Southwest Alaska Network
Inventory & Monitoring Program

National Park Service
U.S. Department of the Interior

Vital Signs Monitoring Resource Briefs

Alagnak **Aniakchak** **Katmai** **Kenai Fjords** **Lake Clark**

May 2016
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Vital Sign Resource Briefs

Vital Signs Inventory and Monitoring

Weather, Climate, and Air Quality

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- KATM Climate
- KEFJ Climate
- Air Quality

Landscape Dynamics and Terrestrial Vegetation

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Alagnak *Aniakchak* *Katmai* *Kenai Fjords* *Lake Clark*

May 2016

Climate at Lake Clark NPP

The Lake Clark region, located in southcentral Alaska, has two distinct climates that are divided southwest to northeast by the Alaska and Aleutian mountain ranges. To the southeast, the Cook Inlet and the Pacific Ocean significantly influence the climate of the region by moderating the transfer of energy and water vapor to and from the atmosphere resulting in a maritime climate. To the northwest, the mountains form a barrier, resulting in climate patterns more typical of Alaska's western interior that are sometimes influenced by the moderating effects of the Bristol Bay to the southwest. Figure 1 provides examples of how mean annual monthly temperatures vary relative to their locations: Silver Salmon (maritime) is more moderate, Chigmit Mountains (higher elevation) is colder, and Snipe Lake (interior) has greater extremes.

Recent winter temperatures have frequently been out of the normal range. Regionally, 2014 and 2015 were the warmest years on record. In Port Alsworth, the recent temperatures for winter and spring months have frequently been near the maximums for the period of record, and 2014 and 2015 have been the hottest years on record. Notably, three of the 10 warmest winters, one of the 10 warmest springs, and seven of the 10 warmest maximum three-day temperature extremes since 1960 have occurred in the last 10 years (Lindsay 2014).

NPS/P. Kirchner

Weather station in the Chigmit Mountains of Lake Clark National Park and Preserve.

Weather Highlights

- 2014 and 2015 were the warmest years on record.
- 2014 and 2015 winter and spring maximum temperatures at Port Alsworth were the hottest years on record.
- Three of the ten warmest winter seasons have occurred in the last 10 years.
- One of the ten warmest spring seasons have occurred in the last 10 years.
- Seven of the ten warmest maximum three-day extremes since 1960 have occurred in the last 10 years.

How climate and weather are different can be summed up by the phrase: climate is what you expect; weather is what you get. *Weather* refers to atmospheric conditions over short periods of time, typically days to weeks. *Climate* refers to the patterns (statistics) of weather over long periods of time, typically 30 years. *Climate change* refers to changes in climate patterns over long periods of time.

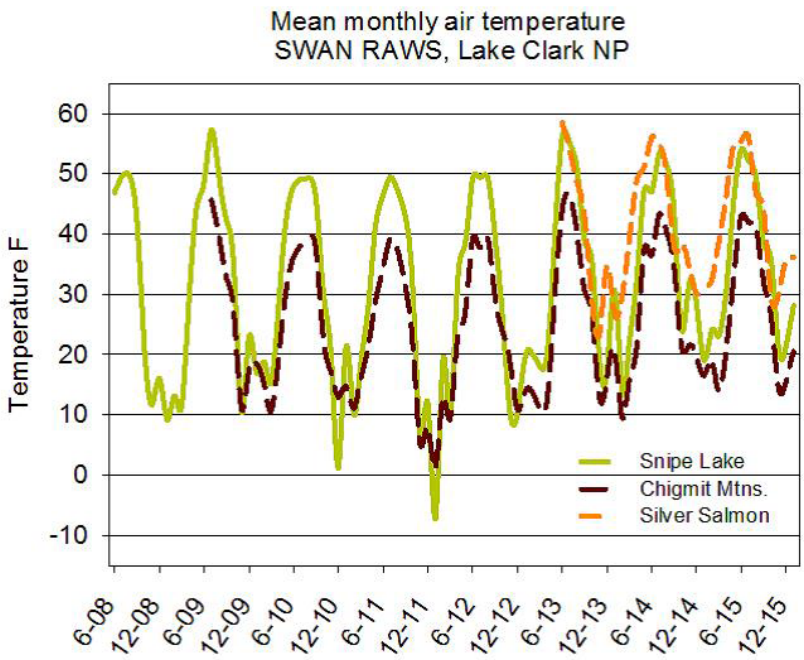

Figure 1. Mean monthly air temperatures for Lake Clark weather stations show climatic differences between Silver Salmon where temperatures are moderate, Chigmit Mountains (the coldest and highest elevation), and Snipe Lake, with the greatest extremes. All show a distinct warming trend, especially in winter, over the past four years (Western Regional Climate Center).

Predictions of future climate, based on conservative model projections, indicate a 3-6°F (1.5-3°C) warming trend over the next 100 years in addition to the warming trend already observed (Figure 2; Monahan and Fisichelli 2014, SNAP 2016). The most warming is predicted to occur during the winter months and will continue to increase the number of days when the temperature is at or above 32°F (0°C); thus, over the long term, precipitation will continue to fall more frequently as rain than snow, snow elevations will rise, and snow will melt earlier and more often—a pattern seen in much of southwest Alaska over the past two years.

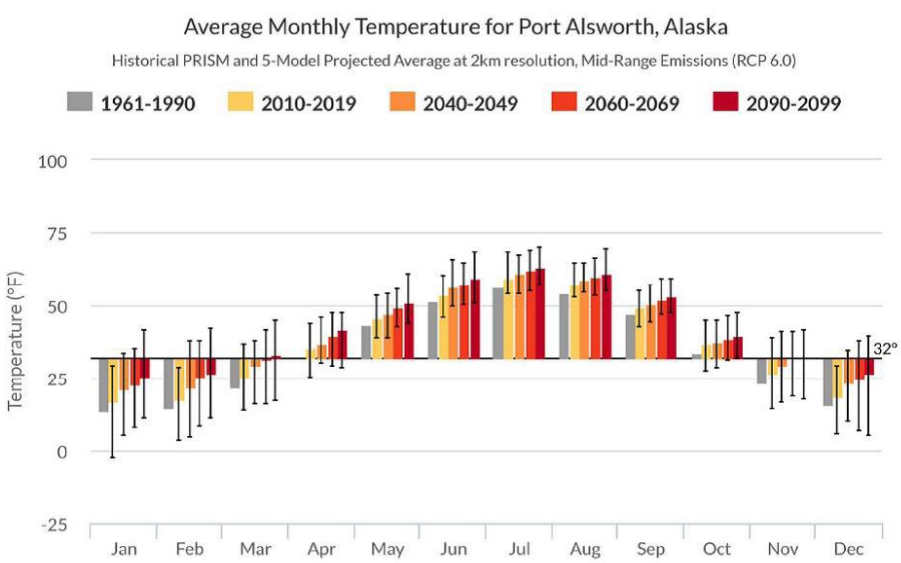

Figure 2. 100 years of average monthly temperature changes, and quantified ranges, based on conservative modeled climate projections (Scenarios Network for Alaska and Arctic Planning [SNAP] 2016).

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Monahan, W. B. and N. A. Fisichelli. 2014. Climate exposure of U.S. national parks in a new era of change. PLoS ONE 9(7): e101302. doi:10.1371/journal.pone.0101302.

