98.8	1.3	0.0	11.3	-0.65	0.28	0.12	4
Echo	2	YAK	FS	59.489	-139.194	17.6	169.0	9	79.4	0.5	0.0	11.4	-0.65	0.25	0.11	4
Antlen	3	YAK	FS	59.463	-139.111	3.6	38.0	6	65.6	3.4	0.0	11.4	-0.65	0.27	0.12	4
Ahrnklin	4	YAK	FS	59.460	-139.100	80.9	387.0	19	36.9	0.3	7.1	17.4	-0.60	0.17	0.08	4
Miller	5	YAK	FS	59.453	-139.059	29.5	413.0	22	39.9	0.4	9.1	17.4	-0.60	0.14	0.07	4
West	6	MAN	TWC/CIV	59.528	-135.351	111.7	995.9	29	20.4	0.0	28.9	43.2	-0.39	NA	NA	1
Taiya	7	MAN	NPS/USGS	59.512	-135.346	273.9	908.3	27	3.7	0.3	19.7	37.1	-0.44	NA	NA	15
Mid Skagway River	8	MAN	STC	59.495	-135.260	101.6	1154.0	32	7.8	0.1	32.7	60.9	-0.33	NA	NA	1
Lower Skagway River	9	MAN	STC	59.457	-135.325	353.4	1097.9	24	9.8	0.4	10.4	56.1	-0.28	NA	NA	1
Pullen	10	MAN	STC	59.452	-135.322	20.4	766.4	25	45.0	1.5	1.3	28.5	-0.51	0.12	0.06	1
Herman	11	MAN	TWC/CIV	59.413	-136.068	11.8	355.5	15	98.0	1.2	0.0	34.3	-0.46	0.20	0.09	4

Location	No.	Region	Site Manager[1]	Latitude	Longitude	Area (km^2)	Elev (m)	slope (deg)	% Forest	% Lake	% Glacier	SI 2080	SWE 2080	Summer sensitivity	Winter sensitivity	Duration (y)
Clear	12	MAN	TWC/CIV	59.382	-136.068	2.3	417.0	21	83.6	0.0	0.0	34.9	-0.45	0.09	0.07	4
West Lake Creek	13	MAN	TWC/CIV	59.337	-135.590	8.7	859.0	28	20.7	0.0	2.9	34.2	-0.46	0.04	0.06	4
Cowee*	14	MAN	UAS	58.652	-134.913	110.5	647.0	24	57.2	0.2	11.1	28.9	-0.50	NA	NA	3
Herbert*	15	MAN	UAS	58.532	-134.783	158.3	892.1	19	23.7	0.5	44.0	33.8	-0.46	NA	NA	3
Peterson OTR*	16	MAN	UAS	58.486	-134.778	23.2	316.0	14	87.8	1.0	0.0	11.4	-0.65	0.25	0.12	3
Salmon	17	MAN	NPS/USGS	58.452	-135.741	93.8	277.0	11	60.6	0.1	0.0	8.6	-0.69	0.27	0.13	8
Neva Lake	18	MAN	ADFG/ARRI	58.406	-135.412	5.0	428.3	25	86.9	7.0	0.0	25.0	-0.54	0.16	0.09	10
Fish	19	MAN	UAS	58.331	-134.591	35.7	484.8	22	71.8	0.2	0.0	20.0	-0.57	0.18	0.10	<1
Peterson	20	MAN	UAS	58.287	-134.670	9.4	327.0	19	87.5	0.0	0.0	11.8	-0.64	0.21	0.11	4
Hilda	21	MAN	UAS	58.227	-134.500	6.8	463.0	23	56.7	0.0	0.0	16.0	-0.60	0.18	0.10	4
Limestone	22	MAN	UAS	58.039	-133.954	32.3	681.0	27	41.7	1.5	0.0	22.6	-0.54	0.15	0.10	4
Japanese	23	MAN	FS	56.774	-132.605	15.6	495.0	26	85.2	0.0	0.0	8.3	-0.65	0.21	0.14	4
Admiralty	24	ABC	UAS	58.175	-134.559	56.1	449.0	24	55.9	1.3	0.0	20.2	-0.57	0.17	0.10	4
Youngs	25	ABC	UAS	58.159	-134.669	14.3	607.0	23	57.3	0.0	0.0	13.1	-0.63	0.18	0.10	4
Tenakee Head	26	ABC	CCC	58.002	-135.905	74.6	507.5	25	35.6	0.4	0.1	19.4	-0.59	0.18	0.11	11
Goose	27	ABC	CCC	57.907	-135.755	69.7	469.0	23	49.5	0.1	0.0	17.1	-0.60	0.19	0.11	11
Long	28	ABC	CCC	57.852	-135.666	49.9	447.0	22	45.7	0.2	0.0	16.8	-0.60	0.20	0.12	11
Seal	29	ABC	CCC	57.822	-135.602	50.5	400.0	20	60.0	0.1	0.0	15.5	-0.62	0.22	0.12	11
Goulding	30	ABC	FS	57.799	-136.224	84.2	292.8	21	41.3	10.6	0.0	13.3	-0.64	0.21	0.12	4
Trap	31	ABC	CCC	57.739	-135.019	11.4	388.0	25	54.8	0.0	0.0	11.6	-0.65	0.18	0.11	6
Black	32	ABC	FS	57.706	-136.099	63.1	296.0	22	54.8	0.7	0.0	11.7	-0.65	0.20	0.12	5
Tonalite aka Kadashan	33	ABC	CCC	57.693	-135.221	43.0	319.0	21	79.5	0.0	0.0	13.1	-0.63	0.21	0.12	7
Klag Lake	34	ABC	ADFG/ARRI	57.640	-136.081	8.0	121.4	12	73.6	16.6	0.0	7.9	-0.68	0.28	0.15	8
Ford Arm	35	ABC	FS	57.581	-135.918	26.8	313.0	23	55.0	1.6	0.0	10.1	-0.66	0.20	0.12	4
Sitkoh	36	ABC	CCC	57.554	-135.009	58.7	298.0	20	78.5	0.0	0.0	13.2	-0.63	0.23	0.13	11

Location	No.	Region	Site Manager[1]	Latitude	Longitude	Area (km^2)	Elev (m)	slope (deg)	% Forest	% Lake	% Glacier	SI 2080	SWE 2080	Summer sensitivity	Winter sensitivity	Duration (y)
Waterfall	37	ABC	FS	57.528	-135.911	17.3	348.8	25	50.1	1.0	0.0	10.0	-0.66	0.19	0.12	4
Kanalku*	38	ABC	ADFG	57.490	-134.372	31.8	351.0	22	79.8	3.4	0.0	12.1	-0.63	0.21	0.13	4
Leos	39	ABC	STA	57.428	-135.858	12.6	340.6	25	60.7	2.5	0.0	6.5	-0.70	0.19	0.12	4
Nakwasina	40	ABC	FS/STA	57.258	-135.329	81.7	636.3	31	22.2	1.3	0.1	19.0	-0.58	0.15	0.11	7
No Name	41	ABC	STA	57.127	-135.379	4.6	325.0	24	75.6	0.0	0.0	NA	NA	0.21	0.13	4
Starrigavan	42	ABC	STA	57.125	-135.331	11.5	440.0	29	62.8	0.1	0.0	NA	NA	0.17	0.12	4
Indian*	43	ABC	NPS	57.053	-135.317	31.8	379.1	27	58.9	0.0	0.0	8.4	-0.67	0.19	0.13	7
Falls Lake	44	ABC	ADFG/ARRI	56.827	-134.693	16.4	393.5	30	34.5	6.0	5.2	11.0	-0.64	0.17	0.12	8
Castle	45	CSI	FS	56.642	-133.267	112.9	168.0	13	91.7	0.1	0.0	8.1	-0.66	0.31	0.18	4
Bedrock	46	CSI	FS	56.625	-132.887	9.2	315.0	20	74.3	0.0	0.0	9.1	-0.64	0.26	0.16	4
Ohmer	47	CSI	FS	56.583	-132.730	8.3	387.0	16	91.7	0.0	0.0	9.1	-0.64	0.29	0.17	4
Kah Sheets	48	CSI	FS	56.530	-133.146	43.8	173.0	11	84.5	4.0	0.0	7.8	-0.66	0.33	0.19	4
Pat	49	CSI	SAWC	56.354	-132.325	14.0	355.6	19	101.0	0.2	0.0	7.8	-0.65	0.28	0.17	<1
McCormack	50	CSI	SAWC	56.312	-132.338	11.7	312.3	21	97.3	0.1	0.0	7.6	-0.65	0.26	0.16	<1
Kunk	51	CSI	FS	56.285	-132.398	15.0	428.0	25	85.6	6.4	0.0	7.6	-0.65	0.23	0.15	4
Thoms	52	CSI	FS	56.197	-132.159	16.1	242.4	10	88.3	8.6	0.0	8.9	-0.64	0.35	0.20	4
Anan	53	CSI	FS	56.179	-131.882	143.2	473.0	20	83.7	5.7	0.0	13.3	-0.60	0.27	0.17	4
Leask	54	CSI	KIC	55.519	-131.523	20.6	160.1	16	93.6	8.3	0.0	7.0	-0.63	0.33	0.20	<1
Lunch	55	CSI	FS	55.509	-131.721	14.6	387.0	25	96.6	1.2	0.0	7.0	-0.63	0.26	0.18	4
Mahoney	56	CSI	KIC	55.420	-131.537	6.5	718.6	24	15.2	10.3	0.0	8.2	-0.62	0.27	0.18	<1
Signal	57	CSI	FS	55.408	-131.701	3.7	316.1	21	99.9	0.1	0.0	8.9	-0.62	0.29	0.19	4
Sarkar	58	POW	FS	55.967	-133.193	70.1	130.2	13	87.2	8.5	0.0	6.9	-0.65	0.34	0.20	1
Luck Creek	59	POW	FS	55.922	-132.765	47.5	369.3	22	88.6	0.1	0.0	9.9	-0.62	0.27	0.17	4
Hatchery	60	POW	SAWC/POWWA	55.910	-132.932	104.8	234.0	13	91.9	3.3	0.0	8.7	-0.63	0.34	0.20	3
Staney	61	POW	USGS	55.801	-133.110	135.1	233.4	15	94.8	0.1	0.0	8.5	-0.63	0.33	0.20	21

