



Mountain Lakes Air and Water Temperature Report

2008-2011 Data Summary, North Coast and Cascades Network

Natural Resource Report NPS/NCCN/NRR—2015/1100



ON THE COVER

Easy Ridge Lake still partly covered in ice, August 29, 2011, North Cascades National Park
Photograph by: NPS

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Contents

	Page
Figures.....	v
Figures (continued)	vi
Figures (continued)	vii
Tables.....	viii
Appendices.....	ix
Executive Summary	x
Acknowledgments.....	xiii
Introduction.....	1
Background.....	3
Factors Influencing Lake Temperature	3
Climate Variation	3
Lake Ecosystem Response to Climate Warming.....	4
Study Area	7
Methods.....	11
Water and Air Temperature Data Collection.....	11
Temperature Response Variables	12
Degree-Day Accumulation	13
Summer and Fall Lake Turnover Date Determination	14
Air Temperature Lapse Rates.....	15
Data Processing, Quality Control, and Analysis	15
Data Completeness	16
Temperature Data Statistical Routines	16
Results and Discussion	17
Data Quality and Completeness	17
Weather Conditions at NCCN Parks during the 2009-2011 Reporting Period	20

Contents (continued)

	Page
Overview of the Seasonal Temperature Cycle in NCCN Lakes	22
Air Temperature Characteristics of NCCN Monitoring Lakes	24
Annual Air Temperature Data	24
Monthly Average Air Temperature	28
Water Temperature Characteristics of NCCN Monitoring Lakes	30
Daily Average Water Temperature ($\text{DAT}_{\text{water}}$) Annual Plots	31
Annual Lake Surface Water Temperature	45
Monthly Average Lake Surface Water Temperature	47
Degree-Day Accumulation	49
Heating Degree-Days (HDD)	49
Freezing Degree-Days (FDD)	53
Index of Thermal Stress (ITS)	54
Literature Cited	57

Figures

	Page
Figure 1. General location of North Cascades, Mount Rainier, and Olympic National Parks long-term lake monitoring sites.	7
Figure 2. Mount Rainier National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.	9
Figure 3. North Cascades National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.	9
Figure 4. Olympic National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.....	10
Figure 5. Water temperature logger array design.....	11
Figure 6. Air and water temperature data completeness by park, for the period of 2008-2011.....	17
Figure 7. Example plot illustrating how air temperature data are affected by snow cover on the logger placed at Bowan Lake, North Cascades National Park 2011.....	19
Figure 8. Multivariate ENSO Index values for the year 2000 to 2012.	20
Figure 9. Comparison of May 1st and June 1st Snow Water Equivalent at SNOTEL stations within Mount Rainier, North Cascades, and Olympic National Parks against 30 year normal (graphed as 100%) for the climatological period 1971 to 2000.....	21
Figure 10. Comparison of the date of summer snowpack meltout at three SNOTEL station within Mount Rainier, North Cascades, and Olympic National Parks against the mean meltout date for the period of record.....	21
Figure 11. Average monthly temperatures at Mount Rainier, North Cascades, and Olympic National Parks SNOTEL weather stations during the ice-free months of June, July, August and September, for sampling years 2009 to 2011.....	22
Figure 12. Example of the seasonal temperature pattern (smoothed hourly temperature data) of a dimictic North Coast and Cascade Network lake at Olympic National Park	23
Figure 13. Comparison of daily variation in surface water temperature during the open water season for North Coast and Cascade Network lakes exhibiting a typical pattern and a pattern influenced by persistent snow or ice in the lake’s catchment	24
Figure 14. Scatter plots, regression equations, and surface lapse rates showing the relationship between average annual air temperature and elevation for all North Coast and Cascades Network lakes combined, 2010 and 2011.	26

Figures (continued)

	Page
Figure 15. Monthly average of daily average air temperatures ($ADAT_{air_mo}$) for all lakes at North Cascades, Mount Rainier, and Olympic National Parks, 2010 and 2011.	29
Figure 16. Pearson correlation coefficients for linear regressions of mean monthly air temperature and elevation for all North Coast and Cascades Network lakes combined during 2010 and 2011.	30
Figure 17. Daily average water temperature ($^{\circ}C$) annual plots for Allen (weakly stratified) and LP19 (strongly stratified) lakes, Mount Rainier National Park, 2009-2011.....	33
Figure 18. Daily average water temperature ($^{\circ}C$) annual plots for Upper Deadwood and LH15 lakes, Mount Rainier National Park (MORA), 2009-2011.....	34
Figure 19. Daily average water temperature ($^{\circ}C$) annual plots for Upper Palisades Lake, Mount Rainier National Park (MORA), 2009-2011	35
Figure 20. Daily average water temperature ($^{\circ}C$) annual plots for Upper Triplet Lake, North Cascades National Park (NOCA), 2009-2011	35
Figure 21. Daily average water temperature ($^{\circ}C$) annual plots for Bowan and Lower Silent lakes, North Cascades National Park (NOCA), 2009-2011	36
Figure 22. Daily average water temperature ($^{\circ}C$) annual plots for Lower Blum and Lower East lakes, North Cascades National Park (NOCA), 2009-2011.....	37
Figure 23. Daily average water temperature ($^{\circ}C$) annual plots for Easy Ridge Lake, North Cascades National Park (NOCA), 2009-2011	38
Figure 24. Daily average water temperature ($^{\circ}C$) annual plots for Ferry Lake, Olympic National Park (OLYM), 2009-2011.....	38
Figure 25. Daily average water temperature ($^{\circ}C$) annual plots for Gladys and Heather lakes, Olympic National Park (OLYM), 2009-2011.....	39
Figure 26. Daily average water temperature ($^{\circ}C$) annual plots for Crazy and Milk lakes, Olympic National Park (OLYM), 2009-2011.....	40
Figure 27. Daily average water temperature ($^{\circ}C$) annual plots for Sunup and Connie lakes, Olympic National Park (OLYM), 2009-2011.....	41
Figure 28. Daily average water temperature ($^{\circ}C$) annual plots for LaCrosse Lake, Olympic National Park (OLYM), 2009-2011.....	42
Figure 29. Differences in summer (blue) and fall (red) turnover dates and length of the ice-free season among North Coast and Cascades Network lakes at Mount Rainier, North Cascades, and Olympic National Parks during 2009 through 2011.	44

Figures (continued)

	Page
Figure 30. The number of days between summer and fall turnover (open water season days- OWS_{day}) at Mount Rainier, North Cascades, and Olympic National Park lakes, 2009-2011.	45
Figure 31. Monthly average of daily average surface water temperatures $^{\circ}C$ for all lakes combined at each North Coast and Cascades Network park, 2009-2011.	48
Figure 32. Relationship between annual average surface water temperature and surface water heating degree-days at North Coast and Cascades Network monitoring lakes, 2009-2011.....	50
Figure 33. Relationships between annual average surface water temperature and air temperature heating degree-days at North Coast and Cascades Network monitoring lakes using a single linear regression for all NCCN lakes with 2009-2011 data and separate linear regressions of 2009-2011 data at four Olympic National Park lakes.	51
Figure 34. Annual air and lake surface water heating degree-days (sum of daily average temperatures $>0^{\circ}C$) for North Coast and Cascades Network lakes, 2009-2011.	52

Tables

	Page
Table 1. Mount Rainier, North Cascades , and Olympic National Parks lake general physiographic characteristics.	10
Table 2. Continuous air and water temperature response variables and calculation.	12
Table 3. Examples of summer and fall turnover date selection at Easy Ridge Lake, North Cascades National Park, 2011.	15
Table 4. Summary of missing water and air temperature data for Mount Rainier, North Cascades, and Olympic National Parks monitoring lakes, during the 2008 through 2011 deployment period.	18
Table 5. Annual average of daily average air temperature ($ADAT_{air_yr}$) at Mount Rainier, North Cascades, and Olympic National Park lakes during 2009 - 2011.	25
Table 6. Highest 7-day moving average of daily maximum (7-DADMax) and lowest 7-day moving average daily minimum (7-DADMin) air temperatures ($^{\circ}C$) during 2009-2011, with occurrence dates (mid-point of 7-day interval).	27
Table 7. Summary of lake turnover dates and date ranges for Mount Rainer, North Cascades, and Olympic National Parks during 2009-2011.	43
Table 8. Annual average lake surface water temperature ($ADAT_{surf_yr}$) at North Coast and Cascade Network lakes during 2009-2011.	46
Table 9. Highest 7-day moving average of daily maximum (7-DADMax) surface water temperatures ($^{\circ}C$) during the year with occurrence dates (mid-point of 7-day interval) for Mount Rainier, North Cascades, and Olympic National Park lakes, 2009-2011.	47
Table 10. The range in $ADAT_{surf_mo}$ values and difference in the range between lakes at each park having the highest and lowest values for the peak open-water months of August and September, 2009-2011.	49
Table 11. Winter severity represented by freezing degree-days (FDD) during the 2009-2010 and 2010-2011 winters at North Coast and Cascades Network lakes.	53
Table 12. Index of Thermal Stress (ITS = sum of degree-days in exceedance of $20^{\circ}C$) values for North Coast and Cascades Network monitoring lakes sampled in 2009.	54

Appendices

	Page
Appendix A. Statistical Routines.....	A-1
Appendix B. Lake Air and Water Temperature Data Availability, 2008-2011	B-1
Appendix C. Monthly Air Temperature Summary Statistics.....	C-1
Appendix D. Summer and Fall Lake Turnover Data	D-1
Appendix E. Monthly Water Temperature Summary Statistics	E-1
Appendix F. Annual Air and Water Degree-Day Summary Statistics.	F-1
Appendix G. Example Application of the Use of Freezing Degree-Days for Ice-on Determination	G-1

Executive Summary

This report provides the first look at continuous air and water temperature data collected between 2008 and 2011, from 20 mountain lakes monitored annually as part of the North Coast and Cascades Network (NCCN) Mountain Lakes Monitoring Protocol (Glesne et al. 2012). Of the 20 “core” reference lakes, six lakes each are at Mount Rainier National Park (MORA) and North Cascades National Park Service Complex (NOCA), and eight lakes are located at Olympic National Park (OLYM). Reference lakes were randomly selected from a target population of lakes ranging from 0.4 to 6.0 ha in surface area and at elevations (1220-2046 m) representing the upper elevation limit of the montane zone (high forest) and subalpine zones of each park. NCCN lakes located in this intermediate elevation zone are considered as ultra-sensitive to climate change due to their unusually low water temperature, and because modest increases in future air temperatures will lead to major changes in lake temperatures and ice-cover duration with consequent effects on their ecological status (Thompson et al. 2005, Parker et al. 2008, Thompson et al. 2009).

The purpose of this report is to provide an initial summary and discussion of continuous air and water temperature data collected from the core monitoring lakes at all three parks during the period of January 2008 through December 2011. This overview includes: an examination of air and water temperature patterns occurring throughout each year at each of the core lakes; a comparison of temperature patterns among lakes in the three parks; an evaluation of temperature response variables that may be useful for reporting climate changes and trends and interpreting biological, chemical, and physical parameters; and an examination of issues related to quality assurance and quality control (QA/QC).

Air and water temperature loggers were initially deployed during the late summers of 2008 through 2009 at all but two lakes at OLYM (started in 2010). Loggers were deployed in the deepest part of each lake, fastened to the rope at three locations to sample temperature at one meter above the lake bottom, at mid-depth, and at 10-50 cm below the water surface. A single air temperature logger was placed in a shaded location near each lake, usually in a tree and approximately four meters above the ground. Loggers were set to record set at either 30-minute or one-hour intervals.

Lake temperature data that were either not recovered or rendered unusable for analyses and reporting were evaluated based on the NCCN Mountain Lake Protocol measurement quality objective (MQO) requirement of >90% data completeness. The MQO for the 2008-2011 deployment periods was exceeded for water temperature data at NOCA and OLYM. The data completeness MQO for air temperature was only exceeded at OLYM. Temperature logger data gaps occurred as a result of vandalism, battery failure, an extreme change in lake water level at one lake, field equipment preparation, and snow accumulation on the air temperature loggers. Snow accumulation on loggers was primarily a problem during 2010 and 2011 as the result of well above normal snowpack persisting into late spring. Suggestions for reducing data loss and replacing missing data are discussed.

Data presented in this report were collected during several years of extreme and opposing weather patterns that correlated closely with El Niño-Southern Oscillation (ENSO) phases. The El Niño phase

tends toward warmer and drier than average conditions with a below average mountain snowpack. In contrast, the La Niña phase is typically cooler and wetter, resulting in deeper and longer lasting mountain snowpack. The first ice-free sampling period of 2009 overlapped with a strong El Niño, while subsequent ice-free periods in 2010 and 2011 occurred during a deep and prolonged La Niña phase. Year-to-year variations in air temperature at the NCCN lakes were affected by ENSO phases. Annual averages of daily average air temperature ($ADAT_{air_yr}$) ranged from 0.4-5.7°C among all lakes sampled during 2009-2011 and consistently declined at all lakes during this period. Monthly average daily average temperatures ($ADAT_{air_mo}$) for January-August and November- also consistently declined at all lakes from 2009 to 2011. The coldest $ADAT_{air_mo}$ at most NCCN lakes occurred in February, 2011 (2.1°C to -8.3°C). Summer peak $ADAT_{air_mo}$ at all lakes was observed in July and August during 2010 (10.2 to 14.8°C), and shifted by a month to August and September in 2011 (9.8 to 12.3°C). Elevation was a major factor influencing within-year variation among lakes. The regression of elevation and $ADAT_{air_yr}$ using data for all NCCN lakes (2010) explained 82% of the variation in $ADAT_{air_yr}$ values. The air temperature lapse rate calculated from the regression equation represented a drop in air temperature of 5.78°C over a 1000-m increase in elevation.

Lake surface water temperature response variables at all three parks were strongly influenced by substantial increases in snowpack, delayed snowmelt and colder than average June 1st air temperatures during the 2010-2011 La Niña phase. Annual average daily average surface temperatures ($ADAT_{surf_yr}$) ranged from a low of 0.1°C (2011) to 6.1°C (2009) and declined at all lakes during the 2009-2011 reporting period. The percent change in $ADAT_{surf_yr}$ values at individual lakes ranged from -9.8% to -71.8% between 2009 and 2010, and from -10.3% to -88.3% between 2010 and 2011. Year-to-year variation in monthly surface $ADAT_{surf_mo}$ values were low during the months of January through June and November and December, with temperatures usually <3°C. There was a consistent year-to-year decline in $ADAT_{surf_mo}$ values at most lakes during the months of July through September, 2009-2011. Peak $ADAT_{surf_mo}$ values occurred at almost all of the NCCN lakes during August of 2009 and 2010, and during September in 2011, and ranged between 3.6°C (2011) to 20.2°C (2009).

Summer and fall turnover dates were estimated to occur when daily average temperatures throughout the water column became uniform at a point near 4°C (temperature of maximum density of water). The number of days between summer and fall turnover dates was used to provide an approximate estimate of the length of ice-free season. Summer turnover dates at NCCN lakes shifted from late-June/early-July to early-July/late-September between 2009 and 2011. On average, summer turnover occurred 55 days later in 2011 than in 2009. Lakes with the greatest delays in summer turnover dates included most lakes at OLYM and lakes located on the west side of the Cascade Crest in NOCA. Fall turnover showed very little year-to-year variation, occurring during late October and early November at all of the NCCN lakes between 2009 and 2011. The above normal snowpack and colder air temperatures in the late springs of 2010 and 2011 delayed ice-out and, consequently, shortened the ice-free season. The average number of ice-free season days for all lakes declined from 119 days in 2009 to 66 days in 2011.

Unlike air temperature, differences in lake water temperature response variables among NCCN lakes were not related to elevation. While year to year variation at any given lake is related to changes in ENSO phases, variation in these responses among NCCN lakes in any given year was likely related to one or more local factors affecting incident radiation, snow accumulation, and lake thawing including: location relative to storm tracks and marine influenced climate patterns, presence of perennial snowfields and/or the depth of late spring snowpack, and the combined effect of aspect and topographic shading.

Example applications and data for several degree-day accumulation metrics were examined. These metrics may be useful for assessment of trends in temperature or used as explanatory attributes in the assessment of other lake monitoring parameters. Heat accumulation throughout the year is represented by Heating Degree-Days (HDD), calculated as the sum of daily average temperatures that are greater than a base temperature of 0°C. HDD values primarily represent heat accumulation during the open water season and consequently can be related to biological productivity, organism growth, and abundance. HDD may be more useful for interpretation of lake temperature trends than other responses where data are reported as an average temperature for a subjectively selected time period. Additionally, preliminary results indicate that air temperature HDD may have potential use for reconstructing past average surface water temperature at individual lakes, if calibrated to nearby SNOTEL or other weather station sites having long-term daily average air temperature datasets.

Freezing degree-days (FDD) were calculated as the sum of daily average air temperatures <0°C for the period starting in the fall when air temperatures drop below 0°C to the late spring/early summer when temperatures are consistently >0°C. FDD as defined above is synonymous with winter severity and could be a useful response variable for tracking trends in air temperature outside of the open water season. FDD has also been used for determining ice-on dates. Thompson et al. (2005) provides a clear explanation on the use of freezing degree-days for hindcasting ice-on dates for earlier years, for which meteorological data are available. Example applications of the use of FDD for determining ice-on dates at NCCN lakes are presented.

Accumulation of degree-days in exceedance of biologically relevant threshold temperatures can be useful in quantifying thermal stress to native taxa. The Index of Thermal Stress (ITS; DeGasperi 2007), calculated as the accumulation of degree-days in exceedance of average daily surface water temperatures >20°C, was applied to the NCCN lake data. Five of the NCCN lakes exceeded the 20°C threshold during the 2009-2011 sampling period, with all exceedances occurring only in 2009. Results indicated that native biota at Sunup Lake (OLYM), and possibly at Upper Deadwood Lake (MORA), may be particularly vulnerable to thermal stress if climate warming occurs.

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Introduction

The North Coast and Cascade Network (NCCN) Mountain Lakes Monitoring Program (Glesne et al. 2012) was developed to characterize and detect substantive trends within a representative set of montane (high forest)/subalpine lakes in each of the three large NCCN parks in Washington. The primary focus of this program centers on the detailed monitoring of physical, chemical and biological trends in 20 “core” reference lakes sampled annually. Six of these core lakes are located at Mount Rainier NP (MORA), six are at North Cascades NP (NOCA), and eight are at Olympic NP (OLYM).

All lakes were selected randomly from a subset of the entire population of similar lakes at each park. The subset, or sample frame, includes lakes found entirely within park boundaries, ranging in size from 0.4 to 6.0 hectares, occurring at elevations from 1220 meters (4000 ft.) extending to the upper limit of the subalpine zone at each park (approximate range of 1700 – 2100 m), and which are not heavily influenced by glacial runoff. Lakes were also required to have a maximum depth greater than 2.5 meters, and be accessible on foot. An additional sampling design objective was to disperse sample lakes across the wide range of annual precipitation encountered within these mountainous NCCN parks.

Documenting trends in lake temperature through time is one of the key objectives in the NCCN Mountain Lakes Monitoring Program because of its significance to a number of lake physical, chemical and biological processes (Glesne et al. 2012). Previous studies have indicated that lakes are good sentinels of climate change because they are very sensitive to environmental changes and can integrate changes in the surrounding landscape and atmosphere (Carpenter et al. 2007, Pham et al. 2008, Williamson et al. 2008, Adrian et al. 2009). Lake elevation, used as one of the site selection criteria, identified a target population of high forest and subalpine lakes that are perhaps at greatest risk to changes in temperature. NCCN lakes located in this intermediate elevation zone (1220 m to 2046 m) are considered as ultra-sensitive due to their unusually low water temperature, and because modest increases in future air temperatures will lead to major changes in lake temperatures and ice-cover duration with consequent effects on their ecological status (Thompson et al. 2005, Parker et al. 2008, Thompson et al. 2009).

The purpose of this report is to provide an initial overview of continuous air and water temperature data collected from the core monitoring lakes at all three parks during the period of January 2008 through December 2011. This overview includes: an examination of air and water temperature patterns occurring throughout each year at each of the core lakes; a comparison of temperature patterns among lakes in the three parks; an evaluation of various temperature response variables useful for reporting changes and trends related to climate or as potential covariates that affect the interpretation of other biological (e.g., species abundance and distribution), chemical (e.g., changes in nutrient concentrations), and physical responses (e.g., water clarity, lake levels, and strength and depth of thermal stratification) measured by the monitoring program; and an examination of issues related to quality assurance and quality control (QA/QC).

Background

Factors Influencing Lake Temperature

Mountain lakes are directly and indirectly influenced by meteorological factors. The water temperature of lakes is a function of the amount of solar radiation absorbed as heat, as well as the thermal gain or loss of heat through direct interactions with surrounding air and sediments. Ice cover, snow cover, and lake water temperature in mountain lake catchments relate directly to air temperature and are consequently influenced by climate change (Thompson et al. 2005). Air and water temperature are often highly correlated on both short and long time scales (Shuter et al. 1983, Livingstone and Dokulil 2001, Arhonditsis et al. 2004). However, local factors such as wind exposure, topographic shading, snow and ice cover in the catchment, lake depth and size, source and volume of inflow, outflow, and valley orientation modify the relationship between air and water temperature (Livingstone 1997, Blenckner 2005, Thompson et al. 2005, Novikmec et al. 2013).

The quantity and timing of the maximum winter snowpack has one of the most direct effects on mountain lake water temperature. NCCN mountain parks typically have spring snowpacks three to six meters in depth. This deep snowpack insulates mountain lakes during spring months and must first melt before direct radiation can be absorbed by the frozen lake surface. Years with deeper snowpacks will have later ice-out dates and shorter ice free periods. The length of this ice free period directly affects the heat balance of a lake; the longer the period of exposure, the more direct radiation that can be absorbed. In addition, deep snowpacks will reside longer within lake basins, contributing prolonged sources of cold, surface meltwater into the lake.

Because of the relationship between air and water temperature, the temperature of mountain lakes is also related to their altitude. In most circumstances, air temperature decreases with elevation, resulting in colder water temperatures and longer periods of ice cover at higher elevations. This rate of change or “lapse rate” is typically around 4 to 6°C/km. Alpine lakes at the highest elevations, with permanent snow cover, are relatively insensitive to long-term temperature change. These lakes require a large increase in temperature before melting can occur. Subalpine lakes at intermediate elevations are much more likely to show strong temperature responses to warming air temperature as contributions of snow and ice meltwater decline along with an increase in the total duration of solar radiation caused by extended open water seasons (Thompson et al. 2005). As with air temperatures, the relationship between altitude and water temperature is modified by within-lake characteristics and local factors related to the geomorphological setting (Livingstone et al. 2005, Novicmek et al. 2013).

Climate Variation

The climate and the effects of human-induced climate warming in the Pacific Northwest are significantly influenced by periodic fluctuations in regional patterns of Pacific Ocean currents and surface water temperatures and can be attributed to two meteorological phenomena, the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) (Strub et al. 1985, Mantua and Hare 2002). The PDO is a long term climate trend, typically shifting between warm/dry and cool/wet phases every 10 to 20 years. ENSO is a shorter term pattern that typically affects weather

conditions for a time span of 6 to 18 months, with the greatest effect during the winter and spring. ENSO has three phases, El Niño, La Niña and Neutral. El Niño years tend toward warmer and drier than average conditions with a below average mountain snowpack. In contrast, La Niña years are typically cooler and wetter, resulting in deeper and longer lasting mountain snowpack. Both PDO and ENSO can significantly influence air temperature and precipitation with consequent effects on the thermal structure (e.g., lake mixing and heat storage, timing of ice out) and biotic communities of lakes in western North America (Strub et al. 1985, Jasby et al. 1990, Arhonditsis et al. 2004).

Lake Ecosystem Response to Climate Warming

The effects of increased water temperature resulting from climate warming is a particularly relevant concern regarding the coldwater lakes located in the mountains of the North Coast and Cascade Network of the National Park Service. Temperature is a critical factor affecting lake physical, chemical, and biological processes, interacting with other climate induced changes (e.g., precipitation, water storage and runoff patterns, cloud cover and incident radiation, wind and fire) to create a variety of interrelated lake ecosystem responses (Schindler et al. 1996a, Schindler 1996b, Parker et al. 2008). Climate induced warming of water temperatures has been documented by numerous authors (e.g., Schindler et al. 1996a, Arhonditsis et al. 2004, Winder and Schindler 2004, Thompson et al. 2005, Coats et al. 2006, Schneider et al. 2009). In addition, prolonged warmer and drier weather has resulted in clearer waters and increased UV-B penetration, deeper thermoclines and euphotic zones, increased water retention resulting from reduced lower inlet flows (Schindler et al. 1996a, Schindler 1996b), extended periods of thermal stratification (Winder and Schindler 2004), and shorter periods of ice cover (Thompson et al. 2009). Observed corresponding changes in water chemistry include: higher concentrations of nitrogen and lower concentrations of phosphorus, decreased dissolved organic carbon, increases in base cations and alkalinity, and increases in pH (Schindler et al. 1996a, Sommaruga-Wögrath et al. 1997). Hypolimnetic dissolved oxygen depletion was attributed to increased water temperature in two relatively large mesotrophic lakes in Switzerland by Jankowski et al. (2006); however, hypolimnetic dissolved oxygen was shown to increase with warmer water temperatures in a climatically sensitive lake in the Austrian Alps (Luoto and Nevalainen 2013).

Changes in physical and chemical characteristics of lakes in response to climate warming have been shown to affect aquatic organisms in numerous ways. Increased primary productivity in response to longer ice-free seasons was reported by Fee et al. (1992). Changes in summer stratification and mixing depth caused a significant change in aquatic community composition through changes in oxygen availability (Luoto and Nevalainen 2013). Increased phytoplankton biomass was observed by Schindler et al. (1996a) as a result of warmer water temperature, deepening thermoclines and greater light penetration. Changes in phytoplankton species composition, timing of spring phytoplankton blooms, vertical distribution of phytoplankton, and changes in seasonal patterns in productivity have been reported (Gerten and Adrian 2002, Winder and Schindler 2004, Winder and Hunter 2008, Wagner and Adrian 2009). Synchronization of phytoplankton blooms with zooplankton consumers can be disrupted, reducing availability of zooplankton food resources and their abundance, with implications to food supply at upper trophic levels (Winder and Schindler 2004, Hampton 2005).

The most direct effects of increasing water temperature on native aquatic organisms is related to thermal stress, consequently affecting their survival, growth, reproduction, distribution and abundance. Many species found in NCCN mountain lakes are specifically adapted to cold water temperatures and exhibit a narrow range of temperature tolerances. Upper lethal temperature limits of these species generally determine their distribution and abundance. However, distribution and abundance are often affected at less than lethal temperatures interacting with other environmental factors including habitat loss, UV radiation exposure, disease outbreaks, and invasive species (Blaustein and Wake 1990, Liss et al. 1995, Knapp 1996, Stuart et al. 2004, Rose et al. 2009) affecting reproduction, growth, and survival. It is likely that the community structure will change as a consequence of future long-term climate warming of these lakes.

Study Area

All of the monitoring lakes studied in this report are located in the NCCN's three largest parks (Figure 1). Mount Rainier National Park (MORA) is located in the 'Cascades' physiographic province in western Washington and encompasses 95,600 ha. North Cascades NPS Complex (NOCA) is located in the 'North Cascades' physiographic province, in northwestern Washington,

and covers 276,901 ha of the Cascade Range from the Canadian border south approximately 80 km to the head of Lake Chelan. Olympic National Park (OLYM) is situated in the Pacific Coast Range on the Olympic Peninsula and occupies an area of 373,384 ha.

All three parks are characterized by deep, forested valleys between high, glaciated mountain peaks. Watersheds typically begin in high elevation glaciers and snow fields, dropping in numerous, cascading streams down precipitous valley walls to classic, U-shaped valley floors carved by glaciers during the Pleistocene. Elevation gradients range from 2400 m at OLYM to 3900 m at MORA.

The bedrock geology varies within and between the three parks. Igneous and sedimentary rocks are commonly found at OLYM and MORA. At NOCA, metamorphic rocks are common

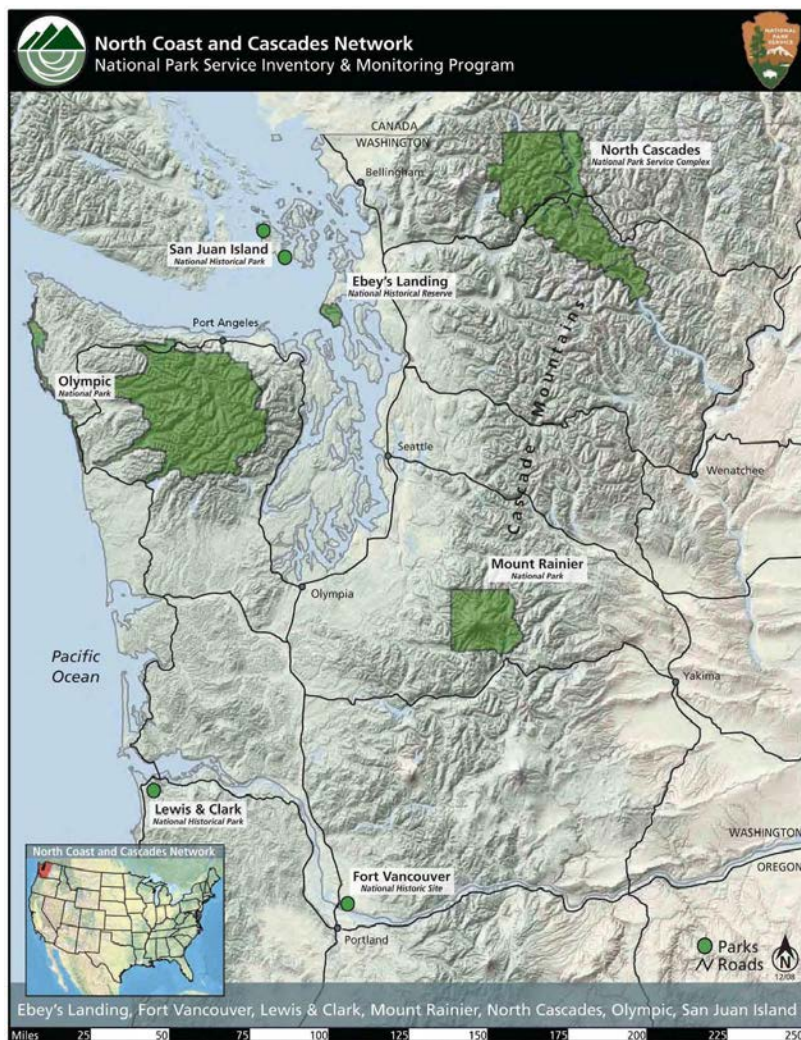


Figure 1. General location of North Cascades, Mount Rainier, and Olympic National Parks long-term lake monitoring sites.

to the eastern slopes of the North Cascade Mountains and igneous rocks predominate on the western slopes. Major soil orders found in association with high forest and subalpine lake catchments in the three parks include spodosols, inceptisols, entisols, and andisols (Henderson et al. 1989, Soil Conservation Service 1994).

Winter rain and snow and summer drought characterize the climate of the Pacific Northwest Parks. Typically two-thirds of the precipitation occurs between October and March when low pressure

systems approach from the Pacific Ocean on the dominant westerlies bringing frequent rain to the lowlands and snow to the mountains (Franklin and Dyrness 1988). High-pressure systems generally dominate during the summer into early fall, keeping the Pacific Northwest comparatively dry. Within each of the parks, major patterns in climate can be attributed to mountains blocking the passage of eastward moving storms resulting in enhanced orographic precipitation on western slopes and rainshadow development on the eastern side of the mountains. The Olympic Mountains create an unusually strong rainshadow effect resulting in extreme changes in precipitation over very short distances. A rainshadow created by Mount Rainier is located in the northeast portion of MORA. At NOCA, the main hydrologic divides include the Skagit Crest and, to the east, the Pacific Crest. Areas east of these divides have significant rainshadows and form barriers to marine and continental The result is that temperatures in eastside areas are substantially lower in winter months and higher during the summer. Sunny days are more common during all seasons (Davy et al. 2006, Mass 2008).

NCCN monitoring lakes are generally located in the regions extending from the upper montane zones, and throughout the subalpine zones of the three parks. The upper extent of the montane zone occurs at elevations ranging from 1220 m at OLYM to 1585 m at NOCA, with the upper extent of the montane zone at MORA falling between these elevations. Characteristic species, in addition to western hemlock (*Tsuga heterophylla*) and Pacific silver fir (*Abies amabilis*), include Douglas fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), noble fir (*Abies procera*), and to a lesser extent, western white pine (*Pinus monticola*). Mountain hemlock (*Tsuga mertensiana*) and Alaska yellow-cedar (*Cupressus nootkatensis*) can also be present near its upper elevation limit (Crawford et al. 2009). The subalpine zones are at elevations ranging from 1295 m (OLYM) to 2134 m (NOCA) with closed forests shifting to tree islands interspersed with low shrublands and herbaceous meadows at higher elevations (Crawford et al. 2009). Dominant tree species of the subalpine zone include mountain hemlock, Alaska yellow-cedar, subalpine fir (*Abies lasiocarpa*), and Pacific silver fir. In addition, whitebark pine (*Pinus albicaulis*), subalpine larch (*Larix lyallii*), and Engelmann spruce (*Picea engelmannii*) are found in tree islands in drier eastern subalpine zones of the parks.

Mountain lakes in these parks can be generally described as ranging from ultra-oligotrophic to mesotrophic, though most are oligotrophic, exhibiting low nutrient inputs and organic productivity. These lakes are also relatively cold, acidic or neutral in pH, and low in concentration of dissolved solids. There is a great deal of variation in water quality among them due to a variety of factors including geographic setting, elevation, aspect, morphology of the lake basin, and geology.

Lake locations at each of the parks are shown in Figures 2-4. All of the lakes are situated within or on the edge of the subalpine zone, where approximately 60% of all lakes and ponds in each of the parks occur. The core lakes are characterized by four morphogenic classes (cirque, moraine-dammed, ice scour, and trough) reflecting their glacial origin. Eleven core monitoring lakes are found in cirque basins with outlet flow controlled by bedrock or moraines. Cirque lakes are scoured depressions, normally positioned near the head of a valley, in the upper reaches of mountainous watersheds. Four lakes at OLYM, four lakes at MORA and three lakes at NOCA are in cirque basins. Three lakes at OLYM, two at NOCA and one at MORA are moraine dammed lakes.

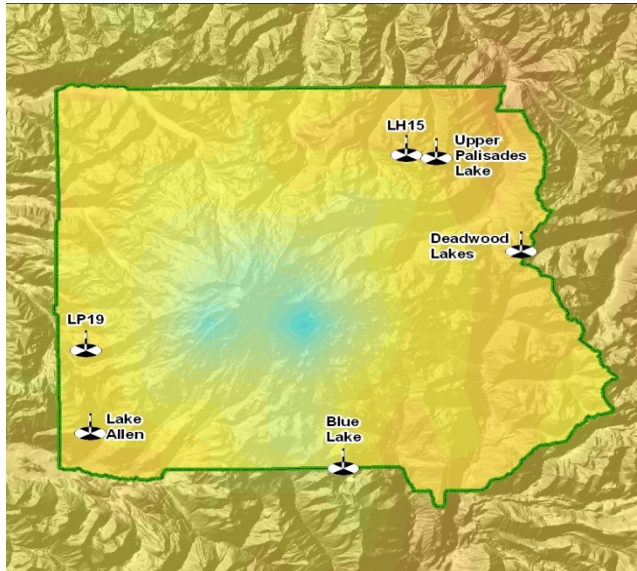


Figure 2. Mount Rainier National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.

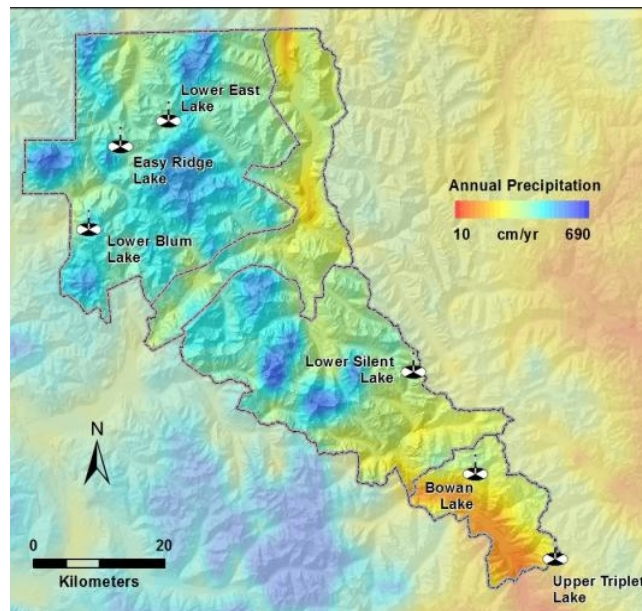


Figure 3. North Cascades National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.

ha). The site selection criterion for target population lakes in the monitoring program was limited to lakes ranging from 0.4 ha to 6.0 ha. Heather Lake (OLYM) is the smallest lake at 0.4 ha (Table 1) and Blue Lake at 6.0 ha (MORA) is the largest. While lake size is well distributed across parks, sample lakes in MORA tend to have larger surface areas, while NOCA lakes generally have smaller surface areas. NCCN core lakes also span a range of maximum depths (Table 1) from 3.6 m (Bowan Lake, NOCA) to 16.2 m (Lower East Lake, NOCA). MORA core lakes are generally deeper, while the majority of the shallowest lakes (<4 m) are within NOCA.

Moraine dammed lakes are valley or cirque lakes principally formed by terminal or lateral moraine dams. One of the lakes at NOCA is classified as an ice scour lake, which usually have an irregular shaped and shallow depression created by glacial scour of bedrock along ridgetops. The remaining lakes at MORA and OLYM are trough lakes which form in a glacially deepened valley depression with a bedrock dam and occasional moraine influence.

While core lakes in each NCCN park have been randomly selected from a sub-population of lakes of similar size, depth and elevation in order to reduce signal variation in a variety of physical, chemical and biological indicators, variation in these selection features still exists. A summary of core lake general physiographic characteristics are presented in Table 1. All core lakes range between 1220 m and 2100 m in elevation (Table 1). Core lakes are generally at a higher elevation in NOCA and lower elevation in OLYM, reflecting differences in the elevation of subalpine zones in these parks due to geographic and climatic conditions. The highest elevation lake is Lower Silent Lake (NOCA) at 2046 m (6713 ft). The lowest elevation lake is Lake Sunup (OLYM) at 1224 m (4015 ft).

Watershed size (Table 1) of the core lakes ranges from 8.3 ha (Lower Silent, NOCA) to 158.6 ha (LH15, MORA). Generally, lake catchments are smaller at NOCA core lakes (8.3-44.1 ha), intermediate at OLYM (9.8-149.0 ha), and highest at MORA (19.8-158.6

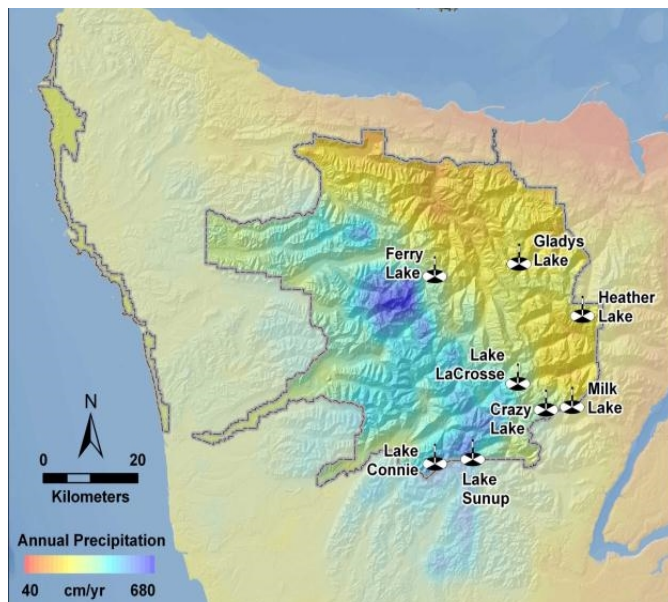


Figure 4. Olympic National Park core monitoring lake locations in relation to shaded precipitation gradient derived from PRISM model.

The three parks generally span a west-east precipitation gradient, from the very wet OLYM, to the drier MORA and NOCA. This precipitation gradient is also present in each park, with the western areas wetter than the eastern areas. Core lakes span the precipitation gradients found in each NCCN park. The greatest gradient is seen at OLYM (196-559 cm/yr), while the gradient at MORA spans 162-304 cm/yr and the gradient at NOCA spans 157-379 cm/yr. The lowest precipitation lake (Upper Triplet at 167 cm/yr) is found in the southeastern portion of NOCA. The highest precipitation lake (Lake Connie at 559 cm/yr) occurs in the southwestern corner of OLYM (Table 1). Precipitation data are based on 1971-2000 PRISM data (Prism 2006).

Table 1. Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks lake general physiographic characteristics.

Park/Lake	Elevation (m)	Aspect	Watershed Area (ha)	Surface Area (ha)	Max Depth (m)	Precip. (cm/yr)
MORA						
Allen	1397	NE	19.8	1.9	7.7	228
Upper Palisades	1785	E	46.6	1.3	15.0	190
LP19	1372	N	37.9	1.6	12.3	242
LH15	1659	NW	158.6	3.1	10.0	185
Upper Deadwood	1600	NW	74.8	2.9	3.8	203
Blue	1352	E	158.3	6.0	12.6	279
NOCA						
Upper Triplet	1998	SW	29.1	1.0	3.9	167
Bowan	1982	S	14.4	0.6	3.6	184
Lower Silent	2046	SW	8.3	1.2	9.4	188
Lower Blum	1511	SW	30.4	2.6	7.9	322
Lower East	1664	S	44.1	3.6	16.2	325
Easy Ridge	1680	W	37.1	1.0	3.7	308
OLYM						
Ferry	1434	N	12.7	1.3	10.9	522
Gladys	1383	NW	149.0	0.5	4.2	242
Heather	1589	N	73.9	0.4	6.6	200
Milk	1435	N	40.9	2.3	13.9	287
Crazy	1457	NE	16.8	1.0	7.7	413
LaCrosse	1447	SW	107.1	3.1	8.0	336
Sunup	1224	E	9.8	0.9	6.0	480
Connie	1300	NE	20.0	2.3	9.1	559

Methods

The methods described below are general, abbreviated descriptions of the methods used in data and sample collection. Full descriptions of sample site selection procedures and protocol methodology are contained in the Protocol for Long Term Monitoring of Mountain Lakes in the North Coast and Cascades Network of National Parks (Glesne et al. 2012).

Water and Air Temperature Data Collection

Detailed methods for continuous temperature data collection, processing, and quality control are given in the NCCN Mountain Lakes Monitoring Protocol (Fradkin et al. 2011; SOP 8, Continuous Air and Water Temperature Sampling).