Scenarios Network for Alaska and Arctic Planning, University of Alaska. 2016. Available at: snap.uaf.edu/sites/all/modules/snap_community_charts/charts.php (accessed March 17, 2016)

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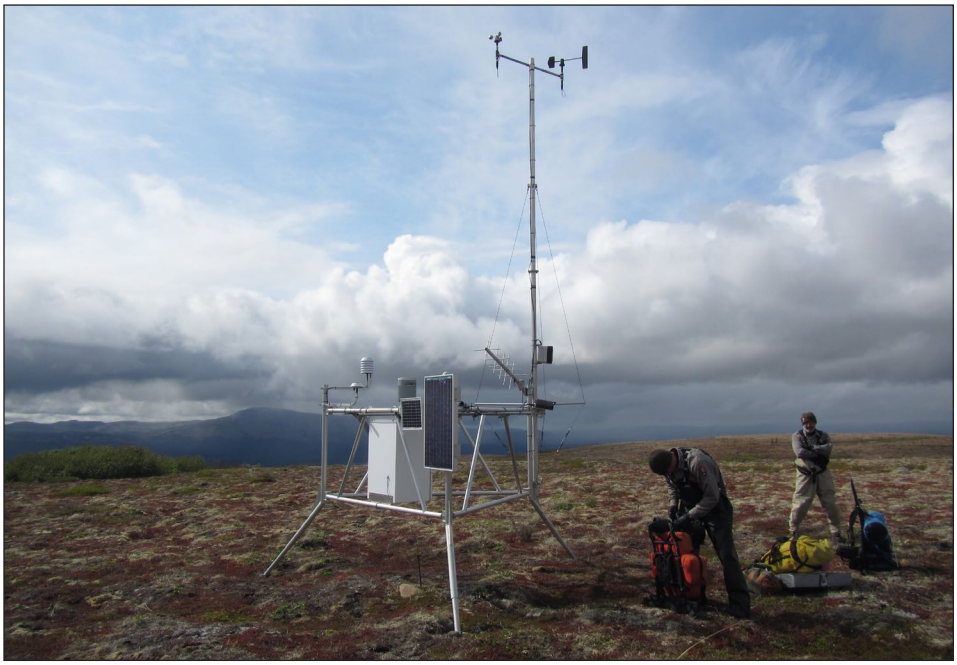
Climate at Katmai NPP

Katmai National Park and Preserve (NPP) is located between the Bering Sea and the Pacific in the Bristol Bay region of Alaska. Both seas have a strong climatic influence on this region because they mediate the transfer of heat and water vapor to and from the atmosphere. These transfers of energy are characterized by persistent seasonal to multi-decadal patterns in particular geographic locations; specifically, seasonal sea ice in the Bering Sea and the distribution of warm vs cool water in the northern Pacific and Gulf of Alaska. The strength of this "maritime" influence can be seen in climate stations where, despite a 1,300' elevation difference and a wide geographic distribution throughout the park, the mean monthly air temperatures are notably similar (Figure 1).

Oscillations in the multi-decadal patterns of Pacific sea-surface temperatures, of approximately 10 to 30 years, are known as the Pacific Decadal Oscillation (PDO). The PDO oscillates between a negative (cool coastal water) phase and positive (warm coastal water) phase (Mantua and Hare 2002). A relationship between a positive PDO and the southward shift of the persistent low pressure over the northwestern Pacific (the Aleutian low) and a change in the course of the jet stream in the upper atmosphere has also been observed (Trenberth and Hurrell 1994). The combined effect of these patterns can intensify or mute the long-term warming trend regionally observed in land-surface temperatures.



NPS/

The Colville Remote Automatic Weather Station (RAWS) at Katmai NPP.

Weather Highlights

- 2014 was the warmest year on record with a mean annual air temperature of 40.5°F, 5.4°F above the 30-year climate normal of 35.1°F.
- The normal temperatures for King Salmon are below freezing between November 10th and March 15th.
- The impacts of warming temperatures on precipitation are variable, but can be seen over the winters of 2001, 2003, 2014, and 2015 where, in spite of having above-normal winter precipitation, the snow fall was 11, 23, 11, and 21 inches, respectively, below the cumulative normal of 46.5 inches.

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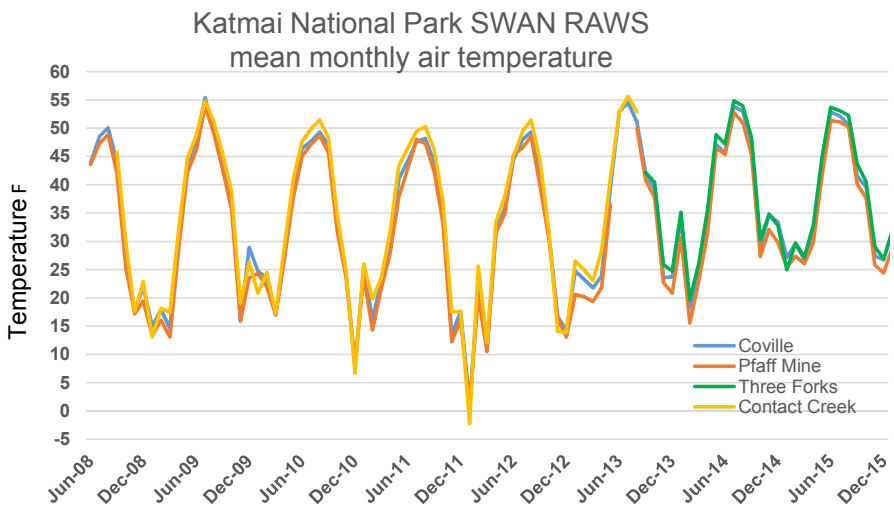

Figure 1. Mean monthly air temperatures from remote automated weather stations (RAWS) in Katmai show climatic similarities, despite elevational differences and geographic distribution, due to the strong maritime influence.

The phase of the multi-decadal PDO shifted abruptly in the late 1970s to a warm phase and then to shorter oscillations of warm and cool phases. These shifts exert a strong influence on land-surface temperatures, and at times may mask a global warming trend in the local instrumental record during cool-phase years. However, when records from King Salmon are plotted with the PDO, a warming trend is evident; for example, 2014 was the warmest on record (Figure 2).

King Salmon has one of the longest continuous instrumental climate records in the region, starting in 1919 with continuous records since 1947. The past three years inclusive of 2015, have had 11 to 15 record daily high temperatures with extended periods of above-normal temperatures in December, January, and February of each year. The combined effects of these patterns have the greatest impact on whether precipitation falls as rain or snow and longevity of the snowpack.

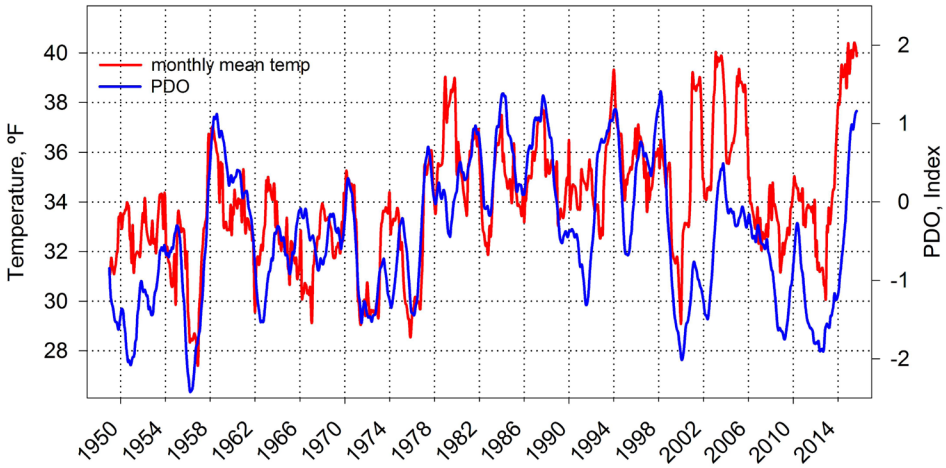

Figure 2. The one year running mean of the King Salmon mean monthly air temperature and the PDO index of sea surface temperatures (Smith et al. 2008).

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Mantua, N. and S. Hare. 2002. The Pacific Decadal Oscillation. *Journal of Oceanography* 58(1):35-44.

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Trenberth, K. E. and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics* 9:303-319.