Location	No.	Region	Site Manager[1]	Latitude	Longitude	Area (km^2)	Elev (m)	slope (deg)	% Forest	% Lake	% Glacier	SI 2080	SWE 2080	Summer sensitivity	Winter sensitivity	Duration (y)
Rio Roberts	62	POW	SAWC/POWWA	55.700	-132.774	32.0	282.0	12	98.4	0.1	0.0	8.6	-0.62	0.35	0.21	4
Elevenmile	63	POW	FS	55.586	-133.278	17.2	169.0	10	85.9	0.6	0.0	5.2	-0.65	0.37	0.22	3
Twelvemile	64	POW	FS	55.343	-132.736	30.8	312.3	19	90.7	0.1	0.0	9.2	-0.60	0.31	0.20	9
Hetta	65	POW	HCA/Kai	55.171	-132.571	22.8	336.0	24	73.9	11.5	0.0	9.2	-0.60	0.28	0.19	4

*Seasonal data collection only

[1]ADFG = Alaska Department of Fish and Game
ARRI = Aquatic Restoration and Research Institute
CCC = Chichagof Conservation Council
CIV = Chilkat Indian Village
FS = US Forest Service,
HCA = Hydaburg Cooperative Association
Kai = Kai Environmental Consulting Services
KIC = Ketchikan Indian Community
NPS = National Park Service
POWWA = Prince of Wales Watershed Association
SAWC = Southeast Alaska Watershed Coalition
STA = Sitka Tribe of Alaska
STC = Skagway Traditional Council
TWC = Takshanuk Watershed Council
UAS = University of Alaska Southeast
USGS = US Geological Survey

Appendix C. Gap Analysis

Existing “gaps” in monitoring coverage were assessed across eight watershed variables – mean watershed elevation, mean watershed slope, percent glacier cover, percent lake cover, summer sensitivity of stream temperature to air temperature, winter sensitivity of stream temperature to air temperature, snow index (SI) (fraction of winter precipitation as snow projected for 2080’s based on a high emissions scenario, RCP 8.5) and projected change in April snow water equivalent (amount of water in the snowpack for 2080 based on a high emissions scenario, RCP 8.5). For the gap analysis, we followed an approach similar to that outlined by Jackson *et al* (2016) for a strategic temperature monitoring network. As described in the strategic sampling plan section, these variables were calculated for HUC12 and HUC14 areas that closely resembled watersheds – that is, the drainage area of the stream leaving the HUC area closely resembles the HUC boundary. These values were used to assess the potential variability in watershed characteristics within five biogeoclimatic zones across the region (Fig. 3) and were compared to characteristics of watersheds that are currently being monitored within those zones (Figs A-C.1-8). The values for “existing” watersheds were divided into 7 bins – 0-15% of the range, 15-30, 30-45, 45-55, 55-70, 70-85, and 85-100%. If no currently monitored watershed fell within one of these bins, a watershed that could fill this gap was identified for potential future monitoring. Although the watershed with the value closest to the center of the bin would be ideal, we prioritized watersheds with road or trail access or other nearby activities (e.g. Forest Service cabin). These “potential” watersheds are listed in Table A-C.1.

This method has several important caveats. First, our set of “existing” watersheds are at the HUC14 and HUC12 scale, but exclude the very large transboundary watersheds at the HUC12 scale, where the methods for monitoring temperature in wadeable streams do not necessarily apply. The median size for these “existing” watersheds is 11 km^2, while the median size of currently monitored sites is 28 km^2. Importantly, the HUC12 scale watersheds were acquired from a Forest Service data set that had modified the USGS data set so that coastal units were more reflective of true drainage areas (F. Biles, personal comm.). Consequently, the watershed units in this data set do not have the same unique 12-digit identifiers as the USGS set. Secondly, the snow index and change in snow-water equivalent were modeled at the HUC12 scale, so HUC14 areas nested within a HUC12 were all assigned the HUC12 values. Last, the summer and winter stream temperature sensitivity models were developed for watersheds with ≤ 10% glacier coverage. As such, these sensitivity values were only applied to watersheds with glacier coverage below that value.

Figure A-C.1. Gap assessment based on watershed elevation.
Figure A-C.2. Gap assessment based on watershed slope
Figure A-C.3. Gap assessment based on percent glacier cover
Figure A-C.4. Gap assessment based on percent lake cover
Figure A-C.5. Gap assessment based on summer sensitivity of stream temperature to air temperature.
Figure A-C.6. Gap assessment based on winter sensitivity of stream temperature to air temperature.
Figure A-C.7. Gap assessment based on watershed Snow Index projected for 2080 based on a high emissions scenario (RCP 8.5).
Figure A-C.8. Gap assessment based on projected change (fraction lost) in April snow-water equivalent from present to 2080 based on a high emissions scenario (RCP 8.5).

Table A-C.1 List of potential monitoring sites to fill current gaps.

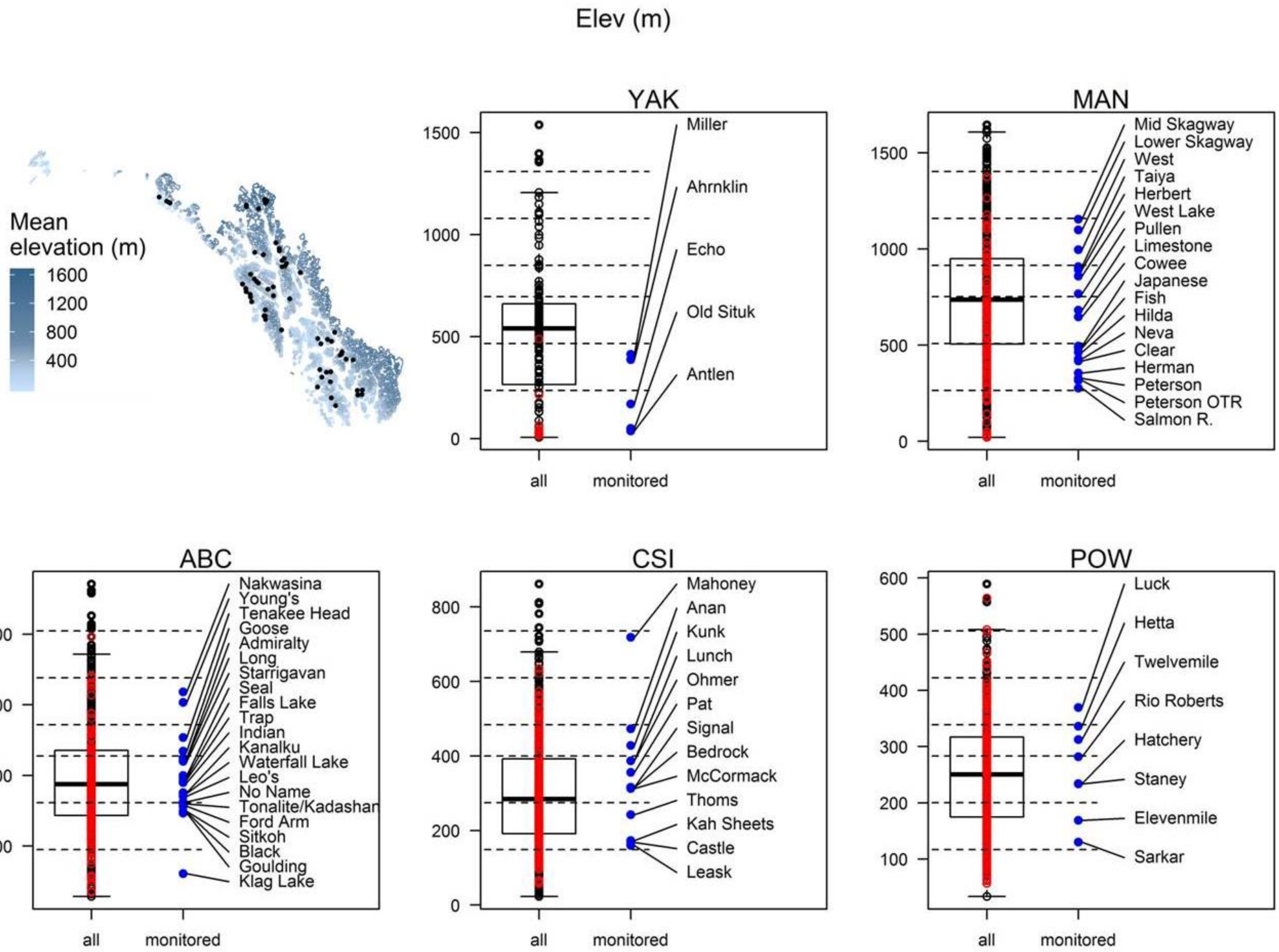

Figure A-C.1. Gap assessment based on watershed elevation. Top left panel: Mean elevation of watersheds at the HUC12 scale. Black dots on the map indicate monitoring locations. Remaining panels: Mean elevation of existing watersheds (black and red; red `indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