We used two sensors manufactured by Onset Computer Corporation, the TidbiT® v2 Temp Logger and the HOBO® Pro v2 Water Temperature Data Logger. Calibration checks (following Schuett-Hames et al. 1999 and Ward 2003) were done to document logger bias and performance to assure the quality of the data. Calibration checks were completed in advance of logger deployment, and the post-deployment calibration checks were done shortly after the sampling results have been downloaded and backed up. A consistent bias of more than 0.2 °C was considered as unacceptable. Loggers with unacceptable pre-deployment calibration results were not deployed. If the post-deployment test did not meet the requirement after two separate tests, then the raw data was flagged in the database and adjusted by the mean difference of the pre- and post-calibration check results to correct for instrument bias. Loggers were set to record temperature at either half-hour or one-hour intervals and were deployed year round.

The lake water temperature array used at MORA and OLYM (Figure 5) consisted of a nylon rope which was anchored to the lake bottom using two rock filled mesh bags (commercially available canoe anchors or nylon mesh bags). The rope was held vertically in the water column by a Styrofoam float which was attached about 1 m below the lake surface. An additional surface buoy was attached to the top of the rope to allow for variations in lake level. Self-contained temperature loggers were fastened to the rope at three locations to provide measurements at one meter above the lake bottom, at mid-depth, and at 10-15 cm below the water surface. At NOCA, where lake water levels show minimal fluctuation, nylon rope was attached to the two anchor bags and then the surface buoy was tied off to the nylon rope so that the buoy and the near surface logger were submerged 0.5 m below the surface. Wilderness compliance made it necessary to sink the surface buoy so that it was not visible to park visitors. Submerging the surface buoy also

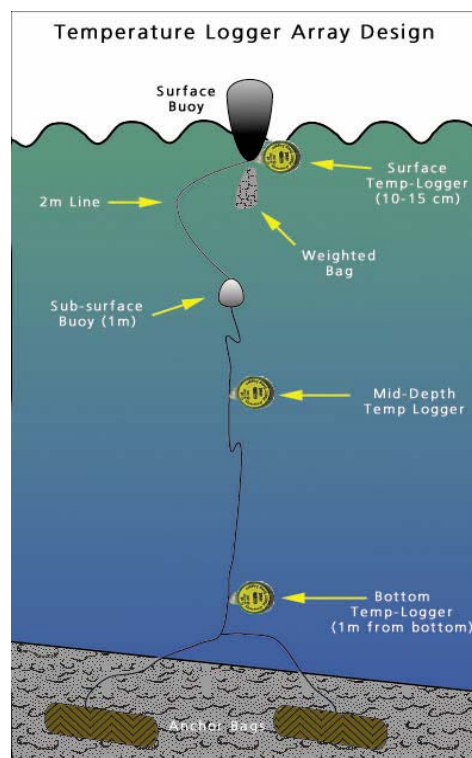


Figure 5. Water temperature logger array design.

minimizes the likelihood of vandalism and the chance of the surface buoy and logger freezing into the ice during winter.

The water temperature array was always anchored at the deepest point in the lake as determined by bathymetry measurements. This location represents the permanent sampling station for all water collection, vertical profiling, Secchi depth measurements and zooplankton sampling.

A single air temperature logger was deployed throughout the year at each lake and placed in a shaded and sheltered area within 30 meters of the lakeshore. If there were no suitable locations within the first 30 m, then the nearest suitable location after that was selected. Placement locations avoided potential avalanche chutes or areas of high snow drift. A clump of mature trees was generally preferred. The logger was hung from a rope and pulley assembly at least 3.5 m above the ground surface to avoid winter burial by snow. During each annual lake visit, park staff uploaded the temperature data from the loggers to a shuttle device or, if necessary, replaced the temperature array loggers with new loggers (in this case, the data from the old loggers was downloaded in the office).

Temperature Response Variables

A number of temperature response variables representing degree-days and seasonal minimums, maximums, and mean temperatures were proposed in the NCCN Mountain Lake Monitoring Protocol for interpreting trends in water temperature and for use as potential covariates for interpretation of biological and chemical parameters sampled in the monitoring project. This report focuses on a subset of response variables listed in the NCCN Mountain Lakes protocol (McDonald and Glesne 2011; SOP 21, Table 21.5) that were expected to be useful for future analyses (Table 2).

Table 2. Continuous air and water temperature response variables and calculation.

Response Variable ¹	Calculation
DAT	Daily average of air and water temperatures from half hour or hourly intervals measured each day.
ADAT	Average of daily average air and water temperatures calculated for months and year.
ADMINT	Average of daily minimum air and water temperatures calculated for months.
ADMT	Average of daily maximum air and water temperatures calculated for months.
7-DADMax	Highest 7-day moving average of daily maximum air and water temperatures during the year with occurrence dates.
7-DADMin	Lowest 7-day moving average of daily minimum air and water temperatures during the year with occurrence dates.
HDD	Heating degree days calculated as the sum of daily average air and water temperatures >0°C for the year.
FDD	Freezing degree-days calculated as the sum of daily average air temperatures <0°C. The period starting when fall (year x) temperatures reach <0°C and when spring (year x+1) temperatures remain <0°C is used for evaluating winter severity. Also evaluated FDD as a tool to assist in determination of ice-on dates for the period starting in late September or early October through December.
ITS	Index of Thermal Stress (DeGasperi 2007) to aquatic organisms. Degree-days calculated as the sum of daily average water temperatures >20°C for the period of June through October.
Summer/Fall Turnover	Dates and days between dates for lake turnover generally following ice-off and preceding ice-on when surface to bottom water temperature becomes uniform at approximately 4°C.

¹All temperature data are recorded in °C.

Degree-Day Accumulation

Degree-day accumulation has been used for forecasting long-term changes in lake surface water temperature (Thompson et al. 2005) and for reconstructing historical ice-on and ice-out dates (Ruosteenoja 1986, Stewart and Haugen 1990, Thompson et al. 2005). The use of degree-day calculations has also been a popular method for explaining variation in growth and development of aquatic organisms (Mills et al. 1989, Gillooly 2000, Neuheimer and Taggart 2007, Uphoff et al. 2013), and for examining patterns in productivity, species abundance, distribution, and diversity related to a range of temperature preferences and/or thermal tolerance limits (de Vlaming and Bury 1970, Anderson 1972, DeGasperi 2007, Pinel-Alloul et al. 2013).

Heating Degree-Days (HDD)

Heat accumulation throughout the year is represented by Heating Degree-Days (HDD), and was calculated as the sum of daily average temperatures that are greater than a base temperature of 0°C. HDD values for air temperature data approximately represent heat accumulation in the spring through fall period with slow to moderate accumulation of degree-days in the spring, rapid accumulation in the summer, and moderate to slow accumulation in the fall and early winter. HDD values for water temperature data more specifically represent the heat accumulation occurring during the period between ice-out and ice-on with negligible accumulation before the lake thaws and again after freeze-up. HDD values for air and water (surface, mid-depth, and bottom) are reported.

The relationship between HDD and annual average surface water temperature was examined using linear regression. Linear regression was also used to examine the relationship between annual average surface water temperature and air temperature HDD for all NCCN lakes (combined 2009-2011 data). Separate regressions at four OLYM lakes (only lakes with data for each of the three years, 2009-2011) were conducted in order to examine the removal of the influence of park and local scale variation.

Freezing Degree-Days (FDD)

Freezing degree-days (FDD) were calculated as the sum of daily average air temperatures <0°C for the period starting when air temperatures drop below 0°C, in the fall of year₁, to the spring/summer of year₂, when temperatures are consistently >0°C. FDD as defined above is synonymous with winter severity and could be a useful response variable for tracking trends in air temperature outside of the open water season. As with HDD, FDD does not rely on the subjective selection of a representative time period for summarizing the data.

FDD was also evaluated as a tool to assist in determination of ice-on dates for the period starting in late September or early October through December. Thompson et al. (2005) provides a clear explanation on the use of freezing degree-days for hindcasting ice-on dates for earlier years for which meteorological data is available. Thompson et al. (2005) and others (Bilello 1964, Williams 1971, Palecki and Barry 1986, Ruosteenoja 1986, and Stewart and Haugen 1990) reported that an accumulation of around 20 FDD provided a good relationship between air temperature and the date of freeze over. Estimates of dates for permanent ice formation, using two lakes from each of the three NCCN parks, were determined using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water

temperature approximately $\leq 4^{\circ}\text{C}$) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C . Permanent lake ice cover was assumed to form during the first extended period of time (>5 days) when air temperatures consistently remained below 0°C and when freezing degree-days began to rapidly accumulate following the fall turnover.

Index of Thermal Stress (ITS)

Thermal preferences and tolerance threshold data for most of the NCCN lake taxa are unknown; however, the long-term monitoring program provides the opportunity to gain a better understanding of temperature limitations by looking at how species respond (distribution, abundance, presence/absence, disease, etc.) to variation or change in temperature threshold data over time. Accumulation of degree-days in exceedance of biologically relevant threshold temperatures can be useful in quantifying thermal stress to native taxa. An index of thermal stress (ITS) was developed for monitoring thermal stress incurred by Sockeye Salmon in Lake Washington, WA (DeGasperi 2007). The ITS for Sockeye was calculated as the accumulation of degree-days in exceedance of a chosen threshold of average daily surface water temperatures $>20^{\circ}\text{C}$. This threshold temperature corresponds to the upper incipient lethal temperature for salmon (i.e., water temperature at which half the population would survive with permanent exposure; Houston 1982).

Thermal stress to native biota was evaluated at ten of the NCCN monitoring lakes that had complete open water season data for the surface and/or mid-depth temperature loggers during the 2009-2011 sampling periods. The $>20^{\circ}\text{C}$ threshold value and methods by DeGasperi (2007) were used to calculate ITS values (sum of degree-days $>20^{\circ}\text{C}$), number of days $>20^{\circ}\text{C}$, average degree-days/day $>20^{\circ}\text{C}$, and occurrence dates

Summer and Fall Lake Turnover Date Determination

Summer and fall lake turnover dates were used to determine approximate periods of ice cover and open water. Ice-on and ice-off dates and the duration of ice cover are useful indicators of climate change (Magnuson et al. 2000); however, in remote mountain lakes they are more difficult to determine than lake turnover dates. The difference between turnover dates provides only an estimate of the ice-free season, since the ice usually thaws out shortly before summer turnover, while stable ice formation can occur anywhere from a day to a month after fall turnover period, depending on surface cooling and wind mixing (Ashton 1986, Fang et al. 1996).

Summer and fall turnover dates were determined as the dates that immediately precede a shift from uniform surface to bottom temperatures to warmer surface water overlying colder deeper waters (summer turnover) or the opposite during the fall. Turnover dates usually occur when water temperature at the surface is generally between 3 to 5°C and precede a steady increase in surface temperature during summer turnover, or a steady decrease in surface temperature during the fall. Examples of turnover date selection are shown in Table 3. Daily differences in temperature between surface and bottom loggers (S-B) are useful to assist in locating summer and fall turnover dates (Table 3). For locating the summer turnover date, the values for S-B gradually increase from negative values to near zero, just prior to a steady increase through the summer. Fall turnover is similarly located by a gradual decline in S-B values to zero. These points were easy to locate for the majority of NCCN monitoring lakes during the 2009-2011 reporting period. Some difficulty in locating

turnover dates can occur for shallow lakes and in years with heavy snow accumulation. In these cases, water temperatures hover around 4°C, moving in and out of inverse stratification for a period of several days, weeks, or even months.

Table 3. Examples of summer and fall turnover date selection at Easy Ridge Lake, North Cascades National Park, 2011 (selected dates are highlighted).

Date	Logger/Daily Ave Temperature (°C)			Surface-Bottom
	Surface	Mid-depth	Bottom	Temp. Diff. (°C)
Summer Turnover				
8/30/2011	2.96	3.76	4.11	-1.15
8/31/2011	3.07	3.91	4.18	-1.11
9/1/2011	3.30	3.90	4.08	-0.77
9/2/2011	3.24	3.78	4.08	-0.84
9/3/2011	3.72	3.76	3.96	-0.24
9/4/2011	4.63	4.49	4.50	0.13
9/5/2011	5.44	4.96	4.86	0.58
9/6/2011	5.95	5.36	5.15	0.80
Fall Turnover				
10/1/2011	5.95	5.90	5.87	0.08
10/2/2011	5.72	5.64	5.60	0.12
10/3/2011	5.46	5.42	5.42	0.03
10/4/2011	4.65	4.62	4.61	0.04
10/5/2011	4.16	4.17	4.18	-0.03
10/6/2011	4.06	3.98	4.00	0.06
10/7/2011	4.20	4.11	4.15	0.06
10/8/2011	4.30	4.29	4.30	0.00
10/9/2011	4.62	4.55	4.57	0.04
10/10/2011	4.41	4.36	4.41	0.00
10/11/2011	2.71	3.04	3.42	-0.71
10/12/2011	0.81	2.40	3.44	-2.63
10/13/2011	0.88	3.16	4.19	-3.31
10/14/2011	0.84	4.12	4.17	-3.33
10/15/2011	0.89	4.19	4.20	-3.31

Air Temperature Lapse Rates

The relationship between air temperature and lake elevation was evaluated by determination of lapse rates. The change in air temperature with increasing elevation is referred to as the “lapse rate” (°C km⁻¹). Annual air temperature lapse rates for NCCN lakes were determined from linear regressions of 2010 and 2011 ADAT_{air_yr} values and lake elevations. In each regression, all lakes were combined to represent the elevation gradient among the three parks (approx. 1200 to 2000 m). Knowledge of lapse rates has been particularly useful in reconstructing air and water temperature variation from long-term meteorological datasets at high elevation lakes (Agustí-Panareda et al. 2000, Agustí-Panareda and Thompson 2002, Thompson et al. 2005).

Data Processing, Quality Control, and Analysis

Procedures for file management, data review and post-deployment calibration checks are given in SOP 8 of the NCCN Mountain Lakes Monitoring Protocol (Fradkin et al. 2011). Quality assurance

and quality control procedures are given in SOP 8 and in SOP 19 (Glesne and Rawhouser 2011; Quality Assurance and Control Plan).

Data Completeness

Quantitative standards for quality control (Measurement Quality Objectives; MQO's) are given in the NCCN Mountain Lakes Monitoring Protocol (Glesne and Rawhouser 2011; Quality Assurance and Control Plan, SOP 19). The MQO for assessing the completeness of data represents a measure of how much data are available for use compared to the total amount of potential data. Datasets that are considered "complete" assume that all data from the time of initial temperature logger deployment through the end of 2011 are available and suitable for analysis. For this monitoring program, the MQO for data completeness is 90%. Percent completeness was calculated by dividing the number of months with missing data by the total number of deployment months for the sampling period, then subtracting from 1.00 and converting to a percentage.

Temperature Data Statistical Routines

Two 'R' statistical software routines were used to summarize the continuous temperature logger data. 'R' statistical software can be freely downloaded from the following website: <http://www.r-project.org/> (accessed 12 March 2014). The first 'R' routine (temp.r; McDonald and Stahl, WEST Inc., 2012 rev.) calculated daily minimum, maximum, and average temperatures to provide outputs of monthly, seasonal, and annual averages of daily minimum (ADMINT), maximum (ADMT), and average (ADAT) temperatures. It also provided outputs of the highest seven day moving average of daily minimum (7-DADMin) and daily maximum (7-DADMax) temperatures for the year with the interval mid-point dates of occurrence. McDonald and Stahl also included two additional routines (site.r and region.r) that were designed to use the output from the temp.r to run single site inference, abrupt change and trend analysis for multiple sites per file, and to produce similar analyses for all sites combined (McDonald and Glesne 2011). However, only the output from temp.r was used for this report. Program documentation and instructions for use of temp.r, site.r, and region.r routines are shown in Appendix A, Attachment A1. An example of an input file is shown in Appendix A, Attachment A2.

The second 'R' routine used in this report (daily.temp.stats.r; Rawhouser, NOCA files, 2013) only provides daily temperature outputs of maximum, minimum, and average temperatures. These outputs (.csv file) were used for developing daily temperature plots and for all calculations of degree-day statistics (Table 2). Input file specifications, output file locations, and execution instructions for daily.temp.stats.r are the same as described in the program documentation for the temp.r routine (Appendix A, Attachment A1). The daily.temp.stats.r script is shown in Appendix A, Attachment A3. All of the routines are available by contacting Ashley Rawhouser, North Cascades National Park, ashley_rawhouser@nps.gov.

Results and Discussion

Data Quality and Completeness

An understanding of factors affecting data quality and its completeness is necessary in order to address issues and make improvements that maximize the utility of the data in the assessment of long term trends and other data applications. This section provides an assessment of the 2008-2011 NCCN lake temperature data that was either not recovered or rendered unusable for analyses and reporting, with recommendations for future improvement. The loss of data during the deployment period is the most significant factor affecting the utility of the data. Data handling procedures and factors influencing precision and bias are also important and were much easier to control.

Percent completeness for air and water temperature data collected during the 2008-2011 deployment period is summarized in Figure 6. The completeness goal for water temperature data (combined surface, mid-depth, and bottom) was exceeded at NOCA (100%) and OLYM (99.2%) but fell short of the goal at MORA (80.4%). The air temperature data completeness goal fell short at both MORA (73.1%) and NOCA (75.6%), and was exceeded at OLYM (96.5%).

A summary of missing data by lake and park is shown in Table 4. Detailed logger information by park, lake, and logger location is shown in Appendix B (Tables B1-B3) and includes initial deployment dates, periods of operation, and date ranges of missing data.

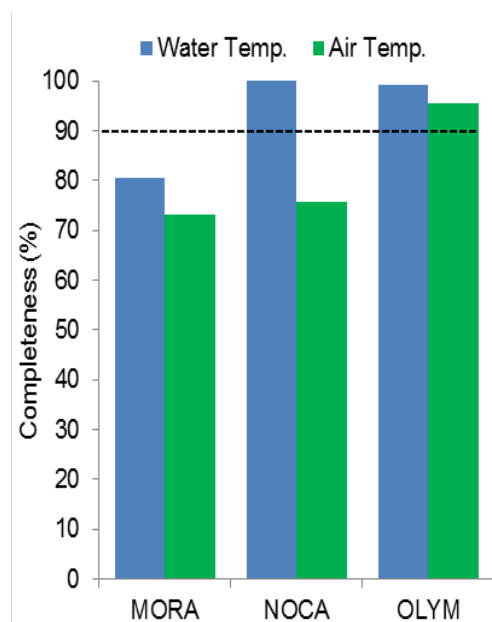


Figure 6. Air and water temperature data completeness by park, for the period of 2008-2011. Dashed line represents Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks MQO completeness criterion.

At MORA, complete data for all loggers was available for three (Allen, Upper Deadwood, and LP19) of the six monitoring lakes (Table 4 and Appendix Table B1). The absence of all water temperature data for Blue Lake during the entire reporting period was attributed to either theft or vandalism; however, all of the air temperature data was intact. Water temperature data for Lake LH15 was complete for all sampling depths. During the 2010 sampling trip at LH15 it was discovered that the air temperature logger at this lake was vandalized, resulting in lost data for the last five months of 2009. In addition the air logger was not re-deployed until 2012, resulting in the loss of all the 2010 and 2011 data. At Upper Palisades Lake, the quality of the surface temperature data for 2010 and 2011 was affected by a significant increase in lake level, resulting in a logger depth of 3m below the surface. These data may be salvageable if the cumulative bias in the data can be resolved by calibration

of these data with surface temperature data collected in future deployments at this lake. The air temperature data logger at Upper Palisades Lake, deployed in 2010, was not found in 2011 and re-deployed in 2012. It is assumed that the logger was stolen.

Table 4. Summary of missing water and air temperature data for Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks monitoring lakes, during the 2008 through 2011 deployment period. Percent missing data was calculated by dividing the number of months with missing data by the total number of deployment months for the sampling period. Percent missing data includes loss and vandalism of data (no data) and data with quality issues (unusable). Surface, mid-depth, and bottom loggers were combined for calculation of water temperature %missing data.

Park	Lake	Water Deploy. Months*	Water Temp. % Missing Data			Air Deploy. Months	Air Temp. % Missing Data		
			No Data	Unusable Data	Total		No Data	Unusable Data	Total
MORA	Allen	96	0.0	0.0	0.0	28	0.0	0.0	0.0
	Blue	84	100.0	0.0	100.0	28	0.0	0.0	0.0
	U Deadwood	95	0.0	0.0	0.0	28	0.0	0.0	0.0
	LH15	106	0.0	0.0	0.0	39	74.4	0.0	74.4
	LP19	108	0.0	0.0	0.0	28	0.0	0.0	0.0
	U Palisades	108	8.3	22.2	30.5	16	100.0	0.0	100.0
	MORA Total	597	15.6	4.0	19.6	167	26.9	0.0	26.9
NOCA	U Triplet	96	0.0	0.0	0.0	28	0.0	0.0	0.0
	Bowan	84	0.0	0.0	0.0	28	0.0	10.7	10.7
	L Silent	84	0.0	0.0	0.0	28	0.0	60.7	60.7
	Easy Ridge	84	0.0	0.0	0.0	28	0.0	57.1	57.1
	L East	84	0.0	0.0	0.0	28	0.0	17.9	17.9
	L Blum	108	0.0	0.0	0.0	28	0.0	0.0	0.0
	NOCA Total	540	0.0	0.0	0.0	168	0.0	24.4	24.4
OLYM	Ferry	120	0.0	0.0	0.0	40	0.0	0.0	0.0
	Gladys	81	0.0	0.0	0.0	27	0.0	0.0	0.0
	Heather	117	1.7	0.0	1.7	43	0.0	0.0	0.0
	Crazy	48	0.0	0.0	0.0	16	0.0	0.0	0.0
	Milk	117	0.0	0.0	0.0	48	0.0	0.0	0.0
	LaCrosse	45	0.0	0.0	0.0	15	0.0	26.7	26.7
	Sunup	120	0.0	0.0	0.0	48	0.0	8.3	8.3
	Connie	117	3.4	0.0	3.4	48	0.0	4.2	4.2
	OLYM Total	765	0.8	0.0	0.8	285	0.0	3.5	3.5

*Combined total deployment months for surface, mid-depth, and bottom water temperature loggers.

Complete data were collected for all of the water temperature loggers at NOCA during the reporting period (Table 4). All air temperature loggers at NOCA remained functional during the entire reporting period; however, the quality of the winter/spring data at four of the six lakes was compromised by burial of the logger under deep winter and spring snowpack. On plots of raw data, snow covered loggers are identified by a narrow line, exhibiting very little daily variation (Figure 7). Bowan Lake air temperature data was affected by snow cover during the period between mid-March and mid-May (Appendix Table B2 and shown in Figure 7). Snow cover on at Lower East Lake affected data collected between February 11 and June 30, 2011 (Appendix Table B2). Air temperature data were affected by logger snow cover during all three years of deployment at Easy Ridge Lake (11/15/2009-6/30/2010 and 12/1/2010-7/12/2011) and Lower Silent Lake (11/13/2009-7/15/2010 and 11/30/2010-7/28/2011; Appendix Table B2).

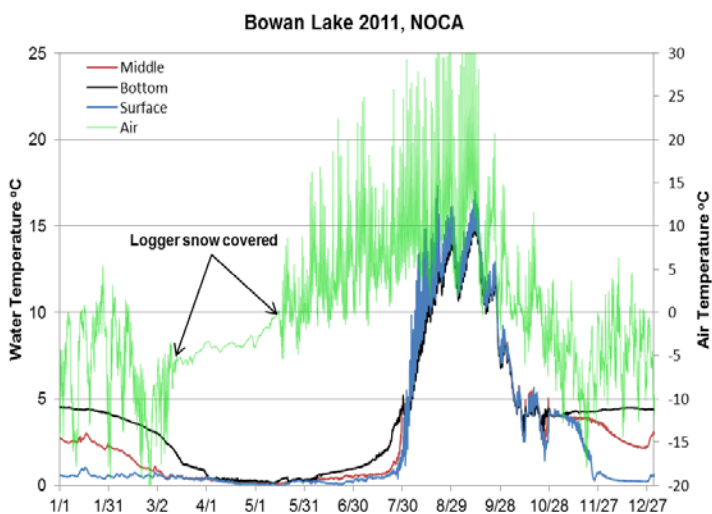


Figure 7. Example plot illustrating how air temperature data are affected by snow cover on the logger placed at Bowan Lake, North Cascades National Park (NOCA) 2011 (smoothed half-hour data intervals).

Almost all of the water temperature data collected at OLYM lakes was usable for reporting. The only exceptions were short time periods occurring in 2009, during August through September at Heather Lake and June through September in Lake Connie. These data gaps were attributed to faulty battery life in several of the deployed loggers. There were also some problems with snow accumulation on air temperature loggers at OLYM (LaCrosse, Sunup, and Connie) during 2011 (Table 4). Data gaps in air temperature at these lakes generally occurred during late winter to early spring (March through early June; Appendix Table B3).

In summary, the MQO for data completeness of 90% was exceeded for water temperature data at NOCA and OLYM, for the 2008-2011 deployment periods. The data completeness MQO for air temperature was only exceeded at OLYM. Temperature logger data gaps occurred as a result of vandalism, battery failure, an extreme change in lake water level at one lake, field equipment preparation (to include additional loggers in anticipation of vandalism or loss), and snow accumulation on air temperature loggers. Snow burial of loggers was primarily a problem during 2010 and 2011 as the result of well above normal snowpack persisting into late spring (discussed in the following section). Suggestions for reducing data loss in the future include the following:

- Replace temperature loggers every field season to reduce incidents of battery failure and to increase preparedness for lost or vandalized loggers.
- Keep deployment time records on all loggers. Return loggers to manufacturer for battery replacement and reconditioning after three years of deployment time.
- Snow accumulation on air temperature loggers may be reduced if the loggers can be placed higher in the tree. However, this is not always possible because the trees are too small or cannot be safely climbed to install a rope and pulley. Alternatively, selecting a taller and climbable tree further away from the lake may be an option. In absence of any other options, it may be possible to replace missing data by developing calibration regressions with existing data collected at the lake and data collected at a nearby monitoring lake, NRCS SNOTEL site, NWS Cooperative weather station, or NPS weather station.

Weather Conditions at NCCN Parks during the 2009-2011 Reporting Period

Lake temperature is influenced by meteorological drivers such as air temperature, solar radiation and winter snowpack. For this reason, it is important to understand the interannual climate variation affecting the study area during the 2009-2011 sampling period. NCCN parks are affected by two climate patterns, the Pacific Decadal Oscillation (PDO) and the El Niño–Southern Oscillation (ENSO). The PDO is a long term climate oscillation, which typically shifts between warm/dry and cool/wet phases every 10 to 20 years. ENSO is a shorter term cycle that typically affects weather conditions for a time span of 6 to 18 months, with the greatest effect during the winter and spring. ENSO has three phases, El Niño, La Niña and Neutral. El Niño years tend toward warmer and drier than average conditions with a below average mountain snowpack. In contrast, La Niña years are typically cooler and wetter, resulting in deeper and longer lasting mountain snowpack. When the cold phase of the PDO occurs with La Niña, the region gets enhanced snowfall.

Standardized values for the PDO index, acquired from the JIASO-University of Washington database (<http://jisao.washington.edu/pdo/PDO.latest>) for the period of January 2000 through July 2012 (Figure 8), indicate that the Pacific Northwest entered a cool/wet phase beginning in the summer of 2007. ENSO phases, however, have had a more obvious influence over variations in mountain lake water temperature. Data presented in this report were collected during several years of extreme and opposing weather patterns that correlated closely with ENSO phases. The first ice-free sampling period of 2009 overlapped with a strong El Niño, while subsequent ice-free periods in 2010 and 2011 occurred during a strong and prolonged La Niña phase (Figure 8). This is most apparent when looking at winter snowpack data for the three years of lake sampling. In 2009, June 1st snowpack averaged only 61% of the 30 year normal (1971 to 2000) at the three NCCN parks. In contrast, snowpacks in La Niña years 2010 and 2011 were well above normal, with the June 1st 2010 snowpack averaging 135% of normal and the 2011 snowpack at 272% of normal due to much delayed melting (Figure 9).

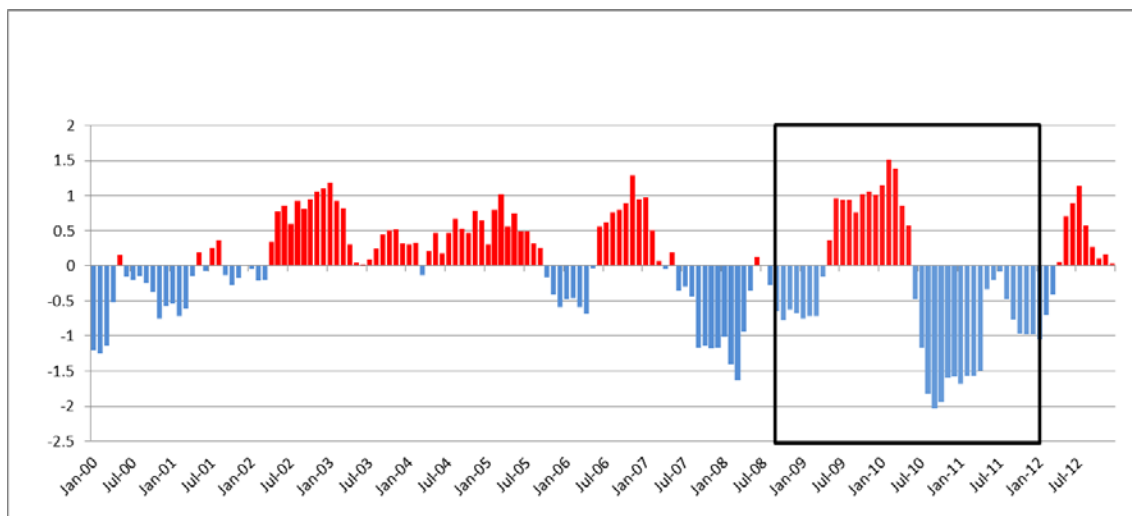


Figure 8. Multivariate ENSO Index values for the year 2000 to 2012. Positive values (red) typically reflect warmer and drier conditions of El Niño, while negative values (blue) indicate cooler and wetter conditions of La Niña, in Mount Rainier, North Cascades, and Olympic National Parks. The box indicates the time period of lake temperature data presented in this report (NOAA 2013).

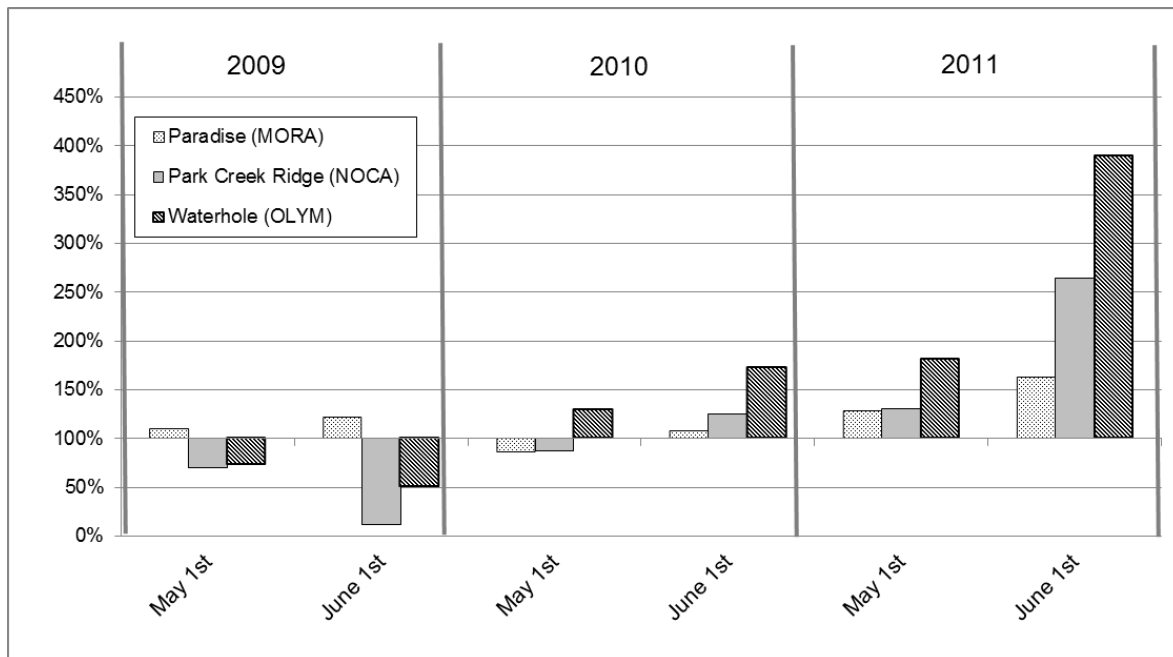


Figure 9. Comparison of May 1st and June 1st Snow Water Equivalent at SNOTEL stations within Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks against 30 year normal (graphed as 100%) for the climatological period 1971 to 2000.

Snowpack persistence exhibited a similar pattern. In 2009, melt out dates at park SNOTEL stations averaged three days earlier than average. In 2010, average melt out was eight days later than normal. In 2011, average melt out was 28 days later than normal (Figure 10).

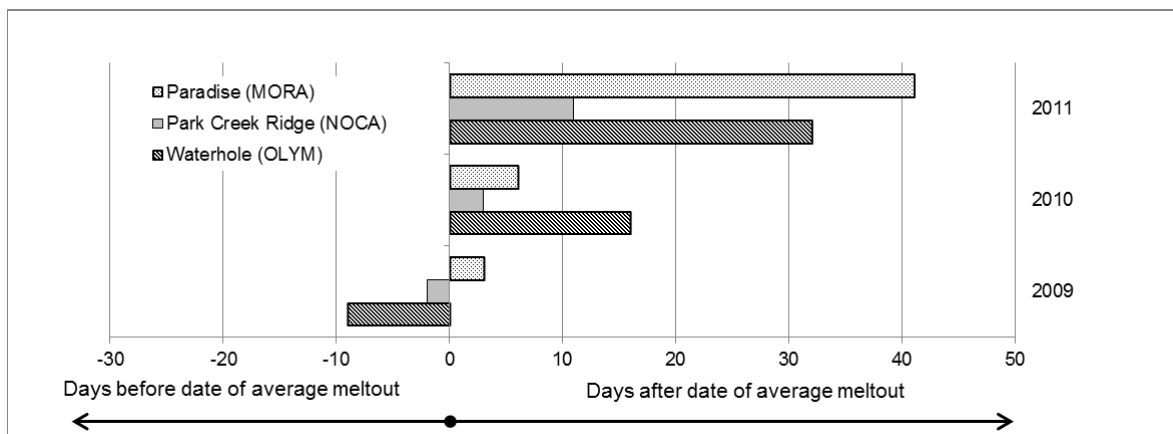


Figure 10. Comparison of the date of summer snowpack meltout at three SNOTEL station within Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks against the mean meltout date for the period of record. Positive values indicate the number of days after the mean date of meltout; negative values indicate the number of days before the mean date of meltout.

An additional effect of ENSO was reflected in air temperatures (Figure 11). The typically ice-free months of June through September had above average temperatures in 2009 and below average temperatures in 2010 and 2011. NCCN park SNOTELs recorded an average departure in temperature of +2.1°C during ice-free months 2009. In contrast, July of 2011 experienced a -3.0°C departure.

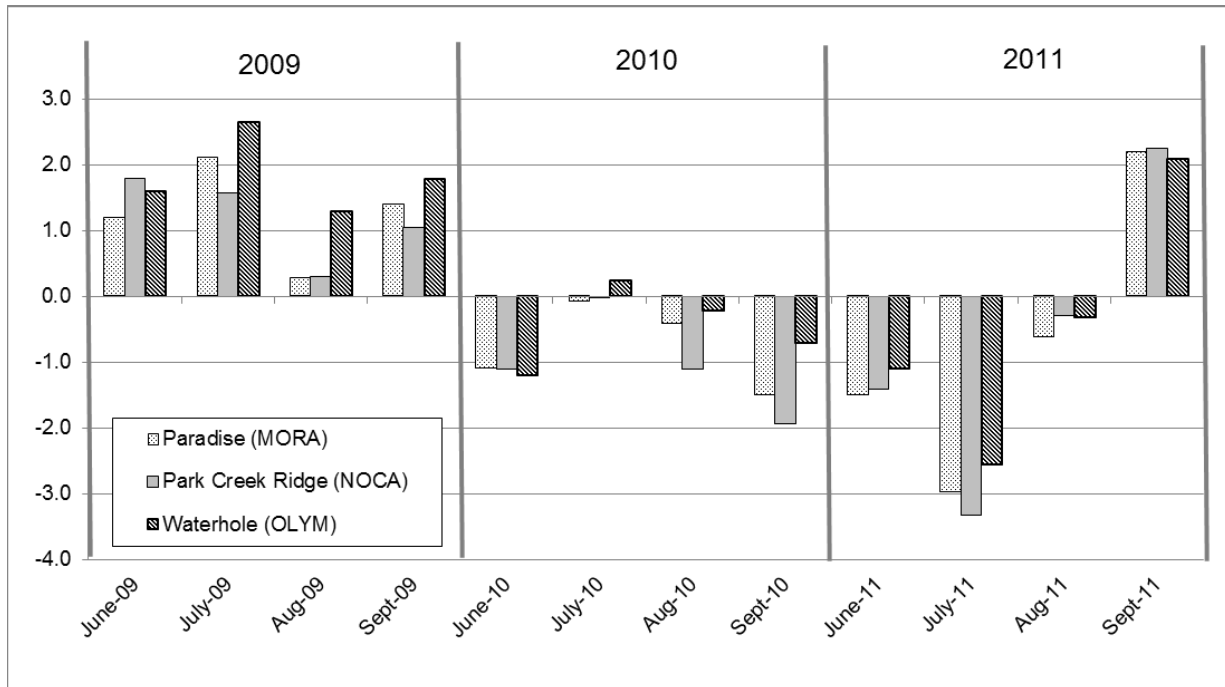


Figure 11. Average monthly temperatures at Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks SNOTEL weather stations during the ice-free months of June, July, August and September, for sampling years 2009 to 2011.

Overview of the Seasonal Temperature Cycle in NCCN Lakes

The dominant heat source to lakes is direct absorption of solar radiation. Additional heat can also be transferred directly from air masses, water vapor, sediments, precipitation, and surface and groundwater inputs. Dominant annual heat loss stems from conduction to colder air masses and to a lesser extent evaporation and outflow of heated surface waters.

A typical annual pattern in lake temperature for NCCN lakes is shown in Figure 12. During the winter, temperature of the water column is inversely stratified under the ice cover and remains relatively steady between 0-3°C near the surface and around 5°C near the bottom. Air temperature gradually increases above freezing after mid-May with corresponding small increases in surface water temperature and decreases in mid-depth and bottom temperatures when the ice begins to thaw or when snow melt first enters the lake. As solar radiation and air temperature continue to increase, water temperature at all depths becomes uniform, near 4°C (temperature of maximum density of water), indicating the onset of ice-out and summer turnover. Summer turnover dates for the NCCN lakes usually occur before the end of July. However, ice-out and summer turnover can be delayed until the end of September, or even persist throughout the year at some lakes, depending on the overlying snow thickness which has to be melted before sunlight can reach the ice.

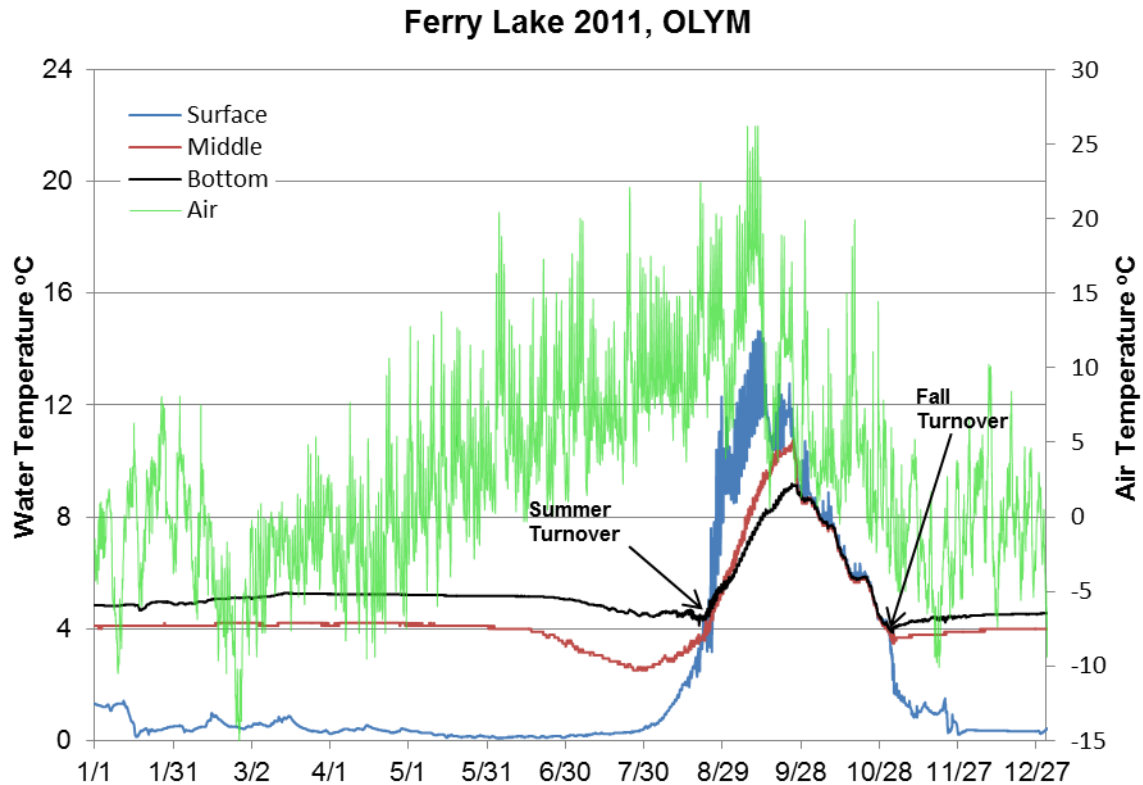


Figure 12. Example of the seasonal temperature pattern (smoothed hourly temperature data) of a dimictic North Coast and Cascade Network lake at Olympic National Park (OLYM).

Lake surface temperature exhibits a rapid rise in temperature and begins to track ambient air temperature following ice-out. For most NCCN lakes, daily fluctuations of surface water temperature are the greatest at the beginning of the open water season and consistently decrease until the lake is frozen. The exception to this can occur at some lakes with persistent snow or ice in their catchment (Figure 13) that contributes cold runoff water over an extended period of time following ice-off. This condition is exacerbated in lakes with larger catchment areas.

Lake stratification, with warmer and less dense waters overlying colder and denser waters below, occurs in deeper lakes as air and surface water temperatures rise through the summer (Figure 12). Stratification persists if the relative thermal resistance to mixing between the epilimnion and metalimnion remains high (larger differences in density). Thermal resistance to mixing decreases as air temperature begins to decline in the fall. During this period surface waters cool, become denser, sinking and mixing with deeper waters to eventually create an isothermal condition throughout the depth profile. Fall turnover occurs near the time when temperatures at all depths are approximately at 4°C (Figure 12). Following fall turnover, inverse temperature stratification develops below the lake surface as the surface water cools from 4°C to 0°C. Stable ice formation can occur at any time in a lake after it has cooled to 4°C (Ashton 1986) and may take anywhere from a day to over a month to form. Surface cooling and reduction in wind mixing are the two main physical processes that facilitate the onset of ice formation (Fang et al. 1996). For small lakes and ponds the ice cover

typically forms sometime after the water has cooled to 4°C, with the actual occurrence generally associated with a calm, clear, cold night.