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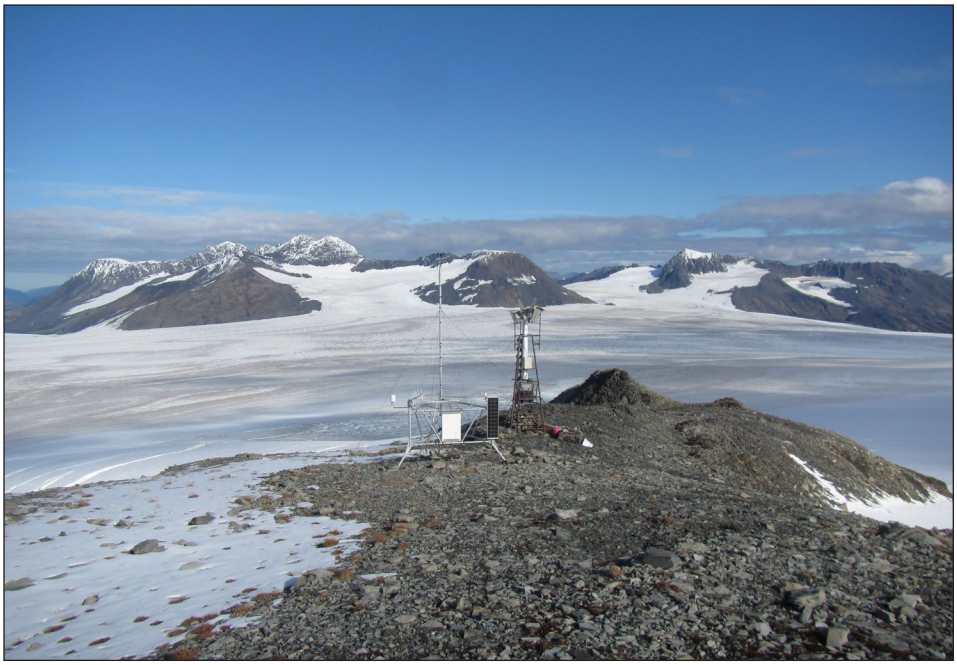
Climate at Kenai Fjords NP

Kenai Fjords National Park (NP) is geographically located in the northern Gulf of Alaska and exhibits a range of climates, from the moderate and ecologically productive coastal zone to the ice-covered expanse of the Kenai Mountains, where below-freezing temperatures and deep snow packs sustain southwest Alaska's largest icefield. Examples of how elevation and proximity to the ocean affect air temperature can be seen in the monthly mean temperatures recorded at the Southwest Alaska Network climate stations found at three different elevations where temperatures drop and the accumulation of snow, versus rain, increases with altitude (Figure 1).

Patterns of Gulf of Alaska sea-surface temperatures in the northern Pacific are an important influence on climate because they mediate the transfer of heat and water vapor to and from the atmosphere. One measure of cyclic changes in sea-surface temperature, known as the Pacific Decadal Oscillation (PDO), shows multi-decadal patterns of approximately 10 to 30 years, which are characterized by the distribution of warm vs cool water in the central and coastal regions of the northern Pacific (Mantua et al. 1997). When the PDO shifts from cool to warm phases, it often influences the land-surface temperatures of the Kenai Fjords region and Alaska.

Long-term land-surface temperature records in the Kenai Fjords region are rare. Seward weather stations, from several different locations, provide a



NPS/P. Kirchner

Remote Automatic Weather Station (RAWS), Harding Ice Field, Kenai Fjords NP.

Weather Highlights

- Temperatures recorded at the Seward airport indicate 2003 and 2015 were tied as the warmest years on record with a mean annual air temperature of 43°F (6°C), 2.5°F (1.4°C) above the 30-year climate normal of 40.5°F (4.7°C).
- During the winter months of 2003, 2014, and 2015, record-high daily temperatures were recorded 18, 12, and 12 times, respectively.
- 2016 has already broken several temperature records.

How climate and weather are different can be summed up by the phrase: climate is what you expect; weather is what you get.
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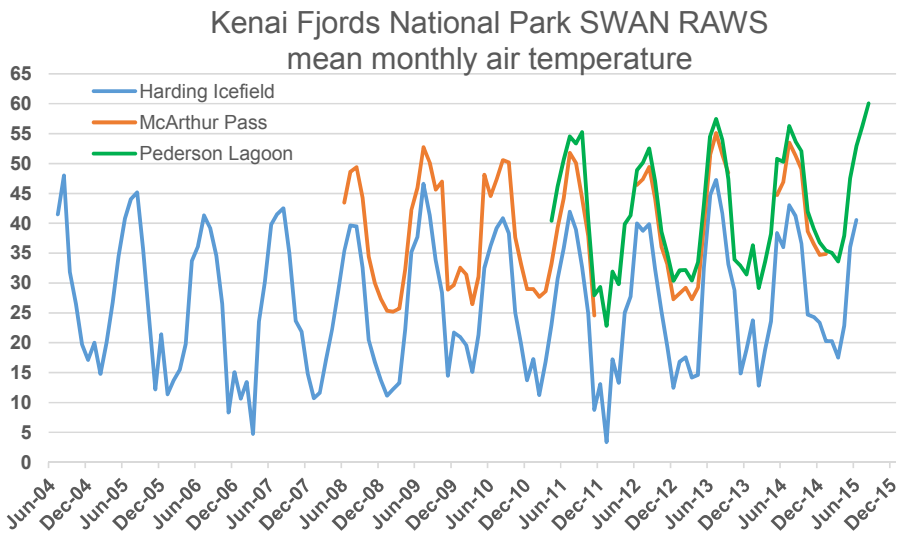

Figure 1. Mean monthly air temperatures from remote automated weather stations (RAWS) in Kenai Fjords show climatic differences due to elevation. Harding Icefield at 4,000 feet is the coldest and Pederson Lagoon at 480 feet is the warmest.

long-term record because they have been intermittently monitored since 1908, but continuous records are only available starting in 1998. When a yearly running mean of these air temperatures are compared to the PDO trends, there is a coherent signal from the PDO in recent years (Figure 2).

Temperatures recorded at the Seward airport indicate 2003 and 2015 were tied as the warmest years on record with a mean annual air temperature of 43°F (6°C), 2.5°F (1.4°C) above the 30-year climate normal of 40.5°F (4.7°C). During the winter months of 2003, 2014, and 2015, record-high daily temperatures were recorded 18, 12, and 12 times, respectively. The combined effects of these patterns have the greatest impact on whether precipitation falls as rain or snow, as well as when and how frequently snow melts. The current year, 2016, has also broken several temperature records.

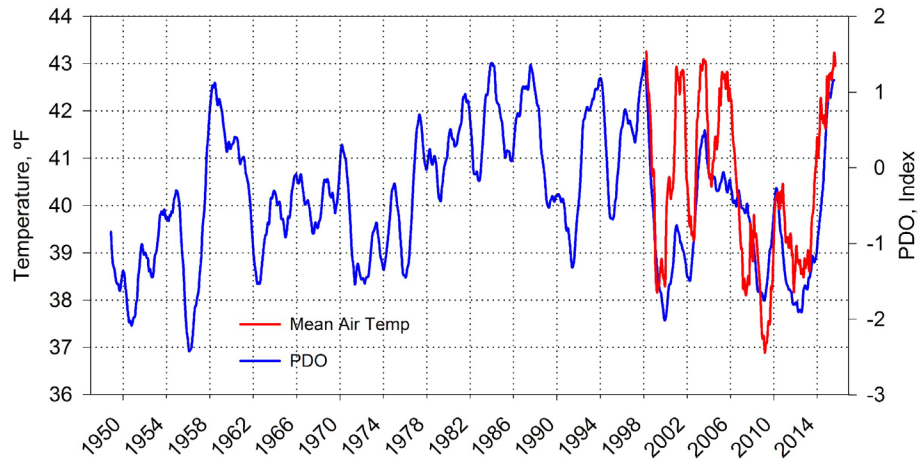

Figure 2. One year running mean of Seward Airport mean monthly air temperature and PDO index, PDO date source National Climate Data Center (Smith et al. 2008).