Slope (deg)

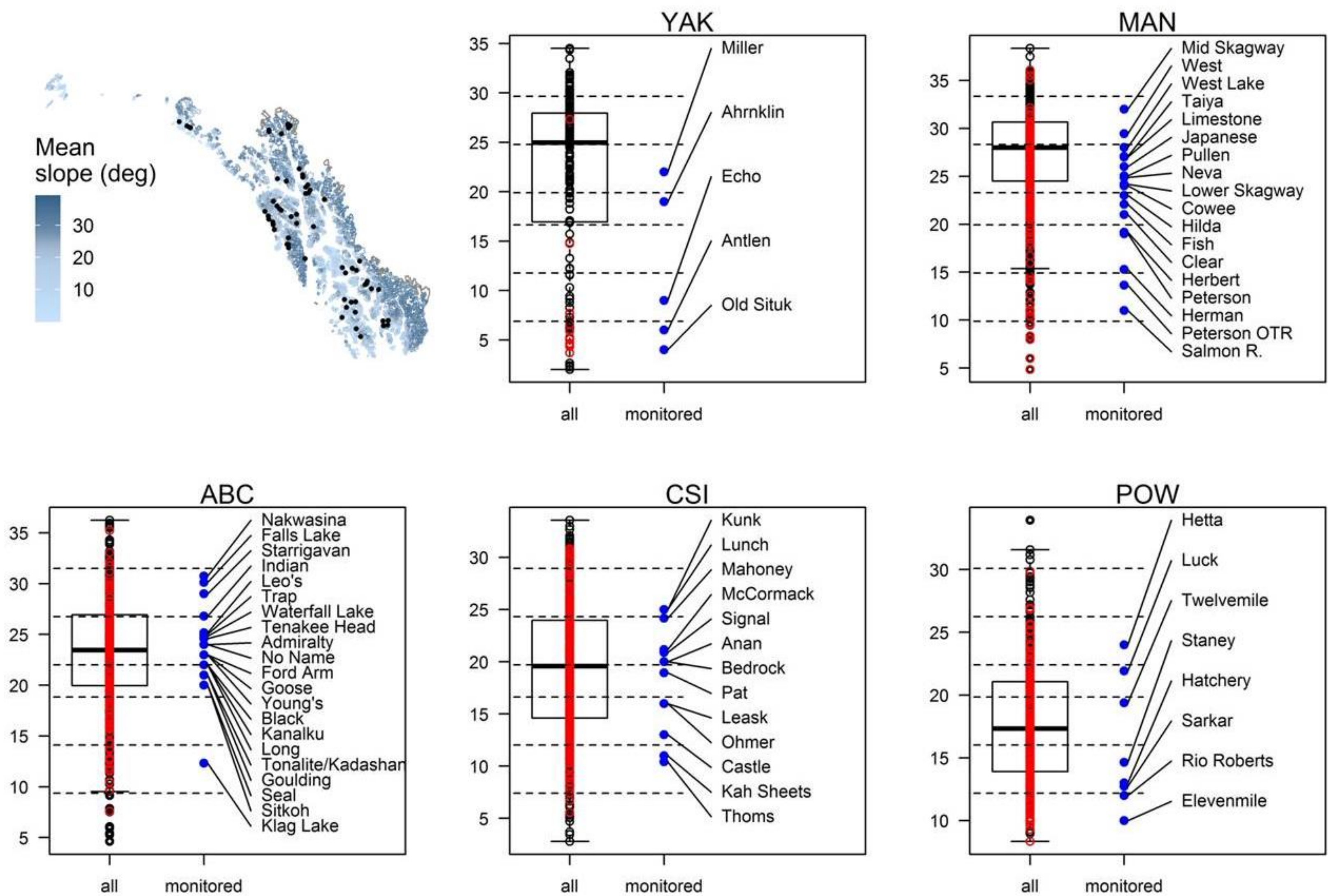

Figure A-C.2. Gap assessment based on watershed slope. Top left panel: Mean slope of watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Mean slope of existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

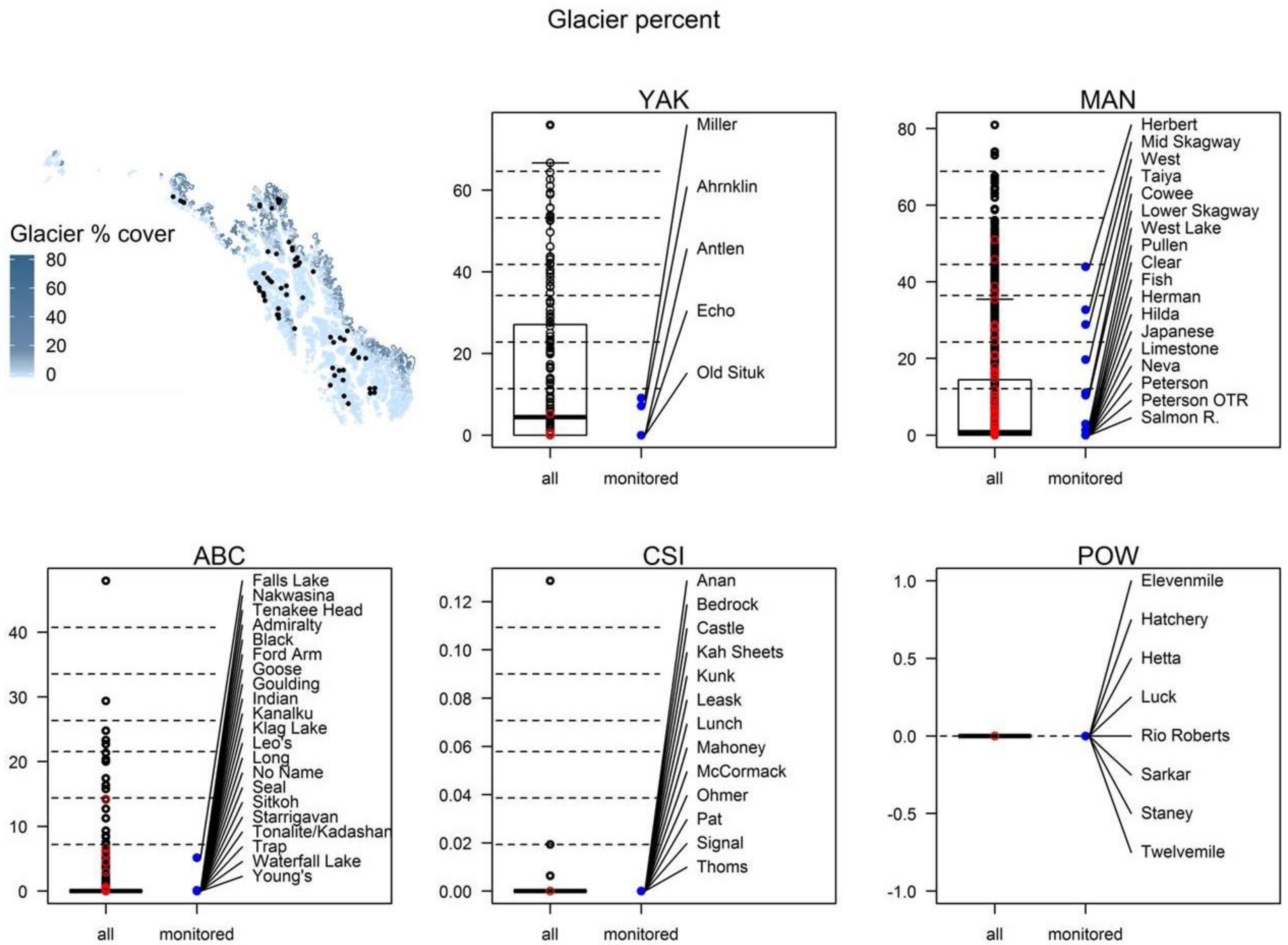

Figure A-C.3. Gap assessment based on percent glacier cover. Top left panel: Percent glacier cover in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Percent glacier cover in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