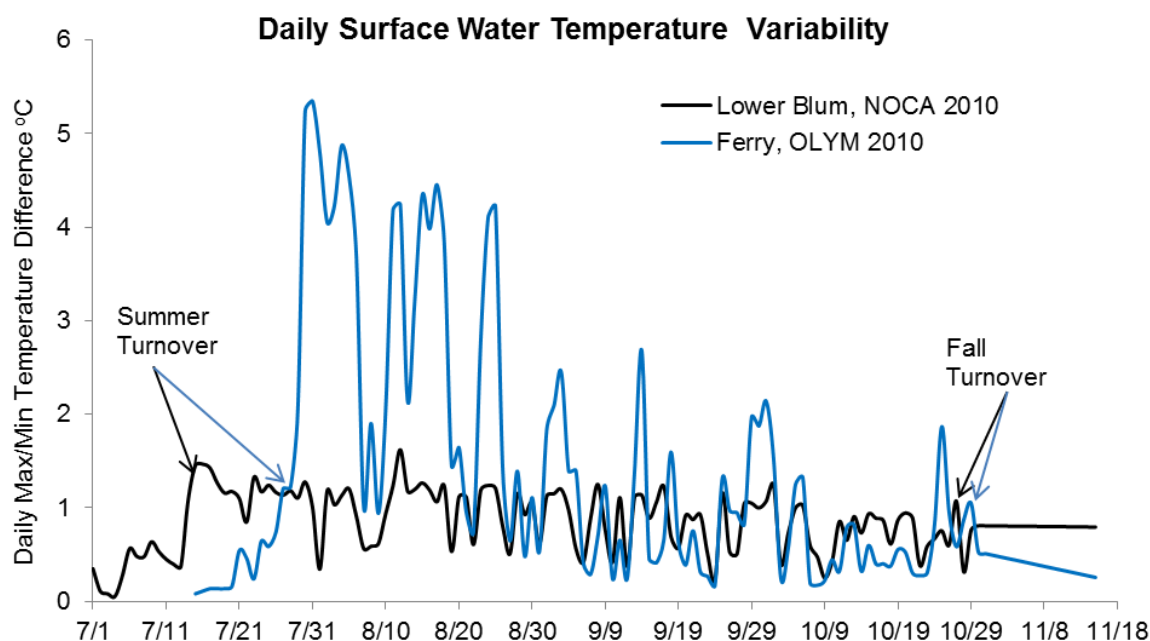


Figure 13. Comparison of daily variation in surface water temperature during the open water season for North Coast and Cascade Network lakes exhibiting a typical pattern (Ferry Lake; blue line) and a pattern influenced by persistent snow or ice in the lake's catchment (Lower Blum Lake; black line).

All lakes at MORA and OLYM generally exhibit a typical pattern in surface water temperature variation. Lower East Lake is the only other NCCN Lake that exhibits a pattern in variation similar to Lower Blum Lake at NOCA. Both lakes are moderately influenced by glaciers in the catchment area.

Wind may subsequently break up this ice cover, and the water will cool further until the winds are calm again. The result is that the initial permanent ice cover and the water temperature beneath it depend on the sequence of meteorological events during the cooling period. As a result, the surface water temperature at ice formation can vary between 0°C to 4°C.

Air Temperature Characteristics of NCCN Monitoring Lakes

Air temperature patterns of NCCN lakes were consistent with changes in ENSO phases between 2009 and 2011, from a strong El Niño in 2009 to a strong and prolonged La Niña in 2010 and 2011 (see previous section on climatic conditions in NCCN parks, Figure 8).

Annual Air Temperature Data

Annual Average Air Temperature ($ADAT_{air_yr}$)

Annual average of daily average air temperature data ($ADAT_{air_yr}$, Table 5) was only available for five lakes at OLYM during 2009, ranging from 3.79°C to 5.73°C. During 2010 and 2011, the $ADAT_{air_yr}$ values were the coldest at NOCA and warmest at OLYM. NOCA $ADAT_{air_yr}$ values ranged from 0.37°C to 2.57°C during 2010, and from 0.77°C to 1.19°C during 2011. OLYM

ADAT_{air_yr} values ranged from 2.62°C to 5.04°C during 2010, and from 1.91°C to 2.72°C during 2011 (Table 5).

There was a significant drop in ADAT_{air_yr} values between 2009 and 2010 for the five lakes at OLYM that had data collected in 2009, ranging from a -11.0% change at Connie Lake to a -25.6% change at Milk Lake. ADAT_{air_yr} values at all NCCN lakes with data dropped between 2010 and 2011 (Table 5). The percent change between these two years ranged between -21.2% at Milk Lake (OLYM) and -54.1% at Lower Blum Lake (NOCA).

Table 5. Annual average of daily average air temperature (ADAT_{air_yr}) at Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Park lakes during 2009 - 2011.¹

Lake	Park	Elevation (m)	Annual Mean Temperature			% Change	
			2009 (°C)	2010 (°C)	2011 (°C)	2009-2010	2010-2011
Blue	MORA	1352	ND	3.31	2.06	ND	-37.8
LP19	MORA	1372	ND	4.03	2.91	ND	-27.8
Allen	MORA	1397	ND	3.49	2.49	ND	-28.7
U Deadwood	MORA	1600	ND	2.05	1.29	ND	-37.1
LH15	MORA	1659	ND	ND	ND	ND	ND
U Palisades	MORA	1785	ND	ND	ND	ND	ND
L Blum	NOCA	1511	ND	2.57	1.18	ND	-54.1
L East	NOCA	1664	ND	2.16	ND	ND	ND
E Ridge	NOCA	1680	ND	ND	ND	ND	ND
Bowan	NOCA	1982	ND	0.37	ND	ND	ND
U Triplet	NOCA	1998	ND	1.36	0.77	ND	-43.4
L Silent	NOCA	2046	ND	ND	ND	ND	ND
Sunup	OLYM	1224	5.73	5.04	ND	-12.0	ND
Connie	OLYM	1300	4.91	4.37	ND	-11.0	ND
Gladys	OLYM	1383	ND	2.62	1.91	ND	-27.1
Ferry	OLYM	1434	4.56	3.62	2.72	-20.6	-24.9
Milk	OLYM	1435	3.87	2.88	2.27	-25.6	-21.2
LaCrosse	OLYM	1447	ND	ND	ND	ND	ND
Crazy	OLYM	1457	ND	ND	2.65	ND	ND
Heather	OLYM	1589	3.79	3.17	2.48	-16.4	-21.8

¹ ND-insufficient data to calculate annual means. Annual means at most of the lakes could not be calculated during 2009 because loggers were not initially deployed until September (also the same for LaCrosse and Crazy lakes, OLYM, in 2010). Missing data for other lakes during 2010 and 2011 are primarily attributed to snow cover on loggers and also to vandalism and logger failure.

Relationship Between Air Temperature and Elevation

Variation in ADAT_{air_yr} values among lakes within years appears to be primarily related to elevation.. Annual air temperature lapse rates for NCCN lakes, determined from linear regressions of 2010 and 2011 ADAT_{air_yr} values and lake elevations, are shown in Table 5. Scatter plots, with regression equations and lapse rates are shown in Figure 14. In the 2010 regression (Figure 14a), the R² value indicated that approximately 82% of the variation in ADAT_{air_yr} values among NCCN lakes was explained by elevation. However, during 2011 only about 50% of the variation (R²=0.492) in ADAT_{air_yr} among lakes was explained by elevation (Figure 14b). This may be the result of having to drop the two lowest elevation sites (Sunup and Connie lakes, OLYM) and one of the highest

elevation sites (Bowen Lake, NOCA) from the regression because of missing data in 2011. It is also possible that variation in local site characteristics affecting surface air temperature, under the unusually cold conditions during 2011, may have influenced the regression.

The lapse rate calculated from the 2010 data represented a drop of 5.78°C over a 1 km increase in altitude ($5.78^{\circ}\text{C km}^{-1}$, Figure 14a). The lapse rate calculated from the 2011 data was similar, but

somewhat lower ($5.45^{\circ}\text{C km}^{-1}$, Figure 14b).

These values represent composite characterization of surface lapse rates for all of the NCCN lakes combined; however, differences in lapse rates among parks and lake sites within the parks are expected. In addition to elevation, differences in slope, aspect, precipitation and relative humidity of the air mass, topographic shading, land cover types (vegetation, snow, soils, etc.) location in valleys or depressions subject to cold air drainage vs. on ridgetops, location on the windward or lee sides of mountains, and presence of lakes and streams can all contribute to substantial geographic and seasonal variation within a region (Bonan 2002, Minder et al. 2010).

Porter (1977) reported a mean annual lapse rate of $4.7^{\circ}\text{C km}^{-1}$ for the Cascade Range, using long term data from weather stations located on both the east and west sides of the Cascade Crest. Henderson et al. (2011) calculated annual lapse rates for the Olympic Peninsula which varied from $4.56^{\circ}\text{C km}^{-1}$, along the coastal zone, to $5.29^{\circ}\text{C km}^{-1}$ in the northeast region of the Olympic Range. An annual model forecasted lapse rate of $5.0^{\circ}\text{C km}^{-1}$ was calculated for MORA for the 2006-2007 water year (Minder et al. 2010). Minder et al. (2010) also reported a mean annual

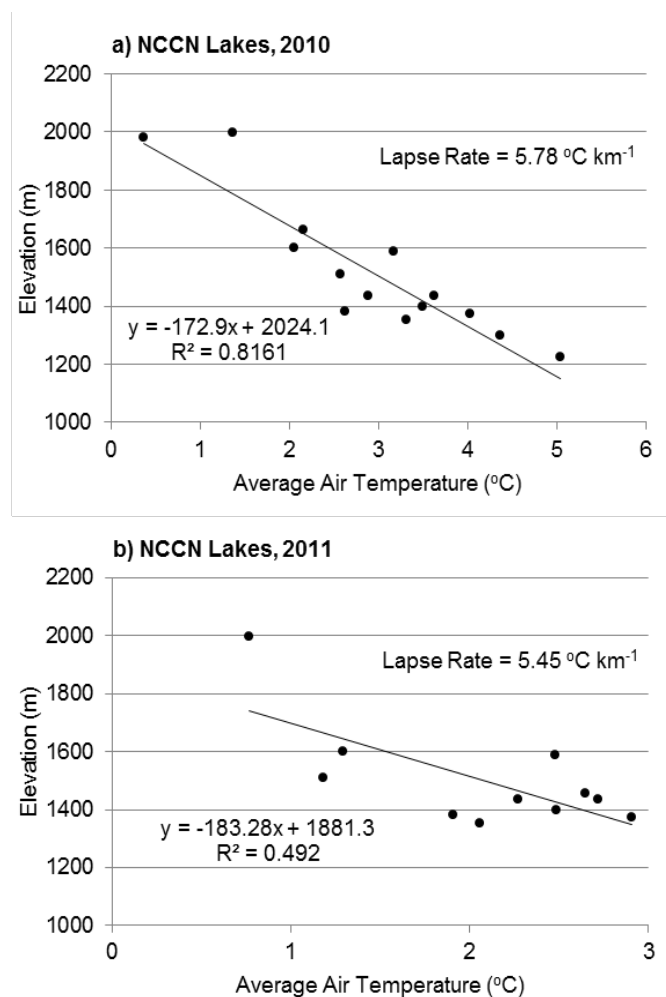


Figure 14. Scatter plots, regression equations, and surface lapse rates showing the relationship between average annual air temperature and elevation for all North Coast and Cascades Network (NCCN) lakes combined, 2010 and 2011.

lapse rate of $4.1^{\circ}\text{C km}^{-1}$, derived from temperature logger data along an elevation gradient in the south central area of MORA for the same period. At NOCA, a mean annual lapse rate of $4.7^{\circ}\text{C km}^{-1}$ was determined from temperature loggers deployed along an elevation gradient starting in Maple Pass and approximately following the Highway 20 corridor down the west side of the mountains.

Annual Maximum and Minimum Air Temperature: 7-Day Moving Average

Annual maximum and minimum air temperatures for all lakes at each park are reported as 7-day moving averages with occurrence dates, in Table 6. The highest 7-day moving average of maximum daily air temperatures (7-DADMax) among all of the NCCN lakes and years sampled occurred at Upper Triplet Lake, located on the east side of the Cascade Crest in NOCA, during the last week of August, 2011 (35.3°C). Other NCCN lakes with 7-DADMax >30°C included Bowan Lake (eastside NOCA, 2010) and Sunup Lake (OLYM, 2009 and 2010).

Table 6. Highest 7-day moving average of daily maximum (7-DADMax) and lowest 7-day moving average daily minimum (7-DADMin) air temperatures (°C) during 2009-2011, with occurrence dates (mid-point of 7-day interval).¹ Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Park Lake	7-DADMax			Occurrence Date			7-DADMin			Occurrence Date		
	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
MORA												
Allen	ND	21.6	24.1	ND	8/15	9/9	ND	-11.0	-11.6	ND	11/22	2/23
LP19	ND	20.7	22.4	ND	8/15	9/9	ND	-10.7	-10.7	ND	11/22	2/23
Blue	ND	24.2	25.0	ND	7/27	9/9	ND	-9.2	-11.2	ND	12/31	11/22
U Deadwood	ND	23.1	24.1	ND	7/27	9/9	ND	-13.2	-15.5	ND	11/25	2/23
LH15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
U Palisades	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NOCA												
U Triplet	ND	32.0	35.3	ND	7/26	8/26	ND	-16.1	-17.9	ND	11/3	2/23
Bowan	ND	30.2	ND	ND	8/15	ND	ND	-18.5	ND	ND	11/24	ND
Lower Silent	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lower Blum	ND	29.3	29.6	ND	7/26	9/9	ND	-10.5	-14.6	ND	11/22	2/23
Lower East	ND	22.4	ND	ND	8/15	ND	ND	-17.4	ND	ND	11/22	ND
Easy Ridge	ND	23.3	ND	ND	8/15	ND	ND	ND	ND	ND	ND	ND
OLYM												
Ferry	29.0	22.1	24.5	7/29	8/15	9/9	-11.5	-11.4	-11.8	12/8	11/21	2/23
Gladys	ND	23.5	23.3	ND	8/15	9/10	ND	-13.3	-14.3	ND	11/21	2/23
Heather	26.4	23.4	22.7	7/29	8/15	9/9	-13.5	-12.7	-13.4	12/9	11/21	2/23
Crazy	ND	ND	26.7	ND	ND	9/10	ND	ND	-12.0	ND	ND	2/23
Milk	26.6	19.6	19.2	7/30	8/15	9/10	-12.4	-11.5	-11.6	12/9	11/25	2/23
LaCrosse	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sunup	31.9	33.7	25.8	7/29	8/16	9/9	-10.8	-9.7	ND	12/9	11/24	ND
Connie	26.8	28.1	25.4	7/29	7/26	7/26	-10.0	-9.7	ND	12/8	11/24	ND

¹ ND-insufficient data to calculate 7-day moving averages and occurrence dates. Response values at most of the NCCN lakes could not be calculated during 2009 because loggers were not initially deployed until September (also the same for LaCrosse and Crazy lakes, OLYM, in 2010). Missing data for other lakes during 2010 and 2011 are primarily attributed to vandalism and logger failure.

7-DADMax occurrence dates (mid-point of the 7-day interval) showed high similarity among the lakes in all three parks. 7-DADMax occurrence dates for the five OLYM lakes sampled in 2009 varied by one day during the end of July. During 2010, 7-DADMax temperatures occurred on August 15th and 16th at ten of the NCCN lakes and July 26th and 27th at the other five lakes with data. 7-DADMax occurrence dates during 2011 were generally three to five weeks later than in 2009 and

2010, with 7-DADMax temperatures occurring at all but two of the lakes on September 9th and 10th (Table 6).

The lowest 7-day moving average of minimum daily air temperatures (7-DADMin) among all of the NCCN lakes and years sampled was -18.5°C, occurring at Bowan Lake (NOCA) on November 22nd, 2010 (Table 6). Other NCCN lakes with 7-DADMin that were colder than -15.0°C included two other NOCA lakes, Upper Triplet Lake (2010 and 2011) and Lower East Lake (2010).

7-DADMin occurrence dates also were similar among the lakes in all three parks. 7-DADMin occurrence dates for the five OLYM lakes sampled in 2009 varied by one day during the second week of December. During 2010, 7-DADMin temperatures occurred between November 21st and 25th at 12 of the 14 NCCN lakes with data. During 2011, 7-DADMin temperatures occurred on February 3rd at all but one of the NCCN lakes (Table 6).

Monthly Average Air Temperature

Monthly average daily average air temperatures (ADAT_{air}) for all lakes at each park, during 2010 and 2011, are shown in Figure 15. Tabular monthly average temperature data for ADAT_{air}, average daily minimum (ADMINT_{air}), and average daily maximum temperature (ADMT_{air}) for all NCCN lakes, sampled between 2008 and 2011, are shown in Appendix C (Tables C1-C20).

In general, monthly average air temperatures (ADAT_{air_mo}) for lake locations at the three NCCN parks exhibited similar patterns (Figure 15). Patterns in the coldest temperatures across all of the NCCN lakes were consistent with the strong negative ENSO index values shown in Figure 8 during this period. The coldest ADAT_{air_mo} values at most NCCN lakes occurred in December 2010 and February 2011 (Figure 15a-f). The lowest ADAT_{air_mo} values, observed during the 2010 through 2011 period, occurred during February 2011 at the two NOCA lakes located on the east side of the Cascade Crest, Bowan Lake (-8.32°C) and Upper Triplet Lake (-7.89°C, Appendix C, Table C7). Summer peak air temperatures at all lakes were observed in July and August during 2010, and shifted by a month to August and September in 2011 (Figure 15). The highest ADAT_{air_mo} values, observed in 2010-2011, occurred at Sunup and Connie lakes at OLYM during July 2010 (14.82 and 13.92°C, respectively, Appendix Tables C19 and C20) and at Upper Triplet Lake (NOCA) during August 2011 (12.68°C).

Elevation explains a significant amount of the variation in ADAT_{air_mo} values among the NCCN lakes during some months. Figure 16 shows correlation coefficients for monthly regressions of NCCN ADAT_{air_mo} values and elevation. Elevation was important in explaining variation in monthly temperatures among lakes during the Jan-Apr and Aug-Dec periods of 2010, and the Jan-Mar and Sept-Dec periods of 2011. The poor correlation between air temperature and elevation during May-July, 2010, and April-August, 2011, suggests that air temperature during these months may have been influenced by differences among lake locations in respect to cold air drainage and onshore/offshore wind patterns.

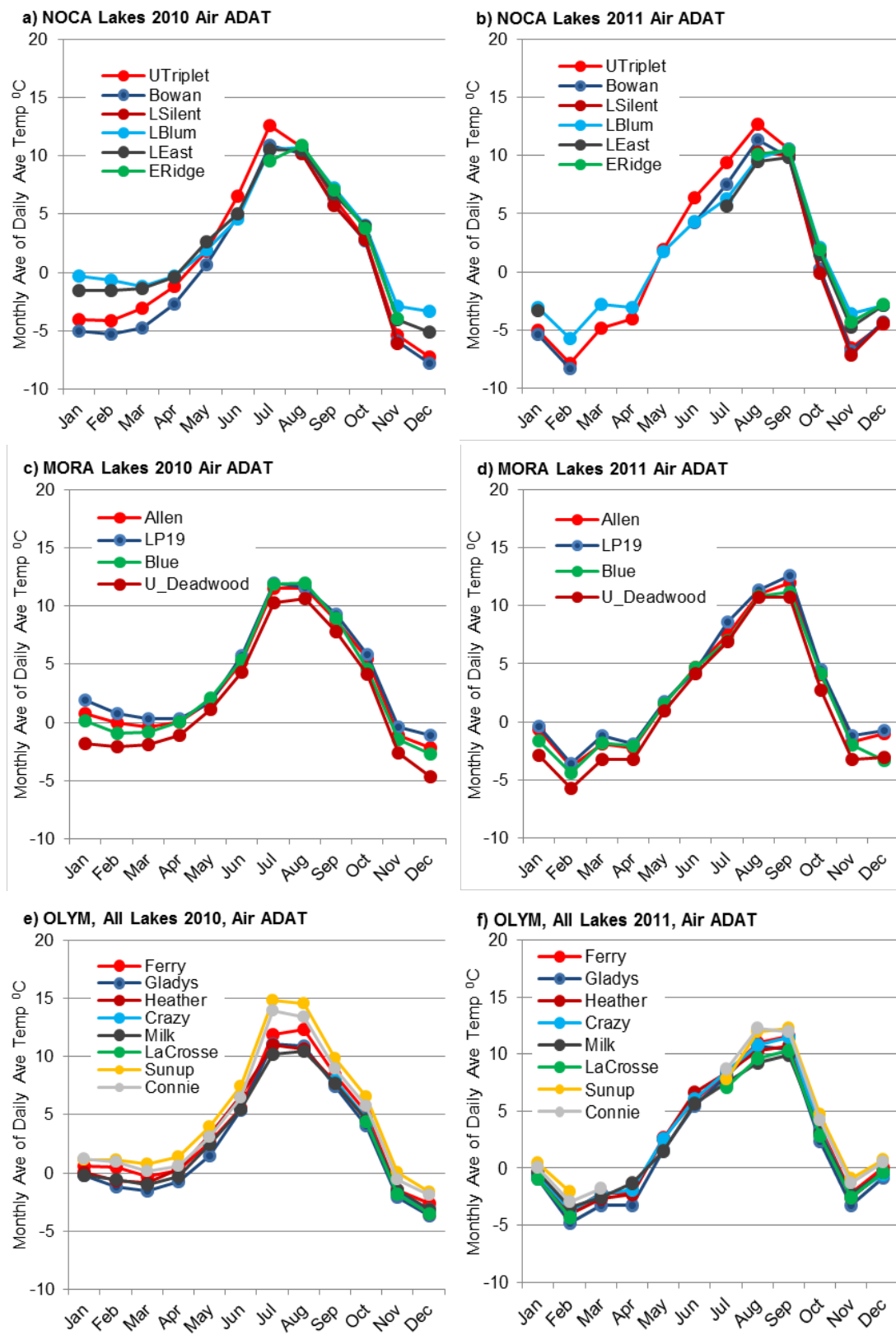


Figure 15. Monthly average of daily average air temperatures ($ADAT_{air_mo}$) for all lakes at North Cascades (NOCA), Mount Rainier (MORA), and Olympic (OLYM) National Parks, 2010 and 2011.

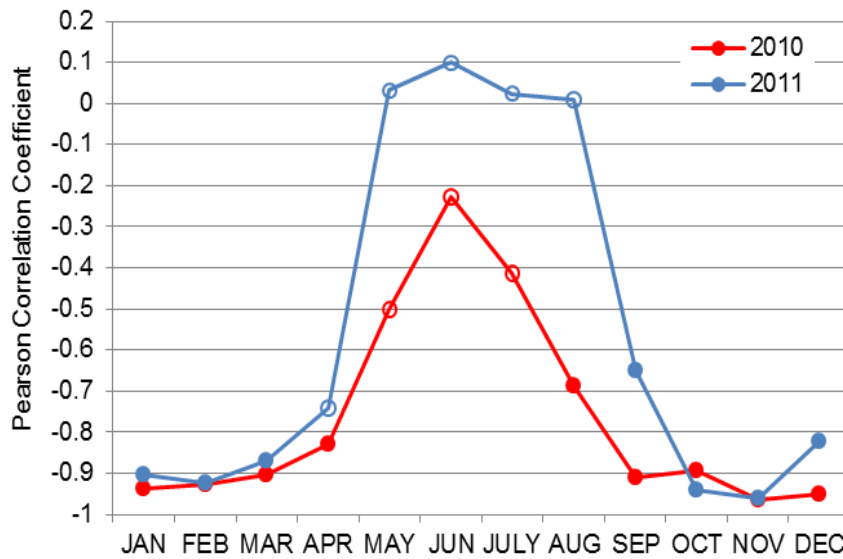


Figure 16. Pearson correlation coefficients for linear regressions of mean monthly air temperature and elevation for all North Coast and Cascades Network lakes combined during 2010 and 2011 (filled circles indicate correlation coefficient $\neq 0$, $p < 0.05$. Sample size for regressions varied by month and year and ranged from 10 to 18 lakes for each month).

In addition to elevation, variation in winter and late fall $ADAT_{air_mo}$ values among lakes at NOCA and MORA appears to be related to differences in location along an east to west gradient, representing a transition from the wetter and warmer marine influenced climate to a drier and colder continental climate. The wider spread in monthly $ADAT_{air_mo}$ values among lakes at MORA and NOCA, observed during January-March and November-December of 2010 and 2011 (Figure 15a-d), was not observed at OLYM lakes during either of these years (Figure 15e-f). West-side lakes had higher air temperatures in the winter due to marine influence while east-side lakes had higher air temperatures in the summer. During the late fall and winter months of 2010 and 2011, lakes located on the west side of the Cascade Crest in NOCA (Lower East and Lower Blum) had higher $ADAT_{air_mo}$ values than those on the east side of the crest (Upper Triplet and Bowan), Figure 15a-b. Similar differences in $ADAT_{air_mo}$ values were observed between west side lakes (LP19 and Allen) and east side lakes (Blue and Upper Deadwood) at MORA (Figure 15c-d).

The differences in air temperatures among lakes within each park narrowed as monthly air temperatures began to gradually increase at all lakes during April and June in 2010, and April and July in 2011. Variation in peak monthly air temperatures among lakes within each of the three parks was observed during July and August of 2010 and shifted to August and September in 2011, as a result of the 2010-2011 severe winter conditions (Figure 15a-f). The pattern of variation in $ADAT_{air_mo}$ values among lakes within each park during the fall was similar to the spring and early summer period, consistently showing only small differences among lakes in each park (Figure 15a-f).

Water Temperature Characteristics of NCCN Monitoring Lakes

Water temperature patterns of NCCN lakes were also consistent with changes in ENSO phases between 2009 and 2011, from a strong El Niño in 2009 to a strong and prolonged La Niña in 2010

and 2011, occurring simultaneously with a cold phase of the PDO (see previous section on climatic conditions in NCCN parks, Figure 8). Lake water temperature response variables at all three parks were strongly influenced by substantial increases in snowpack (Figure 9), delayed snowmelt (Figure 10), and colder than average June air temperatures (2010) and June and July air temperatures (2011) during the 2010-2011 La Niña phase (Figure 11).

Daily Average Water Temperature (DAT_{water}) Annual Plots

Annual plots of DAT_{water} are useful for: assessing year to year changes in temperature patterns and differences among lakes; determining dates of spring/summer and fall turnover and the approximate length of the open water season; providing a quick approximation of the presence, timing and magnitude of summer thermal stratification; and, for observing the timing and magnitude of annual peak temperatures. Annual plots of 2009-2011 DAT_{water} data are presented for all lakes, except Blue Lake (no data), at each of the three NCCN parks in Figures 17-28. Yearly plots for each lake are uniformly scaled and in series to facilitate comparisons among years. The timing of the annual sample trip is represented by star symbols located on the date axis.

Peak Surface Water Temperatures and Annual Sampling Events

A declining trend in ice-free season peak surface water temperature was observed in the annual temperature plots at all of the NCCN lakes between 2009 and 2011 (Figures 17-28). Approximate changes in peak surface water temperatures for MORA and NOCA lakes, between 2009 and 2011, were generally 3-9°C colder in 2011. Surface water peak temperature differences between 2009 and 2011 at OLYM were much more pronounced, ranging from approximately 9°C colder at Ferry Lake (Figure 24) to 15-17°C colder in 2011 at Milk and Connie lakes (Figures 26 and 27).

Star symbols, representing the dates of annual sample trips, located on the horizontal axes of Figures 17-28 and were used to compare how the timing of the annual sample trip corresponded with the period of peak summer surface water temperature and biological productivity in the lake. Consistency in targeting this index period was hoped to reduce some of the variability that could affect interpretation of status and trends of other chemical and biological parameters being monitored under the protocol. Annual sampling dates for most lakes corresponded well with periods of peak summer temperature during 2009; however, correspondence between peak temperatures and annual sampling dates was problematic at several lakes during 2010 and 2011 (*e.g.*, Upper Triplet 2011, Figure 20; Milk 2010, Figure 26). This is likely related to a shift in timing of peak surface water temperatures to later in the season and a narrowing of the peak temperature target period as a result of the colder and wetter weather during these years. Annual sample dates are also affected by the logistical problems of scheduling trips to all of the lakes during years when ice-off is delayed. The 2009 and 2011 open water seasons represent a wide range of climatic conditions and water temperature responses experienced at our mountain lakes, and will prove useful for planning future site visits.

Lake Stratification

Summer thermal stratification occurs when the warm upper water layer (epilimnion) and cold lower water layer (hypolimnion) are separated by a third layer (metalimnion) that is characterized by rapidly decreasing water temperature. Stratification is of interest in the NCCN monitoring program

because increases in the frequency, intensity, and depth of stratification would suggest trends in lake warming (Fradkin and Samora 2011).

Evidence of thermal stratification, approximate strength, and duration can be observed in the daily temperature plots (Figures 17-28) by comparing differences between peak summer surface and mid-depth logger temperatures. Lakes that appeared to be strongly stratified included LP19 (MORA, 2009-2011), Gladys (OLYM, 2010-2011, and Milk (OLYM, 2009). Weakly stratified lakes included Allen (MORA, 2010), Lower East (NOCA, 2010), and Ferry (OLYM, 2009-2011).

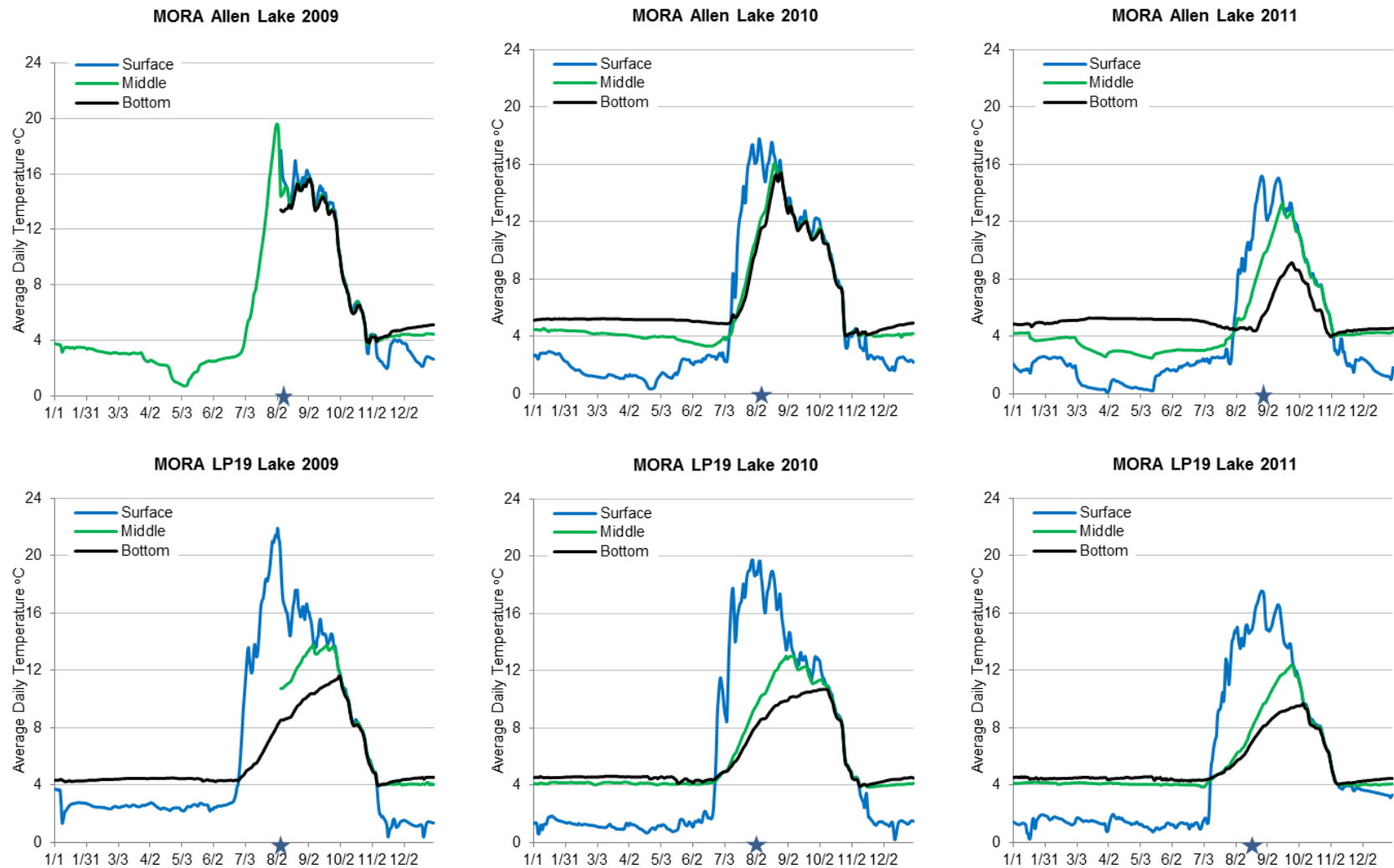


Figure 17. Daily average water temperature (°C) annual plots for Allen (weakly stratified) and LP19 (strongly stratified) lakes, Mount Rainier National Park (MORA), 2009-2011 (stars represent annual sampling events).

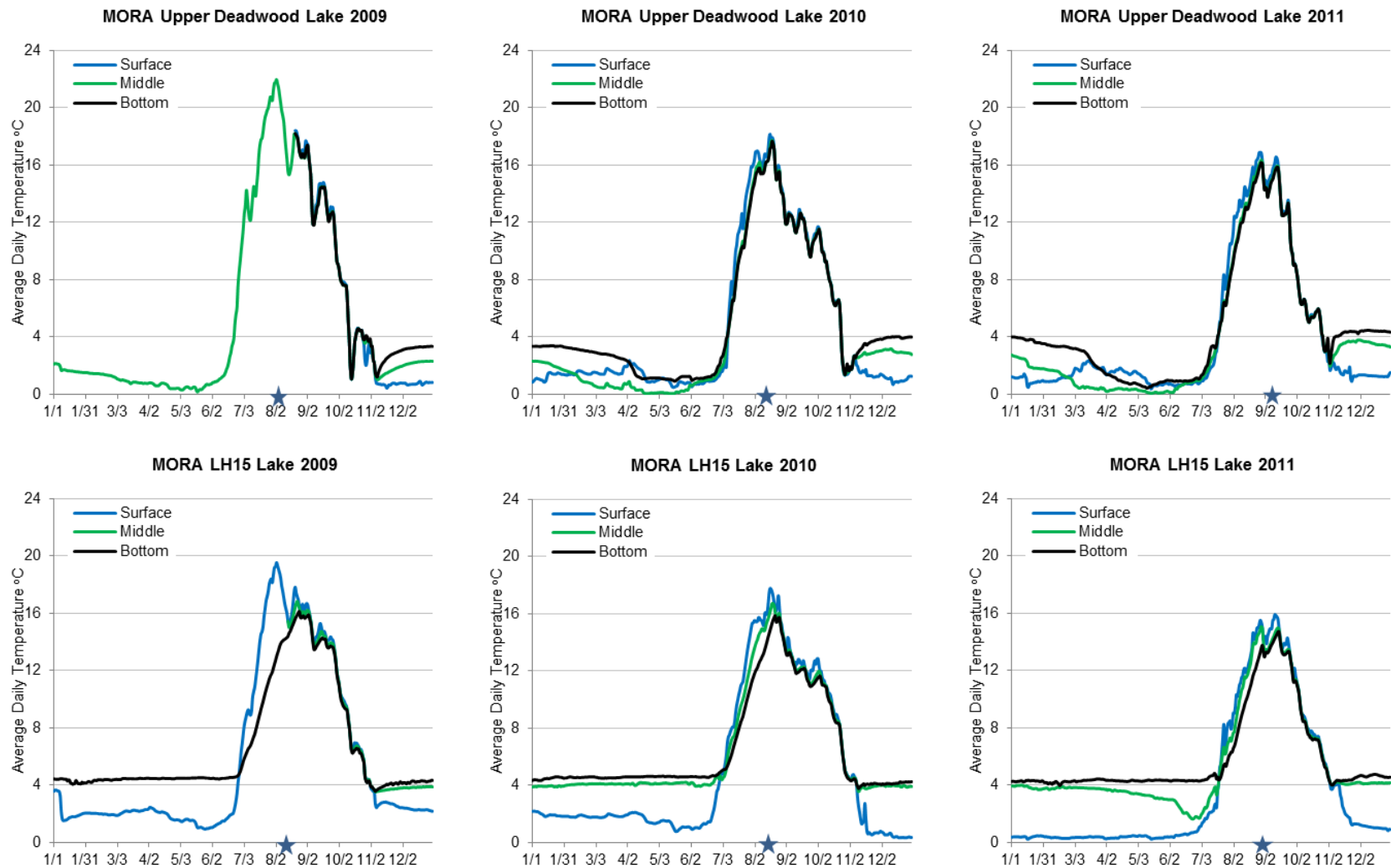


Figure 18. Daily average water temperature (°C) annual plots for Upper Deadwood and LH15 lakes, Mount Rainier National Park (MORA), 2009-2011 (stars represent annual sampling events).

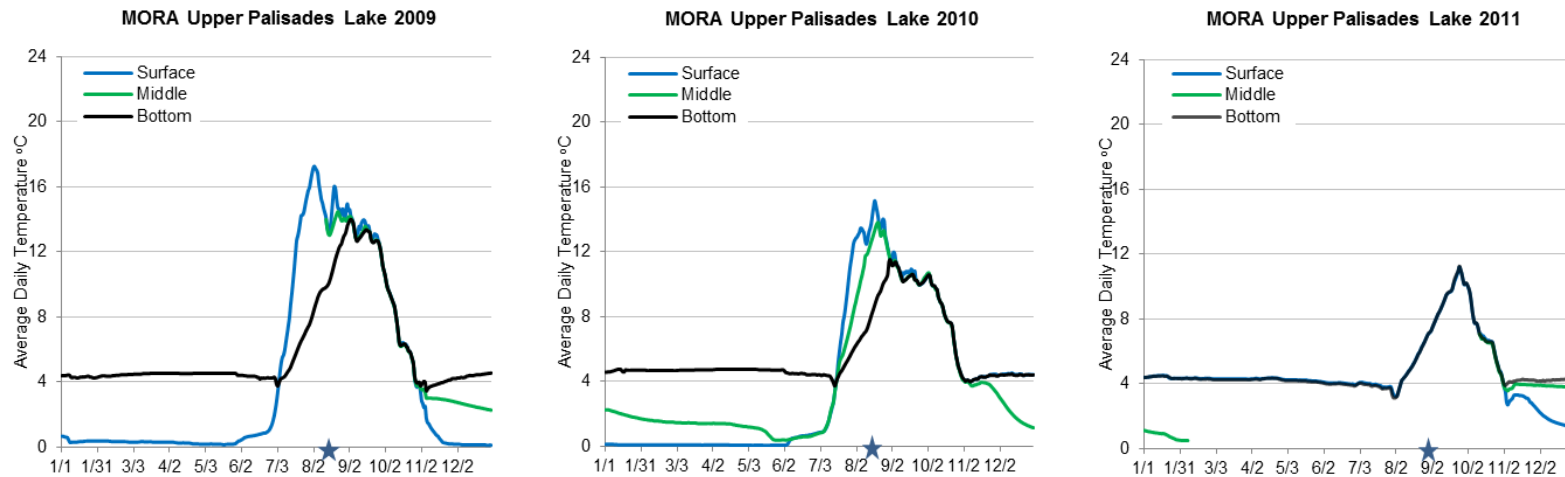


Figure 19. Daily average water temperature (°C) annual plots for Upper Palisades Lake, Mount Rainier National Park (MORA), 2009-2011 (stars represent annual sampling events).

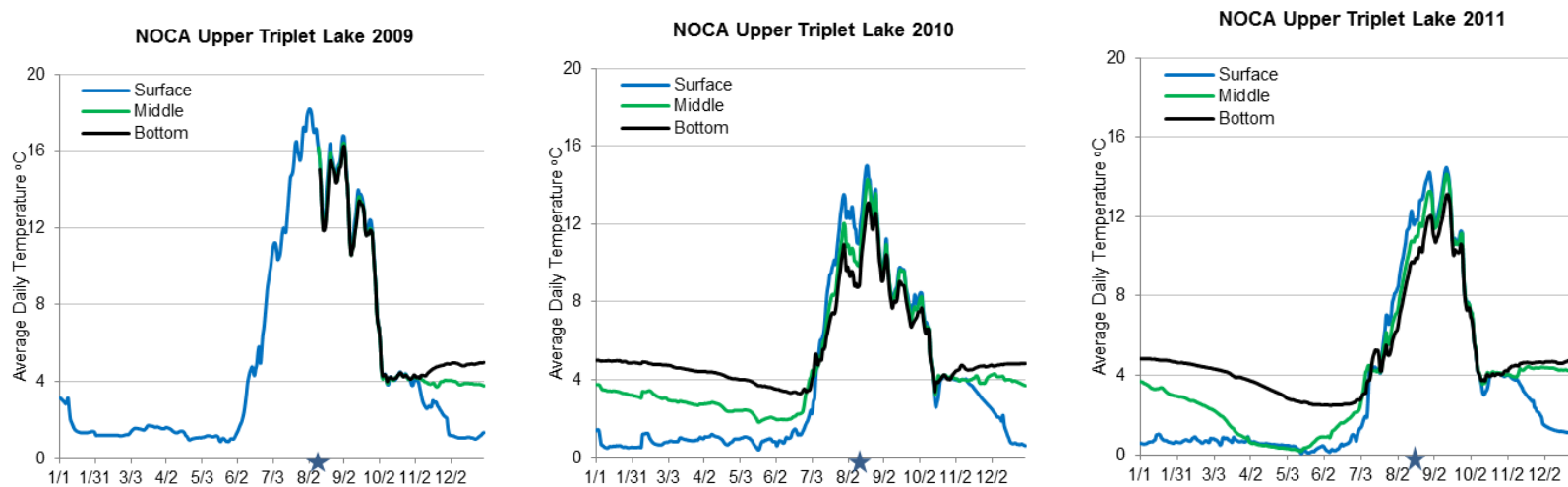


Figure 20. Daily average water temperature (°C) annual plots for Upper Triplet Lake, North Cascades National Park (NOCA), 2009-2011 (stars represent annual sampling events).