References

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Smith, T. M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore. 2008. Improvements on NOAA's Historical Merged Land-Ocean Temperature Analysis (1880-2006). *Journal of Climate* 21:2283-2296.

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Air Quality

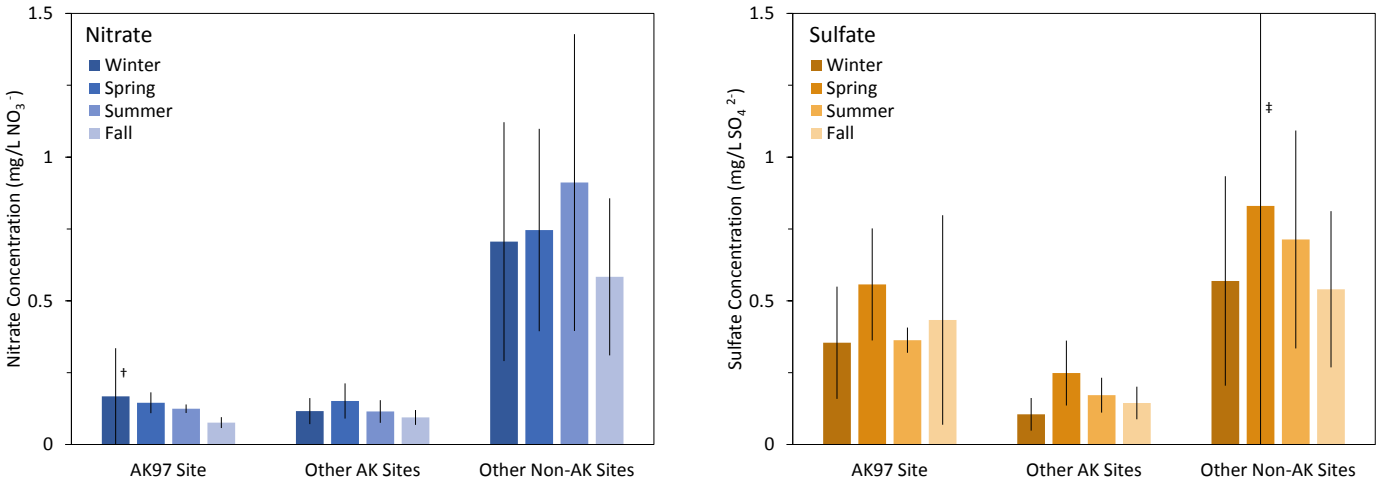
Nitrogen and sulfur oxides are emitted into the atmosphere mainly through the combustion of fossil fuels. Once airborne, these oxides form compounds that can be transported long distances and then deposited in precipitation (rain, snow, etc.) as pollutants, such as nitrate and sulfate. Arctic and subarctic ecosystems are particularly sensitive to the deposition of excess nitrogen and sulfur. Effects include the disruption of ecosystem processes and the alteration of species composition and abundance. Although concentrations of nitrate and sulfate are relatively low at most sites in Alaska where monitoring occurs, atmospheric pathways capable of transporting pollution to the northwest coast of North America are worth noting. As the global human population grows, so does the likelihood that Alaska air quality will be impaired by increasing emissions from other continents.

NPS/ Mills

Some ecosystem types, including high-elevation lakes like the one pictured above, are sensitive to the effects of nutrient enrichment and acidification from atmospheric deposition of nitrogen and sulfur (Sullivan et al. 2011).

Findings

Atmospheric deposition is the process by whereby airborne pollutants, such as nitrate and sulfate, reach the earth. Deposition consists of both wet and dry components. Wet deposition has been monitored in North America

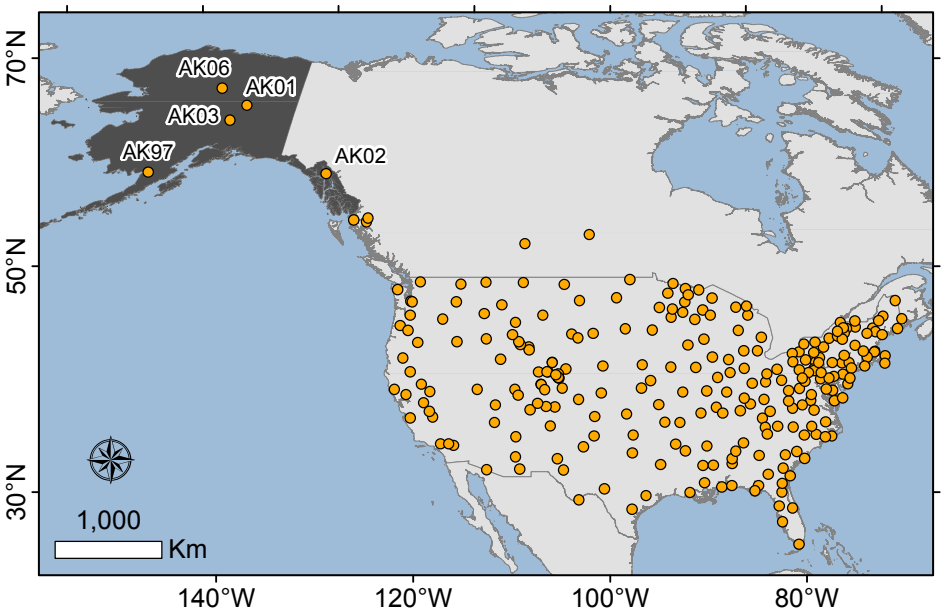


Concentrations of two common pollutants, nitrate (left) and sulfate (right), found in precipitation at the Southwest Alaska Network site, AK97. Concentrations at four other NTN sites in Alaska and 197 NTN sites located elsewhere are shown for comparison. Colored bars represent seasonal averages for the years 2011-2014; black lines indicate standard deviations, where †=0.17 and ‡=2.9 mg/L. Additional data are available at: http://nadp.sws.uiuc.edu/data/ntn/.

NPS/C Turner

Every NTN site uses two instruments to monitor wet deposition: a rain gage (right) and a precipitation collector (left). In 2015, the AK97 site at Katmai National Park and Preserve (pictured) was converted to telemetry, so rain gage data are available online in real time at http://nadp.sws.uiuc.edu/siteOps/ppt/default.aspx.

since 1978 by the National Atmospheric Deposition Program's National Trends Network (NTN). This network currently includes 261 active monitoring sites, one of which is operated by the Southwest Alaska Network (SWAN) and Katmai National Park and Preserve. This site (known as AK97) is located in King Salmon, Alaska, and is one of only five active NTN sites in the state. Recent average nitrate concentrations at AK97 are comparable to those at other Alaska sites, and lower than averages elsewhere on the continent. Average sulfate concentrations at AK97 are more variable, and tend to be intermediate between those at Alaska and non-Alaska sites.



Only five of the 261 currently active NTN sites are located in Alaska (shaded dark gray). AK97 is furthest west of all sites within the network.

Methods

SWAN began monitoring wet deposition in 2009 in order to characterize trends in precipitation chemistry in southwest Alaska. Monitoring methods follow the NTN protocol. According to this protocol, precipitation samples are collected year-round on Tuesdays and sent to a lab in Illinois. The lab provides centralized chemical analyses of biologically important anions and cations (such as nitrate, sulfate, and ammonium). It also provides centralized data validation and organization. Centralization is critical for reliable long-term, large-scale monitoring. Without it, there would be no confidence that differences observed over time or between sites are actual trends, rather than artifacts of variation between labs or methods.