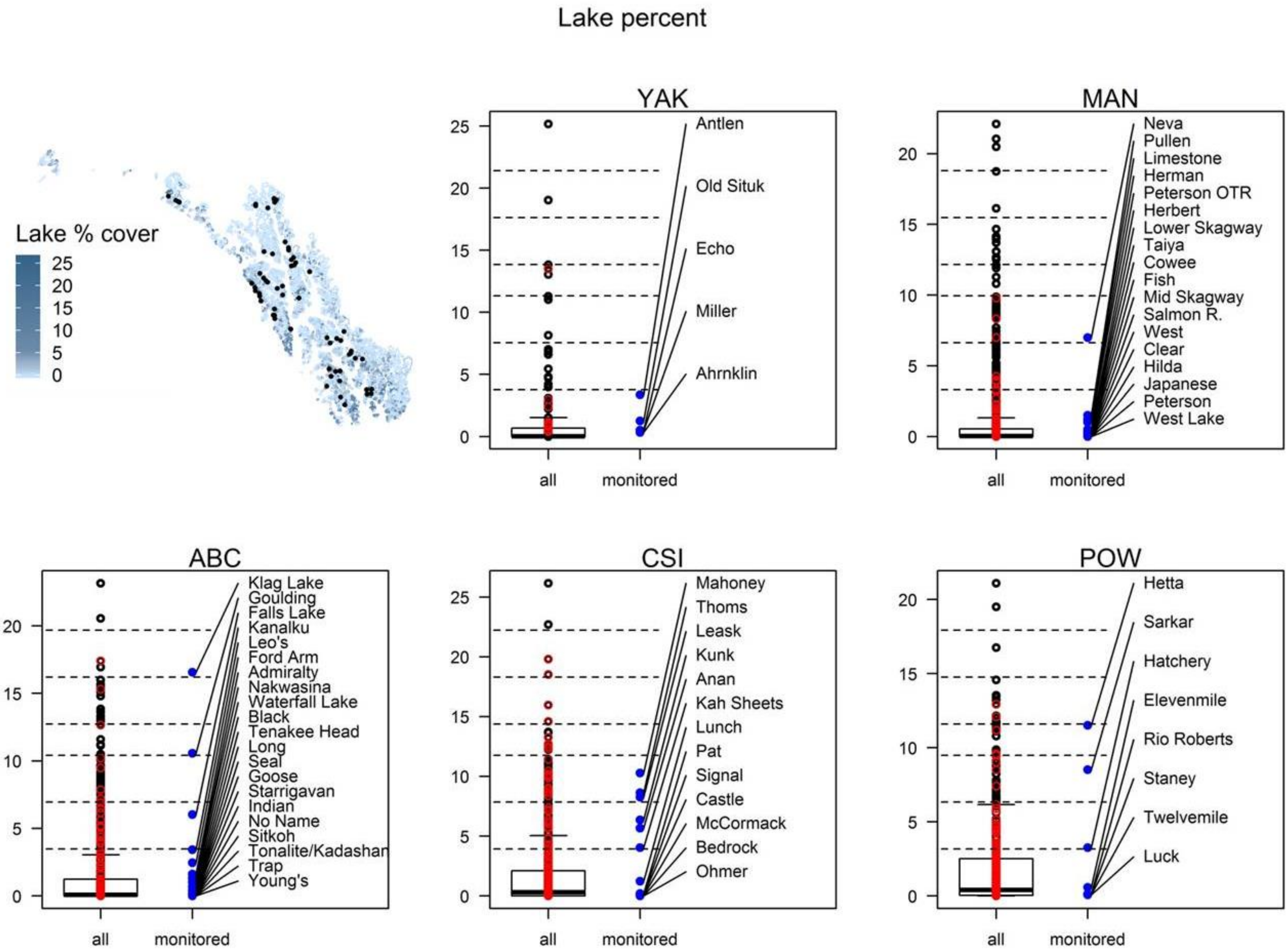

Figure A-C.4. Gap assessment based on percent lake cover. Top left panel: Percent lake cover in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Percent lake cover in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

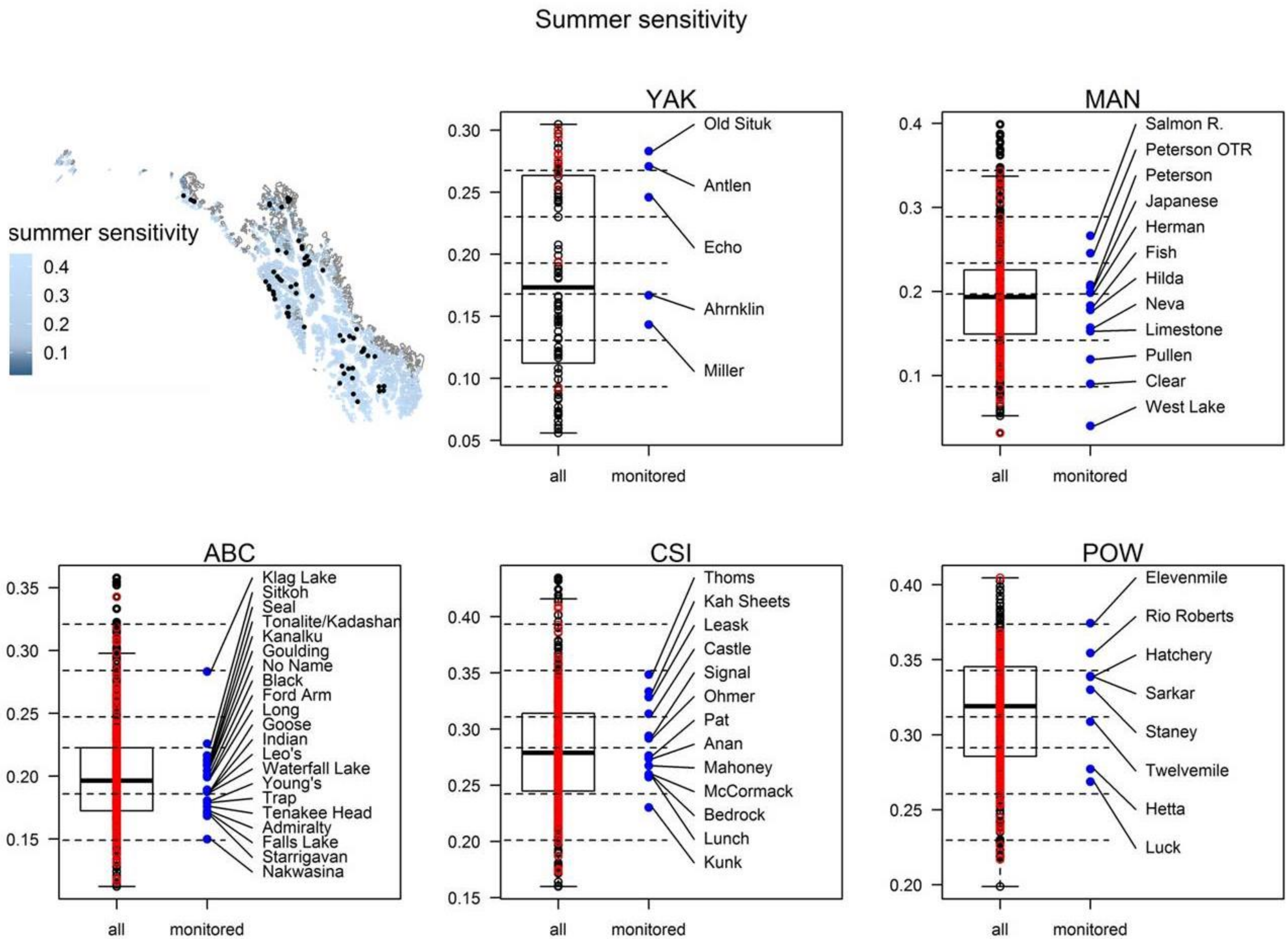

Figure A-C.5. Gap assessment based on summer sensitivity of water temperature to air temperature. Top left panel: Summer sensitivity in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Summer sensitivity in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