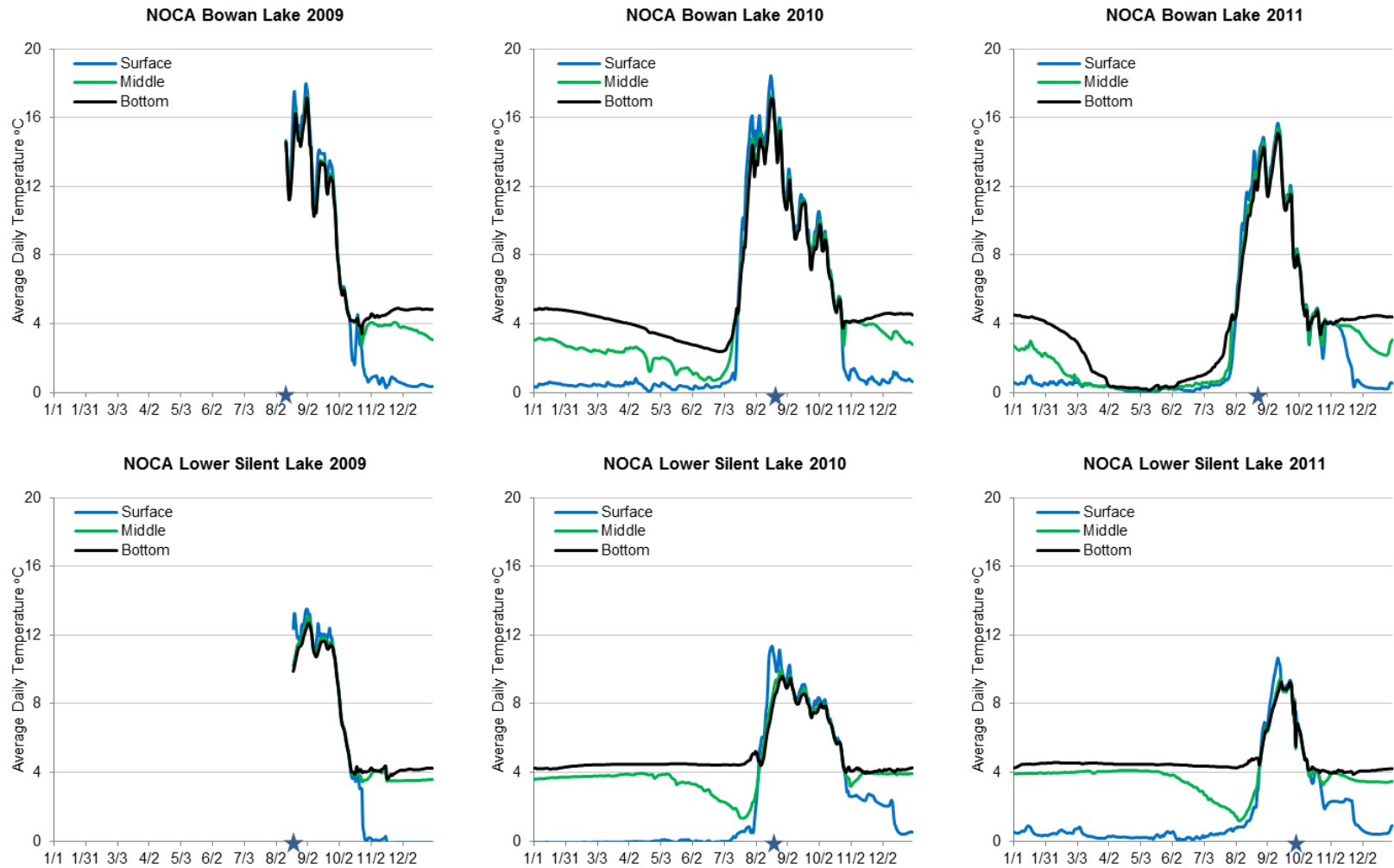


Figure 21. Daily average water temperature (°C) annual plots for Bowan and Lower Silent lakes, North Cascades National Park (NOCA), 2009-2011 (stars represent annual sampling events).

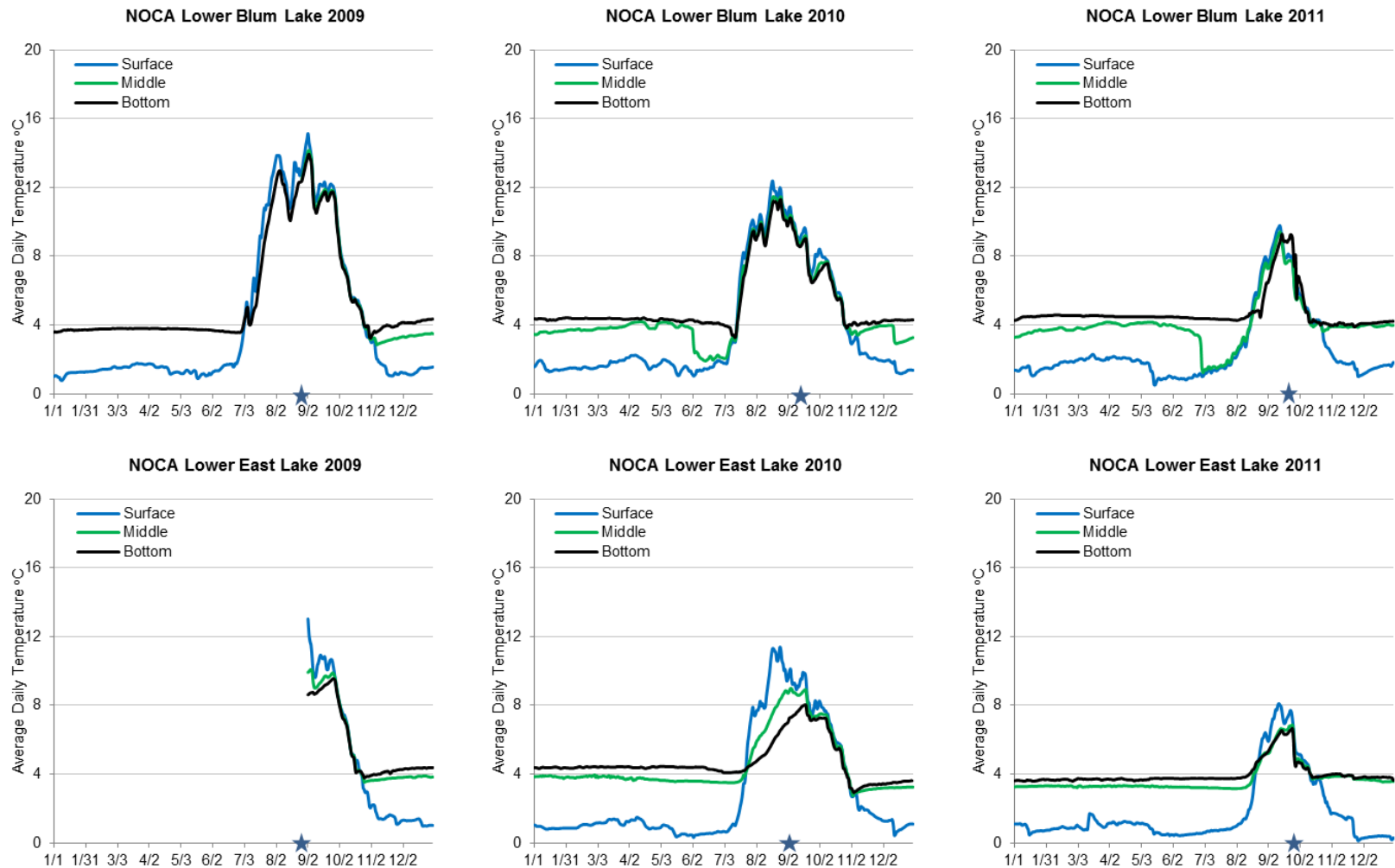


Figure 22. Daily average water temperature (°C) annual plots for Lower Blum and Lower East lakes, North Cascades National Park (NOCA), 2009-2011 (stars represent annual sampling events).

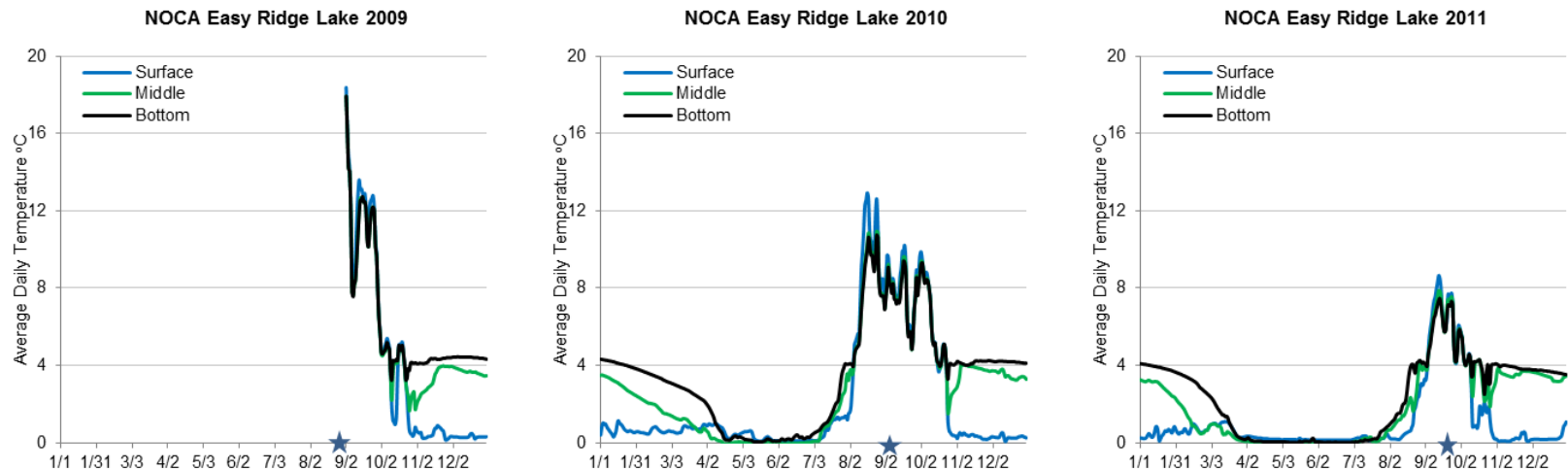


Figure 23. Daily average water temperature (°C) annual plots for Easy Ridge Lake, North Cascades National Park (NOCA), 2009-2011 (stars represent annual sampling events).

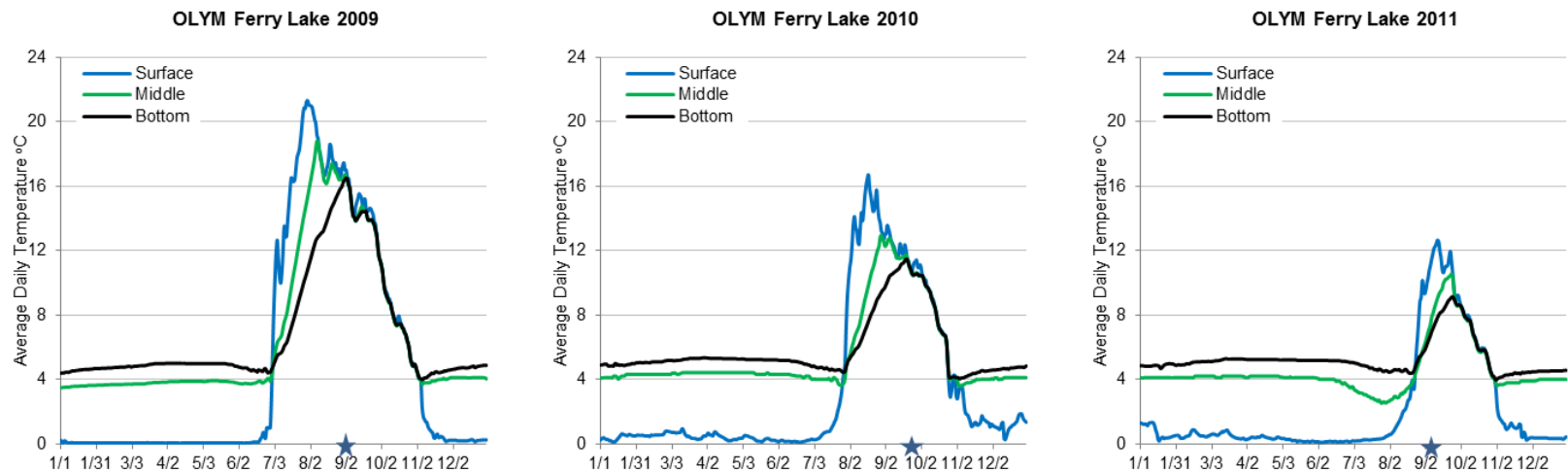


Figure 24. Daily average water temperature (°C) annual plots for Ferry Lake, Olympic National Park (OLYM), 2009-2011 (stars represent annual sampling events).

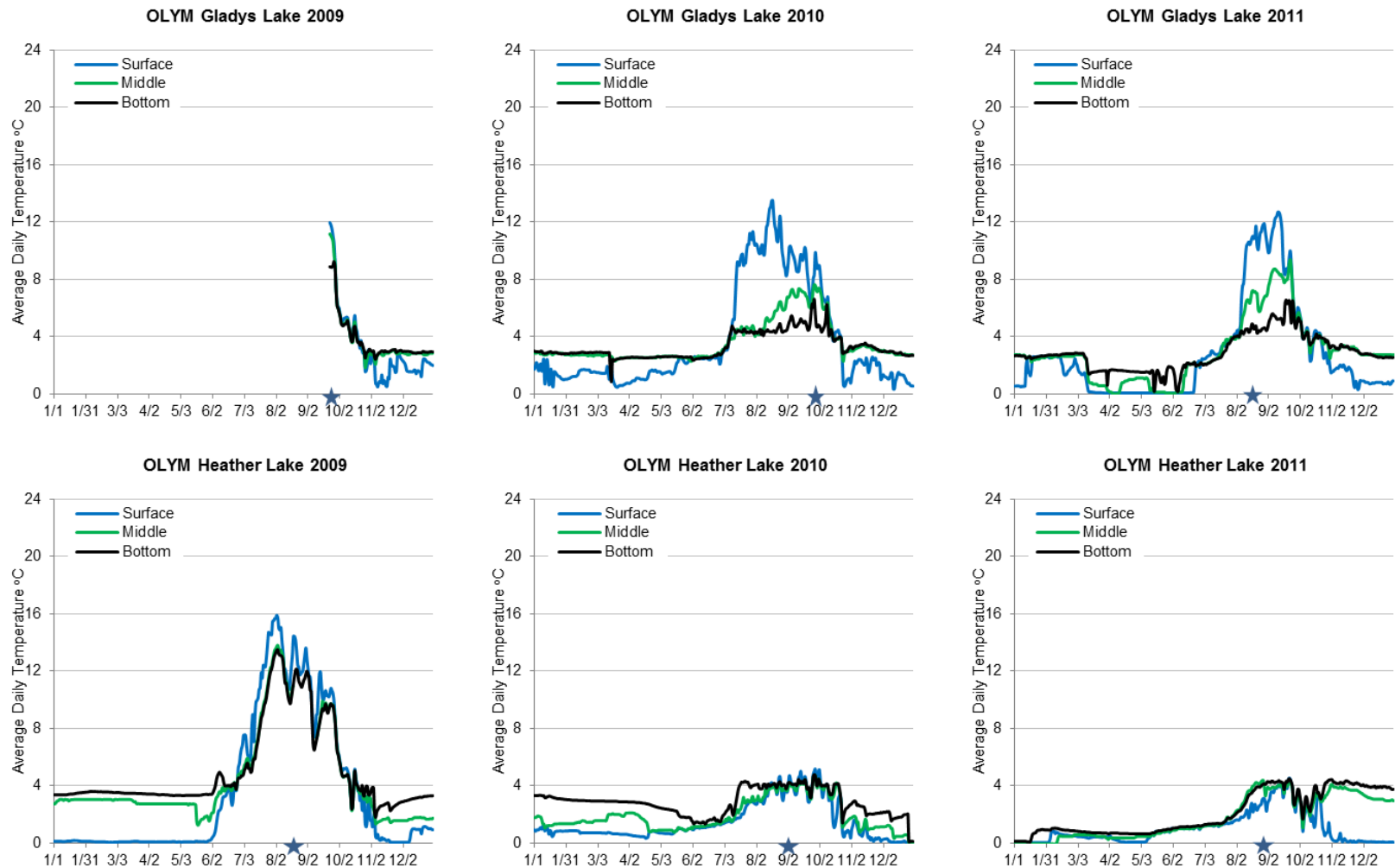


Figure 25. Daily average water temperature (°C) annual plots for Gladys and Heather lakes, Olympic National Park (OLYM), 2009-2011 (stars represent annual sampling events).

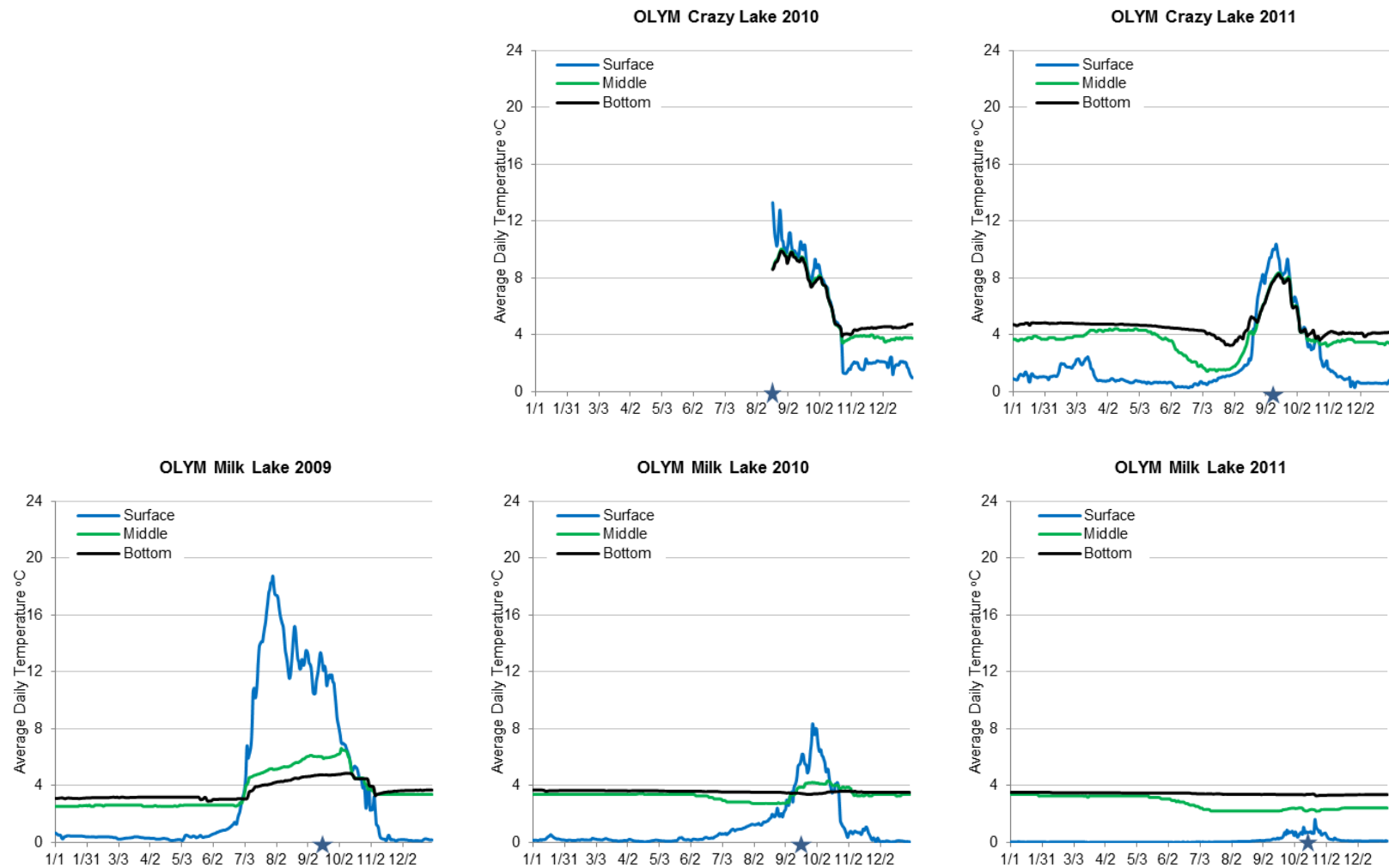


Figure 26. Daily average water temperature (°C) annual plots for Crazy and Milk lakes, Olympic National Park (OLYM), 2009-2011 (stars represent annual sampling events).

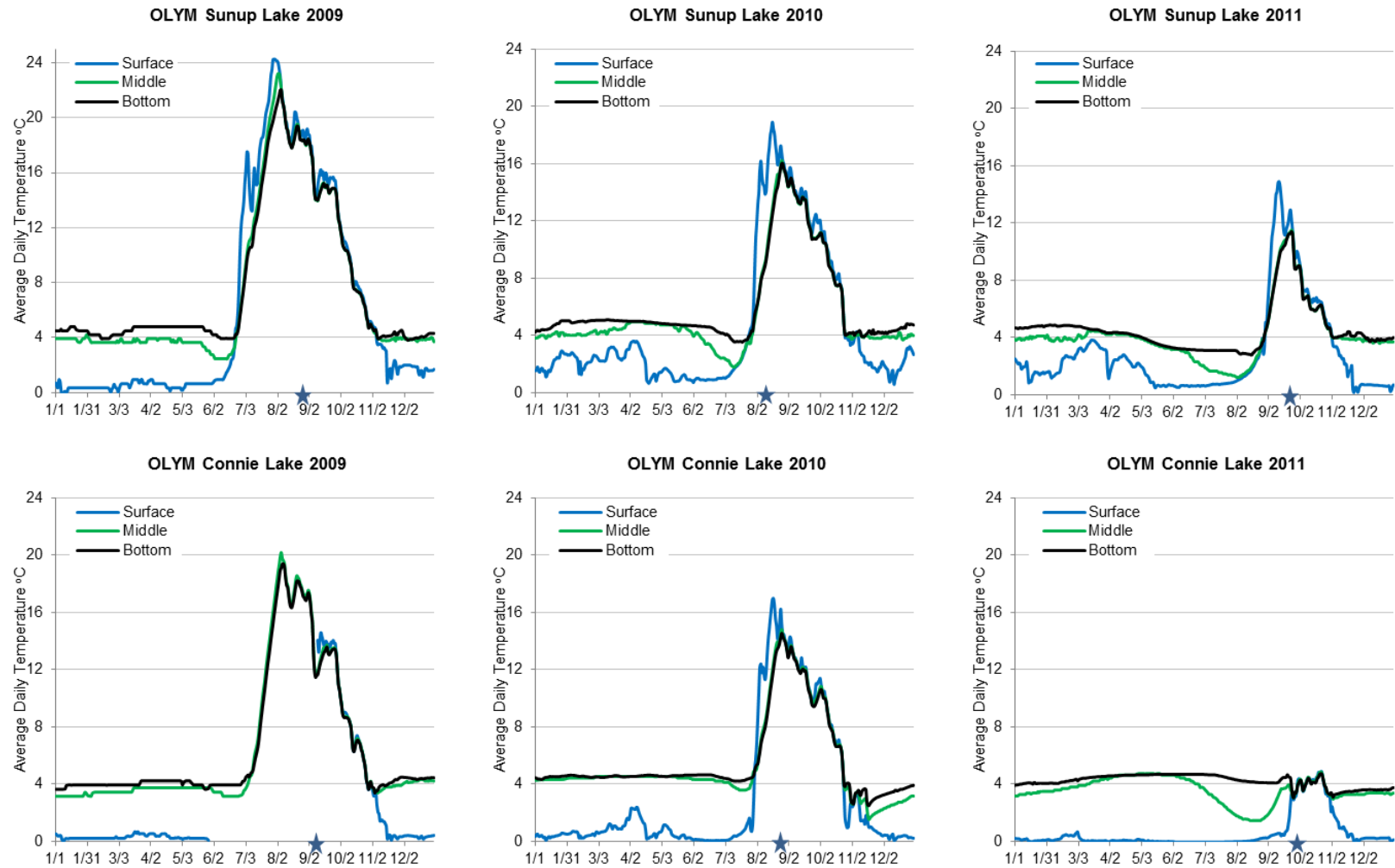


Figure 27. Daily average water temperature (°C) annual plots for Sunup and Connie lakes, Olympic National Park (OLYM), 2009-2011 (stars represent annual sampling event).

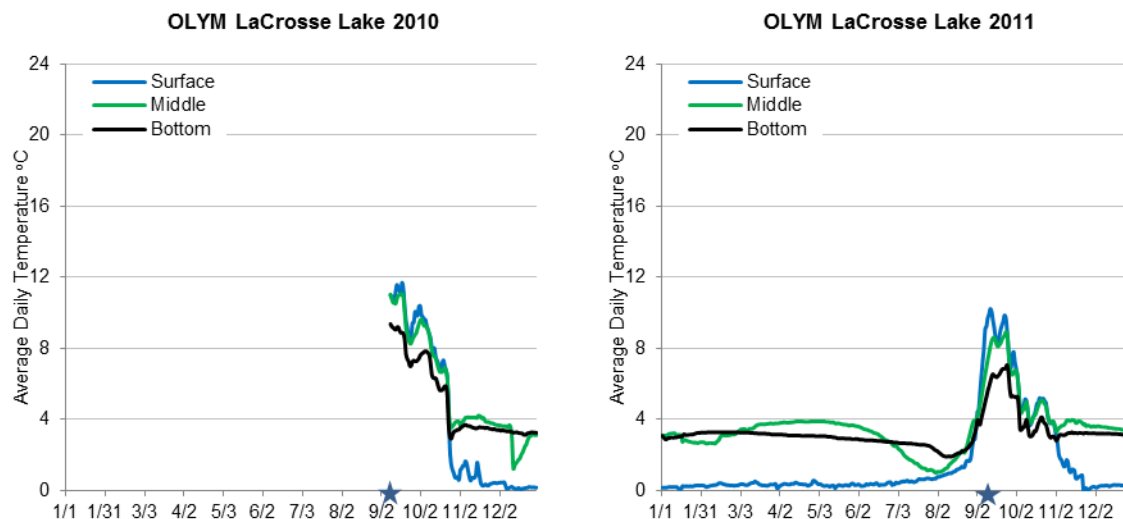


Figure 28. Daily average water temperature (°C) annual plots for LaCrosse Lake, Olympic National Park (OLYM), 2009-2011 (stars represent annual sampling event).

Summer and Fall Turnover

The above average snowpack and colder than average air temperatures in the late spring of 2010 and 2011 delayed ice-out and, consequently shortened the ice-free season. The ice-free season can be approximated by differences in time between summer and fall turnover, as observed in the DAT_{water} plots. In the plots (Figures 17-28), turnover events are estimated to occur when the temperature throughout the water column becomes uniform at a point near 4°C (temperature of maximum density of water). An example of plot location of turnover points is shown in Figure 12 of the Methods section.

The ranges in summer and fall turnover dates for lakes at each of the NCCN parks, during 2009-2011, are summarized in Table 7 and shown in Figure 29. Detailed tabular data of turnover dates and days between summer and fall turnover are presented in (Appendix D, Table D1).

Summer turnover dates were obviously later between 2009 and 2011 for lakes at NOCA and OLYM (Table 7 and Figure 29). Lakes at MORA were not similarly affected, having only a slight delay in dates of summer turnover during the reporting period. The mid-range of summer turnover dates between 2009 and 2011 for MORA lakes changed by 20 days, from 7/1/09 to 7/21/11 (Table 7). The greatest increase in summer turnover dates during the reporting period occurred at OLYM lakes. The mid-range of summer turnover dates for OLYM lakes between 2009 and 2011 changed by 60 days, from 7/1/09 to 8/30/11. The large differences in summer turnover dates during 2010 and 2011 are attributed to persistent and well above normal snowpack as evidenced by June 1st SNOTEL data at each of the parks (Figure 9). June 1st snowpack levels were particularly extreme at OLYM; 170% above average in 2010 and 390% above average in 2011. During these two years, abnormal temperature patterns were observed at three OLYM lakes. Heather and Connie lakes (Figures 25 and 27) fluctuated in and out of inverse stratification throughout the summer and fall in 2010. In 2011,

Heather and Milk lakes (Figures 25 and 26) had extremely low summer water temperatures and remained inversely stratified, despite the lack of permanent ice cover, throughout the entire year.

Table 7. Summary of lake turnover dates and date ranges for Mount Rainer (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks during 2009-2011.

Park/Year	Summer Turnover				Fall Turnover			
	n	Date Range	Day Range	Mid-Range Date	n	Date Range	Day Range	Mid-Range Date
MORA								
2009	2	6/28-7/4	6	7/1	5	10/23-11/5	13	10/30
2010	5	6/24-7/16	22	7/5	4	10/24-11/8	15	11/1
2011	4	7/9-8/1	23	7/21	5	10/26-11/10	15	11/3
NOCA								
2009	1	7/8	-	-	6	10/12-10/30	18	10/21
2010	6	7/8-8/5	28	7/22	6	10/23-10/30	7	10/27
2011	6	7/19-9/4	47	8/12	6	10/10-11/5	26	10/23
OLYM								
2009	5	6/23-7/9	16	7/1	6	10/19-11/4	16	10/27
2010	6	7/10-9/11	62	8/10	8	10/8-11/6	28	10/22
2011	7	7/30-9/29	61	8/30	6	10/10-11/2	23	10/22

The average number of days between summer and fall turnover dates (open water season days-OWS_{days}) for lakes at MORA was 124 days (n=4, range=108-137, Figure 30) in 2010 and 107 days (n=4, range=94-121) in 2011. The average decline in the number of OWS_{days} at MORA lakes (17 days) during 2010-2011 was not as severe as for NOCA (26 days) and OLYM lakes (36 days, Figure 30). However, there was a difference in the number of OWS_{days} between lakes located at both ends of the west (wet) to east (dry) precipitation gradient within MORA. The number of OWS_{days} declined by 22.9% between 2010 and 2011 at Allen lake (west side of MORA) vs. declines at two east side lakes of 8.3% (Upper Deadwood) and 10.9% (LH15) for the same period.

The average number of OWS_{days} for lakes at NOCA was 95 days (n=6, range=79-114) in 2010 and 69 days (n=6, range=36-102) in 2011. Similar to MORA, the location of the lakes along a west to east precipitation gradient appears to be an important variable affecting snow accumulation and consequently summer turnover and the length of the open water season at NOCA lakes. In Figure 30, NOCA lake locations are ordered, from left to right, along the southeast to northwest axis which separates the warmer and drier climatic conditions found east of the orographic divide from the cooler and wetter conditions on the west side of the divide. The number of OWS_{days} at two east side lakes, Bowan and Upper Triplet, varied little between 2010 and 2011 (Figure 30), declining by 4 and 11%, respectively. Change in the number of OWS_{days} was more dramatic at Lower Silent Lake, which is also on the east side but near the divide (32% decline between 2010 and 2011). The remaining lakes located in the northwest portion of the park exhibited the greatest declines in the number of OWS_{days} ranging from 36% (Lower Blum) to 54% (Easy Ridge) between 2010 and 2011.

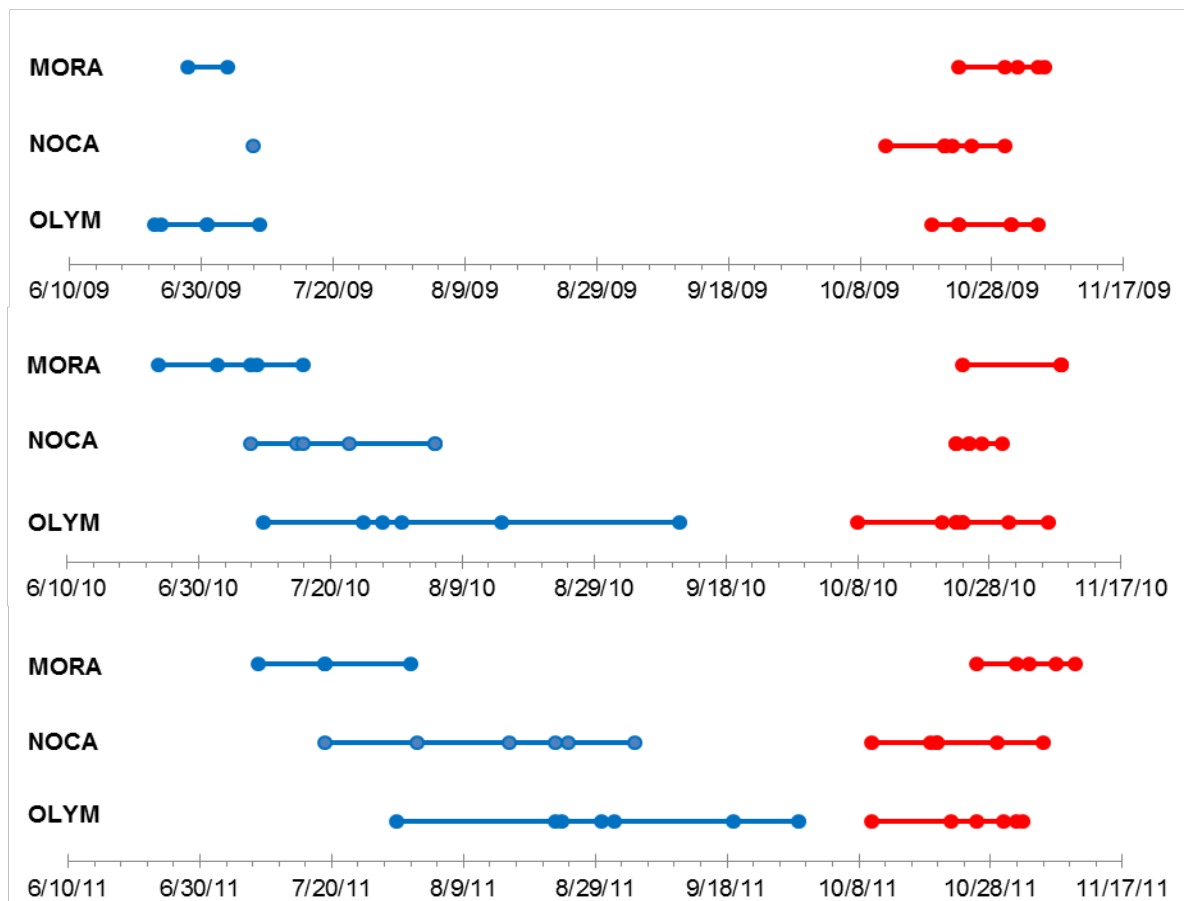


Figure 29. Differences in summer (blue) and fall (red) turnover dates and length of the ice-free season among North Coast and Cascades Network lakes at Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks during 2009 through 2011. Sample size for summer turnover dates during 2009 were lower than following years because the initial deployment of loggers at many of the sites did not occur until later that summer. Missing data for other lakes during 2010 and 2011 are primarily attributed to vandalism and logger failure.

The average number of OWS_{days} for lakes at OLYM declined by a total of 76 days between 2009 and 2011. The average number of OWS_{days} for lakes at OLYM was 120 days ($n=5$, range=105-134, Figure 30) in 2009, 80 days ($n=6$, range=42-105) in 2010, and 44 days ($n=8$, range=approx. 0-84) in 2011. Major differences in the number of OWS_{days} during 2010 and 2011 among lakes at OLYM appear to be related to differences in the amount of snow in the lake catchments and the effects aspect/topographic shading on snowmelt and runoff. Heather and Milk lakes, located in north facing (Table 1) cirque basins, experienced an extreme delay in summer turnover (Appendix D, Table D1) during 2010 resulting in a much shortened open water season at both lakes ($OWS_{days}=54$ and 42, respectively, Figure 30). The situation was more profound in 2011 when both lakes remained amictic (inversely stratified) throughout the year (Figure 30). Crazy and Connie lakes at OLYM also had very short seasons between turnover dates in 2011 (48 and 27 days, respectively; Figure 30). These two lakes are located in northeast facing cirque basins.

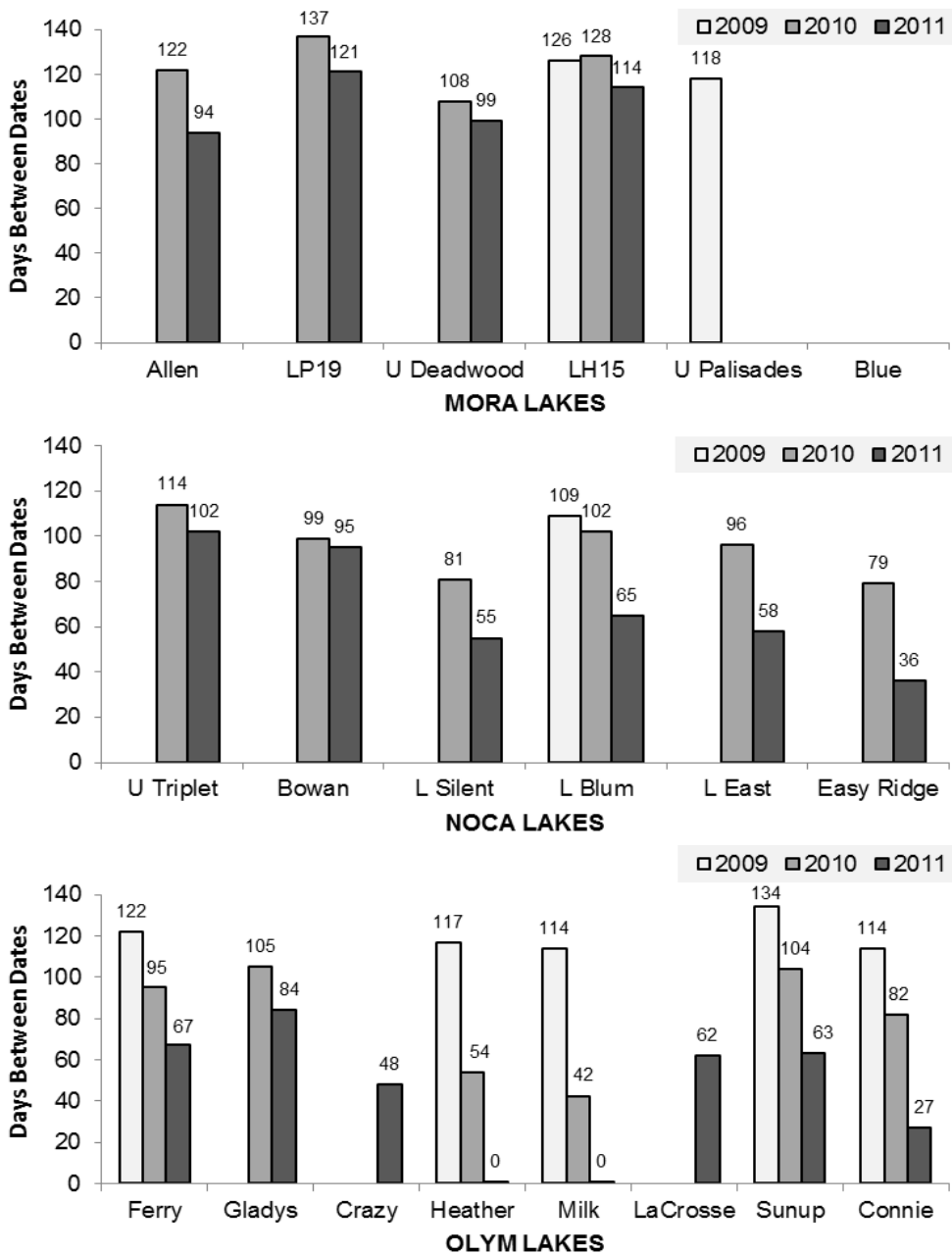


Figure 30. The number of days between summer and fall turnover (open water season days- OWS_{day}) at Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Park lakes, 2009-2011. (Note: days between turnover dates during 2011, at Heather and Milk Lakes, OLYM, were recorded as zero. Both lakes remained inversely stratified throughout the year).

Annual Lake Surface Water Temperature

Annual Average Surface Water Temperature

Annual average of daily average lake surface water temperature ($ADAT_{surf_yr}$) values (Table 8) ranged from a low of 0.13°C at Milk Lake (OLYM, 2011) to 6.12°C at Sunup Lake (OLYM, 2009). $ADAT_{surf_yr}$ values declined at all lakes during the 2009-2011 reporting period (Table 8). Percent

change in ADAT_{surf_yr} values between 2009 and 2010 ranged from -9.8% (Lower Blum, NOCA) to -71.8% at Milk Lake (OLYM). Larger declines in ADAT_{surf_yr} values were observed between 2010 and 2011 at five of the seven lakes having all three years of data. Percent change in 2011 ranged from -10.4% (Upper Triplet, NOCA) to -88.3% at Milk Lake (OLYM).

While year to year variation at any given lake is related to changes in ENSO and PDO phases, variation among NCCN lakes in surface water ADAT values in any given year is likely more related to one or more local factors affecting snow accumulation and lake thawing: geographic location, position relative to storm tracks, presence of perennial snowfields, and the combined effect of aspect and topographic shading.

Table 8. Annual average lake surface water temperature (ADAT_{surf_yr}) at North Coast and Cascade Network lakes during 2009-2011.¹ Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Lake	Park	Elevation (m)	Annual Surface Water Temperature			% Change	
			2009 (°C)	2010 (°C)	2011 (°C)	2009-2010	2010-2011
Blue	MORA	1352	ND	ND	ND	ND	ND
LP19	MORA	1372	ND	5.75	5.16	ND	-10.3
Allen	MORA	1397	ND	5.22	3.97	ND	-23.9
U Deadwood	MORA	1600	ND	4.53	4.00	ND	-11.7
LH15	MORA	1659	5.78	5.06	3.75	-12.5	-25.9
U Palisades	MORA	1785	4.09	ND	ND	ND	ND
L Blum	NOCA	1511	4.20	3.79	2.59	-9.8	-31.7
L East	NOCA	1664	ND	2.97	1.77	ND	-40.4
E Ridge	NOCA	1680	ND	2.14	1.06	ND	-50.5
Bowan	NOCA	1982	ND	3.42	2.78	ND	-18.7
U Triplet	NOCA	1998	5.19	3.74	3.35	-27.9	-10.4
L Silent	NOCA	2046	ND	2.21	1.68	ND	-24.0
Sunup	OLYM	1224	6.12	4.64	2.87	-24.2	-38.1
Connie	OLYM	1300	ND	3.21	0.57	ND	-82.2
Gladys	OLYM	1383	ND	3.70	2.75	ND	-25.7
Ferry	OLYM	1434	4.87	3.41	2.08	-30.0	-39.0
Milk	OLYM	1435	3.93	1.11	0.13	-71.8	-88.3
LaCrosse	OLYM	1447	ND	ND	1.49	ND	ND
Crazy	OLYM	1457	ND	ND	1.97	ND	ND
Heather	OLYM	1589	3.54	1.47	0.99	-58.5	-32.7

¹ ND-insufficient data to calculate annual means. Annual means at most of the North Coast and Cascades Network lakes could not be calculated during 2009 because loggers were not initially deployed until September (also the same for LaCrosse and Crazy lakes, OLYM, in 2010). Missing data for other lakes during 2010 and 2011 are attributed to primarily vandalism and logger failure.