Reference

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Southwest Alaska Network (SWAN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/381. National Park Service, Denver, Colorado.

Contacts

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Carissa Turner, NPS-KATM, carissa_n_turner@nps.gov

Forest Insects

Over the last twenty-five years, roughly 3.7 million acres (1.5 million hectares) of forest in south-central Alaska has been killed by the spruce beetle (*Dendroctonus rufipennis*; Figure 1), a native bark beetle that has shown increased activity with warmer temperatures (Sherriff et al. 2011). During the last five years, native defoliators (e.g., geometrid moths, noctuid moths) have affected alder, willow, and dwarf birch in Lake Clark National Park and Preserve (NPP), and huckleberries and salmonberries in Kenai Fjords National Park (NP). Birch leaf roller (*Epinotia solandriana*) has been on the rise in Lake Clark and Katmai since 2012 (U.S. Forest Service 2016). In 2015, the spruce aphid (*Elatobium abietinum*), introduced from Europe, was confirmed on the western Kenai Peninsula. It has not yet been found on the eastern Kenai Peninsula or in Kenai Fjords NP (U.S. Forest Service 2016).

A warmer climate is known to facilitate the growth of spruce beetle and spruce aphid populations. Warm winters result in lower over-winter mortality of both beetles and aphids. In addition, warm summers accelerate larval development in the spruce beetle, reducing generation time from a two-year life cycle to a single year, allowing the population to increase rapidly. Above-average spring and summer temperatures may also contribute to drought stress in white spruce, weakening the trees and leaving them vulnerable to spruce beetle attack (Csank et al. in press).

NPS/A. Miller

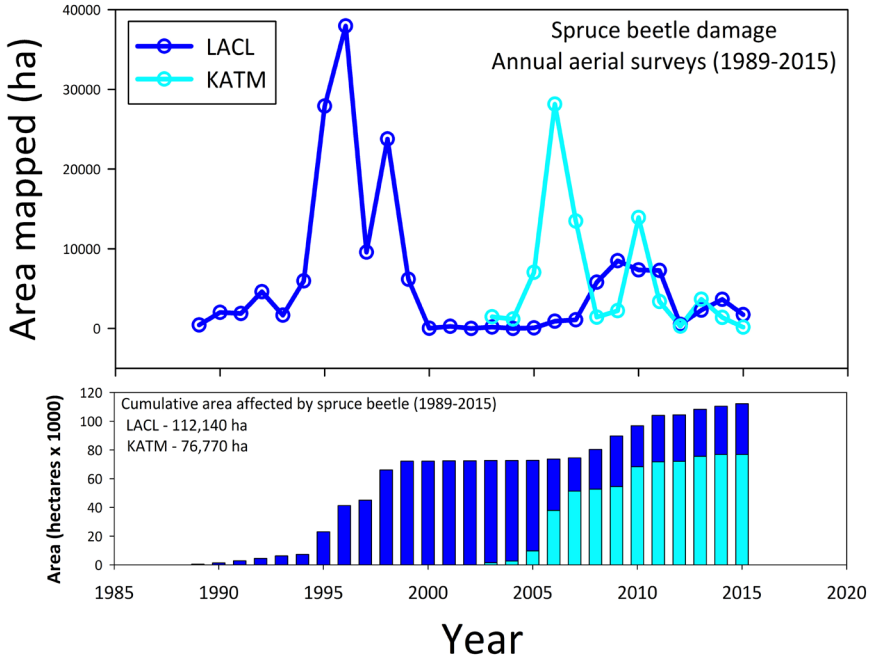


Figure 1. Area (in hectares) of spruce beetle damage by park and year (top), and cumulative area affected in each park through time (bottom), from U.S. Forest Survey aerial survey data (1989-2014; http://foresthealth.fs.usda.gov/portal/). Areas mapped are dependent on flight line locations and may not include all areas affected in a given year, or areas affected in prior years.

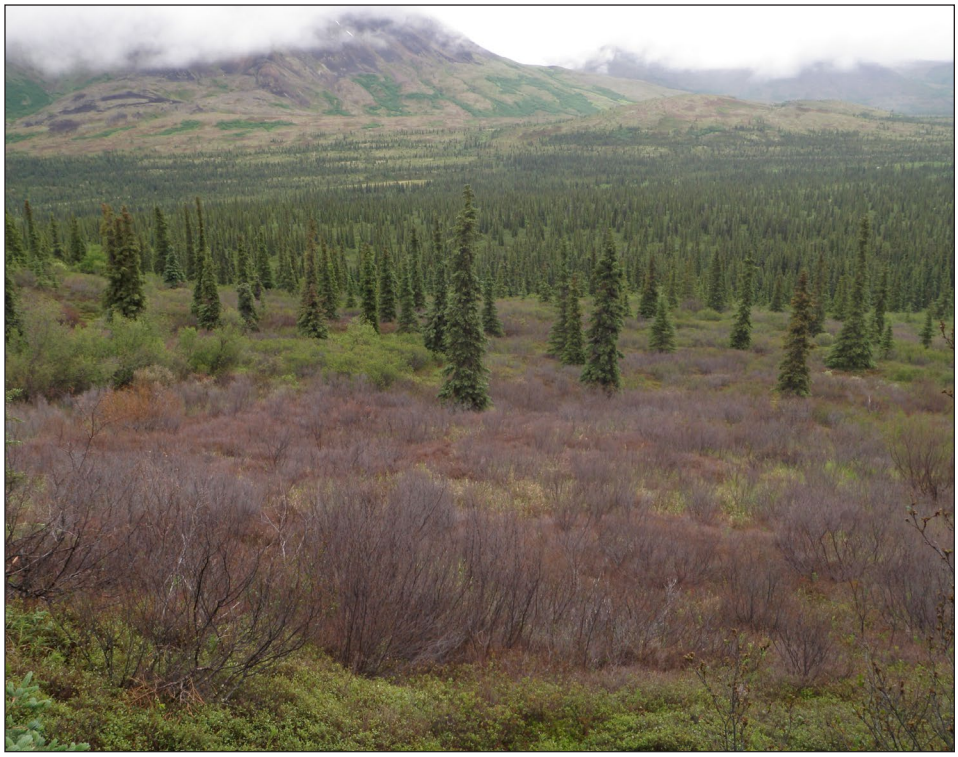
Spruce Beetle Damage in Katmai and Lake Clark

Annual aerial surveys conducted by the U.S. Forest Service and Alaska Department of Natural Resources track general trends in spruce beetle activity. Beetle activity in Lake Clark peaked in the mid-1990s (Figure 1), and has affected approximately 277,100 acres (112,140 ha) of forest to date (Figure 1). Aerial surveys began in Katmai in 2003, following the outbreak in the early to mid-1990s. Beetle activity peaked in 2006, following two warm summers. Recent beetle damage has been centered on Lake Brooks and the Valley of 10,000 Smokes Road, with cumulative damage of approximately 190,450 acres (77,100 ha; Figure 1). Forest plot measurements and tree-ring studies are adding to our understanding of the timing, frequency, and ecological effects of these outbreaks.

Spruce aphids are non-native, and while not yet found in SWAN parks, they are likely to spread from the current infestation on the eastern Kenai Peninsula.

Widespread Alder Damage in Lake Clark

In 2015, roughly 24,410 acres (9,880 ha) of defoliation or dieback were observed across alder and willow stands in the central portions of Lake Clark NPP. U.S. Forest Service entomologists will return to some of these areas in June 2016, in order to collect samples on the ground and to ascertain the cause of damage. A previous defoliation event in interior Lake Clark (2010-2012) led to extensive damage to dwarf birch.



Defoliator damage on dwarf birch near Snipe Lake, Lake Clark NPP, June 2010. Between 2010 and 2012, widespread damage from native defoliators (autumnal and geometrid moths) was observed as far west as Wood-Tikchik State Park. Shrubs had recovered by 2015, but still show many dead branches.