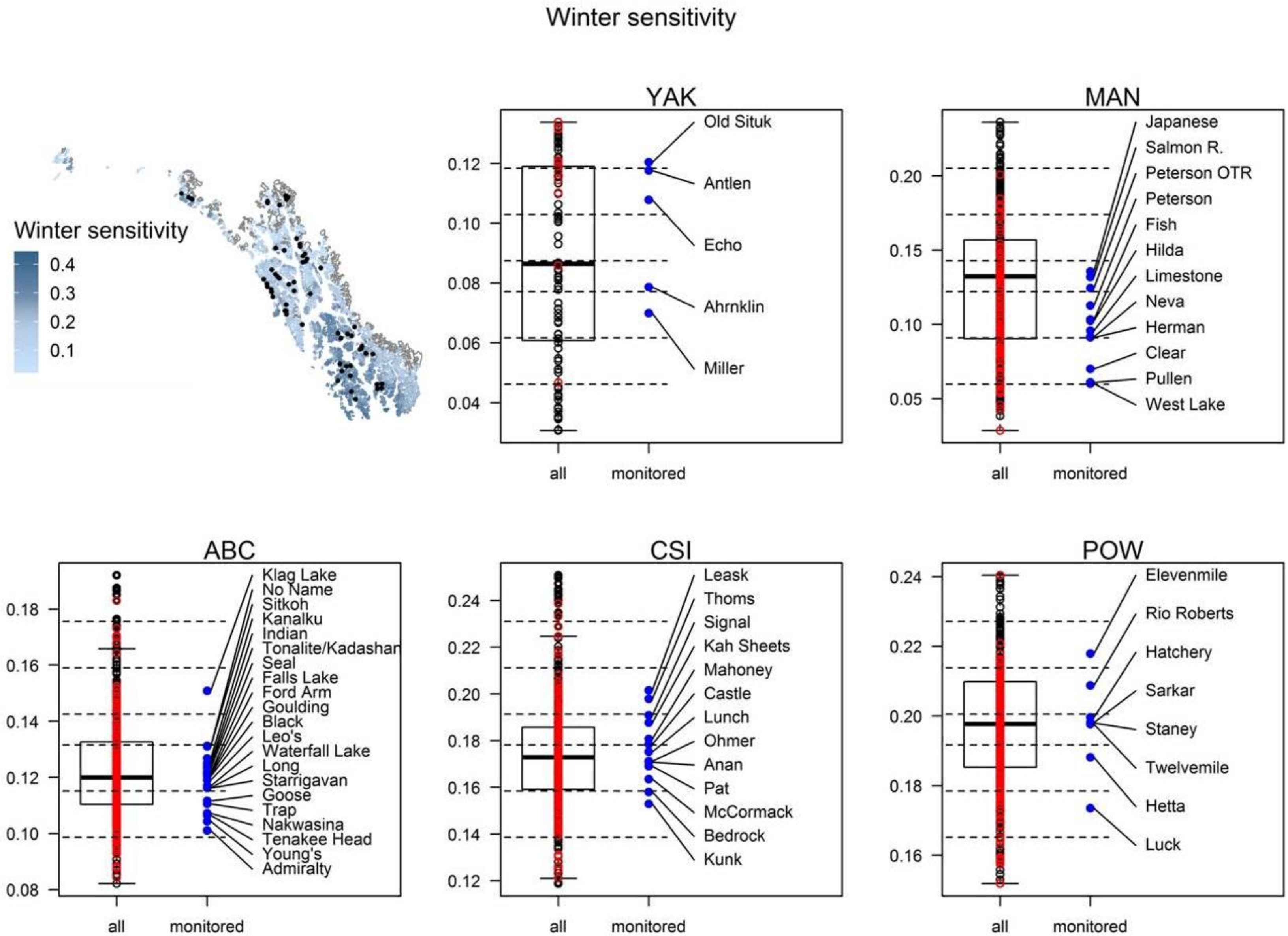

Figure A-C.6. Gap assessment based on winter sensitivity of water temperature to air temperature. Top left panel: Winter sensitivity in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Winter sensitivity in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

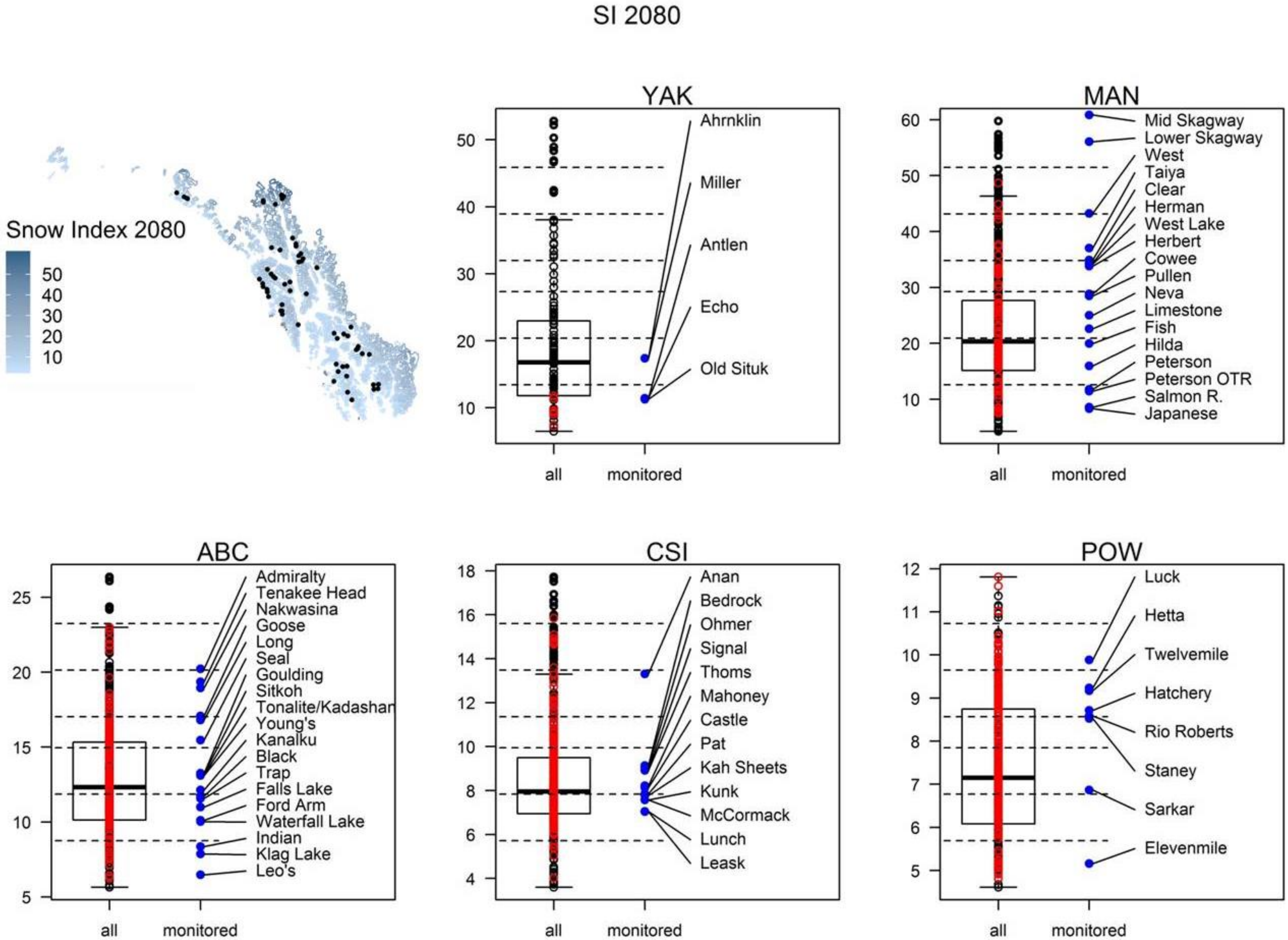

Figure A-C.7. Gap assessment based on watershed Snow Index projected for 2080 based on a high emissions scenario (RCP 8.5). Top left panel: Snow Index in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Snow Index in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

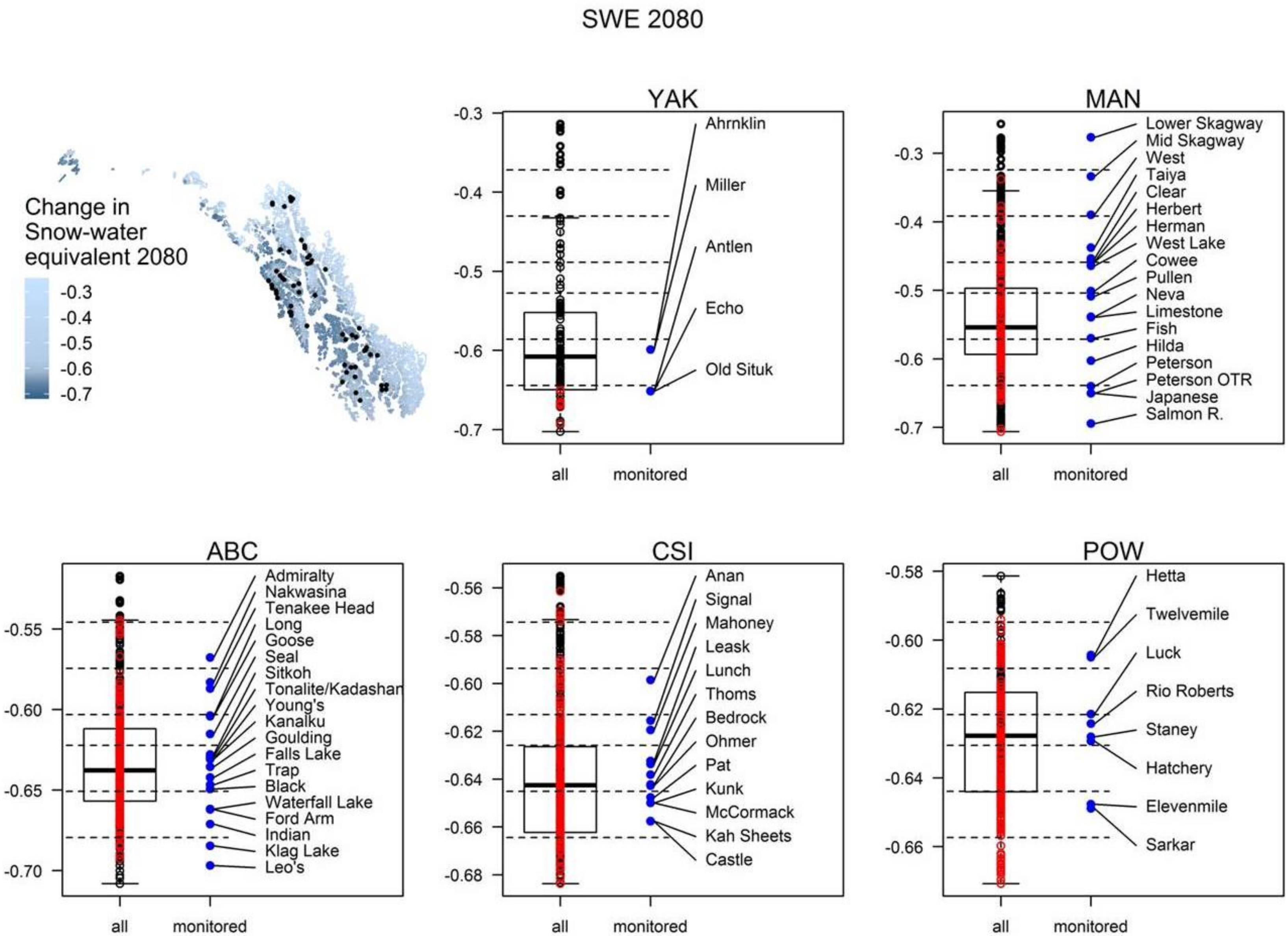

Figure A-C.8. Gap assessment based on projected change (fraction lost) in April snow-water equivalent from present to 2080 based on a high emissions scenario (RCP 8.5). Top left panel: Snow-water equivalent change in watersheds at the HUC12 scale. Black dots indicate monitoring locations. Remaining panels: Snow-water equivalent change in existing watersheds (black and red; red indicates a watershed with a mapped trail or road crossing its boundary) and monitored watersheds (blue). Dotted lines delineate the bins assessed for gaps in coverage, bounded at 0, 15, 30, 45, 55, 70, 85, and 100% of the range of existing watersheds.