Annual Maximum Surface Water Temperature: 7-Day Moving Average

The midpoint of the highest 7-day moving average of daily maximum surface water temperatures (7-DADMax) for all NCCN lakes and years, with occurrence dates, are reported in Table 9. 7-DADMax temperatures for all water temperature loggers (surface, mid-depth, and bottom) at each lake and in each year are shown in Appendix E, Table E1.

7-DADMax values can be useful for assessing the potential for thermal stress on biological communities. Specific thresholds have not been established for most of the native biota in NCCN

lakes; however, the long-term monitoring program presents the opportunity to provide data on how native biota respond (*i.e.*, presence/absence, abundance, reproduction) to prolonged elevated water temperatures. The Washington 7-DADMax standards for lakes allow for no more than a 0.3°C change above natural conditions (WADOE 2006). General 7-DADMax recommendations for salmonids are usually less the 20°C. NCCN lakes showing prolonged elevated water temperatures include Sunup and Ferry lakes at OLYM, and LP19 at MORA, where 7-DADMax temperatures exceeded 20°C in one or more years. The highest surface water 7-DADMax temperature among all of the NCCN lakes and years sampled was 26.1°C, at Sunup Lake (OLYM) during the end of July, 2009. Mid-depth and bottom 7-DADMax temperatures at Sunup Lake also exceeded 20°C during late July and early August of 2009 (Appendix E, Table E1).

Table 9. Highest 7-day moving average of daily maximum (7-DADMax) surface water temperatures (°C) during the year with occurrence dates (mid-point of 7-day interval) for Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Park lakes, 2009-2011.

Park Lake	7-DADMax			Occurrence Date		
	2009	2010	2011	2009	2010	2011
MORA						
Allen		18.4	16.2		7/28	9/10
LP19	22.3	21.3	17.8	8/2	7/27	8/27
Blue						
Upper Deadwood		18.9	18.2		8/18	8/27
LH15	19.6	18.6	16.9	8/3	8/18	9/11
Upper Palisades	17.3	*	*	8/3	*	*
NOCA						
Upper Triplet	18.4	15.1	14.8	8/4	8/18	9/11
Bowan		19.8	16.1		8/17	9/11
Lower Silent		12.7	11.7		8/17	9/11
Lower Blum	15.3	12.4	10.2	9/1	8/18	9/11
Lower East		11.8	8.9		8/18	9/11
Easy Ridge		14.9	9.6		8/16	9/12
OLYM						
Ferry	22.8	17.7	14.2	7/30	8/17	9/10
Gladys		15.1	13.9		8/15	9/10
Heather	18.3	5.7	5.1	8/2	9/29	9/11
Crazy			11.4			9/9
Milk	19.3	8.8	1.7	7/29	9/30	10/24
LaCrosse			11.4			9/11
Sunup	26.1	20.1	15.6	7/30	8/16	9/11
Connie		17.7	5.1		8/17	10/20

*Complete annual data unavailable for calculations subsequent to initial deployment year.

Monthly Average Lake Surface Water Temperature

The following provides an overview of monthly average surface water temperature data for the NCCN lakes sampled during 2009-2011. Monthly ADAT, ADMINT, and ADMT tabular data for all NCCN lakes and logger depth locations (surface, mid-depth and bottom), collected during the period of 2008-2011, are reported in Appendix E (Tables E2-E21).

Monthly averages of daily average surface water temperatures ($ADAT_{surf_mo}$) for all lakes combined at each park, 2009-2011, are shown in Figure 31. Detailed plots of $ADAT_{surf_mo}$ by individual lakes in

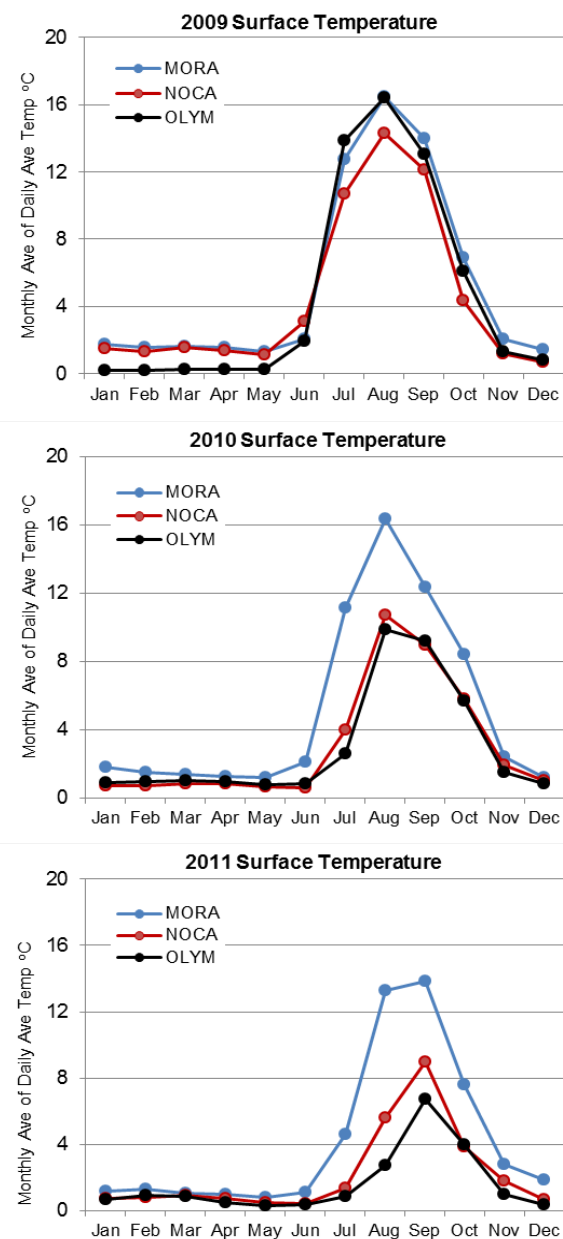


Figure 31. Monthly average of daily average surface water temperatures oC for all lakes combined at each North Coast and Cascades Network park, 2009-2011.

each park for 2009-2011 are presented in Appendix E, Figure E1. $ADAT_{surf_mo}$ values by park varied little (ranging from >0 to 3°C) during the periods of January-June and November-December, 2009-2011 (Figure 31). Peak $ADAT_{surf_mo}$ (combined lake park averages) occurred at all three parks during August of 2009 and 2010, and during September in 2011. A consistent decline in $ADAT_{surf_mo}$ values during the months of July through October 2009-2011 was observed for NOCA and OLYM lakes, and only in July for MORA lakes (Figure 31). The moderate year-to-year changes at MORA lakes appears to be related to less snow accumulation during the late spring, rather than warmer air temperatures (Figure 18) and rapid melting during this period. June 1st snow water equivalent data for MORA was lower than that at NOCA and OLYM during 2010 and 2011 (Figure 9). MORA is farther from the coast and less likely influenced by marine weather patterns than NOCA and OLYM, and MORA lakes generally receive less annual precipitation (Table 1).

The range in $ADAT_{surf_mo}$ values and difference in the range among lakes at each park having the highest and lowest values for the peak open-water months of August and September (2009-2011) are shown in Table 10. The difference in the range of $ADAT_{surf_mo}$ values for August and September generally increased at each park between 2009 and 2011. The difference in the range of $ADAT_{surf_mo}$ values for both August and September also increased between parks in each of the sampled years, with MORA exhibiting the lowest variation and OLYM generally exhibiting the greatest variation, (Table 10).

The highest $ADAT_{surf_mo}$ value recorded at the three parks during 2009-2011 was 20.2°C at Sunup Lake (OLYM) in August, 2009. The lowest $ADAT_{surf_mo}$ was 0.1°C , occurring at Milk and Connie lakes (OLYM) during August, 2011. Colder winter air temperatures (January - April, Figure 15),

greater snow accumulation, and delayed ice-out in 2010 and 2011 were obvious factors influencing the variation in $ADAT_{surf_mo}$ temperature among lakes during the reporting period.

Table 10. The range in $ADAT_{surf_mo}$ values and difference in the range between lakes at each park having the highest and lowest values for the peak open-water months of August and September, 2009-2011. Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Month: Park:	MORA	August NOCA	OLYM	MORA	September NOCA	OLYM
2009						
N	3	2	4	5	6	4
Range °C	15.1-17.2	12.9-15.7	13.2-20.2	13.3-14.5	10.6-13.2	10.0-15.7
Diff. °C	2.1	2.8	7.0	1.2	2.6	5.7
Min-Lake	U Palisades	L Blum	Heather	U Palisades	L East	Heather
Max-Lake	LP19	U Triplet	Sunup	LH15	Bowan	Sunup
2010						
N	4	6	6	4	6	7
Range °C	15.9-17.3	8.0-15.1	1.6-15.8	11.7-12.8	8.0-10.2	4.1-13.4
Diff. °C	1.4	7.1	14.2	0.8	2.2	9.3
Min-Lake	Allen	L Silent	Milk	U Deadwood	Easy Ridge	Heather
Max-Lake	LP19	Bowan	Sunup	LP19	Bowan	Sunup
2011						
N	4	6	8	4	6	8
Range °C	11.0-15.4	1.0-11.7	0.1-9.2	13.2-14.5	6.3-12.2	0.4-11.6
Diff. °C	4.4	10.7	9.1	1.3	5.9	11.2
Min-Lake	Allen	Easy Ridge	Milk/Connie	Allen	Easy Ridge	Milk
Max-Lake	LP19	U Triplet	Gladys	LP19	Bowan	Sunup

Degree-Day Accumulation

The following provides basic information on degree-day accumulation at the NCCN monitoring lakes and some potential data applications that may be useful for assessment of trends and/or used as explanatory attributes in the assessment of other monitoring parameters.

Heating Degree-Days (HDD)

Heat accumulation throughout the year is represented by Heating Degree-Days (HDD), calculated as the sum of daily average temperatures that are greater than a base temperature of 0°C. HDD values derived from water temperature data represent an exact alternative expression of annual average water temperature (Figure 32, $R^2 = 1$) because of similarities in their calculation; annual average temperature represents the average of daily average temperatures (which are always >0°C), and HDD represents the sum of daily average temperatures >0°C. Annual average surface water temperatures can be directly derived from surface water HDD data using the regression equation in Figure 32.

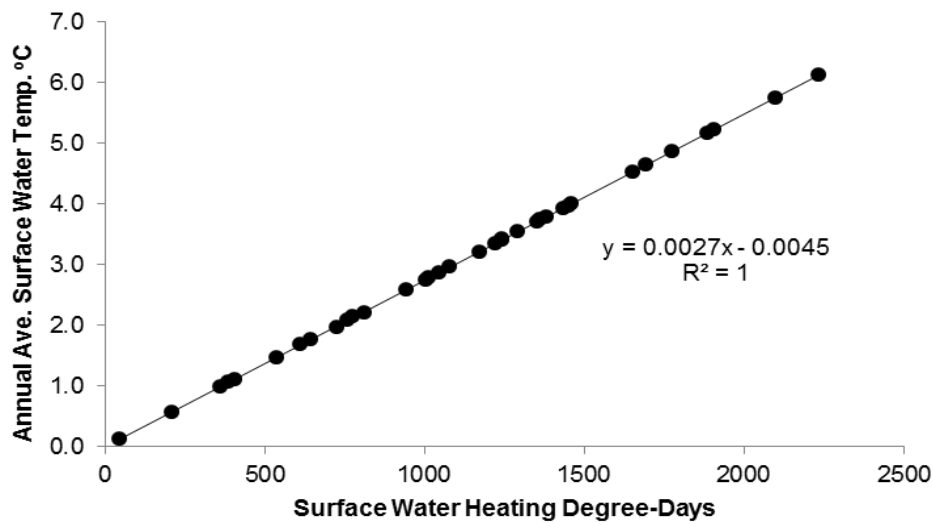


Figure 32. Relationship between annual average surface water temperature and surface water heating degree-days at North Coast and Cascades Network monitoring lakes, 2009-2011. Note that heating degree-days (HDD >0°C) represent an exact alternative expression of annual average surface water temperature because of the similar basis for their calculation.

The relationship between annual average surface water temperature and air temperature HDD for all NCCN lakes (combined 2009-2011 data) is shown in Figure 33a and for four lakes at OLYM having all three years of data in Figure 33b. The regression for the combined 2009-2011 data for all lakes explained only about 35% of the variation between air temperature HDD and average annual surface water temperature. Separate regressions at four OLYM lakes (only lakes with data for each of the three years, 2009-2011) were conducted in order to remove the influence of park and local scale variation. Results from these regressions accounted for >96.5% of the variation (Figure 33b) between annual average surface water temperature and air temperature HDD. These preliminary results indicate that air temperature HDD may have potential use for reconstructing average surface water temperature at individual lakes, if calibrated to nearby SNOTEL or other weather station sites having long-term daily average water temperature datasets (e.g., Thompson et al. 2005).

Annual air and surface water heat accumulation (HDD) values for the NCCN monitoring lakes by park and sampling year are presented in Figure 34. Tabular HDD data for all NCCN lakes by logger location (air, surface, mid-depth and bottom) and year are shown in Appendix F, Tables F1-F3. HDD values consistently declined at all lakes between 2009 and 2011, corresponding to ENSO index patterns (Figure 8) and following the same annual pattern as observed for average air and water temperature data. Air temperature HDD values for 2009 were only available for five of the eight lakes at OLYM and ranged from 1839 to 2371 degree-days (Figure 34e and Appendix Table F3). During 2010 and 2011, air temperature HDD values were lowest at NOCA lakes, ranging between 670 and 1353 degree-days, and highest at OLYM lakes, ranging between 1235-2020 degree-days (Figure 34a, c, e and Appendix Tables F1-F3).

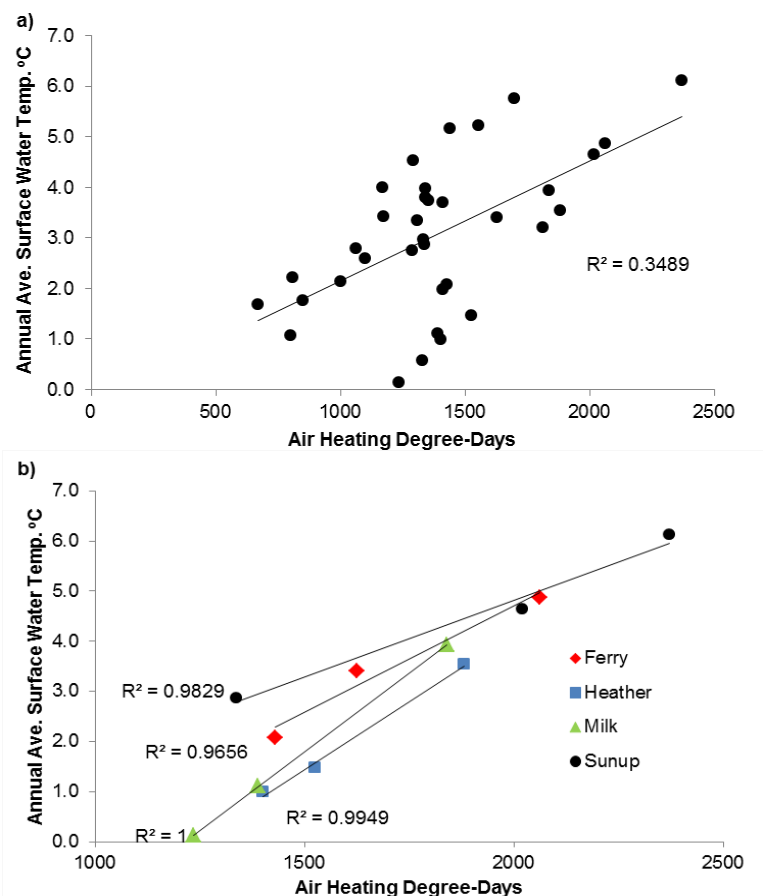


Figure 33. Relationships between annual average surface water temperature and air temperature heating degree-days at North Coast and Cascades Network (NCCN) monitoring lakes using a) a single linear regression for all NCCN lakes with 2009-2011 data and b) separate linear regressions of 2009-2011 data at four Olympic National Park lakes.

Surface water HDD values were the highest at Lake LP19 (MORA) and the lowest at Heather and Milk lakes (OLYM) during the 2009-2011 sampling period (Figure 34). Surface water HDD values were available for nine of the 20 NCCN lakes in 2009 and ranged from 1291 degree-days at Heather Lake to 2294 degree-days at Lake LP19 (Appendix F, Tables F1-F3). Surface water HDD data were available for most of the NCCN lakes in 2010 and 2011. In 2010, surface HDD values ranged from 407 (Milk Lake) to 2098 HDDs (Lake LP19), and from 46 (Milk Lake) to 1885 HDDs (Lake LP19) during 2011 (Appendix F, Tables F1-F3).

Application of HDD water temperature data, for interpretation of temperature trends and use as an explanatory variable in other analyses relevant to the open water season, may be more useful than data reported as an average temperature that is based on a

subjective selection of ice-off and ice-on dates that define the reporting period. Other base temperatures (i.e., >5 , $>10^{\circ}\text{C}$) can be substituted to limit degree-day calculations to those that are relevant to biological productivity, particularly useful for examining aquatic species' growth, development and abundance and are often referred to as "growing degree-days" (GDD).



Figure 34. Annual air and lake surface water heating degree-days (sum of daily average temperatures $>0^{\circ}\text{C}$) for North Coast and Cascades Network lakes, 2009-2011. Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Freezing Degree-Days (FDD)

FDD values for the 2009-2010 and 2010-2011 winters for all NCCN monitoring lakes are shown in Table 11. A significant increase in FDD during the 2010-2011 winter was observed at all lakes having data, with percent change in FDD ranging between 25.8% at Upper Triplet Lake (NOCA) to 79.9% at Allen Lake (MORA). The most severe winter temperatures at each park occurred at east-side lake locations including; Upper Triplet and Bowan lakes (NOCA, FDD = 864 to 1087 degree-days $<0^{\circ}\text{C}$), Upper Deadwood Lake (MORA, FDD = 561 to 745 degree-days $<0^{\circ}\text{C}$), and at Gladys and Heather lakes (OLYM, FDD = 344 to 654 degree-days $<0^{\circ}\text{C}$).

Table 11. Winter severity represented by freezing degree-days (FDD) during the 2009-2010 and 2010-2011 winters at North Coast and Cascades Network lakes. Freezing degree-days (FDD) were calculated as the sum of daily average air temperatures $<0^{\circ}\text{C}$ for the period starting when air temperatures drop below 0°C , in the fall of year₁, to the spring/summer of year₂, when temperatures are consistently $>0^{\circ}\text{C}$. Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Park/Lake	FDD (DAT _{air} <0°C)		Change (%)
	2009-2010	2010-2011	
MORA			
Allen	264	475	79.9
LP19	232	404	74.1
U Deadwood	561	745	32.8
Blue	344	527	53.2
LH15	-	-	-
U Palisades	-	-	-
NOCA			
U Triplet	864	1087	25.8
Bowan	1035	-	-
L Silent	-	-	-
L Blum	405	680	67.9
L East	498	-	-
Easy Ridge	-	-	-
OLYM			
Ferry	298	498	67.1
Gladys	418	654	56.5
Heather	344	577	67.7
Crazy	-	510	-
Milk	311	475	52.7
LaCrosse	-	-	-
Sunup	159	-	-
Connie	203	-	-

FDD has also been used for determining ice-on dates. Thompson et al. (2005) provides a clear explanation on the use of freezing degree-days for hindcasting ice-on dates for earlier years for which meteorological data is available. Thompson et al. (2005) and others (Bilello 1964, Williams 1971, Palecki and Barry 1986, Ruosteenoja 1986, and Stewart and Haugen 1990) reported that an accumulation of around 20 FDD provided a good relationship between air temperature and the date of freeze over. The example application of use of FDD for estimating ice-on dates for six NCCN monitoring lakes is shown in Appendix G, Figures G1-G6. Accumulated FDD for the estimated dates

of ice formation at the example NCCN lakes in Appendix G ranged from 13-28 FDD. The median value of accumulated FDDs at the time of ice formation was 21 and was similar to FDD values reported by Thompson et al. (2005) and others (Bilello 1964, Williams 1971, Palecki and Barry 1986, Ruosteenoja 1986, and Stewart and Haugen 1990).

Index of Thermal Stress (ITS)

ITS values for five NCCN monitoring lakes sampled in 2009 were calculated following methods in DeGasperi (2007) and are shown in Table 12. The five lakes in Table 12 were the only lakes (of the ten lakes with data) that exceeded the 20°C threshold during the 2009-2011 sampling period, all

Table 12. Index of Thermal Stress (ITS = sum of degree-days in exceedance of 20°C) values for North Coast and Cascades Network monitoring lakes sampled in 2009. Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Park	Lake	Logger location	Occurrence date range >20°C	No. of days >20°C	ITS (sum of degree-days >20°C)	Ave. degree-days/day >20°C
MORA	U. Deadwood	Surface	No Data	-	-	-
		Mid-depth	7/27-8/7	12	13.0	1.08
		Bottom	No Data	-	-	-
MORA	LP19	Surface	7/28-8/5	9	10.1	1.12
		Mid-depth	No Data	-	-	-
		Bottom	-	0	0.0	0.00
OLYM	Ferry	Surface	7/27-8/6	11	9.1	0.83
		Mid-depth	-	0	0.0	0.00
		Bottom	-	0	0.0	0.00
OLYM	Connie	Surface	No Data	-	-	-
		Mid-depth	8/6	1	0.2	0.20
		Bottom	-	0	0.0	0.00
OLYM	Sunup	Surface	7/22-8/9, 8/19-20	21	49.0	2.33
		Mid-depth	7/27-8/9	14	25.1	1.79
		Bottom	7/30-8/9	11	11.8	1.07

occurring during 2009. Water temperatures exceeding 20°C occurred in late July and early August at all of the lakes in Table 12. Sunup Lake (OLYM) experienced another exceedance during August 19-20. Water temperatures at Sunup Lake exceeded 20°C throughout the water column during July 30th to August 9th, ranging from 11 days at the bottom logger location to 21 days at the surface logger (Table 12). Surface ITS values for all five lakes in Table 12 ranged from 9.1 degree-days_{>20°C} at Ferry Lake (OLYM) to 49.0 degree-days_{>20°C} at Sunup Lake. ITS surface data were not available for Upper Deadwood (MORA) and Connie (OLYM) lakes; however, exceedances of the 20°C threshold at the mid-depth loggers (Table 12) would indicate that the ITS values at the surface would have been significantly greater.

Results indicate that the cold stenothermal taxa at Sunup Lake may be particularly vulnerable to thermal stress if climate warming occurs. The mid-depth ITS value of 13 observed at Upper Deadwood Lake suggests the possibility that native biota in this lake may also be at risk from future climate warming. The 20°C ITS threshold value (DeGasperi 2007) may be appropriate for assessing

thermal risks for salmon, however may not be suitable for other coldwater lake taxa. For example, 23 taxa of aquatic macroinvertebrates sampled in NOCA lakes during 2011 and 2012 were classified as “cold stenothermal” taxa (generally prefer temperatures $\leq 15^{\circ}\text{C}$) using the thermal preference metric (modified from Poff et al. 2006).

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Appendix A. Statistical Routines

Attachment A1. Program documentation for temp.r, site.r, and region.r R-statistical program routines.

Introduction

There are three programs, developed by Trent McDonald and Michelle Bourassa Stahl (WEST Inc., Laramie WY), that run the analyses identified in the data analysis protocol (McDonald and Glesne 2012) - temp.r, site.r and region.r. These are technically R functions to allow them to be run from the command line in R after sourcing them [i.e. `source("temp.r")` followed by `temp.r()`] however since they run the analyses, they are referred to in this document as programs.

temp.r is a temperature pre-processing program that summarizes the daily lake temperature data into the statistics identified in the data analysis protocol (e.g. ADMT). The output from temp.r is ready for input into site.r – the program that runs the single site inference, abrupt change and trend analyses.

Data for other response variables can be exported directly from the database for input into site.r. While \$park, \$panel, \$watershed and \$visit variables are not used in site.r they are carried through so that output from site.r can be formatted for use in report tables without re-linking the site to these additional classification variables.

Output from site.r will need to be processed prior to input to region.r – the program that runs the regional inference, abrupt change and trend analyses. It is necessary to add the \$region variable to the output from site.r prior to running region.r. In addition, if you want to run region.r across multiple visits (e.g. January, May and September) in addition to adding the \$region variable you must append the individual output files from site.r for these visits prior to running region.r.

region.r expects a single region per file, multiple regions in the file will result in execution failure. In addition, \$park, \$panel and \$watershed are dropped. If any of these variables are desired in report tables, it will be necessary to re-link these to the output from region.r.

There are several analysis approaches identified by McDonald (2005) that are **currently not programmed** in the site.r and region.r analyses.

single site and regional inference

it is possible to estimate the proportion of lakes in a region with temperature > x and place a confidence interval around the estimate from the histograms, smoothed density estimates and CDF's, however this is not currently an option in region.r.

single site and regional (mixed linear model) abrupt change analyses

serial correlation is not accounted for

long term trend at a site (region) is linear (no curvilinear or polynomial trend is fit)

model assumes a response not affected by auxiliary variables (e.g. temperature and flow)

water temperature data follows the same model as other responses and does not take into account patterns of natural change within seasons

single site and regional trend analyses

long term trend at site (region) is linear (no curvilinear or polynomial trend is fit)

model assumes a response not affected by auxiliary variables (e.g. temperature and flow)

water temperature data follows the same model as other responses and does not take into account patterns of natural change within seasons

Restrictions

There are several restrictions or things to consider when analyzing the lake data.

1. Only a single response can be analyzed at a time in a given datafile.
2. While `site.r` can process multiple `$park`, `$panel`, `$watershed` and `$site` variables, `region.r` can only process a single region at a time. Data for multiple regions needs to be in individual input data files for `region.r`.
3. `site.r` will produce inference results for all sites, however will only give abrupt change and trend results for sites with at least three years of data.
4. `region.r` will produce inference results for all sites, will complete CUSUM abrupt change analysis for each year however will only complete linear model abrupt change analysis for sites with at least three years of data and trend analysis for sites with at least two years of data.

Program and Function Descriptions

Programs

<code>temp.r</code>	runs temperature data preprocessing.
<code>site.r</code>	runs the single site inference, abrupt change and trend analyses for multiple sites per file.
<code>region.r</code>	runs the regional inference, abrupt change and trend analyses for a single region per file.

Functions

<code>f.temp.stats.r</code>	computes nine temperature statistics (e.g. ADMT) from daily summaries and outputs to individual statistics data files to use for input into <code>site.r</code> .
<code>f.ma.r</code>	computes centered moving average across a given span.
<code>f.mmaxmin.r</code>	computes centered moving max or min across a given span.
<code>f.site.means.r</code>	completes single site inference analysis. produces table of means, cv of means, and 95% confidence interval on the mean by each site and year. produces histogram of responses by each site and year. produces cdf of responses by each site and year. produces boxplot of responses for each site by year.
<code>f.site.trend.change.r</code>	completes single site change and trend analyses. produces table of change and trend analysis results. produces abrupt change and trend figures by site.
<code>f.region.means.r</code>	completes regional inference analysis. produces table of means, cv of means and 95% confidence interval on mean by each region and year. produces histogram of responses by each region and year. produces cdf of responses by each region and year. produces boxplot of responses for each region and year.
<code>f.region.repvisit.means.r</code>	produces table of means, cv of means, and 95% ci on mean by each site and year (across visits). produces histogram of responses by each site and year (across visits). produce cdf of responses by each site and year (across visits). produce boxplot of responses for each site by year (across visits).

f.region.change.lm.r	completes regional abrupt change analysis based on mixed linear model. produces table of abrupt change analysis results. produces abrupt change figures by region (across sites) and by site.
f.region.change.cusum.r	completes regional abrupt change analysis based on cusum procedure. produces three tables of abrupt change analysis results based on three different tests. produces cusum figures for each year.
f.region.trend.po.r	completes regional trend analysis based on Piepho and Ogutu (2000) mixed linear model. produces table of trend analysis results. produces trend figures (fixed and random site analyses) by region.

Input File Specifications

Programs

temp.r	.csv file with one line per temperature reading with \$spark, \$panel, \$watershed, \$site, \$year, \$season, \$date, \$response and \$label where \$response is temperature data value and \$label is "Temperature".
site.r	.csv file with one or more lines per response reading with \$spark, \$panel, \$watershed, \$site, \$year, \$visit, \$response and \$label where \$response is data value, \$label is response label (e.g. Thalweg Depth) and \$visit is visit (e.g. January) as it will appear in figures and tables.

Single response only per file. Single visit only per file. Multiple parks, panels, watersheds and sites per file.

region.r	.csv file with one line per response reading with \$region, \$site, \$year, \$visit, \$response and \$label where \$response is data value, \$label is response label (e.g. Thalweg Depth) and \$visit is visit (e.g. January) as it will appear in figures and tables.
----------	---

If the response is replicated, there will also be \$se and \$n in the file to indicate the number and se of the mean of the replicates. The latter is used to produce error bars in the appropriate figures.

Single response only per file. Single region only per file. Multiple visits are allowed per file (e.g. January, May and September).

Functions

No input specifications are necessary for the functions as the functions are called from the programs and input is programmed into the program files. Information on input to the functions is in the form of comments at the beginning of the given function.

Output File Naming Conventions

Output files can be either tables (.csv) or figures (.fmt) where .fmt is either .jpg (jpeg) .bmp (bitmap) or .wmf (enhanced windows metafiles). Figure output format is selected by the user during program execution. Table format is fixed as comma delimited. Italics in file names indicate replacement by variable (e.g. 'Thalweg Depth' for *response* or 'WPXX90-01' for *site* or 'ADMT' for *statistic* or 'January' for *visit*). All output files are automatically named within the program or function that produces them. temp.r also produces output data files (.csv) for input into site.r.

Output File Locations

In order to make the programs as efficient as possible to run with minimal input from the user, the output file locations have been forced to an output directory that is created from the working directory. The working directory is the directory where the analyses programs live and from which they are run. Each program gets the working directory (wd) during execution and if the output directories have not been created by a previous run creates the necessary output directories.

temp.r	wd/output/temperature/figures
	wd/output/temperature/tables
	wd/output/temperature/data
site.r	wd/output/site/figures
	wd/output/site/tables
region.r	wd/output/region/figures
	wd/output/region/tables

Output File Names and Number () – For Given Run - and Where Produced

Programs

temp.r	no output.
site.r	/tables/response_site_year_response_visit.csv (for unreplicated response only) (1)
region.r	no output.

Functions

temp.stats.r	/data/temperature_statistic.csv (4)
	/data/temperature_statistic_season.csv (4*number of seasons)
	/data/temperature_statistic_month.csv (9*number of months)
	/tables/temperature_stats_year_dates.csv (1)
	/tables/temperature_stats_season_dates.csv (1)
	/tables/temperature_stats_month_dates.csv (1)
ma.r	no output.
mmaxmin.r	no output.
site.means.r	/tables/response_site_year_means_visit.csv (1)
	/figures/response_hist_site_year_visit.fmt (number of years*number of sites)
	/figures/response_cdf_site_year_visit.fmt (number of years*number of sites)
	/figures/response_box_site_visit.fmt (number of sites)

site.trend.change.r	<i>/tables/response_site_trend_change_visit.csv</i> (1) <i>/figures/response_site_change_site_visit.fmt</i> (number of sites) <i>/figures/response_site_trend_site_visit.fmt</i> (number of sites)
region.means.r	<i>/tables/response_region_visit_year_means.csv</i> (1) <i>/figures/response_region_visit_year_hist.fmt</i> (number of years) <i>/figures/response_region_visit_year_cdf.fmt</i> (number of years) <i>/figures/response_region_visit_box.fmt</i> (1)
region.repvisit.means.r	<i>/tables/response_region_Multiple_site_year_means.csv</i> (1) <i>/figures/response_region_Multiple_site_year_hist.fmt</i> (number of sites*number of years) <i>/figures/response_region_Multiple_site_year_cdf.fmt</i> (number of sites*number of years) <i>/figures/response_region_Multiple_site_box.fmt</i> (number of sites)
region.change.lm.r	<i>/tables/response_region_visit_change_lastyear_LM.csv</i> (1) <i>/figures/response_region_visit_change_all_sites_lastyear_LM.fmt</i> (1) <i>/figures/response_region_visit_change_site_lastyear_LM.fmt</i> (number of years)
region.change.cusum.r	<i>/tables/response_region_visit_change_lastyear_CUSUM_1.csv</i> (1) <i>/tables/response_region_visit_change_lastyear_CUSUM_2.csv</i> (1) <i>/tables/response_region_visit_change_lastyear_CUSUM_3.csv</i> (1) <i>/figures/response_region_visit_change_year_CUSUM.fmt</i> (number of years)
region.trend.po.r	<i>/tables/response_region_visit_trend_lastyear_random_sites_PO.csv</i> (1) <i>/tables/response_region_visit_trend_lastyear_fixed_sites_PO.csv</i> (1) <i>/figures/response_region_visit_trend_lastyear_random_sites_PO.fmt</i> (1) <i>/figures/response_region_visit_trend_lastyear_fixed_sites_PO.fmt</i> (1)

Program and Function Execution Failures

Programs

temp.r	none anticipated.
site.r	quits if multiple responses detected in input data file. quits if multiple visits detected in input data file.
region.r	quits if multiple responses detected in input data file. quits if multiple regions detected in input data file.

Functions

temp.stats.r	none anticipated.
ma.r	none anticipated.
mmaxmin.r	none anticipated.
site.means.r	none anticipated.
site.trend.change.r	none anticipated.
region.means.r	none anticipated.
region.repsite.means.r	none anticipated.
region.change.lm.r	none anticipated.
region.change.cusum.r	none anticipated.
region.trend.po.r	Inter-site (random sites) analysis may fail to converge with the only effect being that the two random site output files (one .csv and one .jpg) will not be produced. The function returns to the program (region.r) and termination is normal.

Program Execution Instructions

Create the desired working directory and move all data input files, analyses programs and functions into this single directory. During execution the output directories for data files, tables and figures will be created as subdirectories (folders) of the working directory.

temp.r To run the temperature preprocessing program, start R and submit the following code in the command window:

```
> source("temp.r")
```

```
> temp.r()
```

You will be prompted to select the input data file.

The output data files from temp.r are ready for input into site.r.

site.r To run the single site inference, abrupt change and trend analyses, start R and submit the following code in the command window:

```
> source("site.r")
```

```
> site.r()
```

You will be prompted to select:

the output file format for figures

which diagnostic figures (if any) to produce

whether or not to run the trend and change analyses

the desired significance level for the trend and change analyses (if previously selected)

the input data file

The output tables from site.r can be modified for input into region.r. The region field needs to be entered for each site. The park, panel and watershed fields can remain in the file, however these fields will be dropped from the regional analyses output files. If regional analysis of multiple visits per site is desired the individual visit output files from the site analysis need to be appended together prior to input into region.r.

region.r

To run the regional inference, abrupt change and trend analyses, start R and submit the following code in the command window:

```
> source("region.r")
```

```
> region.r()
```

You will be prompted to select:

the output file format for figures

which diagnostic figures (if any) to produce

which trend and change analyses (if any) to produce

the desired significance level for the trend and change analyses (if previously selected)

the input data file

which diagnostic figures (if any) to produce if multiple visits per site are detected in the input data file (e.g. January, May and September)

Warnings

relative range of values = # *EPS, is small (axis 2) – this warning is benign – it just means that we do not have a wide range of values for the response axis – this is because in the test data we have many sites with equal data across four years of data collection – this is not likely to happen with actual data.

NaNs produced in: pt(q, df, lower.tail, log.p) – this warning is benign – it originates in the fixed site analysis in the f.region.trend.PO routine and reminds us that the degrees of freedom for some of the automated output is 0 and therefore it cannot calculate pvalues for the individual sites – this is as it should be.

Error Messages

You will get an error message if the inter-site (random sites) regional analysis fails to converge with the only effect being that the two random site output files (one .csv and one .fmt) will not be produced. The function f.region.trend.po returns to the program region.r and termination is normal. I do not recall the actual error message. Additional error messages have not been encountered during the programming and testing of the analyses.

References

McDonald, T. L., and R. S. Glesne. 2011. Standard Operating Procedure 21: Data Analysis and Reporting. *In* Glesne, R. S., S. C. Fradkin, B. A. Samora, J. R. Boetsch, R. E. Holmes and B. Christoe. 2012. Protocol for long-term monitoring of mountain lakes in the North Coast and Cascades Network: Version July 9, 2012. Natural Resource Report NPS/NCCN/NRR—2012/549. National Park Service, Fort Collins, Colorado.

Attachment A2. Example temperature data input file (UTriplet_Surf_2010.csv) for temp.r and daily.temp.stats.r data summary routines.

park	panel	watershed	site	year	season	date	response	label
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 0:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 0:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 1:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 1:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 2:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 2:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 3:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 3:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 4:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 4:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 5:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 5:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 6:00	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 6:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 7:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 7:30	1.371	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 8:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 8:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 9:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 9:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 10:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 10:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 11:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 11:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 12:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 12:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 13:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 13:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 14:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 14:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 15:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 15:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 16:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 16:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 17:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 17:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 18:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 18:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 19:00	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 19:30	1.398	temperature
NOCA	1	Stehekin	UpTriplet_surf	2010	winter	1/1/2010 20:00	1.398	temperature

Attachment A3. Daily temperature summary routine (daily.temp.stats.r) script.

```
# Create Directories

wd <- getwd()

dir.create("daily_output/dailystats", recursive=TRUE,
showWarnings=FALSE)

outpathfig <- file.path(wd, "daily_output", "dailystats", fsep="/")

data.df <- read.csv(choose.files(caption="Select the input data (.csv
file)"), head=T, as.is=T)

data.df$date <- as.Date(data.df$date, "%m/%d/%Y")

# SELECT THE DATA TO BE ANALYZED.

response <- data.df$response
label <- data.df$label[1]

# DETERMINE INDICES OF SITE AND DATE IN TAPPLY OF ROWS OF DATA FRAME
# (ASSIGNS A UNIQUE INDEX TO EACH SITE AND DATE)

indices <- tapply(seq(1:nrow(data.df)),data.df[,c("site", "year",
"date")])

u.indices <- unique(indices)

# INITIALIZE MIN, MAX, AVG AND PARK, PANEL, WATERSHED, SITE, YEAR, DATE
# AND SEASON VECTORS.

mn <- NULL
mx <- NULL
xn <- NULL
av <- NULL
```

```

pk <- NULL
pn <- NULL
ws <- NULL
st <- NULL
yr <- NULL
sn <- NULL
dt <- NULL

# LOOP THROUGH THE UNIQUE INDICES AND CALCULATE DAILY TEMPERATURE
SUMMARIES.

for(i in u.indices)
{
  x.df <- data.df[i==indices,]
  mn <- c(mn, min(x.df$response, na.rm = TRUE))
  mx <- c(mx, max(x.df$response, na.rm = TRUE))
  xn <- c(xn, max(x.df$response, na.rm = TRUE)-min(x.df$response, na.rm
= TRUE))
  av <- c(av, mean(x.df$response, na.rm = TRUE))
  pk <- c(pk, x.df$park[1])
  pn <- c(pn, x.df$panel[1])
  ws <- c(ws, x.df$watershed[1])
  st <- c(st, x.df$site[1])
  yr <- c(yr, x.df$year[1])
  sn <- c(sn, x.df$season[1])
  dt <- c(dt, x.df$date[1])
}

# COMBINE VECTORS INTO A DATA FRAME AND SORT BY SITE AND DATE.

```

```
class(dt) <- "Date"

daily.df <- data.frame(site=st, year=yr, date=dt, min=mn, max=mx,
range=xn, avg=av)

daily.df <- daily.df[order(daily.df$site, daily.df$date),]

write.csv(daily.df, "daily_output/dailystats/Daily_temp_stats.csv")
```


Appendix B. Lake Air and Water Temperature Data Availability, 2008-2011

Table B1. Summary of available air and water temperature logger data collected at Mount Rainier National Park (MORA), 2008-2011.

MORA Lakes	Year	Temperature Logger				Comments
		Surface	Mid-depth	Bottom	Air	
Allen	2008		Sep-Dec			Mid-depth started in 2008. Remaining loggers started in 2009.
	2009	Sep-Dec	All	Sep-Dec	Sep-Dec	
	2010	All	All	All	All	
	2011	All	All	All	All	
Blue	2009	No Data	No Data	No Data	Sep-Dec	All loggers started in 2009. Water loggers vandalized - no data 2009-2011.
	2010	No Data	No Data	No Data	All	
	2011	No Data	No Data	No Data	All	
Upper Deadwood	2008		Oct-Dec			Mid-depth started in 2008. Remaining loggers started in 2009.
	2009	Sep-Dec	All	Sep-Dec	Sep-Dec	
	2010	All	All	All	All	
	2011	All	All	All	All	
LH15	2008	Oct-Dec		Oct-Dec	Oct-Dec	Surface, bottom, and air loggers started in 2008. Mid-depth logger started in 2009. Air temperature logger found vandalized in 2010, replaced in 2012.
	2009	All	Sep-Dec	All	Jan-Jul	
	2010	All	All	All	No Data	
	2011	All	All	All	No Data	
LP19	2008	Sep-Dec		Sep-Dec		Surface and bottom loggers started in 2008. Mid-depth and air loggers started in 2009.
	2009	All	Sep-Dec	All	Sep-Dec	
	2010	All	All	All	All	
	2011	All	All	All	All	
Upper Palisades ¹	2008	Sep-Dec		Sep-Dec		Surface and bottom loggers started in 2008. Mid-depth logger started in 2009. Air logger started in 2010. Lake level up in 2010-2011 putting the surface logger at 3m depth. Data gap for mid-depth from 2/7/2011-10/12/2011. Air logger not found in 2011 and not replaced until 2012 due to miscommunication.
	2009	All	Sep-Dec	All		
	2010	All	All	All	No Data	
	2011	All	Jan, Nov-Dec	All	No Data	

¹ Upper Palisades Lake surface temperature data affected by lake level increase with logger depth at 3m in 2010 and 2011.

Table B2. Summary of available air and water temperature logger data collected at North Cascades National Park (NOCA), 2008-2011.

NOCA Lakes	Year	Temperature Logger				Comments ¹
		Surface	Mid-depth	Bottom	Air	
Bowen	2009	Sep-Dec	Sep-Dec	Sep-Dec	Sep-Dec	All loggers started in 2009. *Snow cover on air temperature logger 3/13/11 to 5/13/11.
	2010	All	All	All	All	
	2011	All	All	All	Jan, Feb, Jun-Dec	
Easy Ridge	2009	Sep-Dec	Sep-Dec	Sep-Dec	Sep, Oct	All loggers started in 2009. *Snow cover on air temperature logger 11/15/09 to 6/30/10 and 12/1/10 to 7/12/11.
	2010	All	All	All	Jul-Nov	
	2011	All	All	All	Aug-Dec	
Lower Blum	2008	Sep-Dec		Sep-Dec		Surface and bottom loggers started in 2008. Mid-depth and air loggers started in 2009.
	2009	All	Sep-Dec	All	Sep-Dec	
	2010	All	All	All	All	
	2011	All	All	All	All	
Lower East	2009	Sep-Dec	Sep-Dec	Sep-Dec	Sep-Dec	All loggers started in 2009. *Snow cover on air temperature logger 2/11/11 to 6/4/11.
	2010	All	All	All	All	
	2011	All	All	All	Jan, Jul-Dec	
Lower Silent	2009	Sep-Dec	Sep-Dec	Sep-Dec	Sep, Oct	All loggers started in 2009. *Snow cover on air temperature logger 11/13/09 to 7/15/10 and 11/30/10 to 7/28/11.
	2010	All	All	All	Aug-Nov	
	2011	All	All	All	Aug-Dec	
Upper Triplet	2008	Sep-Dec				Surface logger started in 2008. Mid-depth, bottom, and air loggers started in 2009.
	2009	All	Sep-Dec	Sep-Dec	Sep-Dec	
	2010	All	All	All	All	
	2011	All	All	All	All	

¹ Air temperature data affected by snow cover during time periods noted in the comments.