Non-native Spruce Aphid Arrives on the Kenai Peninsula

The spruce aphid (*Elatobium abietinum*) was found in Homer and in Halibut Cove in 2015. The U.S. Forest Service crew flew a survey on the eastern side of the Kenai Peninsula, including the Kenai Fjords coastline, in late February of this year, and have not (yet) found it there. Additional surveys are planned for this summer.

Originally from Europe, the spruce aphid (*Elatobium abietinum*) was introduced to the Pacific Northwest in 1910. In Alaska, it is well known in southeast forests, where it has damaged coastal Sitka spruce stands since at least the early 1960s.

References

Csank, A.Z., A. E. Miller, R. L. Sherriff, E. E. Berg, and J. M. Welker. 2016. Tree-ring isotopes reveal drought sensitivity in trees killed by spruce beetle outbreaks in south-central Alaska. *Ecological Applications* (in press).

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Seasonal Processes

Seasonal processes are are natural cycles such as lake ice formation and break-up, snowpack accumulation and melt, and vegetation growth and senescence. Climate and ecological processes are integrally linked. For example, snow-covered area of a catchment, snow depth, snow water equivalent, and snow season length control the timing and volume of stream flow in the spring. Snowmelt dates influence the timing of leaf-out, and both snowpack and green-up influence wildlife movement at the start of the growing season. Spatial variation in snow and growing season length is driven in large part by elevation, latitude, and proximity to the ocean. Variation in lake ice affects lake temperatures and water levels, and largely controls human and wildlife travel routes over the course of the winter.

Wolves crossing Lake Telaquana, Lake Clark National Park and Preserve.

Jerry/Jeanette Mills

Methods

Since 2005, the Southwest Alaska Network (SWAN) has collaborated with the USGS-Earth Resources Observation Systems (EROS) Data Center and the University ofAlaska Fairbanks-Geographic Information Network of Alaska (GINA) to use Moderate Resolution Imaging Spectroradiometer (MODIS) data to monitor changes in seasonal processes. Lake ice has been manually interpreted for 17 lakes on the Kenai and Alaska Peninsulas since 2001 (http://science.nature.nps.gov/im/units/swan/monitor/lake_ice_about.cfm; Figure 1). Growing

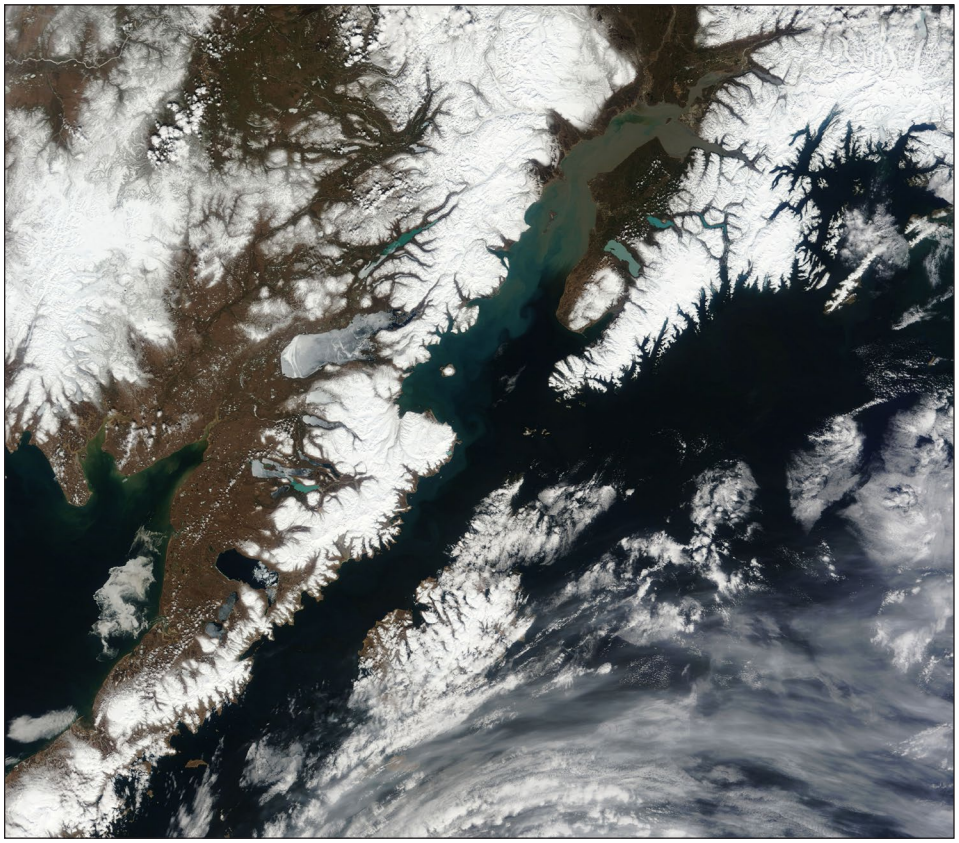

Figure 1. MODIS Terra image showing ice formation on Lake Iliamna and Naknek Lake, and snow cover extent, January 28, 2010. MODIS data are used to calculate lake ice, snow season, and growing season metrics.

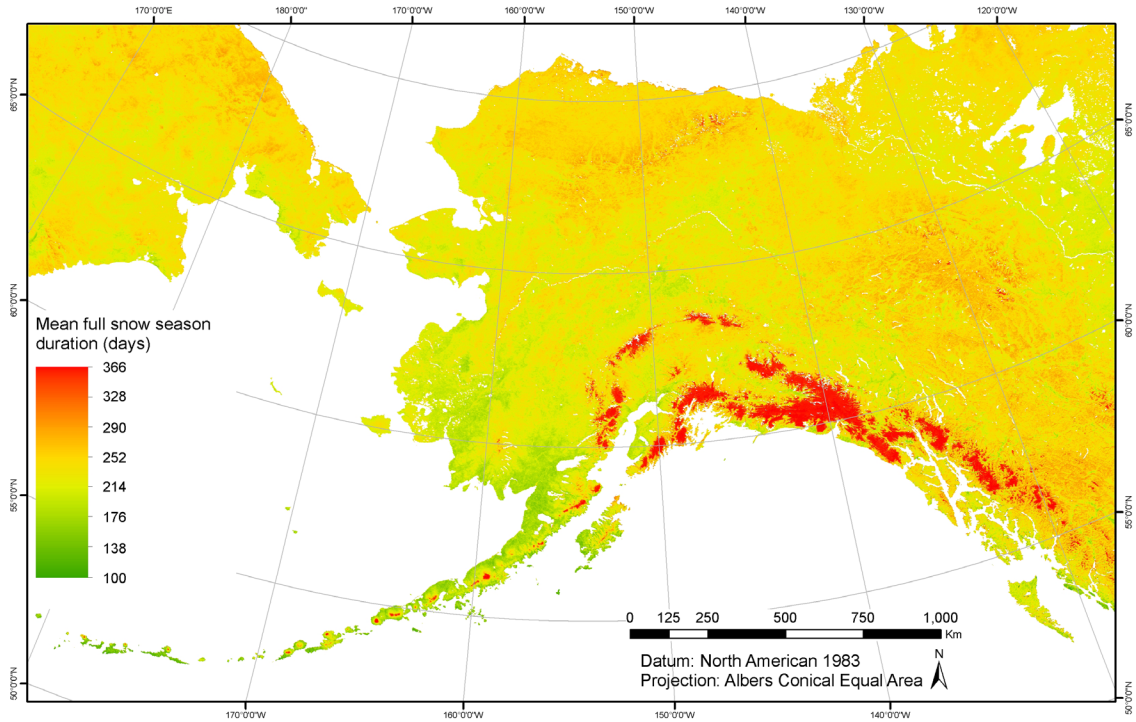

Figure 2. Mean full snow season duration across Alaska (2001-2013). Red areas indicate year-round snow on glaciers and permanent snowfields. Warm colors (orange) show areas of earliest snow onset or late snowmelt, whereas cooler colors (green) show areas with the shortest snow season; e.g., lowland coastal areas in southwest Alaska. (Figure from Lindsay et al. 2015).

season and snow season metrics derived from MODIS are available on GINA's website (2001-2015; http://www.gina.alaska.edu/projects). Time-lapse cameras installed at three remote weather stations in SWAN parks have been used to capture data on the timing of snowfall, green-up, and senescence. Images are archived with the PhenoCam Network at Harvard Forest (2010-present).