Table A-C.1. Watersheds identified as potential monitoring sites to fill current gaps in coverage.

Zone	HUC14*	Name	Latitude (center)	Longitude (center)	Area (km^2)	Elevation (m)	Slope (deg)	Lake (% cover)	Glacier (% cover)	SI (rcp 8.5, 2080)	SWE (rcp 8.5, 2080)	Summer sensitivity	Winter sensitivity	Accessibility	Gap coverage[#]
ABC	19010204080102	Upper Greens Creek	58.0810	-134.619	38.8	678	25.8	0.0	0.0	23.0	-0.54	0.16	0.10	Accessible	Elev6, SWE7, WS1
ABC	19010212020501	Upper Baranof River	57.0321	-135.018	24.9	820	31.5	0.0	20.0	21.4	-0.56	NA	NA	No road/trail access	Elev7, Slope7, Glac3
ABC	19010212120101	Upper Katlian River	57.1375	-135.085	16.4	793	31.8	0.0	14.1	23.0	-0.55	NA	NA	Accessible	Glac2, Elev6, Slope7, SWE7
ABC	19010212020602	19010212020602	56.9981	-134.874	8.1	713	29.2	0.0	29.4	22.7	-0.54	NA	NA	No road/trail access	Glac5, Elev6
ABC	19010204070107	Lake Alexander	57.6711	-134.178	14.3	217	13.7	15.3	0.0	16.5	-0.59	0.27	0.15	Accessible	Lake5, Slope3
ABC	NA	Hasselborg Creek	57.6580	-134.291	295.6	291	17.7	9.5	0.3	14.5	-0.61	0.24	0.13	Accessible	Slope3, Lake3, WS4
ABC	19010212110401	Medvejie Lake	57.0224	-135.099	18.7	663	33.1	7.9	0.0	16.4	-0.60	0.14	0.11	Accessible	SS1
ABC	19010212120302	19010212120302	57.0649	-135.664	10.8	183	11.5	0.0	0.0	7.5	-0.68	0.31	0.17	Accessible	SS6, WS6
CSI	19010210050502	Slo Duc Creek	56.9254	-133.784	16.4	113	9.1	0.1	0.0	6.7	-0.68	0.34	0.18	Accessible	Elev1, SWE1, Slope1
CSI	NA	Olive Creek	56.1568	-132.354	43.8	496	24.1	4.0	0.0	13.3	-0.60	0.24	0.16	Accessible	Elev5, SWE6
CSI	19010102010403	19010102010403	55.8867	-131.217	20.5	812	29.9	2.8	0.0	13.7	-0.59	0.21	0.15	No road/trail access	Elev7, SI6, Slope7
CSI	19010102040201	Headwaters Ketchikan Creek	55.3883	-131.613	21.5	429	29.4	13.3	0.0	10.6	-0.60	0.23	0.17	Accessible	Lake4, Slope7
CSI	19010102090202	Tamgas Lake	55.0686	-131.456	18.8	249	24.8	16.0	0.0	5.4	-0.63	0.27	0.19	Accessible	Lake5, SI1
CSI	NA	Ella Creek	55.4826	-131.079	55.4	298	21.3	14.6	0.0	10.4	-0.60	0.29	0.19	Accessible	Lake5, SI4
CSI	NA	Falls Creek	55.6368	-131.224	93.8	518	29.9	7.4	0.0	15.8	-0.56	0.21	0.16	Accessible	SI7, SWE7
CSI	19010210020302	Ambler Peak	56.9774	-133.215	22.7	480	25.5	0.4	0.0	11.0	-0.63	0.20	0.13	Accessible	SS1, WS1
CSI	19010102040301	Government Creek	55.3343	-131.715	5.9	96	8.8	1.5	0.0	6.0	-0.64	0.39	0.23	Accessible	SS6, WS6, Elev1
MAN	19010302140702	19010302140702	58.4192	-135.827	11.5	21	4.9	0.0	0.0	7.5	-0.71	0.32	0.15	Accessible	Elev1, Slope1, SS6, WS5
MAN	191010100601010 4	North Fork Texas Creek	56.0861	-130.149	26.3	1177	NA	0.0	36.8	32.8	-0.44	NA	NA	Accessible	Elev6
MAN	NA	Mendenhall Glacier	58.4763	-134.516	268.5	882	19.8	1.5	45.8	33.5	-0.46	NA	NA	Accessible	Glac5
MAN	NA	Cascade Creek	57.0257	-132.683	60.1	896	28.1	4.0	11.9	30.6	-0.46	NA	NA	Accessible	Lake2
MAN	NA	Punchbowl Lake	55.5014	-130.740	41.8	469	23.9	22.1	0.0	14.0	-0.57	0.27	0.18	No road/trail access	Lake7, WS6
MAN	NA	Captain William Moore Creek	59.5330	-135.133	351.0	1099	NA	0.4	15.5	48.7	-0.34	NA	NA	Accessible	SI6
MAN	19010303110904	19010303110904- Four Winds Mountain	59.4929	-136.106	4.5	984	35.5	0.0	15.7	32.4	-0.47	NA	NA	Accessible	Slope7

Zone	HUC14*	Name	Latitude (center)	Longitude (center)	Area (km^2)	Elevation (m)	Slope (deg)	Lake (% cover)	Glacier (% cover)	SI (rcp 8.5, 2080)	SWE (rcp 8.5, 2080)	Summer sensitivity	Winter sensitivity	Accessibility	Gap coverage#
POW	19010103100203	Gutchi Creek	55.8673	-133.096	12.7	86	9.9	2.1	0.0	6.6	-0.65	0.37	0.21	Accessible	Elev1, SI2
POW	19010103130101	Headwaters Black Bear Creek	55.5554	-132.892	19.3	503	29.8	5.7	0.0	11.6	-0.60	0.22	0.16	Accessible	Elev6, SI7, Slope6, SS1, WS1
POW	19010103030301	Twin Island Lake	56.1643	-133.220	10.3	240	15.1	12.1	0.0	7.7	-0.65	0.31	0.19	Accessible	Lake5
POW	19010103090701	Perue Peak	56.2238	-133.485	21.5	417	24.1	0.5	0.0	10.2	-0.63	0.24	0.16	Accessible	SS2, WS1, SWE3
POW	19010103110802	19010103110802-Frontal Edna Bay	55.9406	-133.682	5.0	108	10.2	0.0	0.0	5.5	-0.66	0.36	0.21	Accessible	SWE1
POW	NA	Black Bear Creek	55.5774	-132.914	45.5	418	23.1	2.9	0.0	11.8	-0.59	0.27	0.18	Accessible	SWE7, SI7
POW	NA	Hessa Lake	54.8679	-132.184	72.2	138	11.5	6.2	0.0	6.5	-0.61	0.39	0.23	No road/trail access	WS7
YAK	19010406050302	South Dome-Finger Glacier	58.4971	-137.181	6.6	771	28.4	0.0	17.3	28.9	-0.52	NA	NA	No road/trail access	Elev4, SI4, SWE4, Glac3
YAK	NA	Butler Glacier	59.9259	-139.096	85.2	948	22.9	0.0	42.1	36.8	-0.44	NA	NA	No road/trail access	Elev5, Glac5, SWE5, SI5
YAK	19010405100301	Hanging Glacier	59.8569	-138.957	21.6	1064	25.5	0.0	53.6	23.9	-0.55	NA	NA	No road/trail access	Elev5, Slope6, Glac6, SWE3, SI3
YAK	NA	North Crillon Glacier	58.6395	-137.315	196.0	1182	26.0	2.9	55.6	38.1	-0.44	NA	NA	No road/trail access	Elev6, Slope6, Glac6, SWE5, SI5
YAK	19010303120501	Saksaia Glacier	59.3723	-136.410	18.1	1355	27.1	0.0	52.5	48.3	-0.35	NA	NA	No road/trail access	Elev7, Slope6, Glac5, SWE7, SI7
YAK	19010406030201	19010406030201	58.9921	-137.902	33.3	465	21.2	4.8	12.9	13.7	-0.64	NA	NA	No road/trail access	Lake2, Glac2
YAK	19010405100302	Cascading Glacier	59.8061	-139.038	24.7	666	25.3	11.3	34.8	24.1	-0.55	NA	NA	No road/trail access	Lake3, Glac4
YAK	19010405130214	Humpback Creek	59.6368	-139.550	6.2	56	9.4	19.0	0.0	11.8	-0.65	0.24	0.10	No road/trail access	Lake6, WS5
YAK	19010406040202	Lower Desolation Glacier	58.7867	-137.544	24.2	1366	30.2	0.0	64.3	42.4	-0.40	NA	NA	No road/trail access	SI6, SWE6
YAK	19010405140601	Upper Situk River	59.6503	-139.372	39.8	215	14.8	13.5	0.5	11.4	-0.65	0.19	0.09	Accessible	Slope3, Lake4, SS5
YAK	19010405130211	19010405130211-Mount Mallott	59.7029	-139.434	11.0	487	27.3	0.4	5.2	11.8	-0.65	0.09	0.05	Accessible	Slope6, Elev3, SS1, WS2
YAK	19010404040301	19010404040301-Alsek Glacier	59.1173	-137.999	4.0	628	34.4	0.0	2.3	13.2	-0.64	0.06	0.04	No road/trail access	Slope7, WS1
YAK	19010406040601	Upper Echo Creek	58.7196	-137.655	17.7	578	27.9	0.0	3.2	14.3	-0.63	0.12	0.07	No road/trail access	SS2, slope6, Elev3
YAK	19010404020306	19010404020306	59.3915	-138.193	5.8	297	17.1	0.0	0.0	24.7	-0.55	0.18	0.09	No road/trail access	SS4

*Sites with NA are from the Forest Service data set that is similar to USGS HUC12.