Table B3. Summary of available air and water temperature logger data collected at Olympic National Park (OLYM), 2008-2011.

OLYM Lakes	Year	Temperature Logger				Comments ¹
		Surface	Mid-depth	Bottom	Air	
Ferry	2008	Sep-Dec	Sep-Dec	Sep-Dec	Sep-Dec	All loggers started in 2008.
	2009	All	All	All	All	
	2010	All	All	All	All	
	2011	All	All	All	All	
Gladys	2009	Oct-Dec	Oct-Dec	Oct-Dec	Oct-Dec	All loggers started in 2009.
	2010	All	All	All	All	
	2011	All	All	All	All	
Heather	2008	Oct-Dec	Oct-Dec	Oct-Dec	Jun-Dec	All loggers started in 2008. Mid-depth logger battery failure 8/19/09 to 9/10/09.
	2009	All	Jan-Jul, Oct-Dec	All	All	
	2010	All	All	All	All	
	2011	All	All	All	All	
Crazy	2010	Sep-Dec	Sep-Dec	Sep-Dec	Sep-Dec	All loggers started in 2010.
	2011	All	All	All	All	
Milk	2008	Oct-Dec	Oct-Dec	Oct-Dec	All	Air logger started in 2005. Surface, mid-depth, and bottom loggers started in 2008.
	2009	All	All	All	All	
	2010	All	All	All	All	
	2011	All	All	All	All	
LaCrosse	2010	Oct-Dec	Oct-Dec	Oct-Dec	Oct-Dec	All loggers started in 2010. *Snow cover on air temperature logger 3/8/11 to 6/4/11.
	2011	All	All	All	Jan, Feb, Jul-Dec	
Sunup	2008	Sep-Dec	Sep-Dec	Sep-Dec	All	Air logger started in 2006. Surface, mid-depth, and bottom loggers started in 2008. *Snow cover on air temperature logger 3/9/11 to 6/4/11.
	2009	All	All	All	All	
	2010	All	All	All	All	
	2011	All	All	All	Jan, Feb, Jul-Dec	
Connie	2008	Oct-Dec	Oct-Dec	Oct-Dec	Jan, Jun-Dec	Air logger started in 2006. Surface, mid-depth, and bottom loggers started in 2008. Surface logger battery failure 5/29/09 to 9/10/09. Unknown air temperature logger failure 2/6/08 to 5/17/08. *Snow cover on air temperature logger 4/7/11 to 5/13/11.
	2009	Jan-May, Oct-Dec	All	All	All	
	2010	All	All	All	All	
	2011	All	All	All	Jan-Mar, Jun-Dec	

¹Air temperature data affected by snow cover during time periods noted in the comments

Appendix C. Monthly Air Temperature Summary Statistics

Table C1. Allen Lake, Mount Rainier National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									10.73	3.14	-0.09	-2.97
Air	2010	0.79	-0.01	-0.40	0.08	1.79	5.19	11.55	11.56	8.80	5.45	-1.10	-2.19
Air	2011	-0.65	-3.84	-1.92	-2.25	1.53	4.65	7.52	11.04	11.97	4.10	-1.75	-0.98
ADMINT													
Air	2009									6.68	0.61	-2.02	-5.14
Air	2010	-0.72	-1.83	-3.02	-2.31	-0.40	2.29	7.57	8.14	5.90	2.72	-3.20	-3.87
Air	2011	-2.60	-6.10	-4.39	-4.57	-0.93	2.26	4.36	7.54	8.51	1.91	-4.07	-3.55
ADMT													
Air	2009									15.05	5.88	1.84	-0.26
Air	2010	2.30	2.36	2.40	2.61	4.63	8.43	15.97	15.37	11.83	8.79	0.69	-0.36
Air	2011	1.23	-1.68	-0.03	-0.04	4.09	7.99	12.01	15.44	16.46	6.66	0.61	2.16

Table C2. LP19 Lake, Mount Rainier National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									11.14	3.67	0.57	-2.76
Air	2010	1.90	0.73	0.33	0.34	1.75	5.72	11.97	11.61	9.27	5.85	-0.43	-1.06
Air	2011	-0.39	-3.55	-1.22	-1.87	1.73	4.42	8.63	11.37	12.59	4.54	-1.15	-0.74
ADMINT													
Air	2009									6.98	1.17	-1.64	-4.73
Air	2010	0.13	-1.15	-2.51	-2.01	-0.33	2.97	8.37	8.52	6.50	3.16	-2.71	-2.97
Air	2011	-2.01	-5.58	-3.61	-4.13	-0.62	2.21	5.53	8.33	9.40	2.12	-3.59	-3.30
ADMT													
Air	2009									15.11	6.17	2.79	-0.46
Air	2010	3.77	2.89	3.14	2.82	4.39	8.70	15.55	14.96	11.96	8.55	1.74	1.31
Air	2011	1.19	-1.61	0.67	0.38	4.23	7.37	12.07	14.86	16.27	6.95	1.50	2.19

Table C3. Blue Lake, Mount Rainier National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT). Water temperature data loggers vandalized in 2009-2011.

Logger*	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									10.29	3.27	-0.16	-4.95
Air	2010	0.14	-0.96	-0.86	0.04	2.09	5.41	11.92	11.96	8.99	4.62	-1.43	-2.67
Air	2011	-1.65	-4.42	-1.84	-2.06	1.54	4.70	7.01	10.85	11.13	4.19	-1.96	-3.30
ADMINT													
Air	2009									5.97	0.39	-2.27	-7.53
Air	2010	-2.14	-3.84	-4.43	-2.77	-0.82	1.86	6.39	7.63	5.86	1.93	-3.56	-4.92
Air	2011	-4.54	-7.93	-4.64	-4.77	-1.01	1.71	2.67	5.58	6.62	1.97	-5.01	-6.34

Table C3. Blue Lake, Mount Rainier National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT). Water temperature data loggers vandalized in 2009-2011 (continued).

Logger*	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADMT													
Air	2009									15.68	6.43	2.16	-2.13
Air	2010	2.49	2.09	2.85	2.81	5.46	9.69	18.32	17.14	12.60	8.43	0.78	-0.30
Air	2011	0.93	-1.64	0.07	0.19	4.37	8.45	12.54	17.52	17.39	6.76	1.35	0.02

Table C4. Upper Palisades Lake, Mount Rainier National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009							NO DATA					
Air	2010							NO DATA					
Air	2011							NO DATA					
ADMINT													
Air	2009							NO DATA					
Air	2010							NO DATA					
Air	2011							NO DATA					
ADMT													
Air	2009							NO DATA					
Air	2010							NO DATA					
Air	2011							NO DATA					

Table C5. Upper Deadwood Lake, Mount Rainier National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.62	1.49	-1.65	-6.24
Air	2010	-1.84	-2.12	-1.87	-1.09	1.10	4.37	10.32	10.61	7.81	4.19	-2.64	-4.64
Air	2011	-2.86	-5.69	-3.26	-3.26	0.98	4.12	6.94	10.75	10.75	2.71	-3.23	-3.01
ADMINT													
Air	2009									4.56	-1.71	-4.16	-9.21
Air	2010	-3.68	-4.24	-5.28	-4.12	-2.15	0.74	4.35	5.66	4.39	0.96	-5.44	-6.64
Air	2011	-5.63	-9.11	-5.52	-6.81	-2.29	0.68	2.59	5.26	6.15	0.39	-6.39	-6.73
ADMT													
Air	2009									15.21	5.00	0.78	-2.90
Air	2010	0.06	0.05	1.75	2.00	4.72	8.95	17.34	16.57	11.62	8.27	-0.49	-2.80
Air	2011	-0.51	-2.80	-1.27	-0.37	4.34	8.43	12.83	17.69	16.71	5.80	-0.18	0.83

Table C6. LH15 Lake, Mount Rainier National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008										2.81	0.68	-6.22
Air	2009	-2.65	-4.50	-5.45	-1.74	2.19	4.95	12.09	*	*	*	*	*
Air	2010	*	*	*	*	*	*	*	*	*	*	*	*
Air	2011	*	*	*	*	*	*	*	*	*	*	*	*
ADMINT													
Air	2008										-0.66	-2.05	-9.19
Air	2009	-6.12	-9.26	-9.61	-5.78	-2.13	0.85	6.81	*	*	*	*	*
Air	2010	*	*	*	*	*	*	*	*	*	*	*	*
Air	2011	*	*	*	*	*	*	*	*	*	*	*	*
ADMT													
Air	2008										6.07	3.71	-3.34
Air	2009	0.88	-0.02	-2.07	2.27	7.24	10.54	17.76	*	*	*	*	*
Air	2010	*	*	*	*	*	*	*	*	*	*	*	*
Air	2011	*	*	*	*	*	*	*	*	*	*	*	*

*Air temperature loggers vandalized or stolen.

Table C7. Upper Triplet Lake, North Cascades National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.50	-0.87	-3.98	-8.08
Air	2010	-4.01	-4.13	-3.09	-1.22	1.87	6.55	12.56	10.71	6.34	2.92	-5.40	-7.28
Air	2011	-5.00	-7.89	-4.79	-4.01	1.88	6.41	9.38	12.68	10.52	0.26	-6.49	-4.45
ADMINT													
Air	2009									4.25	-4.37	-6.69	-11.17
Air	2010	-6.75	-7.68	-8.20	-5.93	-3.28	0.65	5.97	5.56	2.53	-0.67	-8.59	-9.96
Air	2011	-8.02	-11.59	-9.41	-9.69	-3.67	0.16	2.78	6.24	5.12	-2.63	-9.90	-8.38
ADMT													
Air	2009									20.66	5.28	-1.42	-4.97
Air	2010	-1.22	1.88	5.61	5.70	10.89	17.76	25.52	20.53	13.70	9.86	-2.29	-4.58
Air	2011	-1.97	-2.73	1.65	4.47	10.90	15.49	20.98	28.24	23.02	4.99	-3.05	-0.76

Table C8. Bowan Lake, North Cascades National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									8.58	-1.11	-4.44	-8.27
Air	2010	-5.05	-5.25	-4.71	-2.71	0.70	4.89	10.87	10.24	5.84	2.74	-5.88	-7.74
Air	2011	-5.36	-8.32	*	*	*	4.25	7.50	11.36	9.83	0.20	-6.75	-4.28
ADMINT													
Air	2009									4.36	-3.90	-6.59	-11.55
Air	2010	-7.74	-8.34	-8.48	-5.96	-3.22	1.01	5.77	5.81	2.78	-0.34	-9.03	-10.09
Air	2011	-8.43	-12.00	*	*	*	0.60	2.92	6.16	5.52	-2.20	-9.90	-7.76
ADMT													
Air	2009									15.68	2.89	-2.14	-5.12
Air	2010	-2.93	-2.16	0.07	1.31	8.30	11.33	19.86	19.42	10.42	7.47	-3.07	-5.85
Air	2011	-2.78	-4.87	*	*	*	11.12	15.48	24.33	19.87	3.49	-3.56	-0.87

*Air temperature logger covered with snow.

Table C9. Lower Silent Lake, North Cascades National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.27	-1.05	*	*
Air	2010	*	*	*	*	*	*	*	10.19	5.71	2.79	-6.11	*
Air	2011	*	*	*	*	*	*	*	10.28	10.01	-0.12	-7.14	-4.37
ADMINT													
Air	2009									3.96	-4.37	*	*
Air	2010	*	*	*	*	*	*	*	5.46	2.33	-0.65	-9.69	*
Air	2011	*	*	*	*	*	*	*	5.46	5.34	-2.63	-10.08	-7.54
ADMT													
Air	2009									20.00	4.78	*	*
Air	2010	*	*	*	*	*	*	*	19.12	12.49	9.02	-1.55	*
Air	2011	*	*	*	*	*	*	*	18.91	19.07	4.49	-3.34	-0.14

*Air temperature logger covered with snow.

Table C10. Lower Blum Lake, North Cascades National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.47	1.64	-1.41	-4.91
Air	2010	-0.29	-0.67	-1.17	-0.32	1.93	4.57	10.51	10.76	7.28	4.04	-2.87	-3.35
Air	2011	-3.07	-5.75	-2.83	-3.02	1.75	4.30	6.30	9.74	10.54	2.13	-3.60	-2.85
ADMINT													
Air	2009									5.59	-0.64	-3.39	-7.21
Air	2010	-2.42	-3.04	-4.26	-2.79	-0.90	1.59	6.19	7.43	4.60	1.37	-5.12	-5.37
Air	2011	-5.14	-8.49	-5.46	-5.80	-1.04	1.84	2.88	5.59	6.79	0.00	-6.53	-5.64

Table C10. Lower Blum Lake, North Cascades National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADMT													
Air	2009									16.58	4.90	0.95	-1.64
Air	2010	2.14	4.30	3.36	3.73	7.26	11.00	21.61	17.59	11.56	8.71	-0.02	-1.10
Air	2011	-0.85	-2.46	-0.08	0.87	6.91	9.53	14.75	19.12	17.58	5.64	-0.43	1.28

Table C11. Lower East Lake, North Cascades National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.84	0.95	-1.82	-5.46
Air	2010	-1.50	-1.57	-1.33	-0.37	2.65	5.00	10.59	10.46	6.71	3.96	-4.03	-5.08
Air	2011	-3.32	*	*	*	*	*	5.65	9.51	9.82	1.48	-4.74	-2.90
ADMINT													
Air	2009									5.02	-2.04	-4.61	-8.51
Air	2010	-4.13	-4.75	-5.32	-3.27	-1.48	1.68	5.54	6.42	3.82	0.91	-6.80	-7.30
Air	2011	-5.02	*	*	*	*	*	1.92	4.31	5.83	-0.85	-7.57	-6.24
ADMT													
Air	2009									18.91	7.35	4.55	3.73
Air	2010	3.61	7.03	7.57	5.78	9.94	9.57	16.53	16.25	10.91	10.61	-0.78	-1.50
Air	2011	-1.14	*	*	*	*	*	13.64	16.11	14.85	4.18	-1.19	0.89

*Air temperature logger covered with snow.

Table C12. Easy Ridge Lake, North Cascades National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009									9.88	0.71	*	*
Air	2010	*	*	*	*	*	*	9.59	10.87	7.12	3.83	-3.91	*
Air	2011	*	*	*	*	*	*	*	10.15	10.50	1.91	-4.29	-2.79
ADMINT													
Air	2009									5.32	-1.85	*	*
Air	2010	*	*	*	*	*	*	4.99	6.54	4.28	0.86	-6.34	*
Air	2011	*	*	*	*	*	*	*	5.36	6.25	-0.62	-7.04	-5.60
ADMT													
Air	2009									17.60	4.15	*	*
Air	2010	*	*	*	*	*	*	15.87	16.67	11.44	7.83	-1.35	*
Air	2011	*	*	*	*	*	*	*	16.59	16.30	6.70	-0.84	1.59

*Air temperature logger covered with snow.

Table C13. Ferry Lake, Olympic National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008									11.98	5.02	2.75	-3.57
Air	2009	0.96	-0.98	-3.07	1.82	5.42	9.15	15.76	13.50	10.85	3.55	-0.27	-2.54
Air	2010	0.62	0.49	-0.32	0.27	2.67	5.59	11.89	12.31	8.40	5.20	-1.50	-2.58
Air	2011	-0.59	-3.82	-2.22	-2.17	2.70	6.00	8.33	10.96	11.57	3.58	-2.23	0.03
ADMINT													
Air	2008									8.74	2.35	0.33	-5.62
Air	2009	-1.54	-4.33	-6.18	-2.43	1.03	5.50	11.93	10.50	7.43	1.35	-2.18	-4.57
Air	2010	-1.02	-1.79	-3.44	-2.58	-0.34	2.36	8.09	9.11	5.89	2.61	-3.97	-4.14
Air	2011	-2.64	-6.06	-4.80	-5.71	-1.16	2.35	4.85	7.59	8.37	1.14	-4.47	-2.60
ADMT													
Air	2008									19.15	10.09	5.19	-1.38
Air	2009	3.37	4.89	1.46	8.80	11.83	14.32	21.58	17.43	15.46	7.00	1.74	-0.49
Air	2010	2.30	4.30	3.93	4.23	6.98	9.47	16.26	16.23	11.34	9.25	0.92	-0.73
Air	2011	1.38	-1.24	.93	2.22	7.70	10.92	13.24	15.46	16.04	7.63	0.52	2.59

Table C14. Gladys Lake, Olympic National Park, 2009-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2009										2.08	-1.18	-3.66
Air	2010	-0.24	-1.20	-1.53	-0.73	1.50	5.40	11.09	10.90	7.44	4.09	-2.06	-3.68
Air	2011	-0.91	-4.83	-3.23	-3.26	1.59	5.47	8.11	10.73	10.46	2.39	-3.29	-0.86
ADMINT													
Air	2009										-0.64	-3.64	-6.14
Air	2010	-2.36	-3.76	-4.82	-3.78	-1.80	1.61	5.68	6.31	4.22	1.12	-4.92	-5.61
Air	2011	-3.32	-7.55	-5.87	-7.14	-2.19	1.72	3.85	6.01	6.51	-0.23	-6.25	-4.22
ADMT													
Air	2009										5.52	1.12	-1.06
Air	2010	1.67	1.79	2.99	3.09	6.47	10.01	17.52	16.70	11.03	7.69	0.45	-1.50
Air	2011	1.31	-2.01	-0.25	1.41	6.56	10.08	12.99	16.64	15.61	5.62	-0.32	2.22

Table C15. Heather Lake, Olympic National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008						7.28	11.73	11.66	10.63	4.51	3.02	-4.29
Air	2009	1.29	-2.14	-3.82	0.65	4.59	8.47	14.66	12.63	10.47	2.53	-0.74	-3.57
Air	2010	0.08	-0.70	-0.85	0.35	3.29	6.68	11.01	10.64	7.76	4.57	-1.71	-3.46
Air	2011	-0.44	-4.07	-2.62	-2.29	2.59	6.59	8.38	10.34	10.72	2.97	-2.54	-0.39
ADMINT													
Air	2008						2.58	6.97	7.74	7.06	1.66	-0.14	-7.35
Air	2009	-1.66	-5.30	-7.15	-3.21	0.76	5.21	10.55	9.10	6.62	0.12	-3.24	-5.90
Air	2010	-1.76	-2.91	-4.18	-3.27	-0.96	2.05	6.33	7.09	4.67	1.75	-4.47	-5.28
Air	2011	-3.01	-6.97	-5.23	-6.48	-1.63	2.26	4.52	6.70	7.44	0.48	-5.35	-3.51
ADMT													
Air	2008						14.22	19.09	17.27	15.52	8.12	6.59	-0.06
Air	2009	5.36	1.78	0.20	5.42	9.44	12.89	19.63	17.24	15.42	5.53	1.55	-0.77
Air	2010	2.24	2.83	3.87	6.38	10.46	13.88	18.03	16.41	11.98	9.43	1.35	-1.15
Air	2011	2.53	-0.32	1.06	3.36	8.79	13.24	14.54	16.96	15.28	7.09	1.01	4.16

Table C16. Crazy Lake, Olympic National Park, 2010-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2010									8.02	4.71	-1.62	-3.13
Air	2011	-0.57	-3.71	-2.26	-1.90	2.52	6.03	8.43	10.81	11.44	3.31	-2.36	-0.50
ADMINT													
Air	2010									5.40	2.18	-4.12	-4.82
Air	2011	-3.05	-6.41	-4.90	-6.08	-1.47	2.38	4.54	7.07	7.64	0.81	-4.93	-3.27
ADMT													
Air	2010									11.16	7.93	0.58	-1.27
Air	2011	1.82	-0.45	1.09	3.09	7.64	10.83	13.87	16.14	17.76	7.97	0.34	2.41

Table C17. Milk Lake, Olympic National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008	-3.77	-0.93	-2.87	-1.25	5.31	6.56	10.24	10.99	10.37	4.23	2.47	-3.75
Air	2009	0.84	-2.02	-3.12	1.03	4.61	8.37	14.43	12.33	10.02	3.11	-0.47	-3.13
Air	2010	-0.23	-0.55	-0.97	-0.27	2.42	5.44	10.21	10.43	7.71	4.60	-1.49	-3.11
Air	2011	-0.36	-3.41	-2.54	-1.34	1.53	5.67	7.51	9.26	9.88	3.12	-2.32	-0.36
ADMINT													
Air	2008	-6.94	-4.11	-6.40	-5.45	2.11	2.53	6.31	8.02	7.52	1.74	0.18	-6.20
Air	2009	-2.03	-5.45	-6.65	-3.02	0.68	5.14	10.71	9.20	6.76	0.93	-2.61	-5.46
Air	2010	-1.56	-2.15	-3.64	-2.44	-0.57	2.32	7.14	7.56	5.29	2.32	-4.14	-4.84
Air	2011	-3.07	-6.25	-3.75	-1.99	-0.59	2.38	4.43	6.59	7.08	0.96	-4.89	-3.14
ADMT													
Air	2008	2.32	5.01	1.86	4.22	9.56	11.28	14.30	14.33	15.10	7.79	5.37	-0.71
Air	2009	6.88	3.82	1.25	6.16	9.34	12.45	18.63	15.99	13.84	6.44	2.21	1.82
Air	2010	1.26	2.35	2.95	2.45	6.15	9.60	14.12	14.04	10.34	8.32	1.97	0.25
Air	2011	4.35	2.02	-0.75	-0.69	3.70	9.59	11.25	13.30	13.53	6.37	1.14	4.00

*Air temperature logger covered with snow.

Table C18. LaCrosse Lake, Olympic National Park, 2010-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2011	-0.92	-4.31	*	*	*	*	7.09	9.60	10.32	2.85	-2.52	-0.33
ADMINT													
Air	2010										1.76	-4.44	-5.07
Air	2011	-3.33	-6.82	*	*	*	*	4.09	6.16	6.79	0.49	-5.23	-3.32
ADMT													
Air	2010										7.74	0.38	-1.77
Air	2011	1.22	-2.16	*	*	*	*	10.78	14.48	14.68	5.78	1.01	3.06

*Air temperature logger covered with snow.

Table C19. Sunup Lake, Olympic National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008	-2.82	0.15	-1.17	0.61	7.41	8.92	13.71	13.37	12.98	5.59	3.49	-2.53
Air	2009	2.64	-0.18	-1.93	2.77	6.78	11.17	17.07	14.23	11.96	4.49	0.69	-1.33
Air	2010	1.13	1.15	0.77	1.42	3.93	7.48	14.82	14.56	9.86	6.53	0.07	-1.63
Air	2011	0.42	-2.12	*	*	*	*	7.79	11.94	12.27	4.69	-0.97	0.73
ADMINT													
Air	2008	-5.30	-2.65	-4.60	-3.49	3.07	4.09	8.88	9.21	9.40	2.89	1.27	-4.85
Air	2009	0.18	-2.90	-4.66	-0.97	3.04	7.44	12.57	10.58	8.05	2.17	-1.10	-3.89
Air	2010	-0.09	-0.63	-2.05	-1.38	1.06	3.95	10.40	10.42	6.95	3.50	-2.51	-3.19
Air	2011	-2.04	-4.78	*	*	*	*	4.68	7.78	8.43	2.52	-3.08	-2.08
ADMT													
Air	2008	0.89	4.96	4.89	7.51	14.56	16.28	22.56	20.24	19.15	9.47	6.19	0.16
Air	2009	5.62	3.95	2.21	8.54	12.48	16.52	23.83	20.33	18.53	8.44	3.27	3.15
Air	2010	2.78	4.92	5.31	5.96	8.50	12.62	22.30	22.48	14.96	13.08	4.51	1.91
Air	2011	5.07	2.90	*	*	*	*	11.98	17.15	16.96	7.31	1.85	3.88

*Air temperature logger covered with snow.

Table C20. Connie Lake, Olympic National Park, 2008-2011 monthly air temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Air	2008	-3.19	*	*	*	*	7.06	11.92	11.80	12.35	5.10	3.19	-3.05
Air	2009	2.12	-0.60	-2.91	1.59	5.28	9.58	16.04	13.39	11.10	4.05	0.44	-1.54
Air	2010	1.18	0.91	0.13	0.58	3.08	6.44	13.92	13.42	8.97	5.76	-0.58	-1.86
Air	2011	0.04	-2.96	-1.80	*	*	1.72	8.69	12.21	11.92	4.21	-1.31	0.56
ADMINT													
Air	2008	-5.51	*	*	*	*	3.35	8.16	8.53	9.17	2.36	0.98	-4.84
Air	2009	-0.18	-3.23	-5.45	-1.63	2.08	6.45	12.40	10.27	7.87	2.02	-1.36	-3.50
Air	2010	0.00	-0.56	-2.30	-1.68	0.48	3.36	9.65	10.06	6.46	3.38	-2.70	-3.10
Air	2011	-1.84	-4.95	-3.60	*	*	0.33	5.02	7.55	8.09	2.24	-3.26	-1.83
ADMT													
Air	2008	-0.36	*	*	*	*	12.96	17.48	15.16	17.20	7.92	5.56	-0.90
Air	2009	5.18	2.68	0.05	5.39	8.29	12.69	19.34	16.75	14.52	6.45	2.35	0.97
Air	2010	2.53	2.94	2.89	3.14	7.06	11.22	22.46	17.33	11.59	8.49	1.34	-0.27
Air	2011	2.07	-0.67	0.24	*	*	6.57	16.72	22.08	16.55	6.30	1.04	3.30

* Air temperature logger covered with snow April-May 2011; Unknown failure February-May 2008.

Appendix D. Summer and Fall Lake Turnover Data

Table D1. Summer and fall turnover dates and days between dates at all North Coast and Cascades Network monitoring lakes, 2009-2011.

Mount Rainier National Park				North Cascades National Park				Olympic National Park			
Lake	Summer Turnover	Fall Turnover	Days Between Dates	Lake	Summer Turnover	Fall Turnover	Days Between Dates	Lake	Summer Turnover	Fall Turnover	Days Between Dates
Allen	No Data	11/5/09	No Data	U Triplet	No Data	10/30/09	No Data	Ferry	7/1/09	10/31/09	122
	7/9/10	11/8/10	122		7/8/10	10/30/10	114		7/28/10	10/31/10	95
	8/1/11	11/3/11	94		7/19/11	10/29/11	102		8/24/11	10/30/11	67
LP19	No Data	11/4/09	No Data	Bowen	No Data	10/21/09	No Data	Gladys	No Data	10/23/09	No Data
	6/24/10	11/8/10	137		7/16/10	10/23/10	99		7/10/10	10/23/10	105
	7/9/11	11/7/11	121		8/2/11	11/5/11	95		7/30/11	10/22/11	84
U Deadwood	No Data	10/23/09	No Data	L Silent	No Data	10/12/09	No Data	Heather	6/24/09	10/19/09	117
	7/8/10	10/24/10	108		8/5/10	10/25/10	81		8/15/10 ³	10/8/10 ³	54 ³
	7/19/11	10/26/11	99		8/25/11	10/19/11	55		9/19/11 ⁴	None ⁴	0
LH15	6/28/09	11/1/09	126	L Blum	7/8/09	10/25/09	109	Crazy	No Data	10/24/10	No Data
	7/3/10	11/8/10	128		7/15/10	10/25/10	102		8/23/11	10/10/11	48
	7/19/11	11/10/11	114		8/16/11	10/20/11	65	Milk	7/1/09	10/23/09	114
U Palisades	7/4/09	10/30/09	118	L East	No Data	10/22/09	No Data		9/11/10	10/23/10	42
	7/16/10	No Data ¹	No Data		7/23/10	10/27/10	96		None ⁵	None ⁵	0
	No Data ¹	11/1/11	No Data		8/23/11	10/20/11	58	LaCrosse	No Data	10/24/10	No Data
Blue ²	No Data	No Data	No Data	Easy Ridge	No Data	10/21/09			9/1/11	11/2/11	62
					8/5/10	10/23/10	79		6/23/09	11/4/09	134
					9/4/11	10/10/11	36	Connie	7/25/10	11/6/10	104
									8/30/11	11/1/11	63
									7/9/09	10/31/09	114
									7/31/10	10/21/10	82
									9/29/11 ⁶	10/26/11 ⁶	27 ⁶

¹Lake levels very high during 2010 and 2011. Surface logger depth was at 3m when retrieved in summer of 2011.

²Water temperature data lost or vandalized in 2009-2011.

³Days and dates are approximated for 2010. Heather Lake daily average surface temperature fluctuated between 3°C and 5°C between turnover dates. The lake also fluctuated in and out of inverse stratification during this period.

⁴Days and dates are approximated for 2011. Heather Lake remained inversely stratified for the entire year. Daily average surface temperatures gradually increased through 9/3/11, fluctuated between 3°C and 4.5°C and then steadily declined after 10/2/11.

⁵Milk Lake inversely stratified for entire year with a maximum daily average temperature of 1.6°C in October.

⁶Days and dates are approximated for 2011. Connie Lake was inversely stratified to 9/29/11 and fluctuated in and out of inverse stratification until 10/26/11. Daily average surface temperatures for this period fluctuated between 3.5°C and 4.8°C before steadily declining after 10/26/11.

Appendix E. Monthly Water Temperature Summary Statistics

Table E1. Highest 7-day moving average of daily maximum (7-DADMax) surface, mid-depth, and bottom water temperatures (°C) with occurrence dates for the North Coast and Cascades Network annual monitoring lakes, 2009-2011 (occurrence dates represent the mid-point of 7-day interval). Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Park Lake	7-DADMax:Surface			Occurrence Date			7-DADMax:Middle			Occurrence Date			7-DADMax:Bottom			Occurrence Date		
	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
MORA																		
Allen		18.4	16.2		7/28	9/10	19.5	15.9	13.0	8/2	8/19	9/15		15.3	12.5		8/23	9/23
LP19	22.3	21.3	17.8	8/2	7/27	8/27		13.1	12.4		9/3	9/23	11.5	10.7	9.6	9/30	10/7	10/4
Blue																		
Upper Deadwood		18.9	18.2		8/18	8/27	22.3	17.6	16.3	8/2	8/18	8/28		17.6	16.2		8/18	8/28
LH15	19.6	18.6	16.9	8/3	8/18	9/11		16.6	15.3		8/19	8/27	16.0	15.8	14.5	8/25	8/23	9/13
Upper Palisades	17.3	*	*	8/3	*	*		13.8	*		8/20	*	13.9	11.4	11.1	9/3	9/2	9/24
NOCA																		
Upper Triplet	18.4	15.1	14.8	8/4	8/18	9/11	14.2	14.2		8/19	9/12	14.2		13.0	13.3		8/20	9/12
Bowan		19.8	16.1		8/17	9/11	17.3	15.3		8/18	9/12	17.3		17.0	15.1		8/18	9/12
Lower Silent		12.7	11.7		8/17	9/11	9.9	10.6		8/27	9/25	9.9		9.6	10.0		8/27	9/25
Lower Blum	15.3	12.4	10.2	9/1	8/18	9/11	11.6	9.4		8/20	9/12	11.6		11.4	9.4		8/22	9/11
Lower East		11.8	8.9		8/18	9/11	9.3	6.9		9/2	9/22	9.3		8.1	6.6		9/17	9/23
Easy Ridge		14.9	9.6		8/16	9/12	10.9	7.9		8/18	9/12	10.9		10.5	7.6		8/18	9/12
OLYM																		
Ferry	22.8	17.7	14.2	7/30	8/17	9/10	18.5	12.7	10.5	8/8	8/31	9/22	16.4	11.4	9.1	9/2	9/18	9/24
Gladys		15.1	13.9		8/15	9/10		7.7	9.1		9/29	9/8		6.2	6.9		9/26	9/20
Heather	18.3	5.7	5.1	8/2	9/29	9/11	*	4.7	4.5	*	9/29	8/26	13.5	4.9	5.3	8/4	7/22	9/2
Crazy			11.4			9/9			8.4			9/14			8.3			9/14
Milk	19.3	8.8	1.7	7/29	9/30	10/24	6.5	4.3	3.4	10/6	9/27	1/24	4.9	3.7	3.5	10/11	1/9	2/7
LaCrosse			11.4			9/11			8.8			9/22			7.1			9/23
Sunup	26.1	20.1	15.6	7/30	8/16	9/11	23.1	15.9	11.4	8/3	8/26	9/23	21.7	15.8	11.4	8/5	8/27	9/22
Connie		17.7	5.1		8/17	10/20	19.9	14.5	4.8	8/7	8/27	10/21	19.2	14.4	4.7	8/7	8/26	9/21

*Complete annual data not available for calculations subsequent to initial deployment year.

Table E2. Allen Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									14.23	6.64	3.35	2.86
Surface	2010	2.72	1.57	1.17	0.91	1.66	2.44	9.97	15.92	12.19	8.28	3.21	2.18
Surface	2011	2.00	2.30	0.54	0.59	0.89	1.94	2.57	10.96	13.19	8.22	2.76	1.66
Mid-depth	2008									12.15	7.50	3.88	3.92
Mid-depth	2009	3.52	3.22	2.99	1.96	1.67	2.75	10.01	15.38	13.87	6.61	4.23	4.43
Mid-depth	2010	4.44	4.32	4.15	3.96	3.83	3.44	6.24	13.70	11.81	8.22	4.13	4.10
Mid-depth	2011	3.99	3.87	3.08	2.90	2.73	3.03	3.39	6.93	11.94	8.13	4.16	4.25
Bottom	2009									13.79	6.55	4.41	4.97
Bottom	2010	5.19	5.20	5.20	5.16	5.14	4.97	6.18	13.05	11.73	8.16	4.26	4.72
Bottom	2011	4.94	4.98	4.75	4.76	4.72	4.63	4.52	6.73	11.31	8.08	4.35	4.75
ADMINT													
Surface	2009									13.69	6.35	3.20	2.80
Surface	2010	2.67	1.55	1.16	0.88	1.60	2.35	8.97	15.26	11.80	7.94	2.93	2.12
Surface	2011	1.93	2.27	0.50	0.56	0.84	1.85	2.36	9.98	12.60	8.01	2.53	1.61
Mid-depth	2008									11.86	7.26	3.72	3.90
Mid-depth	2009	3.47	3.21	2.97	1.93	1.63	2.73	9.54	15.11	13.69	6.43	4.18	4.40
Mid-depth	2010	4.42	4.31	4.13	3.94	3.81	3.42	6.01	13.47	11.70	8.09	4.09	4.08
Mid-depth	2011	3.95	3.86	3.05	2.89	2.72	3.02	3.33	6.72	11.78	8.03	4.12	4.24
Bottom	2009									13.63	6.39	4.35	4.97
Bottom	2010	5.18	5.20	5.20	5.16	5.13	4.96	6.05	12.85	11.63	8.03	4.18	4.71
Bottom	2011	4.91	4.98	4.73	4.75	4.72	4.62	4.49	6.59	11.19	7.98	4.26	4.74
ADMT													
Surface	2009									15.18	7.01	3.56	2.92
Surface	2010	2.76	1.60	1.19	0.95	1.71	2.58	11.56	16.94	12.82	8.90	3.49	2.24
Surface	2011	2.06	2.33	0.59	0.62	0.92	2.02	2.82	12.35	14.28	8.58	2.99	1.70
Mid-depth	2008									12.52	7.95	4.03	3.95
Mid-depth	2009	3.54	3.23	3.01	1.99	1.70	2.78	10.71	15.66	14.05	6.80	4.29	4.45
Mid-depth	2010	4.45	4.34	4.17	3.97	3.84	3.47	6.52	13.98	11.94	8.39	4.18	4.12
Mid-depth	2011	4.02	3.88	3.11	2.91	2.75	3.04	3.46	7.15	12.12	8.25	4.20	4.26
Bottom	2009									14.01	6.74	4.46	4.98
Bottom	2010	5.20	5.21	5.21	5.16	5.14	4.98	6.34	13.28	11.85	8.32	4.34	4.74
Bottom	2011	4.95	4.99	4.77	4.76	4.72	4.63	4.54	6.89	11.45	8.21	4.45	4.77

Table E3. LP19 Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									12.63	8.55	4.60	3.80
Surface	2009	2.74	2.46	2.53	2.44	2.49	3.21	15.40	17.21	14.37	8.69	2.15	1.25
Surface	2010	1.40	1.27	1.06	1.00	1.13	3.43	15.68	17.33	12.84	9.28	2.76	1.26
Surface	2011	1.31	1.55	1.44	1.48	1.06	1.20	7.58	15.38	14.45	8.65	4.08	3.44
Mid-depth	2009									13.39	8.69	4.23	4.06
Mid-depth	2010	4.14	4.16	4.16	4.11	4.08	4.21	6.80	11.25	12.11	9.09	4.10	4.03
Mid-depth	2011	4.15	4.12	4.12	4.08	4.03	4.00	4.71	7.70	11.40	8.57	4.21	4.03
Bottom	2008									8.41	7.89	4.59	4.20
Bottom	2009	4.29	4.36	4.44	4.46	4.40	4.33	6.01	9.02	10.81	8.53	4.29	4.46
Bottom	2010	4.54	4.57	4.59	4.55	4.42	4.39	6.12	9.10	10.35	8.83	4.17	4.41
Bottom	2011	4.49	4.45	4.50	4.47	4.48	4.33	4.75	6.78	9.00	8.21	4.31	4.37

Table E3. LP19 Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADMINT													
Surface	2008									12.31	8.41	4.49	3.74
Surface	2009	2.66	2.45	2.52	2.42	2.44	3.04	14.85	16.45	13.79	8.48	1.98	1.20
Surface	2010	1.34	1.25	1.03	0.97	1.08	2.95	14.20	16.44	12.31	8.96	2.54	1.19
Surface	2011	1.22	1.53	1.41	1.43	1.02	1.14	6.61	14.58	14.08	8.49	3.96	3.41
Mid-depth	2009									13.29	8.59	4.19	4.03
Mid-depth	2010	4.13	4.16	4.16	4.10	4.08	4.17	6.67	11.13	12.05	8.99	4.06	4.03
Mid-depth	2011	4.15	4.11	4.11	4.08	4.03	3.99	4.63	7.56	11.26	8.48	4.15	4.02
Bottom	2008									8.35	7.82	4.52	4.18
Bottom	2009	4.27	4.35	4.43	4.46	4.39	4.29	5.93	8.95	10.73	8.42	4.24	4.43
Bottom	2010	4.51	4.56	4.59	4.53	4.34	4.31	6.04	9.05	10.29	8.74	4.13	4.37
Bottom	2011	4.44	4.44	4.49	4.46	4.42	4.28	4.70	6.71	8.93	8.14	4.23	4.34
ADMT													
Surface	2008									12.96	8.72	4.70	3.84
Surface	2009	2.82	2.48	2.54	2.46	2.52	3.43	16.08	18.41	15.49	9.10	2.29	1.29
Surface	2010	1.47	1.28	1.08	1.03	1.18	4.08	17.69	18.76	13.76	9.98	2.98	1.35
Surface	2011	1.41	1.58	1.47	1.53	1.09	1.26	8.84	16.37	14.88	8.88	4.19	3.47
Mid-depth	2009									13.53	8.81	4.27	4.08
Mid-depth	2010	4.16	4.17	4.17	4.12	4.08	4.25	6.94	11.37	12.21	9.22	4.14	4.05
Mid-depth	2011	4.16	4.12	4.12	4.08	4.04	4.01	4.82	7.86	11.58	8.68	4.26	4.04
Bottom	2008									8.51	7.98	4.66	4.22
Bottom	2009	4.31	4.36	4.45	4.47	4.41	4.36	6.09	9.11	10.92	8.66	4.35	4.49
Bottom	2010	4.55	4.57	4.59	4.56	4.50	4.48	6.19	9.17	10.43	8.95	4.23	4.44
Bottom	2011	4.53	4.47	4.51	4.48	4.51	4.38	4.80	6.85	9.09	8.30	4.38	4.39

Table E4. Blue Lake, Mount Rainier National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT). Water temperature data loggers vandalized in 2009-2011.

Logger*	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT							NO DATA						
ADMINT							NO DATA						
ADMT							NO DATA						

Table E5. Upper Palisades Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									11.32	7.14	3.02	1.38
Surface	2009	0.39	0.34	0.31	0.24	0.18	0.82	9.93	15.12	13.26	7.00	0.98	0.13
Surface	2010*	0.09	0.08	0.08	0.07	0.05	0.52	5.04	13.34	10.70	8.04	4.22	4.43
Surface	2011*	4.42	4.33	4.30	4.32	4.21	4.03	3.91	5.17	9.39	7.08	3.09	1.68
Mid-depth	2009									13.01	6.96	3.02	2.50
Mid-depth	2010	1.97	1.55	1.42	1.34	0.82	0.53	3.91	11.89	10.53	8.03	3.80	1.90
Mid-depth	2011	0.86	**	**	**	**	**	**	**	**	**	3.87	3.84
Bottom	2008									10.90	7.05	3.93	4.18
Bottom	2009	4.31	4.39	4.51	4.52	4.52	4.30	5.49	10.66	12.95	7.02	3.91	4.39
Bottom	2010	4.66	4.67	4.70	4.74	4.71	4.47	4.64	8.37	10.52	8.06	4.21	4.40
Bottom	2011	4.41	4.30	4.25	4.29	4.16	3.97	3.82	5.15	9.42	7.05	4.17	4.23
ADMINT													
Surface	2008									10.87	6.96	2.88	1.33
Surface	2009	0.38	0.33	0.30	0.23	0.17	0.78	9.51	14.62	12.86	6.80	0.86	0.13
Surface	2010*	0.09	0.08	0.08	0.07	0.05	0.50	4.80	12.99	10.45	7.91	4.17	4.41
Surface	2011*	4.41	4.33	4.29	4.31	4.21	4.02	3.81	5.03	9.24	6.92	3.00	1.66
Mid-depth	2009									12.82	6.80	2.97	2.49
Mid-depth	2010	1.96	1.55	1.42	1.34	0.81	0.52	3.70	11.62	10.39	7.87	3.72	1.87
Mid-depth	2011	0.85	**	**	**	**	**	**	**	**	**	3.80	3.82
Bottom	2008									10.79	6.95	3.85	4.16
Bottom	2009	4.30	4.38	4.51	4.52	4.52	4.27	5.38	10.55	12.83	6.89	3.86	4.37
Bottom	2010	4.65	4.66	4.69	4.73	4.71	4.46	4.53	8.26	10.44	7.94	4.16	4.37
Bottom	2011	4.40	4.29	4.25	4.28	4.15	3.96	3.73	5.05	9.29	6.92	4.12	4.21
ADMT													
Surface	2008									11.86	7.38	3.18	1.54
Surface	2009	0.40	0.34	0.31	0.24	0.18	0.85	10.31	15.77	13.88	7.22	1.10	0.14
Surface	2010*	0.09	0.08	0.08	0.07	0.05	0.54	5.33	13.76	11.05	8.17	4.28	4.45
Surface	2011*	4.44	4.34	4.30	4.33	4.21	4.04	4.00	5.35	9.57	7.26	3.21	1.70
Mid-depth	2009									13.32	7.16	3.07	2.51
Mid-depth	2010	1.98	1.56	1.43	1.35	0.84	0.55	4.15	12.24	10.84	8.26	3.90	1.94
Mid-depth	2011	0.87	**	**	**	**	**	**	**	**	**	3.96	3.86
Bottom	2008									10.99	7.16	4.02	4.19
Bottom	2009	4.32	4.39	4.51	4.53	4.53	4.33	5.58	10.77	13.05	7.16	3.96	4.40
Bottom	2010	4.68	4.67	4.70	4.74	4.72	4.49	4.74	8.48	10.58	8.19	4.26	4.41
Bottom	2011	4.43	4.30	4.25	4.29	4.16	3.98	3.91	5.29	9.58	7.16	4.21	4.25

*Surface logger submerged 3m below surface because of lake level rise in 2010 and 2011.