Snow Season Length and Lake Ice Vary with Winter Temperature

Snow cover is highly variable in coastal areas of southwest Alaska where snow often melts out several times during a winter. These snow "on-off" events can occur up to four or more times a year in western Katmai and the Bristol Bay lowlands (Lindsay et al. 2015). Mean snow season length varies from year-round at the highest elevations, to less than 100 days (approximately 3 months) at some coastal sites (Figure 2).

Lake ice can be similarly variable: typically lakes on the Kenai and Alaska Peninsulas do not completely freeze (>90% ice cover) until mid-November or mid-January, and in some years, such as the strong El Niño winter of 2002-2003, and the warm winter of 2014-2015, the largest lakes did not freeze at all (Reed et al. 2009; Hayward et al. 2016). The interannual variability in freeze-up start dates likely reflects the characteristic oscillation between warm and cold temperatures over several weeks in the late fall and early winter. In contrast, break-up occurs more rapidly than freeze-up, and the timing of final break-up dates (<10% ice cover) generally range from late April to early May. Variability in break-up dates can be as great as 31 days, and changes in the timing of break-up dates are likely a better indicator of broad-scale climate effects than changes in the timing of freeze-up (Hayward et al. 2016).

To date, the 14-year lake ice record does not show a trend, although long-term (150-year) trends across the Northern Hemisphere indicate a decrease of up to 12 days per century in lake ice season length (1846-1995; Magnuson et al. 2000). Future reductions in the duration of lake ice cover in southwest and southcentral Alaska would likely be associated with thinner ice, reduced albedo, warmer lake-water temperature, increased turbidity, increased light input, and decreased opportunities for winter recreation, ice-fishing, and trapping.

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Vegetation Monitoring

Vegetation is integral to ecosystem function, energy transfer, and element cycling. It drives ecosystem productivity, provides habitat and forage for wildlife, and food and materials for subsistence. Because vegetation responds directly to environmental drivers, it serves as a useful indicator of environmental change.

NPS/A Miller

Treeline site near Snipe Lake, Lake Clark NPP.

Methods

Vegetation composition and structure are monitored at the community scale using plot measurements to characterize stand structure, species composition, and selected environmental variables. Tree cores collected as part of a related study by Humboldt State University have been used to describe forest age structure and to characterize the effect of climate on the growth of white spruce. Vegetation monitoring began in 2009, and 2014-2015 marked the first five-year resurvey of forest and woodland plots in Lake Clark and Katmai National Parks and Preserves (NPPs).

NPS/A Miller

USFWS cooperator, Dr. Ed Berg, cores a tree at treeline, Dumpling Mountain, Katmai NPP.

Warming Drives Tree Growth ...*and* Beetle Activity

Warming over recent decades (1960-2010) has resulted in increased growth in white spruce, particularly near treeline in Lake Clark, where average June temperatures have increased by roughly 1.5°C (Figure 1a, d). Warmer summers have also been implicated in

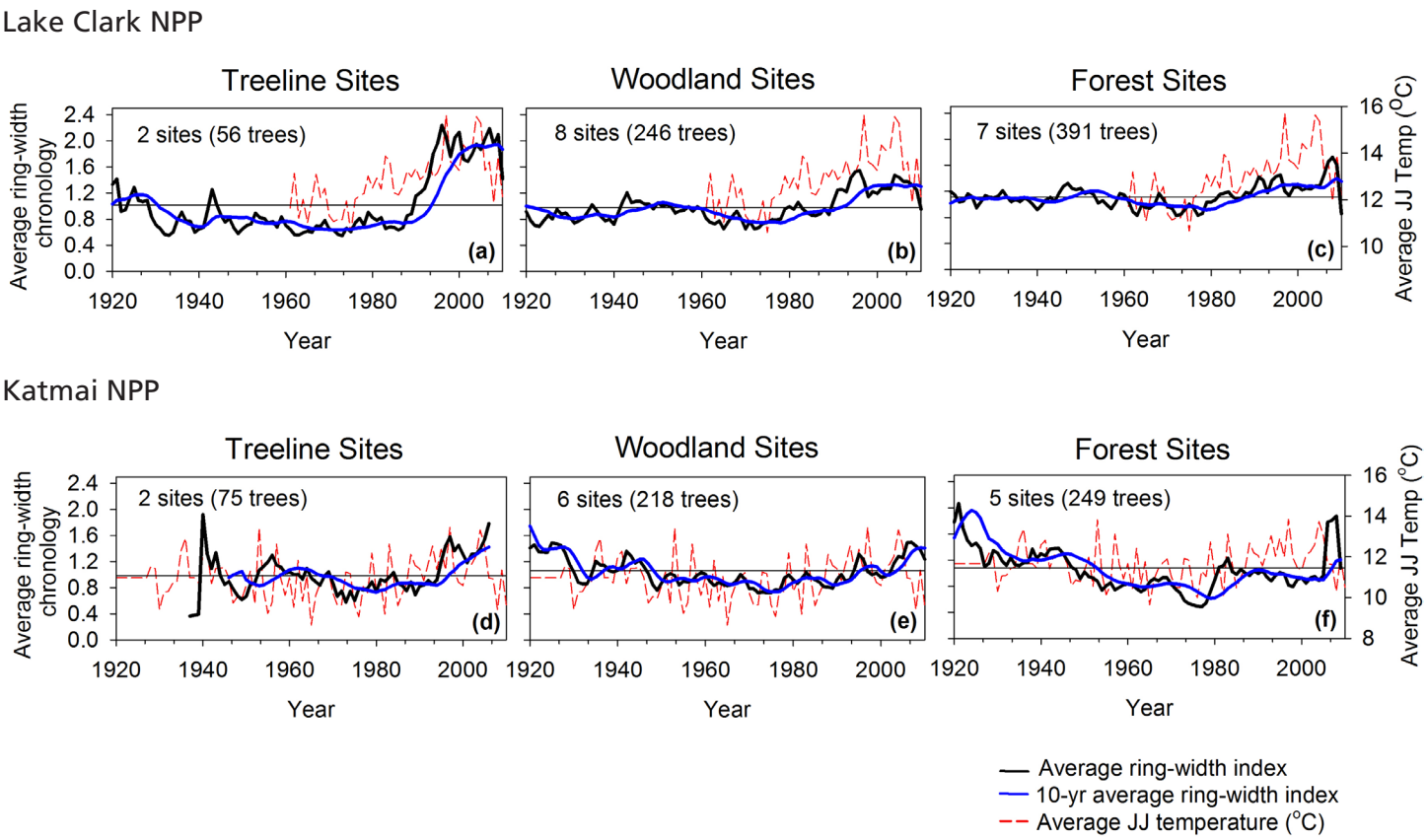

Figure 1. Annual average (black line) and 10-year smoothed average (blue line) of ring-width growth for upper treeline, open woodlands, and low-elevation closed-canopy forest sites in Lake Clark (a-c) and Katmai (d-f) National Parks and Preserves. The red dashed line in each graph represents the average June-July (JJ) temperature (°C) from COOP climate stations in Port Alsworth, and King Salmon, Alaska, respectively. Treeline growth in both parks has increased markedly over the last four decades, particularly in Lake Clark NPP, which has seen greater increases in summer temperatures (R. Sherriff, unpublished data).

the spruce beetle outbreak in Katmai and southern Lake Clark. In forest sites affected by the spruce beetle, growth has increased only slightly (Lake Clark) or has decreased (Katmai) since the 1960s (Figure 1f). In Katmai, where a flare-up in spruce beetle activity has been observed in the last five years, the number of dead trees has increased in the largest diameter classes (≥20 cm diameter at breast height [DBH]; Figure 2). Tree mortality has remained relatively stable in the Lake Clark stands, but both parks have shown reductions in live tree counts in the larger size classes, due in part to windthrow. An increase in live saplings (≤2 cm DBH) in Katmai is likely associated with the loss of forest canopy, and the resulting increase in light that could reach the forest floor (Figure 2).