[#]Abbreviations are: Elev = Elevation, Lake = % Lake cover, Glac = % Glacier cover, SI = Snow Index, SWE = change in snow water equivalent, SS = summer sensitivity, WS = winter sensitivity. Numbers correspond to the bins: 1 = 0-15%, 2 = 15-30%, 3 = 30-45%, 4 = 45-55%, 5 = 55-70%, 6 = 70-85%, 7 = 85-100% of range.

Appendix D. Supporting information for gap analysis

Description of models supporting climate vulnerability indices

To further address the goal of understanding the impacts of climate change on stream temperatures and aquatic resources in the region, we propose strategically selecting watersheds that are projected to range from relatively insensitive to highly sensitive to climate change. As previously discussed, climate impacts on thermal regimes are uncertain, and sampling across the range of projected sensitivities will allow us to assess our projections about how climate change is affecting our region's streams. Two models were used to characterize the sensitivity of watersheds to climate change. One model addresses the amount of winter precipitation falling as snow (Fig. A-D.1); the other addresses the sensitivity of winter and summer stream temperatures to air temperature (Fig. A-D.2).

The sensitivities of watersheds to climate change are related to geographic position (e.g. latitude), as well as variables like elevation and slope (Fig. A-D.3). Therefore, by capturing the range of geomorphic variables across the different biogeoclimatic zones in the monitoring scheme, we are likely to capture a range of sensitivities to climate change. However, we explicitly address climate sensitivity in the strategic sampling plan because of the focus of this network on understanding climate impacts on aquatic resources.

Model 1: Snowpack Vulnerability
Climate projection models indicate that winters in Southeast Alaska will be warmer with a greater proportion of winter precipitation falling as rain. As the climate warms, some watersheds will transition from snowpack-dominant to rainfall-dominant, with important implications for the region's aquatic ecosystems. We used a output from snow vulnerability model developed by Littell *et al* (2018) to characterize the projected dominant form of winter precipitation and change in form: Snow Index (SI) is the fraction of winter (October through March) precipitation that falls as snow, and the change in snow water equivalent (SWE) is the change in water in the snowpack on April 1 from historical average. These model outputs are provided at the HUC12 scale. We used projections for the 2080's that were based on RCP 8.5 (high emissions scenario) (Fig. A-D.1) to characterize monitored and existing watersheds and inform the gap analysis.

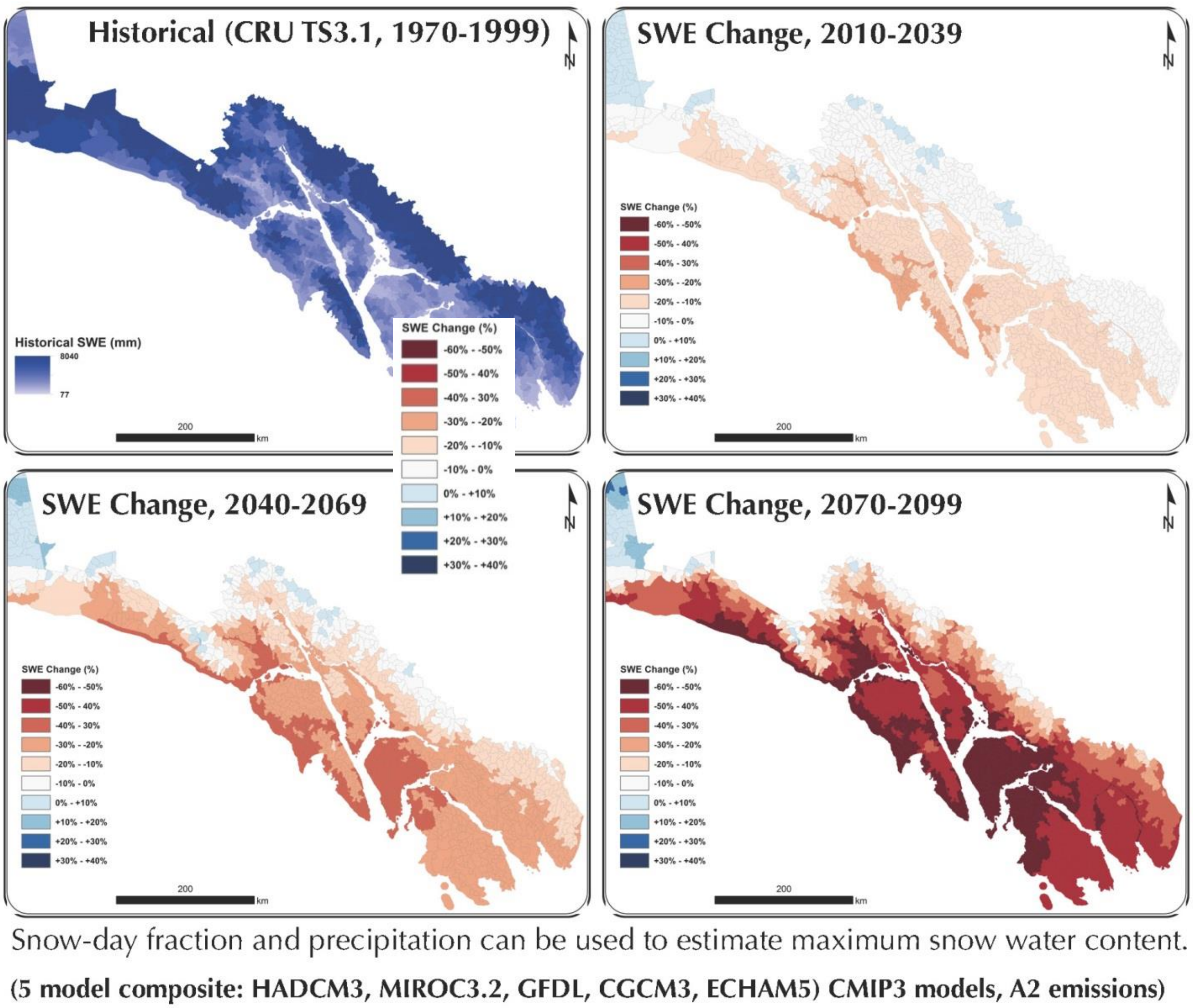

Figure A-D.1. Historical winter snow water equivalent and projected fraction of winter precipitation as snow (from Littell 2017).

Model 2: Stream temperature sensitivity to air temperature

The seasonal stream temperature sensitivity model developed by Winfree et al (2018) was used to identify streams with a range of sensitivities to air temperature (Fig. A-D.2). The summer and winter sensitivity values are a function of mean watershed slope and watershed latitude. The model was applied to each monitored and "existing" watershed in the region, with the exception of watersheds with greater than 10% glacier coverage.

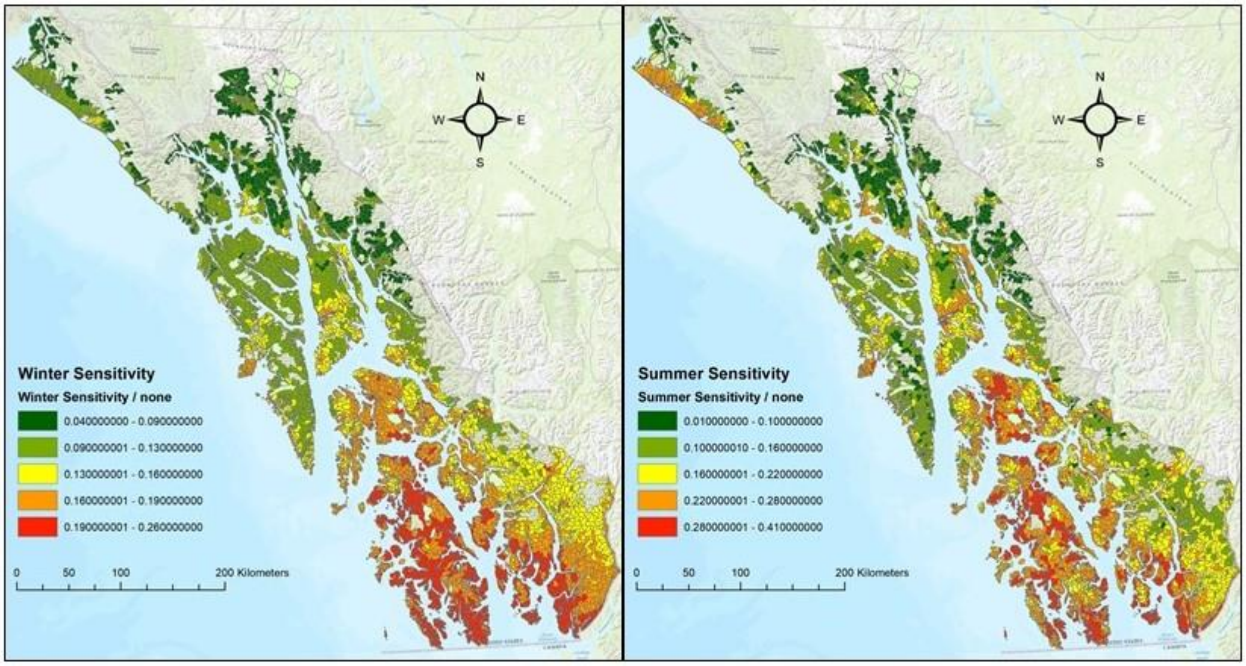

Figure A-D.2. Summer and winter stream temperature sensitivity to air temperature for southeast Alaska watersheds. Units of sensitivity represent the change in water temperature (°C) associated with a 1 °C increase in air temperature. For example, a sensitivity of 0.4 indicates that stream water temperature will increase 0.4 °C with a 1°C increase in air temperature.