**Mid-depth logger failure.

Table E6. Upper Deadwood Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									13.59	4.84	1.03	0.75
Surface	2010	1.22	1.45	1.54	1.51	0.83	0.86	9.15	16.19	11.67	6.89	1.58	1.05
Surface	2011	0.98	1.04	1.90	1.56	0.86	0.70	4.20	14.35	13.66	5.65	1.61	1.29
Mid-depth	2008										5.88	1.98	1.85
Mid-depth	2009	1.70	1.38	0.88	0.60	0.43	2.98	16.16	18.12	13.40	4.98	1.74	2.19
Mid-depth	2010	2.08	1.16	0.52	0.28	0.14	0.99	7.99	15.68	11.52	6.84	2.64	2.98
Mid-depth	2011	2.19	1.47	0.47	0.32	0.15	0.60	3.88	13.30	13.40	5.64	3.27	3.53
Bottom	2009									13.37	5.01	2.48	3.25
Bottom	2010	3.34	3.11	2.70	1.40	1.10	1.27	8.00	15.53	11.50	6.86	3.15	3.95
Bottom	2011	3.79	3.35	2.50	1.00	0.68	0.95	4.08	13.04	13.35	5.64	4.00	4.40
ADMINT													
Surface	2009									12.93	4.39	0.89	0.72
Surface	2010	1.18	1.42	1.51	1.46	0.78	0.79	7.84	15.33	11.20	6.46	1.43	1.00
Surface	2011	0.92	1.00	1.85	1.52	0.80	0.66	3.52	13.26	12.95	5.34	1.45	1.27
Mid-depth	2008										5.61	1.81	1.82
Mid-depth	2009	1.67	1.37	0.85	0.58	0.38	2.73	15.54	17.63	12.93	4.60	1.66	2.18
Mid-depth	2010	2.06	1.13	0.48	0.25	0.10	0.95	7.59	15.25	11.20	6.53	2.55	2.95
Mid-depth	2011	2.17	1.45	0.42	0.29	0.13	0.57	3.61	12.90	12.95	5.41	3.17	3.52
Bottom	2009									12.90	4.64	2.36	3.22
Bottom	2010	3.32	3.09	2.68	1.37	1.07	1.19	7.44	15.02	11.18	6.52	3.04	3.92
Bottom	2011	3.75	3.32	2.46	0.98	0.65	0.91	3.71	12.47	12.90	5.39	3.87	4.38
ADMT													
Surface	2009									14.59	5.34	1.16	0.77
Surface	2010	1.26	1.47	1.58	1.55	0.88	0.94	10.89	17.39	12.35	7.43	1.73	1.09
Surface	2011	1.04	1.07	1.96	1.60	0.90	0.74	5.00	15.97	14.79	6.01	1.77	1.30
Mid-depth	2008										6.20	2.16	1.87
Mid-depth	2009	1.73	1.40	0.90	0.63	0.48	3.35	16.93	18.69	13.91	5.31	1.82	2.21
Mid-depth	2010	2.10	1.18	0.57	0.32	0.18	1.05	8.56	16.12	11.94	7.20	2.72	3.01
Mid-depth	2011	2.21	1.49	0.52	0.35	0.18	0.64	4.29	13.85	13.89	5.93	3.35	3.56
Bottom	2009									13.87	5.35	2.60	3.27
Bottom	2010	3.37	3.13	2.71	1.43	1.12	1.35	8.56	16.02	11.91	7.25	3.26	3.98
Bottom	2011	3.83	3.37	2.54	1.03	0.71	0.99	4.46	13.58	13.87	5.94	4.11	4.42

Table E7. LH15 Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008										7.96	3.56	3.86
Surface	2009	2.19	1.99	2.14	2.01	1.29	2.14	12.89	17.12	14.53	7.51	2.82	2.30
Surface	2010	1.95	1.82	1.83	1.76	1.21	1.73	9.64	15.98	12.61	9.22	2.07	0.45
Surface	2011	0.38	0.32	0.36	0.36	0.36	0.56	4.08	12.48	14.18	7.95	2.73	1.04
Mid-depth	2009									14.27	7.41	3.70	3.84
Mid-depth	2010	3.92	4.06	4.09	4.11	4.14	4.15	8.39	15.14	12.18	8.98	3.99	3.95
Mid-depth	2011	3.85	3.79	3.78	3.56	3.19	2.25	4.26	11.77	13.54	7.79	4.15	4.14
Bottom	2008										7.70	4.09	4.27
Bottom	2009	4.27	4.32	4.44	4.46	4.49	4.54	8.62	14.68	14.01	7.28	3.94	4.23

Table E7. LH15 Lake, Mount Rainier National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bottom	2010	4.46	4.55	4.53	4.59	4.60	4.62	7.60	14.00	12.01	8.83	4.12	4.15
Bottom	2011	4.28	4.17	4.34	4.30	4.32	4.31	4.84	10.20	13.33	7.70	4.33	4.63
ADMINT													
Surface	2008										7.75	3.41	3.82
Surface	2009	2.13	1.98	2.12	1.99	1.26	1.99	12.45	16.69	14.13	7.28	2.73	2.28
Surface	2010	1.94	1.81	1.82	1.74	1.18	1.62	9.21	15.36	12.16	8.86	1.83	0.43
Surface	2011	0.36	0.31	0.35	0.35	0.33	0.50	3.29	11.17	13.50	7.70	2.47	1.02
Mid-depth	2009									14.07	7.25	3.65	3.79
Mid-depth	2010	3.89	4.05	4.08	4.09	4.13	4.03	8.11	14.91	12.06	8.84	3.88	3.91
Mid-depth	2011	3.82	3.76	3.75	3.52	3.16	2.17	3.86	11.08	13.36	7.67	4.10	4.08
Bottom	2008										7.58	3.97	4.24
Bottom	2009	4.21	4.29	4.42	4.45	4.48	4.49	8.43	14.56	13.90	7.14	3.87	4.20
Bottom	2010	4.45	4.54	4.51	4.59	4.59	4.59	7.41	13.85	11.93	8.71	4.02	4.12
Bottom	2011	4.25	4.12	4.32	4.29	4.30	4.27	4.67	9.96	13.21	7.59	4.26	4.60
ADMT													
Surface	2008										8.24	3.74	3.93
Surface	2009	2.25	2.00	2.15	2.03	1.32	2.32	13.40	17.60	14.98	7.77	2.91	2.30
Surface	2010	1.97	1.83	1.84	1.78	1.24	1.87	10.24	16.83	13.29	9.86	2.39	0.48
Surface	2011	0.40	0.34	0.37	0.37	0.38	0.62	5.09	14.07	15.20	8.36	3.03	1.06
Mid-depth	2009									14.50	7.62	3.74	3.90
Mid-depth	2010	3.96	4.07	4.10	4.13	4.15	4.25	8.76	15.41	12.37	9.18	4.10	3.98
Mid-depth	2011	3.88	3.83	3.81	3.59	3.22	2.32	4.86	12.67	13.82	7.96	4.20	4.18
Bottom	2008										7.85	4.21	4.30
Bottom	2009	4.32	4.34	4.45	4.47	4.50	4.59	8.85	14.82	14.19	7.45	4.01	4.26
Bottom	2010	4.48	4.56	4.54	4.60	4.61	4.66	7.83	14.18	12.12	9.00	4.19	4.18
Bottom	2011	4.31	4.21	4.35	4.31	4.32	4.33	5.01	10.47	13.49	7.85	4.40	4.65

Table E8. Upper Triplet Lake, North Cascades National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									10.81	4.76	4.02	3.49
Surface	2009	1.90	1.21	1.56	1.29	1.06	4.61	13.48	15.69	12.63	4.43	2.89	1.12
Surface	2010	0.67	0.79	0.90	0.96	0.87	1.17	7.97	12.55	8.89	5.10	3.55	1.40
Surface	2011	0.70	0.71	0.74	0.57	0.30	0.49	4.48	11.68	11.53	4.38	3.14	1.27
Mid-depth	2009									12.34	4.45	4.00	3.91
Mid-depth	2010	3.42	3.22	2.85	2.63	2.18	2.26	7.31	11.62	8.69	5.19	4.01	4.03
Mid-depth	2011	3.30	2.67	1.52	0.47	0.43	1.49	4.61	10.59	11.37	4.55	4.23	4.28
Bottom	2009									12.26	4.48	4.57	4.92
Bottom	2010	4.96	4.84	4.58	4.27	3.81	3.41	6.74	10.64	8.26	5.06	4.61	4.80
Bottom	2011	4.78	4.52	4.08	3.38	2.66	2.55	4.46	9.51	10.74	4.50	4.56	4.69
ADMINT													
Surface	2008									10.25	4.60	4.00	3.43
Surface	2009	1.84	1.20	1.54	1.27	1.02	4.20	12.88	14.87	11.80	4.20	2.80	1.11
Surface	2010	0.64	0.75	0.89	0.94	0.83	1.03	7.08	11.89	8.40	4.86	3.51	1.35
Surface	2011	0.68	0.68	0.69	0.55	0.26	0.40	3.99	11.06	10.90	4.21	3.07	1.24

Table E8. Upper Triplet Lake, North Cascades National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mid-depth	2009									11.79	4.29	3.97	3.88
Mid-depth	2010	3.39	3.19	2.83	2.61	2.16	2.20	6.64	11.09	8.37	5.01	3.95	4.00
Mid-depth	2011	3.28	2.64	1.49	0.45	0.41	1.45	4.24	9.92	10.85	4.39	4.20	4.25
Bottom	2009									11.70	4.31	4.53	4.91
Bottom	2010	4.95	4.82	4.57	4.26	3.80	3.38	6.05	10.11	7.93	4.87	4.58	4.79
Bottom	2011	4.78	4.52	4.06	3.37	2.65	2.54	4.15	8.84	10.26	4.33	4.52	4.68
ADMT													
Surface	2008									11.27	4.96	4.05	3.53
Surface	2009	1.94	1.21	1.58	1.31	1.10	5.09	14.10	16.87	13.86	4.73	2.98	1.14
Surface	2010	0.70	0.82	0.92	0.99	0.90	1.36	9.24	13.36	9.47	5.44	3.60	1.46
Surface	2011	0.73	0.74	0.79	0.58	0.32	0.57	5.09	12.56	12.33	4.65	3.23	1.30
Mid-depth	2009									12.94	4.64	4.04	3.93
Mid-depth	2010	3.47	3.24	2.86	2.64	2.19	2.35	8.00	12.22	9.05	5.43	4.06	4.06
Mid-depth	2011	3.33	2.69	1.55	0.48	0.46	1.52	5.03	11.33	11.86	4.78	4.26	4.29
Bottom	2009									12.81	4.70	4.61	4.94
Bottom	2010	4.97	4.85	4.58	4.28	3.82	3.44	7.44	11.18	8.62	5.30	4.64	4.80
Bottom	2011	4.79	4.53	4.09	3.40	2.67	2.56	4.79	10.20	11.26	4.69	4.59	4.69

Table E9. Bowan Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									13.16	3.61	0.71	0.41
Surface	2010	0.49	0.42	0.44	0.43	0.34	0.33	6.35	15.13	10.16	5.91	0.84	0.79
Surface	2011	0.59	0.56	0.43	0.19	0.11	0.17	0.67	11.00	12.19	4.53	2.53	0.32
Mid-depth	2009									12.62	4.59	3.96	3.53
Mid-depth	2010	3.04	2.55	2.41	2.20	1.59	0.88	6.30	14.52	9.92	6.36	4.00	3.23
Mid-depth	2011	2.52	1.49	0.49	0.24	0.18	0.39	1.13	10.38	12.00	4.62	3.85	2.60
Bottom	2009									12.49	4.75	4.62	4.85
Bottom	2010	4.85	4.64	4.25	3.74	3.10	2.58	6.49	14.26	9.66	6.28	4.27	4.58
Bottom	2011	4.37	3.62	1.69	0.32	0.27	0.68	2.17	9.93	11.73	4.68	4.22	4.43
ADMINT													
Surface	2009									12.10	3.06	0.64	0.40
Surface	2010	0.47	0.40	0.41	0.39	0.29	0.26	5.18	13.94	9.36	5.29	0.77	0.74
Surface	2011	0.55	0.51	0.39	0.16	0.09	0.13	0.50	9.55	11.40	4.15	2.37	0.29
Mid-depth	2009									12.07	4.32	3.91	3.50
Mid-depth	2010	3.01	2.53	2.38	2.16	1.55	0.84	5.87	13.94	9.44	5.95	3.95	3.20
Mid-depth	2011	2.47	1.46	0.46	0.21	0.16	0.34	1.01	9.71	11.37	4.24	3.77	2.55
Bottom	2009									11.91	4.46	4.57	4.81
Bottom	2010	4.81	4.63	4.24	3.72	3.09	2.57	5.97	13.62	9.19	5.88	4.22	4.57
Bottom	2011	4.35	3.60	1.64	0.29	0.24	0.64	2.07	9.24	11.14	4.33	4.17	4.42
ADMT													
Surface	2009									14.99	4.27	0.78	0.42
Surface	2010	0.50	0.43	0.47	0.47	0.39	0.38	8.00	16.94	11.47	6.90	0.96	0.83
Surface	2011	0.63	0.60	0.48	0.24	0.13	0.20	0.89	13.15	13.11	4.99	2.74	0.34
Mid-depth	2009									13.14	4.93	4.01	3.57
Mid-depth	2010	3.07	2.57	2.43	2.24	1.62	0.91	6.76	15.11	10.51	6.82	4.06	3.28
Mid-depth	2011	2.57	1.54	0.54	0.29	0.19	0.42	1.26	11.03	12.54	5.11	3.91	2.66

Table E9. Bowan Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bottom	2009									12.95	5.04	4.66	4.88
Bottom	2010	4.87	4.64	4.25	3.75	3.11	2.60	6.99	14.81	10.07	6.63	4.34	4.60
Bottom	2011	4.39	3.64	1.74	0.38	0.30	0.71	2.30	10.60	12.23	5.01	4.26	4.44

Table E10. Lower Silent Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									11.85	4.03	0.01	-0.09
Surface	2010	-0.08	-0.07	-0.06	-0.02	0.04	-0.02	0.36	8.04	8.63	6.22	2.52	1.18
Surface	2011	0.52	0.49	0.36	0.24	0.29	0.21	0.45	2.36	8.75	3.98	2.00	0.51
Mid-depth	2009									11.57	4.93	3.78	3.55
Mid-depth	2010	3.68	3.76	3.83	3.87	3.62	2.91	1.84	7.10	8.39	6.20	3.78	3.92
Mid-depth	2011	3.95	3.99	4.05	4.10	4.02	3.42	2.20	2.75	8.13	4.32	3.75	3.46
Bottom	2009									11.38	5.09	4.05	4.19
Bottom	2010	4.24	4.40	4.47	4.48	4.50	4.45	4.55	7.03	8.27	6.24	4.09	4.16
Bottom	2011	4.46	4.56	4.54	4.49	4.47	4.42	4.34	4.75	8.11	4.61	4.03	4.14
ADMINT													
Surface	2009									11.28	3.62	-0.02	-0.09
Surface	2010	-0.09	-0.08	-0.06	-0.03	0.03	-0.04	0.19	7.24	8.27	5.88	2.46	1.14
Surface	2011	0.50	0.47	0.34	0.23	0.26	0.17	0.40	1.94	8.11	3.64	1.94	0.49
Mid-depth	2009									11.37	4.75	3.72	3.54
Mid-depth	2010	3.67	3.76	3.82	3.86	3.60	2.86	1.77	6.80	8.22	6.04	3.74	3.91
Mid-depth	2011	3.95	3.98	4.04	4.10	4.02	3.39	2.16	2.50	7.58	4.11	3.70	3.45
Bottom	2009									11.16	4.89	3.97	4.19
Bottom	2010	4.23	4.39	4.46	4.48	4.49	4.45	4.51	6.72	8.08	6.07	4.00	4.14
Bottom	2011	4.45	4.56	4.53	4.49	4.47	4.42	4.33	4.50	7.55	4.43	3.97	4.14
ADMT													
Surface	2009									12.91	4.42	0.15	-0.09
Surface	2010	-0.08	-0.07	-0.06	-0.02	0.04	-0.01	0.59	9.17	9.18	6.72	2.62	1.23
Surface	2011	0.55	0.51	0.39	0.25	0.31	0.23	0.50	2.82	9.78	4.26	2.08	0.52
Mid-depth	2009									11.78	5.14	3.82	3.56
Mid-depth	2010	3.68	3.76	3.83	3.89	3.63	2.95	1.91	7.45	8.64	6.44	3.84	3.93
Mid-depth	2011	3.95	4.00	4.06	4.10	4.03	3.44	2.24	3.08	8.98	4.52	3.79	3.46
Bottom	2009									11.65	5.33	4.10	4.20
Bottom	2010	4.25	4.40	4.47	4.48	4.50	4.46	4.58	7.32	8.46	6.46	4.19	4.19
Bottom	2011	4.47	4.57	4.54	4.49	4.48	4.42	4.35	5.03	8.95	4.84	4.07	4.15

Table E11. Lower Blum Lake, North Cascades National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									9.55	5.34	2.18	1.10
Surface	2009	1.13	1.39	1.63	1.49	1.18	1.65	7.94	12.87	12.28	5.84	1.71	1.33
Surface	2010	1.52	1.49	1.78	1.90	1.59	1.50	5.57	10.73	8.96	6.28	2.42	1.55
Surface	2011	1.38	1.73	2.05	2.05	1.22	0.95	1.48	4.65	8.11	4.22	1.73	1.50
Mid-depth	2009									11.88	5.80	3.11	3.41
Mid-depth	2010	3.58	3.72	3.85	4.03	4.01	2.25	5.29	10.25	8.58	6.10	3.71	3.42
Mid-depth	2011	3.54	3.75	3.94	4.07	4.08	3.59	1.67	4.55	7.77	4.33	3.90	3.98
Bottom	2008									8.84	5.15	3.25	3.38
Bottom	2009	3.68	3.76	3.80	3.79	3.75	3.62	6.88	11.94	11.68	5.74	3.81	4.21
Bottom	2010	4.34	4.39	4.37	4.33	4.28	4.15	5.59	10.05	8.39	5.97	4.10	4.28
Bottom	2011	4.31	4.36	4.28	4.30	4.24	4.13	3.16	4.69	7.64	4.45	4.26	4.30
ADMINT													
Surface	2008									9.07	5.03	1.96	1.06
Surface	2009	1.11	1.38	1.62	1.47	1.12	1.52	7.36	12.38	11.86	5.60	1.58	1.31
Surface	2010	1.48	1.48	1.76	1.86	1.55	1.36	5.13	10.28	8.63	5.99	2.28	1.50
Surface	2011	1.33	1.71	2.02	2.02	1.15	0.90	1.37	4.28	7.74	4.03	1.66	1.47
Mid-depth	2009									11.67	5.65	3.07	3.40
Mid-depth	2010	3.57	3.71	3.84	4.01	4.00	2.14	5.06	10.01	8.40	5.95	3.60	3.38
Mid-depth	2011	3.52	3.74	3.93	4.06	4.07	3.51	1.61	4.36	7.56	4.22	3.88	3.96
Bottom	2008									8.67	5.00	3.12	3.36
Bottom	2009	3.66	3.75	3.79	3.78	3.74	3.55	6.60	11.72	11.46	5.56	3.74	4.19
Bottom	2010	4.32	4.38	4.37	4.32	4.26	4.09	5.35	9.80	8.25	5.86	4.00	4.25
Bottom	2011	4.30	4.36	4.28	4.29	4.23	4.11	3.00	4.47	7.42	4.35	4.23	4.30
ADMT													
Surface	2008									10.15	5.73	2.43	1.15
Surface	2009	1.15	1.40	1.64	1.50	1.23	1.78	8.75	13.55	12.99	6.28	1.85	1.35
Surface	2010	1.55	1.50	1.79	1.93	1.64	1.62	5.98	11.27	9.48	6.73	2.60	1.60
Surface	2011	1.42	1.75	2.08	2.07	1.27	1.02	1.60	5.21	8.70	4.43	1.79	1.51
Mid-depth	2009									12.14	5.98	3.15	3.42
Mid-depth	2010	3.60	3.73	3.85	4.05	4.03	2.37	5.58	10.59	8.84	6.29	3.84	3.45
Mid-depth	2011	3.56	3.76	3.95	4.08	4.10	3.67	1.75	4.82	8.05	4.45	3.92	3.99
Bottom	2008									9.05	5.36	3.36	3.41
Bottom	2009	3.70	3.76	3.80	3.80	3.76	3.69	7.23	12.26	11.98	5.97	3.88	4.23
Bottom	2010	4.37	4.39	4.37	4.35	4.31	4.19	5.87	10.37	8.62	6.14	4.18	4.30
Bottom	2011	4.33	4.37	4.29	4.30	4.25	4.15	3.31	5.03	7.97	4.55	4.28	4.32

Table E12. Lower East Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									10.60	5.31	1.56	1.20
Surface	2010	0.88	0.97	1.22	1.13	0.68	0.54	2.87	9.51	8.93	6.23	2.00	1.02
Surface	2011	0.83	0.84	1.09	1.16	0.74	0.49	0.74	3.08	6.99	3.73	1.22	0.35
Mid-depth	2009									9.55	5.39	3.72	3.84
Mid-depth	2010	3.86	3.85	3.82	3.72	3.61	3.56	3.93	7.27	8.31	6.04	3.06	3.22
Mid-depth	2011	3.29	3.31	3.29	3.31	3.28	3.24	3.19	3.89	6.07	4.08	3.84	3.62

Table E12. Lower East Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bottom	2009									9.00	5.38	4.10	4.34
Bottom	2010	4.37	4.39	4.42	4.39	4.42	4.32	4.22	5.72	7.46	5.90	3.26	3.52
Bottom	2011	3.63	3.66	3.71	3.69	3.72	3.75	3.75	4.30	5.93	4.09	3.91	3.81
ADMINT													
Surface	2009									10.18	5.05	1.50	1.19
Surface	2010	0.86	0.96	1.20	1.09	0.64	0.48	2.49	8.95	8.59	6.00	1.87	0.98
Surface	2011	0.80	0.83	1.04	1.14	0.70	0.44	0.67	2.71	6.57	3.34	1.18	0.33
Mid-depth	2009									9.39	5.27	3.71	3.83
Mid-depth	2010	3.84	3.80	3.76	3.70	3.60	3.56	3.83	7.03	8.18	5.95	3.02	3.21
Mid-depth	2011	3.28	3.29	3.26	3.30	3.27	3.23	3.18	3.76	5.90	3.95	3.82	3.61
Bottom	2009									8.92	5.25	4.07	4.33
Bottom	2010	4.36	4.38	4.41	4.38	4.41	4.28	4.18	5.66	7.39	5.80	3.21	3.51
Bottom	2011	3.62	3.65	3.68	3.68	3.71	3.73	3.72	4.18	5.81	4.00	3.87	3.78
ADMT													
Surface	2009									11.18	5.74	1.64	1.22
Surface	2010	0.89	0.98	1.24	1.16	0.71	0.60	3.33	10.28	9.47	6.57	2.16	1.07
Surface	2011	0.85	0.86	1.14	1.19	0.77	0.55	0.80	3.53	7.60	4.13	1.30	0.38
Mid-depth	2009									9.75	5.51	3.73	3.86
Mid-depth	2010	3.87	3.88	3.92	3.75	3.62	3.56	4.06	7.55	8.51	6.17	3.11	3.23
Mid-depth	2011	3.30	3.32	3.30	3.32	3.30	3.24	3.20	4.06	6.27	4.20	3.86	3.64
Bottom	2009									9.10	5.50	4.11	4.35
Bottom	2010	4.38	4.40	4.42	4.40	4.43	4.35	4.27	5.80	7.62	6.01	3.32	3.53
Bottom	2011	3.64	3.68	3.72	3.69	3.73	3.76	3.77	4.41	6.05	4.15	3.93	3.82

Table E13. Easy Ridge Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009									12.07	3.16	0.46	0.31
Surface	2010	0.70	0.59	0.71	0.64	0.30	0.10	0.79	8.20	8.02	5.04	0.34	0.29
Surface	2011	0.47	0.64	0.77	0.24	0.16	0.14	0.23	0.99	6.31	2.39	0.19	0.28
Mid-depth	2009									11.48	3.82	3.23	3.69
Mid-depth	2010	3.04	1.94	1.04	0.13	-0.02	-0.02	1.25	7.49	7.60	5.35	3.78	3.50
Mid-depth	2011	2.93	1.14	0.52	0.00	-0.04	-0.05	0.18	1.90	6.09	3.64	3.58	3.42
Bottom	2009									11.47	4.38	4.27	4.41
Bottom	2010	4.11	3.49	2.68	0.75	0.12	0.23	1.76	7.44	7.47	5.72	4.16	4.19
Bottom	2011	3.91	3.15	1.18	0.09	0.06	0.03	0.26	2.64	5.92	4.07	3.92	3.68
ADMINT													
Surface	2009									11.04	2.61	0.41	0.29
Surface	2010	0.65	0.58	0.68	0.61	0.28	0.09	0.60	6.98	7.28	4.57	0.29	0.27
Surface	2011	0.41	0.60	0.75	0.24	0.16	0.14	0.20	0.65	5.41	1.91	0.16	0.26
Mid-depth	2009									10.85	3.41	3.19	3.67
Mid-depth	2010	3.02	1.93	1.01	0.11	-0.03	-0.03	1.14	6.86	7.16	5.00	3.73	3.46
Mid-depth	2011	2.91	1.10	0.50	-0.01	-0.05	-0.06	0.15	1.67	5.56	3.30	3.53	3.40
Bottom	2009									10.81	4.01	4.24	4.40
Bottom	2010	4.10	3.48	2.67	0.71	0.11	0.20	1.68	6.79	6.95	5.39	4.12	4.18
Bottom	2011	3.90	3.13	1.15	0.08	0.04	0.02	0.23	2.46	5.35	3.71	3.90	3.68

Table E13. Easy Ridge Lake, North Cascades National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADMT													
Surface	2009									13.53	3.80	0.52	0.32
Surface	2010	0.75	0.61	0.73	0.67	0.32	0.11	0.96	9.95	9.08	5.63	0.39	0.31
Surface	2011	0.53	0.68	0.80	0.25	0.17	0.14	0.26	1.38	7.58	2.97	0.23	0.30
Mid-depth	2009									12.13	4.27	3.27	3.70
Mid-depth	2010	3.06	1.96	1.06	0.15	-0.01	-0.01	1.36	8.18	8.09	5.70	3.83	3.52
Mid-depth	2011	2.96	1.19	0.55	0.00	-0.03	-0.04	0.21	2.19	6.67	4.09	3.62	3.44
Bottom	2009									12.07	4.75	4.29	4.42
Bottom	2010	4.12	3.50	2.70	0.79	0.13	0.26	1.89	8.03	7.93	6.03	4.22	4.19
Bottom	2011	3.92	3.17	1.22	0.09	0.08	0.04	0.28	2.95	6.50	4.47	3.93	3.69

Table E14. Ferry Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									11.91	6.95	2.33	0.33
Surface	2009	0.07	0.05	0.05	0.05	0.05	0.35	15.02	18.21	14.76	7.74	1.28	0.21
Surface	2010	0.38	0.57	0.54	0.42	0.30	0.17	1.81	13.95	11.92	7.55	1.86	1.17
Surface	2011	0.77	0.54	0.54	0.38	0.20	0.13	0.27	3.39	10.89	6.44	1.09	0.35
Mid-depth	2008									11.10	6.88	3.50	3.40
Mid-depth	2009	3.57	3.67	3.76	3.87	3.87	3.82	9.66	16.96	14.32	7.62	3.97	4.10
Mid-depth	2010	4.19	4.31	4.39	4.42	4.36	4.24	4.01	9.22	11.53	7.52	3.87	4.08
Mid-depth	2011	4.10	4.15	4.18	4.19	4.11	3.88	2.93	3.68	8.86	6.31	3.79	3.98
Bottom	2008									10.12	6.90	4.10	4.28
Bottom	2009	4.55	4.73	4.89	4.99	4.95	4.60	7.35	13.84	14.29	7.67	4.35	4.75
Bottom	2010	4.91	5.08	5.25	5.29	5.22	5.08	4.66	7.31	10.71	7.57	4.33	4.68
Bottom	2011	4.86	5.02	5.22	5.23	5.19	5.15	4.75	4.72	7.91	6.40	4.30	4.51
ADMINT													
Surface	2008									11.21	6.76	2.02	0.27
Surface	2009	0.05	0.05	0.05	0.05	0.05	0.05	13.45	17.54	14.22	7.54	1.16	0.20
Surface	2010	0.36	0.55	0.52	0.39	0.28	0.15	1.51	12.82	11.53	7.28	1.61	1.09
Surface	2011	0.72	0.51	0.51	0.36	0.19	0.12	0.25	2.75	10.12	6.29	0.98	0.34
Mid-depth	2008									10.92	6.77	3.42	3.39
Mid-depth	2009	3.56	3.67	3.76	3.87	3.87	3.77	9.30	16.71	14.16	7.51	3.92	4.09
Mid-depth	2010	4.17	4.31	4.38	4.42	4.35	4.22	3.96	8.97	11.44	7.42	3.84	4.07
Mid-depth	2011	4.10	4.15	4.16	4.18	4.10	3.85	2.88	3.55	8.66	6.23	3.77	3.97
Bottom	2008									10.03	6.80	4.04	4.27
Bottom	2009	4.54	4.72	4.89	4.98	4.95	4.53	7.20	13.72	14.16	7.57	4.30	4.74
Bottom	2010	4.89	5.07	5.25	5.29	5.22	5.07	4.58	7.19	10.63	7.47	4.27	4.67
Bottom	2011	4.85	5.01	5.21	5.23	5.19	5.14	4.73	4.62	7.82	6.33	4.25	4.51
ADMT													
Surface	2008									13.16	7.20	2.57	0.41
Surface	2009	0.09	0.05	0.06	0.05	0.05	0.86	17.10	19.24	15.80	8.07	1.41	0.22
Surface	2010	0.41	0.58	0.57	0.44	0.31	0.18	2.15	15.53	12.55	7.96	2.07	1.23
Surface	2011	0.82	0.57	0.57	0.40	0.21	0.15	0.28	4.17	12.16	6.67	1.26	0.35
Mid-depth	2008									11.30	7.02	3.58	3.41
Mid-depth	2009	3.57	3.67	3.77	3.87	3.88	3.86	10.07	17.24	14.47	7.74	4.01	4.10

Table E14. Ferry Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mid-depth	2010	4.20	4.31	4.41	4.42	4.36	4.25	4.08	9.50	11.63	7.65	3.90	4.10
Mid-depth	2011	4.11	4.15	4.19	4.20	4.13	3.89	2.96	3.83	9.12	6.41	3.81	3.98
Bottom	2008									10.23	7.03	4.14	4.29
Bottom	2009	4.55	4.73	4.90	4.99	4.95	4.66	7.50	13.98	14.44	7.81	4.40	4.76
Bottom	2010	4.93	5.08	5.26	5.30	5.23	5.09	4.73	7.42	10.80	7.70	4.38	4.69
Bottom	2011	4.88	5.02	5.22	5.23	5.19	5.15	4.77	4.82	8.03	6.50	4.33	4.52

Table E15. Gladys Lake, Olympic National Park, 2009-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2009										4.15	1.58	1.87
Surface	2010	1.45	1.43	1.09	1.17	1.87	2.48	7.41	10.91	8.89	4.45	2.04	1.04
Surface	2011	1.69	2.17	0.60	0.05	0.05	0.56	3.09	9.20	9.65	3.70	1.44	0.78
Mid-depth	2009										4.06	2.79	2.81
Mid-depth	2010	2.80	2.71	2.58	2.52	2.56	2.62	4.15	5.24	6.93	4.57	3.17	2.81
Mid-depth	2011	2.55	2.62	1.37	0.60	0.43	1.23	2.89	5.92	7.76	3.89	3.13	2.73
Bottom	2009										4.10	2.93	2.92
Bottom	2010	2.88	2.86	2.57	2.54	2.59	2.55	4.11	4.39	5.08	4.03	3.29	2.83
Bottom	2011	2.60	2.75	1.95	1.60	1.37	1.69	2.72	4.40	5.44	3.97	3.17	2.63
ADMINT													
Surface	2009										3.72	1.29	1.79
Surface	2010	1.16	1.40	1.00	1.13	1.82	2.40	6.03	9.57	8.26	4.09	1.81	0.92
Surface	2011	1.53	2.11	0.54	0.05	0.05	0.44	2.91	7.94	8.74	3.28	1.29	0.75
Mid-depth	2009										3.76	2.67	2.79
Mid-depth	2010	2.78	2.67	2.51	2.52	2.53	2.56	3.65	4.79	6.61	4.34	3.12	2.78
Mid-depth	2011	2.50	2.61	1.32	0.57	0.38	1.15	2.81	5.46	7.39	3.64	3.10	2.73
Bottom	2009										3.84	2.80	2.88
Bottom	2010	2.84	2.85	2.48	2.53	2.57	2.51	3.62	3.95	4.64	3.73	3.23	2.79
Bottom	2011	2.55	2.74	1.87	1.55	1.11	1.49	2.66	3.96	4.94	3.70	3.09	2.61
ADMT													
Surface	2009										4.57	1.91	1.94
Surface	2010	1.76	1.45	1.19	1.21	1.92	2.54	9.31	12.64	9.71	5.00	2.29	1.13
Surface	2011	1.79	2.25	0.67	0.05	0.05	0.64	3.39	10.77	10.79	4.18	1.66	0.80
Mid-depth	2009										4.33	2.88	2.83
Mid-depth	2010	2.82	2.73	2.61	2.53	2.58	2.69	4.67	5.82	7.36	4.86	3.21	2.83
Mid-depth	2011	2.58	2.63	1.42	0.63	0.47	1.30	3.02	6.47	8.22	4.26	3.18	2.73
Bottom	2009										4.36	3.03	2.95
Bottom	2010	2.91	2.88	2.68	2.54	2.60	2.60	4.70	4.92	5.55	4.34	3.36	2.87
Bottom	2011	2.64	2.77	2.03	1.62	1.52	1.83	2.82	4.98	6.07	4.31	3.26	2.66

Table E16. Heather Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008										3.57	1.58	0.33
Surface	2009	0.13	0.08	0.08	0.08	0.09	3.04	10.35	13.19	10.02	3.90	0.42	0.71
Surface	2010	0.86	0.77	0.66	0.57	0.80	1.13	1.98	3.47	4.08	2.52	0.68	0.10
Surface	2011	0.02	0.53	0.41	0.15	0.53	1.03	1.28	2.23	3.59	1.87	0.18	0.07
Mid-depth	2008										4.28	2.23	2.61
Mid-depth	2009	2.99	3.03	2.91	2.73	2.22	3.65	8.14	*	*	4.02	1.71	1.68
Mid-depth	2010	1.41	1.43	1.82	1.51	0.91	1.22	2.28	3.55	3.95	3.10	1.24	0.63
Mid-depth	2011	-0.05	0.27	0.51	0.35	0.62	1.01	1.41	3.43	3.76	2.84	3.78	3.08
Bottom	2008										4.37	2.76	3.34
Bottom	2009	3.42	3.56	3.46	3.36	3.34	4.19	7.87	11.70	8.97	4.16	2.69	3.12
Bottom	2010	3.19	2.96	2.90	2.73	2.12	1.51	3.26	4.01	4.11	3.44	2.34	1.63
Bottom	2011	0.44	0.92	0.74	0.66	0.77	1.13	1.46	3.25	4.04	3.30	4.20	3.90
ADMINT													
Surface	2008										2.95	1.15	0.22
Surface	2009	0.11	0.07	0.08	0.07	0.06	2.21	8.20	11.93	9.21	3.37	0.22	0.65
Surface	2010	0.78	0.76	0.66	0.55	0.77	1.00	1.56	2.78	3.52	2.03	0.51	0.09
Surface	2011	0.02	0.50	0.39	0.14	0.48	0.94	1.13	1.75	2.87	1.33	0.10	0.06
Mid-depth	2008										3.98	1.98	2.58
Mid-depth	2009	2.92	3.00	2.87	2.73	2.08	3.16	7.65	*	*	3.73	1.62	1.66
Mid-depth	2010	1.35	1.41	1.80	1.46	0.89	1.12	1.95	3.14	3.62	2.85	1.16	0.56
Mid-depth	2011	-0.10	0.24	0.49	0.35	0.60	1.00	1.38	3.26	3.40	2.60	3.74	3.07
Bottom	2008										4.07	2.51	3.31
Bottom	2009	3.41	3.55	3.46	3.35	3.33	3.89	7.46	11.35	8.64	3.87	2.52	3.11
Bottom	2010	3.17	2.96	2.90	2.73	2.11	1.41	3.00	3.62	3.79	3.19	2.20	1.58
Bottom	2011	0.42	0.92	0.73	0.66	0.76	1.12	1.44	3.18	3.63	3.00	4.11	3.86
ADMT													
Surface	2008										4.20	1.98	0.46
Surface	2009	0.16	0.10	0.09	0.09	0.15	4.12	13.33	14.89	11.11	4.47	0.56	0.75
Surface	2010	0.94	0.78	0.67	0.58	0.83	1.26	2.62	4.39	4.75	3.01	0.86	0.14
Surface	2011	0.02	0.57	0.42	0.16	0.57	1.10	1.53	2.86	4.50	2.44	0.32	0.11
Mid-depth	2008										4.66	2.48	2.67
Mid-depth	2009	3.02	3.03	2.94	2.73	2.32	4.29	8.82	*	*	4.31	1.79	1.71
Mid-depth	2010	1.44	1.45	1.83	1.54	0.94	1.33	2.68	4.00	4.29	3.35	1.34	0.67
Mid-depth	2011	0.01	0.32	0.52	0.36	0.63	1.02	1.46	3.65	4.09	3.16	3.86	3.11
Bottom	2008										4.69	3.02	3.38
Bottom	2009	3.44	3.58	3.47	3.37	3.35	4.53	8.19	11.96	9.28	4.44	2.80	3.13
Bottom	2010	3.21	2.97	2.91	2.74	2.13	1.64	3.67	4.57	4.44	3.71	2.46	1.67
Bottom	2011	0.45	0.93	0.74	0.66	0.78	1.13	1.47	3.40	4.78	3.70	4.32	3.95

*Mid-depth logger battery failure.

Table E17. Crazy Lake, Olympic National Park, 2010-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2010									9.50	5.21	1.93	1.85
Surface	2011	1.04	1.43	1.58	0.77	0.65	0.42	0.84	3.44	8.61	3.61	0.99	0.60

Table E17. Crazy Lake, Olympic National Park, 2010-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mid-depth	2010									8.87	5.56	3.87	3.70
Mid-depth	2011	3.73	3.74	4.13	4.34	4.04	2.58	1.57	3.63	7.48	3.95	3.52	3.44
Bottom	2010									8.74	5.68	4.39	4.57
Bottom	2011	4.77	4.81	4.76	4.72	4.60	4.40	3.79	4.55	7.37	4.22	4.13	4.09
ADMINT													
Surface	2010									9.08	4.99	1.83	1.75
Surface	2011	0.99	1.40	1.50	0.74	0.62	0.37	0.80	2.87	7.99	3.26	0.88	0.59
Mid-depth	2010									8.76	5.47	3.83	3.66
Mid-depth	2011	3.71	3.73	4.12	4.32	4.02	2.54	1.54	3.44	7.32	3.82	3.49	3.43
Bottom	2010									8.63	5.58	4.36	4.54
Bottom	2011	4.75	4.81	4.75	4.71	4.60	4.39	3.76	4.29	7.18	4.06	4.09	4.08
ADMT													
Surface	2010									10.11	5.60	2.04	1.96
Surface	2011	1.10	1.48	1.64	0.78	0.67	0.45	0.88	4.20	9.55	3.94	1.08	0.62
Mid-depth	2010									9.01	5.69	3.90	3.72
Mid-depth	2011	3.76	3.76	4.15	4.37	4.06	2.61	1.58	3.82	7.67	4.08	3.55	3.45
Bottom	2010									9.69	8.02	4.54	4.74
Bottom	2011	4.84	4.84	4.80	4.74	4.69	4.50	4.29	6.34	8.25	5.93	4.25	4.17

Table E18. Milk Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008										4.61	2.10	1.24
Surface	2009	0.44	0.37	0.31	0.22	0.38	1.13	11.77	14.06	11.70	5.42	0.78	0.15
Surface	2010	0.24	0.17	0.16	0.10	0.15	0.29	0.87	1.61	4.88	4.22	0.59	0.07
Surface	2011	0.02	0.02	0.01	0.00	0.00	0.00	0.02	0.07	0.35	0.71	0.19	0.09
Mid-depth	2008										4.40	2.89	2.50
Mid-depth	2009	2.53	2.60	2.60	2.53	2.62	2.63	4.65	5.46	6.03	5.18	3.41	3.37
Mid-depth	2010	3.37	3.37	3.37	3.38	3.37	3.22	2.86	2.73	3.67	4.05	3.40	3.35
Mid-depth	2011	3.35	3.26	3.25	3.26	3.18	2.80	2.26	2.20	2.25	2.30	2.36	2.41
Bottom	2008										4.40	3.12	3.02
Bottom	2009	3.10	3.14	3.16	3.17	3.11	3.03	3.77	4.41	4.72	4.63	3.58	3.65
Bottom	2010	3.64	3.64	3.63	3.62	3.60	3.58	3.54	3.51	3.43	3.52	3.54	3.51
Bottom	2011	3.51	3.49	3.49	3.48	3.46	3.45	3.40	3.38	3.36	3.34	3.33	3.35
ADMINT													
Surface	2008										4.11	1.71	1.16
Surface	2009	0.42	0.37	0.30	0.21	0.35	1.03	10.69	13.44	11.11	5.06	0.55	0.15
Surface	2010	0.22	0.15	0.15	0.09	0.13	0.26	0.81	1.40	4.18	3.75	0.48	0.05
Surface	2011	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.05	0.23	0.43	0.15	0.08
Mid-depth	2008										4.31	2.86	2.50
Mid-depth	2009	2.52	2.58	2.60	2.52	2.60	2.61	4.54	5.38	5.96	5.08	3.39	3.37
Mid-depth	2010	3.37	3.37	3.37	3.37	3.37	3.21	2.85	2.73	3.52	3.97	3.37	3.34
Mid-depth	2011	3.35	3.26	3.24	3.26	3.18	2.79	2.25	2.20	2.22	2.25	2.35	2.41
Bottom	2008										4.33	3.07	3.01
Bottom	2009	3.09	3.14	3.16	3.17	3.09	3.03	3.74	4.38	4.69	4.60	3.54	3.65
Bottom	2010	3.63	3.64	3.63	3.61	3.59	3.57	3.54	3.51	3.42	3.51	3.53	3.51
Bottom	2011	3.51	3.49	3.49	3.47	3.46	3.45	3.39	3.38	3.36	3.33	3.32	3.34

Table E18. Milk Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT) (continued).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADMT													
Surface	2008										5.07	2.43	1.35
Surface	2009	0.46	0.38	0.32	0.23	0.41	1.26	13.09	14.89	12.52	5.85	1.01	0.16
Surface	2010	0.27	0.18	0.17	0.11	0.17	0.31	0.91	1.84	5.60	4.84	0.76	0.09
Surface	2011	0.03	0.02	0.01	0.00	0.00	0.02	0.02	0.08	0.50	1.19	0.28	0.11
Mid-depth	2008										4.51	2.91	2.52
Mid-depth	2009	2.55	2.62	2.61	2.57	2.62	2.65	4.78	5.54	6.09	5.26	3.43	3.37
Mid-depth	2010	3.37	3.37	3.37	3.42	3.37	3.23	2.86	2.76	3.81	4.10	3.44	3.35
Mid-depth	2011	3.35	3.26	3.26	3.26	3.19	2.82	2.27	2.20	2.28	2.33	2.37	2.41
Bottom	2008										4.48	3.16	3.03
Bottom	2009	3.11	3.15	3.17	3.17	3.12	3.04	3.83	4.45	4.75	4.67	3.60	3.66
Bottom	2010	3.64	3.64	3.63	3.62	3.60	3.58	3.54	3.51	3.44	3.54	3.54	3.51
Bottom	2011	3.51	3.49	3.49	3.49	3.46	3.45	3.41	3.38	3.37	3.35	3.34	3.35

Table E19. LaCrosse Lake, Olympic National Park, 2010-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2010										6.52	0.74	0.20
Surface	2011	0.20	0.29	0.33	0.35	0.28	0.34	0.55	1.28	8.13	4.75	1.10	0.24
Mid-depth	2010										6.89	3.96	2.83
Mid-depth	2011	2.94	2.90	3.60	3.85	3.77	3.14	1.61	1.96	7.19	4.65	3.73	3.49
Bottom	2010										5.79	3.53	3.27
Bottom	2011	3.06	3.27	3.21	3.09	2.96	2.79	2.58	2.19	5.67	3.67	3.16	3.17
ADMINT													
Surface	2010										6.12	0.56	0.15
Surface	2011	0.17	0.27	0.31	0.33	0.25	0.29	0.48	0.97	7.26	4.44	0.93	0.21
Mid-depth	2010										6.72	3.85	2.72
Mid-depth	2011	2.89	2.87	3.57	3.84	3.76	3.10	1.53	1.85	6.91	4.47	3.65	3.47
Bottom	2010										5.63	3.46	3.21
Bottom	2011	3.03	3.27	3.20	3.09	2.96	2.78	2.56	2.09	5.41	3.50	3.07	3.16
ADMT													
Surface	2010										7.07	0.95	0.26
Surface	2011	0.23	0.31	0.36	0.38	0.31	0.38	0.62	1.61	9.28	5.25	1.29	0.27
Mid-depth	2010										7.08	4.05	2.93
Mid-depth	2011	2.97	2.92	3.62	3.85	3.78	3.16	1.68	2.09	7.50	4.86	3.81	3.50
Bottom	2010										5.98	3.59	3.31
Bottom	2011	3.09	3.27	3.21	3.09	2.97	2.79	2.59	2.30	6.00	3.88	3.23	3.18

Table E20. Sunup Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008									14.26	7.34	2.69	0.91
Surface	2009	0.31	0.33	0.67	0.54	0.58	3.36	18.23	20.15	15.73	8.45	2.75	1.74
Surface	2010	1.99	2.24	2.61	2.22	1.17	0.92	2.65	15.77	13.38	8.06	2.51	1.93
Surface	2011	1.68	2.04	3.29	2.27	0.98	0.61	0.74	2.10	11.55	6.65	1.99	0.63
Mid-depth	2008									13.63	7.06	3.87	3.70
Mid-depth	2009	3.91	3.67	3.72	3.87	3.48	3.38	15.04	19.66	15.12	8.17	3.98	3.88
Mid-depth	2010	4.01	4.08	4.37	4.87	4.58	3.34	2.71	11.75	12.85	7.78	3.89	3.91
Mid-depth	2011	3.98	3.86	4.27	4.17	3.53	2.76	1.58	2.29	9.20	6.27	3.93	3.73
Bottom	2008									13.55	7.00	4.10	4.22
Bottom	2009	4.56	4.12	4.58	4.79	4.71	4.36	14.25	19.36	15.12	8.18	4.26	4.06
Bottom	2010	4.62	4.97	5.04	4.94	4.75	4.50	3.88	11.53	12.83	7.78	4.15	4.44
Bottom	2011	4.73	4.83	4.57	4.27	3.64	3.18	3.09	3.17	9.07	6.25	4.16	3.89
ADMINT													
Surface	2008									13.49	6.95	2.29	0.70
Surface	2009	0.24	0.30	0.62	0.50	0.57	2.90	16.87	19.51	15.08	8.16	2.47	1.62
Surface	2010	1.85	2.11	2.55	2.11	1.11	0.87	2.43	14.75	12.92	7.62	2.27	1.81
Surface	2011	1.56	1.97	3.19	2.20	0.93	0.57	0.71	1.81	10.69	6.33	1.78	0.61
Mid-depth	2008									13.47	6.92	3.74	3.66
Mid-depth	2009	3.88	3.66	3.68	3.83	3.46	3.24	14.66	19.40	14.91	8.03	3.90	3.78
Mid-depth	2010	3.94	4.06	4.32	4.86	4.55	3.29	2.54	11.48	12.71	7.63	3.83	3.85
Mid-depth	2011	3.93	3.78	4.24	4.16	3.51	2.73	1.55	2.19	8.99	6.17	3.88	3.67
Bottom	2008									13.38	6.87	3.95	4.18
Bottom	2009	4.54	4.09	4.56	4.79	4.68	4.26	13.99	19.16	14.93	8.04	4.15	3.99
Bottom	2010	4.55	4.96	5.03	4.93	4.75	4.49	3.77	11.27	12.69	7.64	4.02	4.37
Bottom	2011	4.69	4.81	4.57	4.27	3.62	3.17	3.09	3.07	8.84	6.15	4.11	3.83
ADMT													
Surface	2008									15.68	7.91	3.05	1.16
Surface	2009	0.47	0.36	0.72	0.56	0.60	3.91	20.11	21.27	16.82	8.88	3.03	1.82
Surface	2010	2.09	2.36	2.67	2.31	1.21	0.95	2.98	17.19	14.07	8.72	2.77	2.06
Surface	2011	1.78	2.09	3.38	2.33	1.03	0.64	0.77	2.34	12.76	7.10	2.24	0.66
Mid-depth	2008									13.90	7.26	3.99	3.74
Mid-depth	2009	3.95	3.68	3.79	3.92	3.51	3.55	15.51	19.91	15.34	8.33	4.07	3.97
Mid-depth	2010	4.08	4.11	4.40	4.88	4.60	3.38	2.90	12.06	13.02	7.95	3.98	3.95
Mid-depth	2011	4.03	3.93	4.31	4.18	3.55	2.78	1.61	2.44	9.43	6.41	3.97	3.79
Bottom	2008									13.76	7.15	4.23	4.26
Bottom	2009	4.63	4.17	4.59	4.79	4.72	4.47	14.53	19.57	15.32	8.35	4.36	4.14
Bottom	2010	4.67	4.99	5.04	4.94	4.76	4.51	3.99	11.79	12.98	7.95	4.26	4.50
Bottom	2011	4.75	4.83	4.58	4.28	3.65	3.19	3.09	3.27	9.34	6.38	4.22	3.96

Table E21. Connie Lake, Olympic National Park, 2008-2011 monthly water temperature values (°C) for average daily average (ADAT), average daily minimum (ADMINT), and average daily maximum temperature (ADMT).

Logger	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ADAT													
Surface	2008										6.39	2.56	0.72
Surface	2009	0.22	0.21	0.39	0.37	0.19	**	**	**	**	7.08	1.25	0.33
Surface	2010	0.37	0.46	0.93	1.21	0.52	0.07	0.76	13.40	11.90	6.87	1.56	0.31
Surface	2011	0.08	0.25	0.09	0.05	0.00	-0.06	-0.05	0.07	1.28	4.09	0.81	0.19
Mid-depth	2008										6.22	3.06	2.89
Mid-depth	2009	3.16	3.39	3.58	3.73	3.73	3.25	8.98	18.06	13.49	7.06	3.73	4.20
Mid-depth	2010	4.31	4.42	4.52	4.52	4.47	4.28	3.90	10.71	11.63	7.19	2.45	2.69
Mid-depth	2011	3.34	3.63	4.10	4.58	4.69	4.27	2.78	1.56	3.15	4.11	3.20	3.34
Bottom	2008										6.05	3.18	3.47
Bottom	2009	3.83	3.93	4.01	4.22	3.97	3.94	8.64	17.68	13.32	6.99	3.99	4.40
Bottom	2010	4.47	4.54	4.51	4.57	4.57	4.59	4.33	10.46	11.50	7.16	3.09	3.56
Bottom	2011	4.02	4.13	4.45	4.60	4.65	4.66	4.54	4.16	4.07	4.06	3.42	3.61
ADMINT													
Surface	2008										6.11	2.14	0.66
Surface	2009	0.20	0.20	0.35	0.35	0.17	**	**	**	**	6.84	1.05	0.31
Surface	2010	0.33	0.42	0.89	1.12	0.47	0.05	0.51	12.28	11.48	6.49	1.39	0.27
Surface	2011	0.06	0.24	0.06	0.03	-0.01	-0.07	-0.07	0.05	1.00	3.86	0.65	0.18
Mid-depth	2008										6.09	2.88	2.88
Mid-depth	2009	3.14	3.36	3.58	3.73	3.72	3.23	8.62	17.81	13.24	6.90	3.68	4.17
Mid-depth	2010	4.28	4.41	4.52	4.51	4.45	4.28	3.83	10.46	11.51	7.01	2.34	2.66
Mid-depth	2011	3.33	3.62	4.09	4.57	4.67	4.24	2.74	1.54	3.01	3.99	3.18	3.32
Bottom	2008										5.90	3.04	3.43
Bottom	2009	3.80	3.92	4.00	4.22	3.91	3.93	8.38	17.46	13.09	6.82	3.92	4.39
Bottom	2010	4.44	4.51	4.49	4.56	4.56	4.59	4.26	10.17	11.35	6.99	2.96	3.53
Bottom	2011	4.00	4.12	4.43	4.59	4.65	4.66	4.53	4.15	3.95	3.94	3.37	3.58
ADMT													
Surface	2008										6.86	2.79	0.80
Surface	2009	0.25	0.21	0.43	0.41	0.21	**	**	**	**	7.37	1.38	0.35
Surface	2010	0.41	0.50	0.98	1.28	0.57	0.10	1.06	14.82	12.53	7.46	1.74	0.35
Surface	2011	0.09	0.27	0.12	0.06	0.01	-0.06	-0.05	0.10	1.65	4.40	0.96	0.21
Mid-depth	2008										6.41	3.18	2.92
Mid-depth	2009	3.18	3.41	3.58	3.73	3.73	3.29	9.40	18.31	13.73	7.24	3.77	4.22
Mid-depth	2010	4.33	4.42	4.52	4.52	4.47	4.29	3.97	10.95	11.79	7.36	2.55	2.71
Mid-depth	2011	3.36	3.64	4.12	4.60	4.69	4.29	2.81	1.58	3.30	4.26	3.21	3.36
Bottom	2008										6.20	3.32	3.49
Bottom	2009	3.85	3.93	4.01	4.22	4.02	3.96	8.97	17.95	13.60	7.17	4.06	4.43
Bottom	2010	4.50	4.56	4.53	4.58	4.58	4.60	4.39	10.79	11.68	7.33	3.20	3.59
Bottom	2011	4.05	4.14	4.46	4.60	4.66	4.66	4.55	4.17	4.22	4.20	3.48	3.63

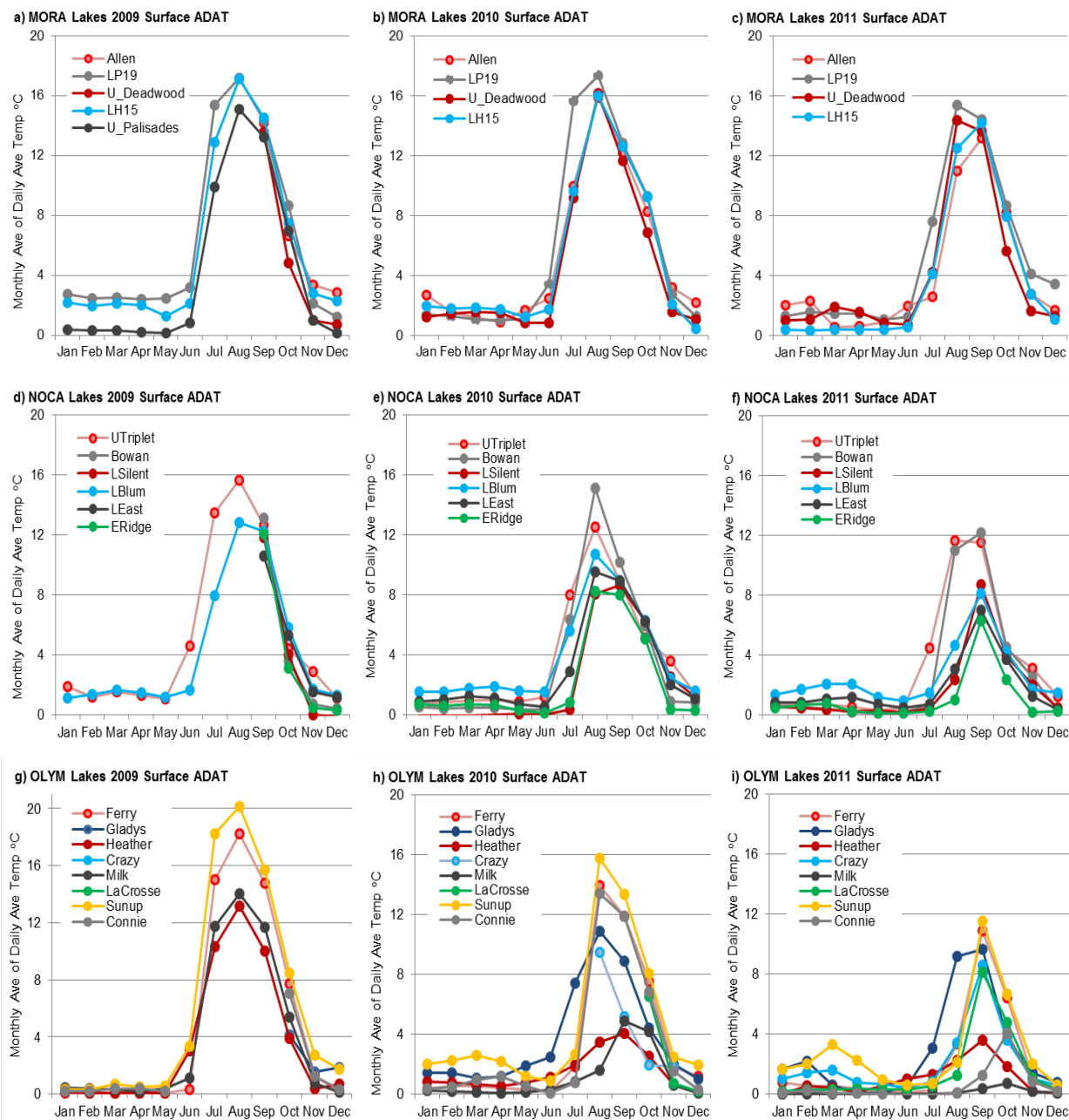


Figure E1. Monthly average of daily average lake surface water temperatures °C ($ADAT_{surf_mo}$) for all lakes by North Coast and Cascades Network parks, 2009-2011. Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM).

Appendix F. Annual Air and Water Degree-Day Summary Statistics.

Table F1. Air and water annual heating degree-days (>0°C) for Mount Rainier National Park lakes during 2009-2011.

Logger/Yr	Allen	LP19	Blue	Upper Deadwood	LH15	Upper Palisades
Air						
2009	-	-	-	-	-	-
2010	1553	1698	1527	1291	-	-
2011	1340	1441	1286	1169	-	-
Surface						
2009	-	2294	-	-	2109	1493
2010	1905	2098	-	1652	1845	-
2011	1451	1885	-	1461	1370	-
Mid-depth						
2009	2157	-	-	1979	-	-
2010	2207	2203	-	1619	2354	-
2011	1776	1983	-	1473	2013	-
Bottom						
2009	-	2114	-	-	2418	2161
2010	2406	2134	-	1893	2381	2075
2011	2084	1952	-	1731	2154	1800

Table F2. Air and water annual heating degree-days (>0°C) for North Cascades National Park lakes during 2009-2011.

Logger/Yr	Upper Triplet	Bowan	Lower Silent	Lower Blum	Lower East	Easy Ridge
Air						
2009	-	-	-	-	-	-
2010	1353	1172	810	1340	1333	1002
2011	1309	1064	670	1101	851	801
Surface						
2009	1893	-	-	1529	-	-
2010	1363	1242	815	1384	1080	778
2011	1222	1015	612	945	647	388
Mid-depth						
2009	-	-	-	-	-	-
2010	1743	1708	1602	1793	1643	1072
2011	1509	1216	1461	1493	1350	713
Bottom						
2009	-	-	-	2020	-	-
2010	2002	2096	1852	1957	1708	1275
2011	1838	1464	1730	1645	1458	877

Table F3. Air and water annual heating degree-days (>0°C) for Olympic National Park lakes during 2009-2011.

Logger/Yr	Ferry	Gladys	Heather	Crazy	Milk	LaCrosse	Sunup	Connie
Air								
2009	2061	-	1882	-	1839	-	2372	2141
2010	1626	1410	1525	-	1390	-	2020	1815
2011	1429	1287	1402	1410	1235	-	1337	1329
Surface								
2009	1777	-	1291	-	1434	-	2235	-
2010	1244	1352	538	-	407	-	1693	1173
2011	761	1005	363	729	46	542	1047	212
Mid-depth								
2009	2418	-	-	-	1330	-	2687	2333
2010	2013	1299	702	-	1220	-	2075	1982
2011	1646	1068	644	1402	999	1301	1505	1300
Bottom								
2009	2467	-	1825	-	1324	-	2822	2410
2010	2132	1209	1041	-	1300	-	2235	2051
2011	1923	1047	756	1707	1248	1179	1665	1533

Appendix G. Example Application of the Use of Freezing Degree-Days for Ice-on Determination

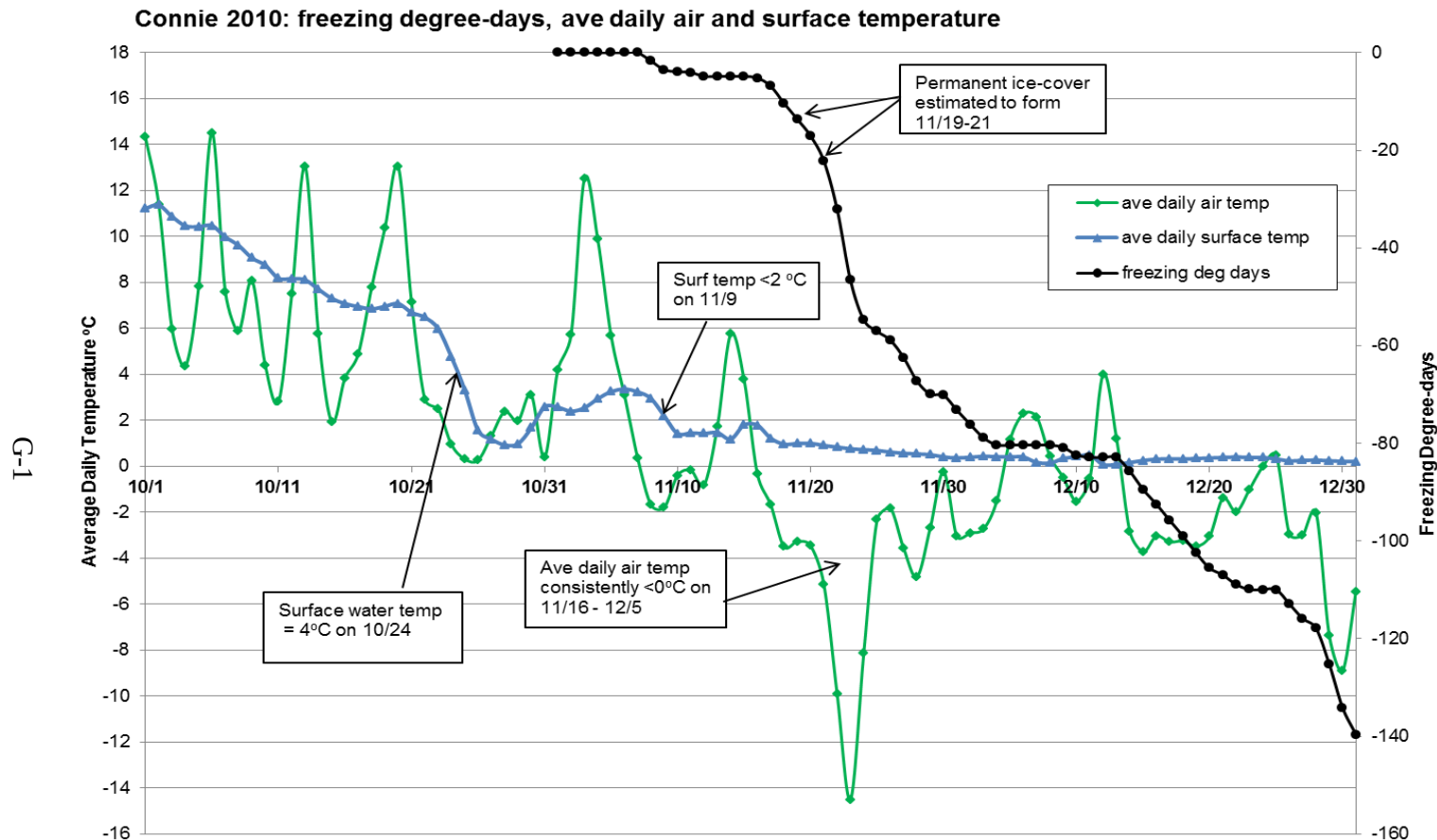


Figure G1. Lake ice-on estimation for Connie Lake (Olympic National Park), 2010, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

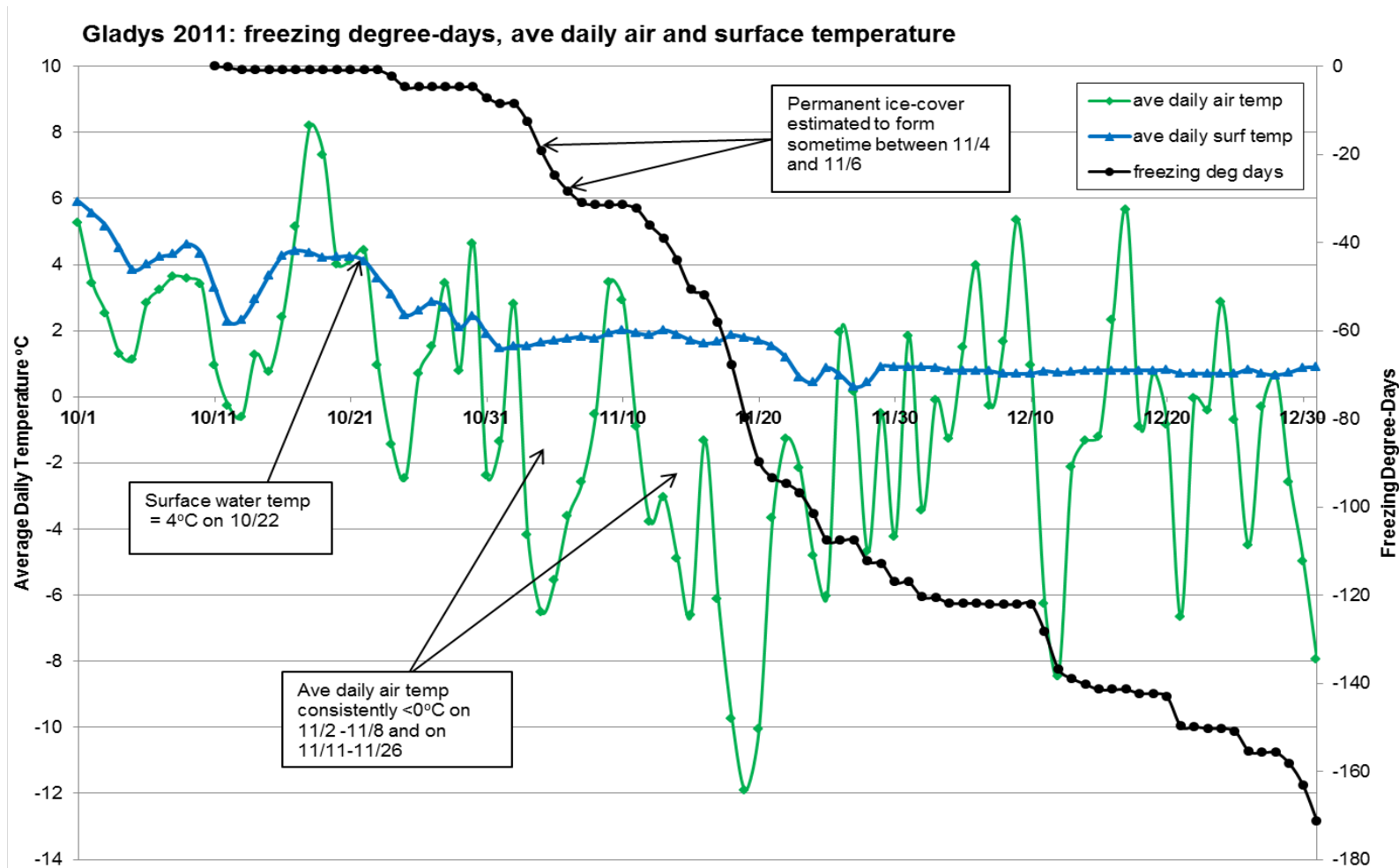


Figure G2. Lake ice-on estimation for Gladys Lake (Olympic National Park), 2011, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

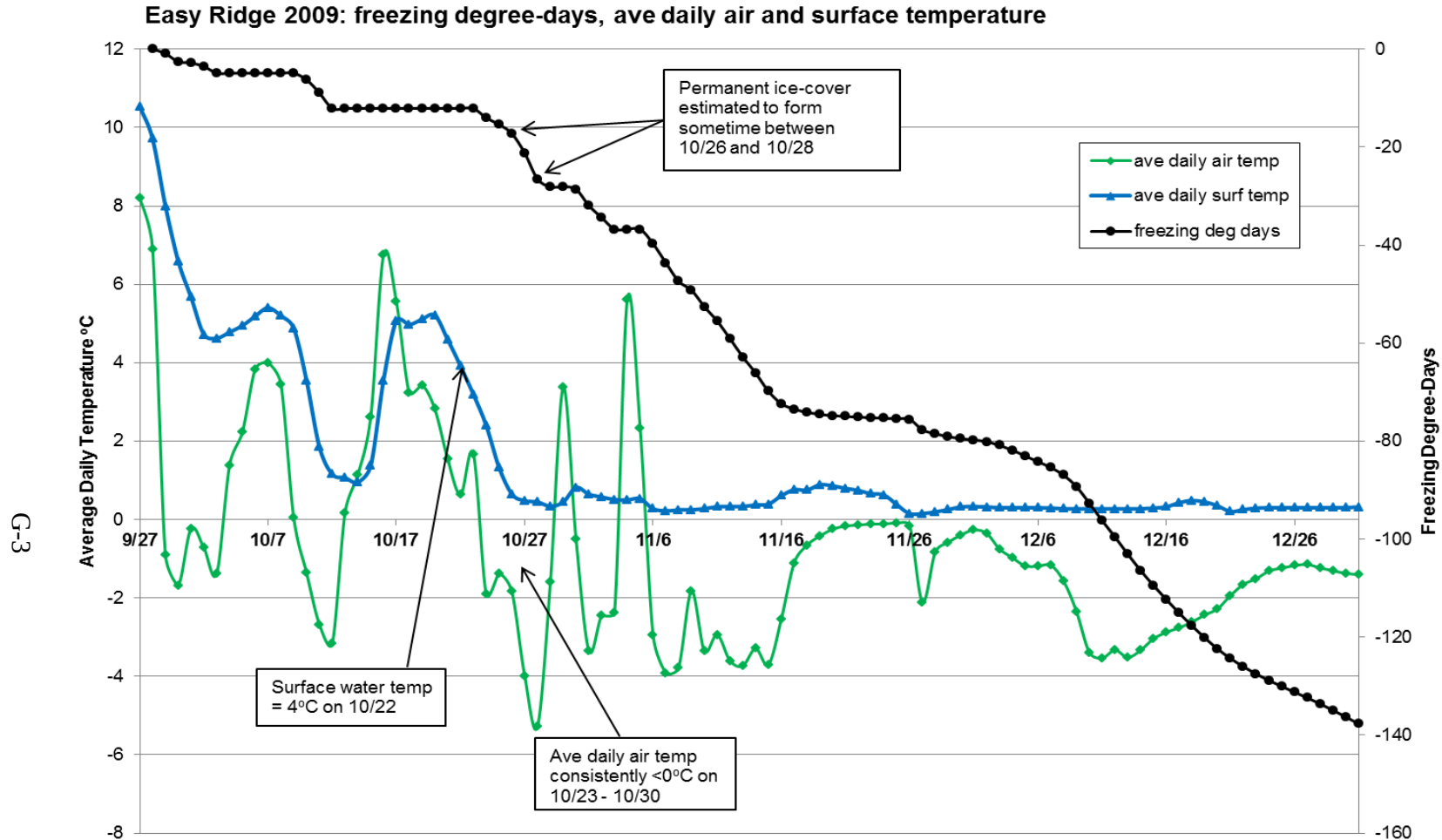


Figure G3. Lake ice-on estimation for Easy Ridge Lake (North Cascades National Park), 2009, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

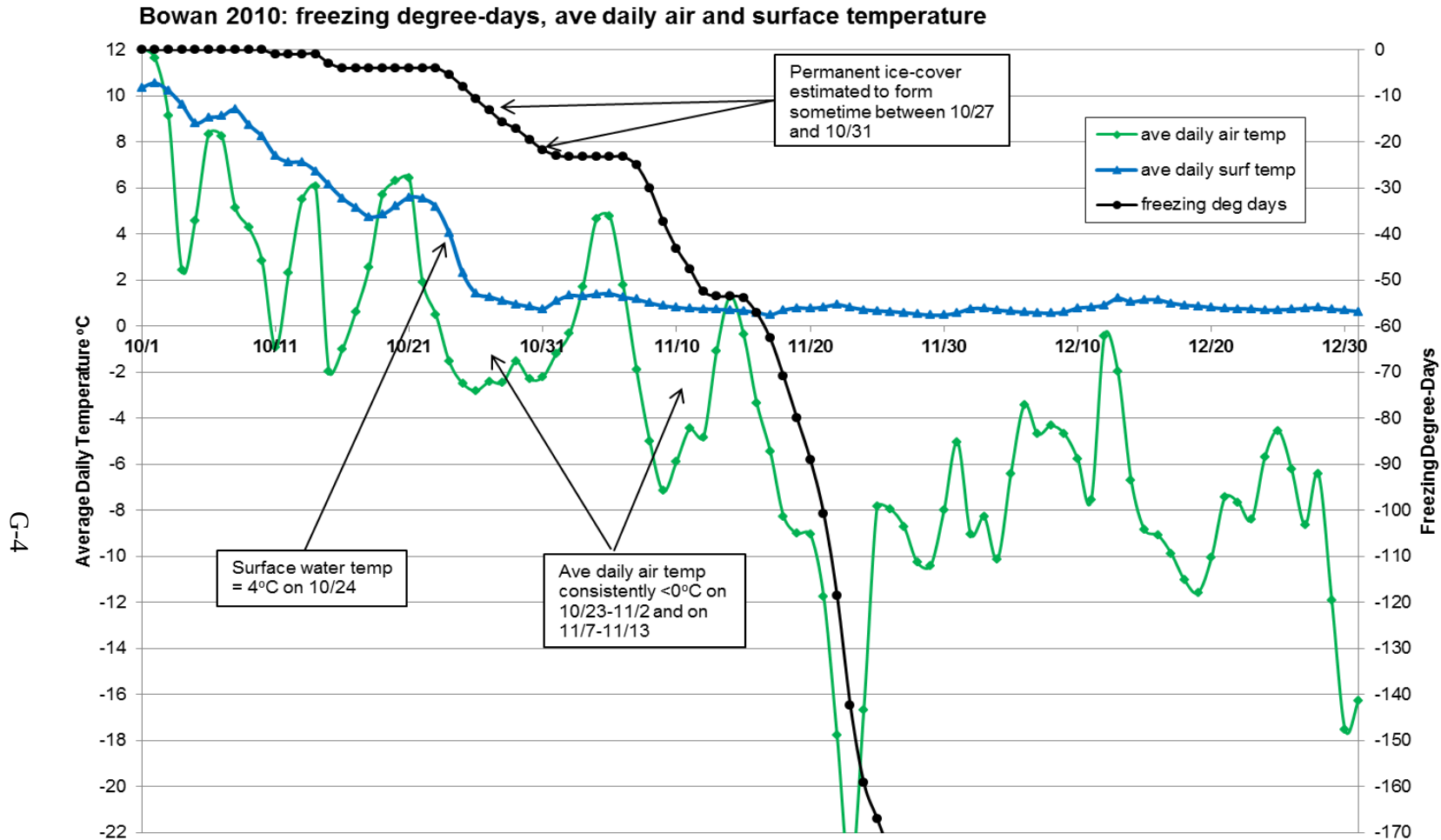


Figure G4. Lake ice-on estimation for Bowan Lake (North Cascades National Park), 2010, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

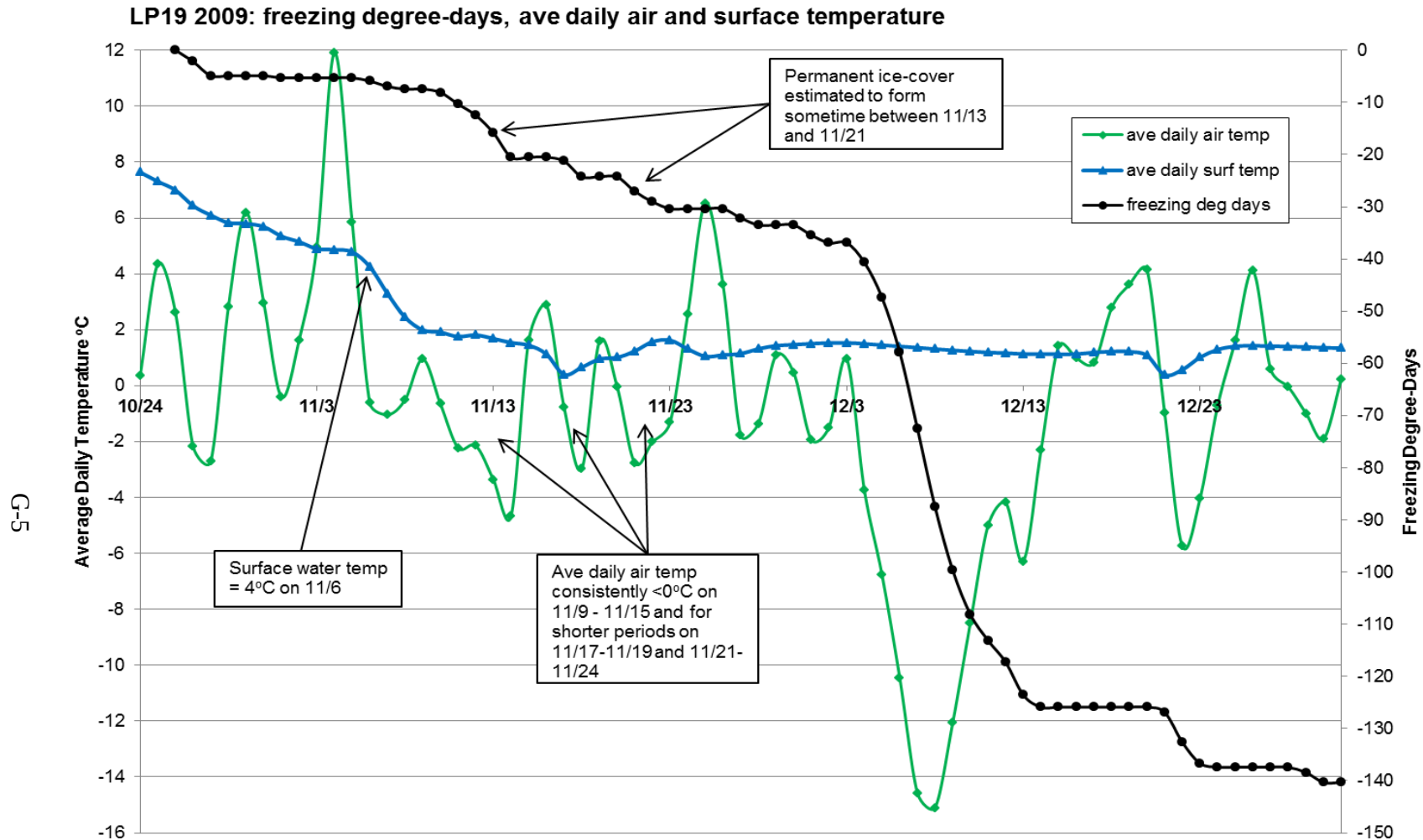


Figure G5. Lake ice-on estimation for LP19 Lake (Mount Rainier National Park), 2009, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

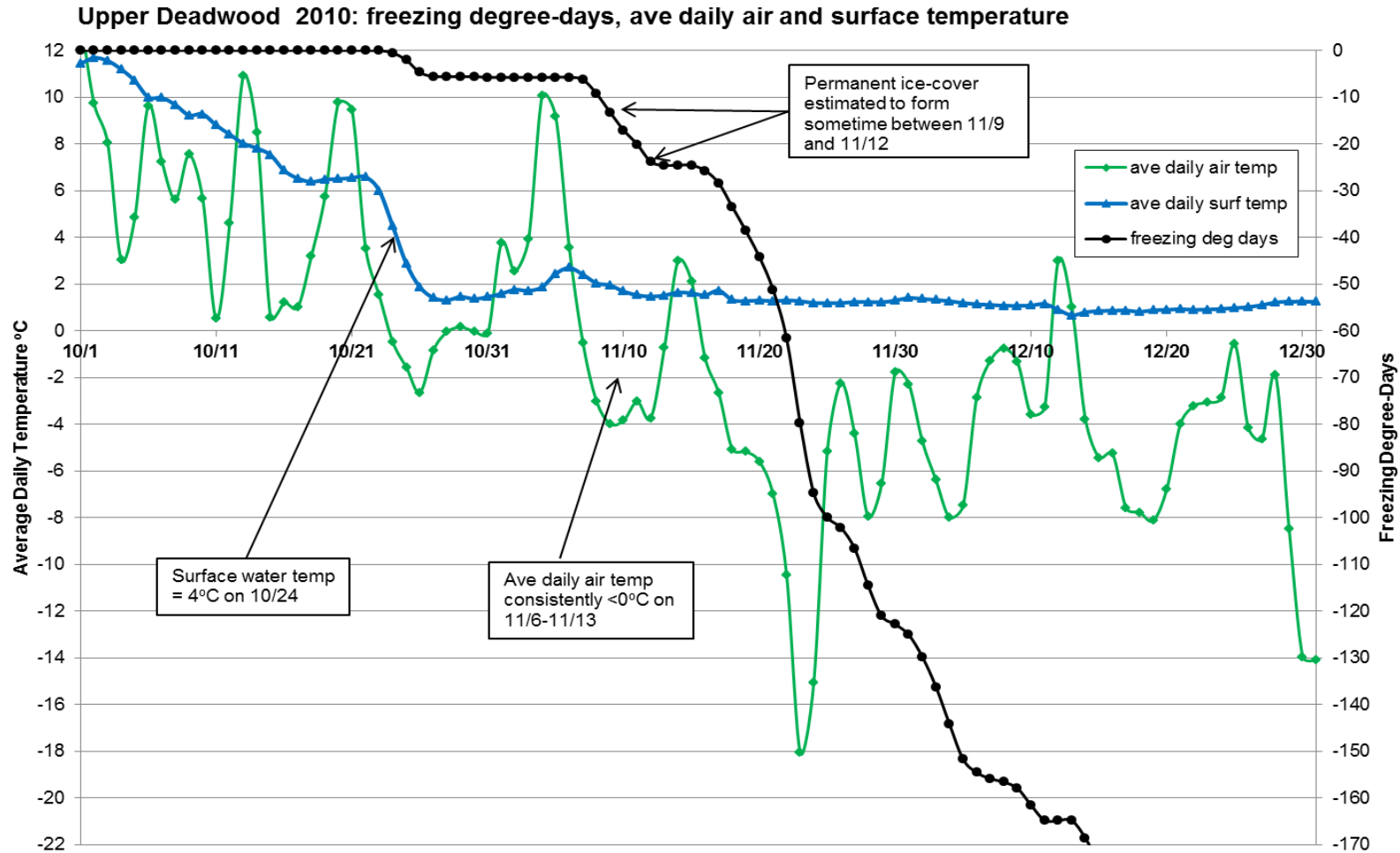


Figure G6. Lake ice-on estimation for Upper Deadwood Lake (Mount Rainier National Park), 2010, using average daily air temperature, average daily surface water temperature, and freezing degree-days. Ice formation begins after fall turnover (surface water temperature approximately 4°C) when air temperatures decline below 0°C and, in general, when surface water temperatures fall below 2°C. Permanent lake ice cover generally forms during the first extended period of time (>5 days) when air temperatures consistently remain below 0°C and, when freezing degree-days begin to rapidly accumulate. Thompson et al. (2005) and others have reported that an accumulation of approximately 20 freezing degree-days was found to provide a good relationship between air temperature and the date of freeze-over.

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