Relationships among watershed and climate sensitivity characteristics

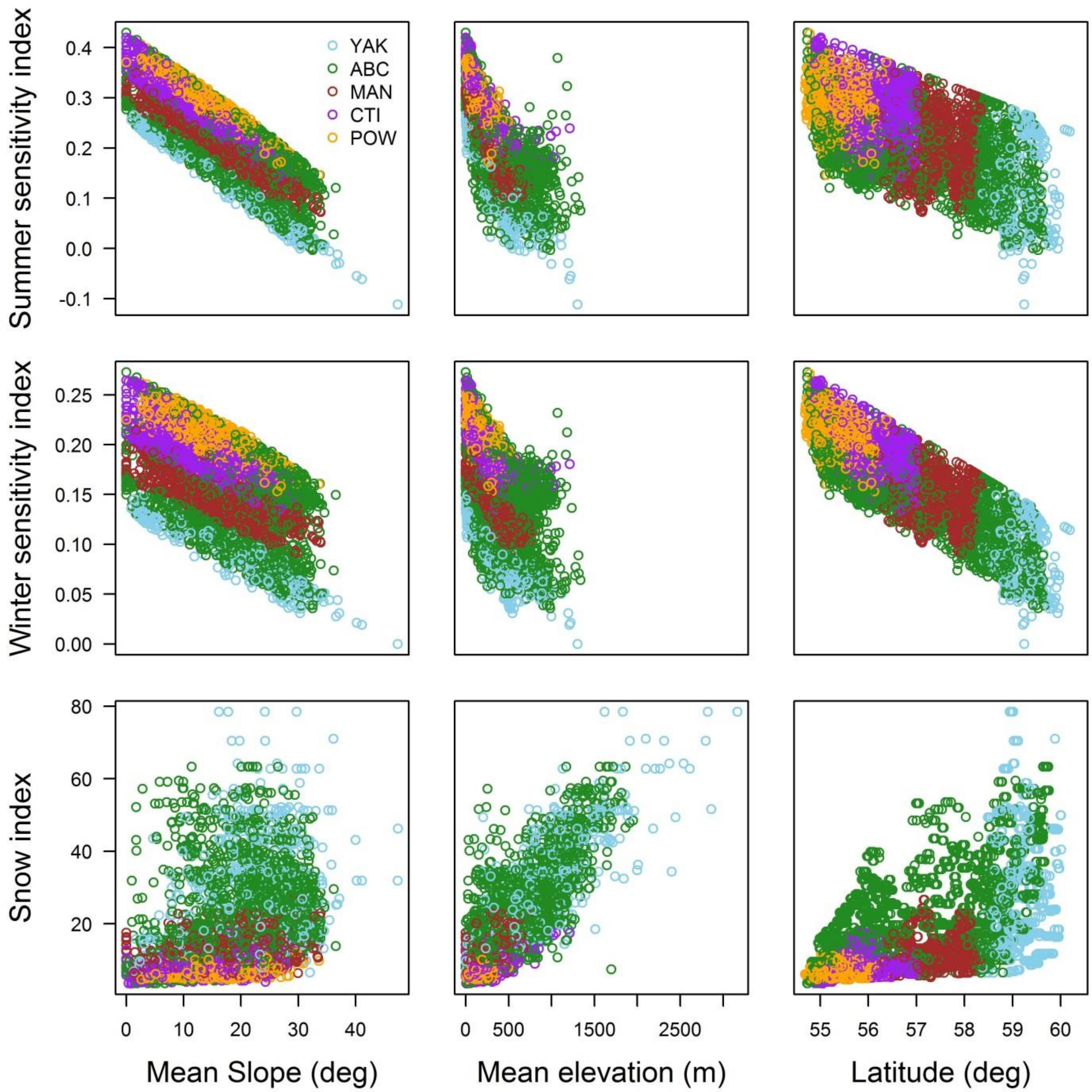

Figure A-D.3. Relationships among climate sensitivity indices and watershed characteristics. The summer and winter sensitivity indices are based on regression equations that include slope and elevation, and show strong correlations with these variables. Note that these indices were not calculated for watersheds with greater than 10% glacier cover. Mean elevation is most closely correlated with the snow index.

Relationships among climate sensitivity variables

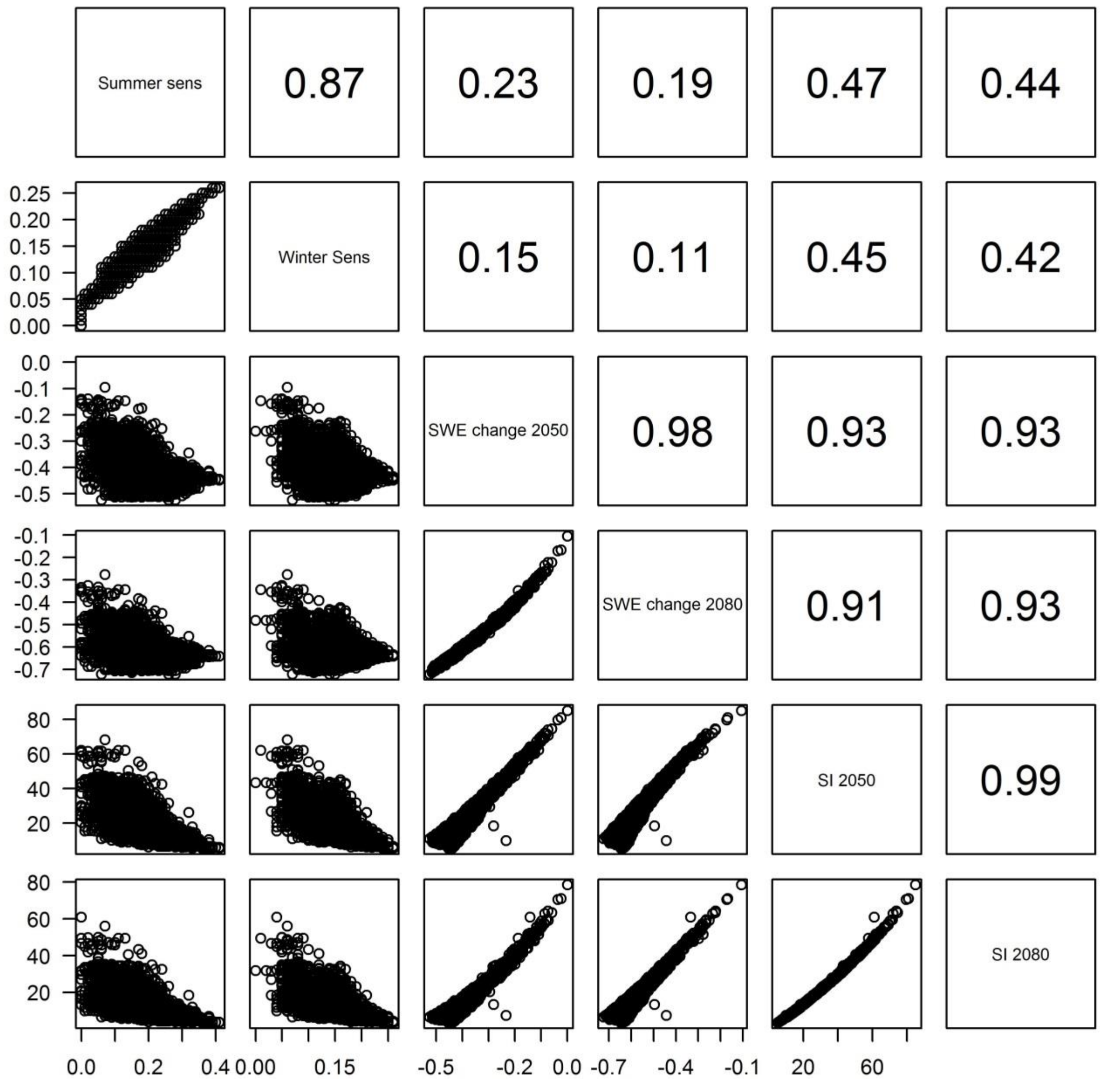

Figure A-D.4. Relationships among climate sensitivity variables. Summer and winter sensitivity are closely related to each other, and SWE change and Snow Index (SI) for both 2050 and 2080 are all closely related to one another. Values in the upper right panels are r^2 associated with the relationships in the lower left panels.