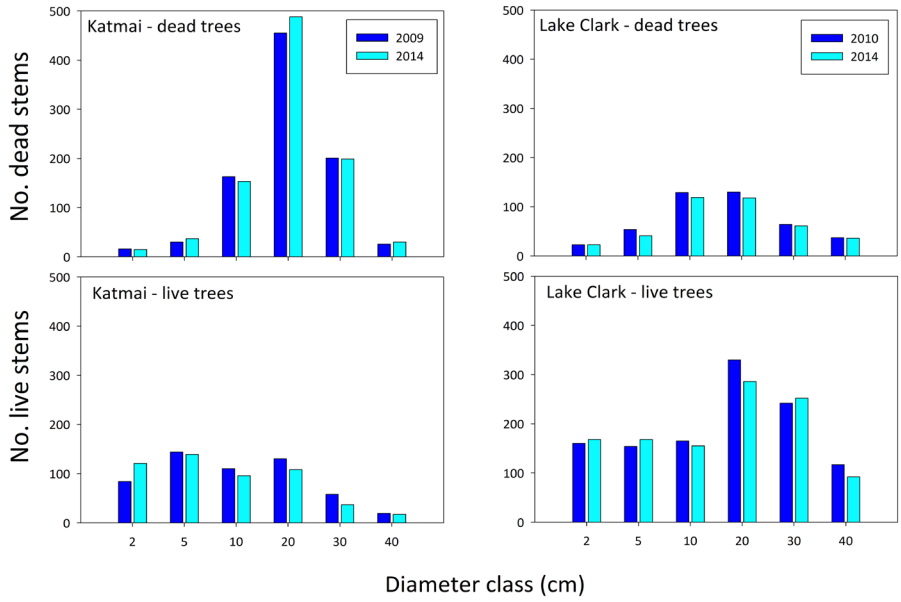

Figure 2. Frequency of live and dead white spruce in forest monitoring plots in Katmai (n=11) and Lake Clark (n=13) National Parks and Preserves. Stem counts were recorded in five diameter classes (diameter at breast height [DBH]) in 2009 and 2010. The high counts for dead trees in Katmai reflect the recent spruce beetle activity at these sites.

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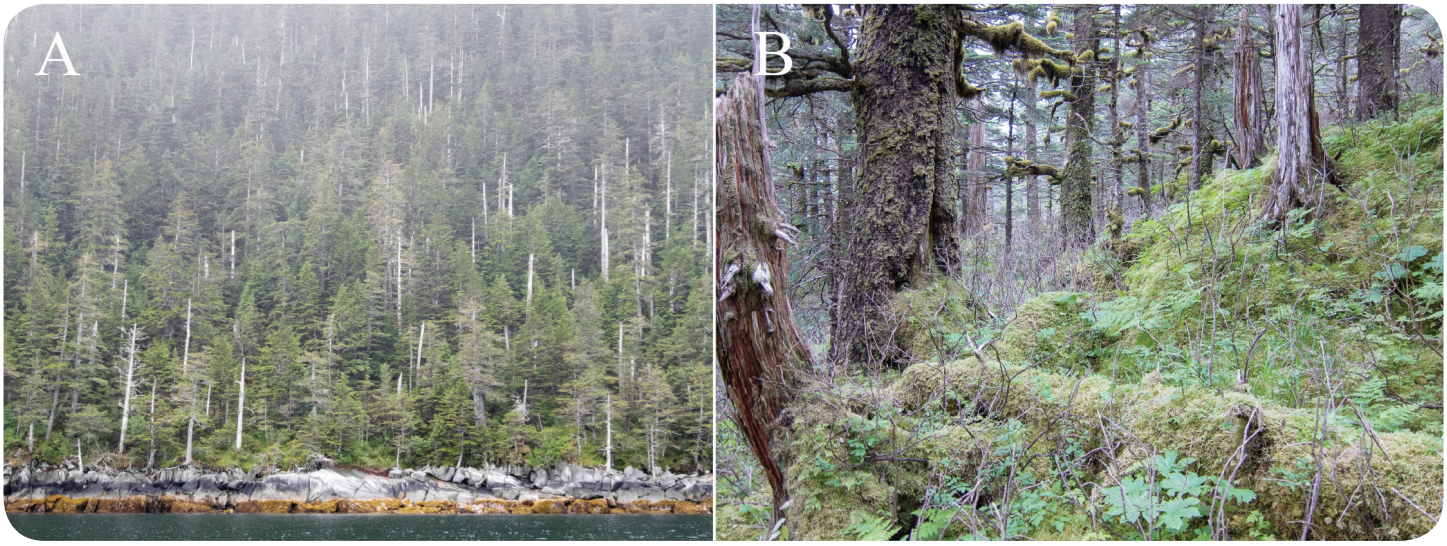
Coastal Forest Monitoring

Importance

Kenai Fjords National Park (NP) is well known for its dramatic coastal scenery, and the park's forests are one of the prominent features of this landscape. Vegetation patterns in the park are shaped by physical factors including topography, climate, substrate (soils and geology), and disturbance (such as avalanches or pests). Changing environmental conditions including a warming climate and increasing climate variability, shifting atmospheric chemistry and pollutant loads, and increasing variability in plant diseases and pests are expected to affect vegetation throughout Alaska in the future. An important priority for Kenai Fjords NP is to monitor its coastal forests for these changes. Measuring the relationships between these environmental conditions and coastal forest growth will help to better understand how ecological change may affect park resources.



Shoreline view of a mature Sitka spruce-mountain hemlock forest at Square Bay (A), and a view of the understory vegetation at Chance Cove (B). Defoliator damage on huckleberry at Chance Cove resulted in extensive dieback of the existing branches in 2013, shown in the foreground (B). Many shrubs are starting to re-sprout at the base. Both sites are near McArthur Pass, on the East Arm of Nuka Bay.

Methods

In order to assess future changes to Kenai Fjord's forests, nine monitoring plots were established in 2013 in mature Sitka spruce-mountain hemlock stands along the outer fjords in the park. This forest type was selected in part because it is one of the oldest and most commonly encountered along the Kenai Fjord coastline. Plot measurements included a suite of landscape attributes, tree measurements (diameter, height) for estimates of basal area and above-ground biomass, tree and seedling density, canopy covers, and coarse woody debris (CWD) loads. Epiphytic lichens were sampled using the widely established U.S. Forest Service's Forest Inventory and Analysis lichen sampling protocol. Plots will be resampled every ten years.

Taking a tree core sample at Kenai Fjords National Park.

Preliminary Findings

Coastal forests in Kenai Fjords NP are characterized by 200-500 year old trees, a range of age and size classes that contribute to structural complexities, a low density of standing snags, and CWD loads that comprise less than 1% of above-ground biomass (Miller and Walton, 2014). Most sites were characterized by a high number of young trees (saplings) in the understory, a proportion of which had died due to shading. This is characteristic of a stable population with continuous mortality, rather than one driven by disturbance. Minimum age estimates based on tree-ring counts show a peak of tree establishment after the end of the Little Ice Age (ca. 1850), although many trees at our sites were much older, establishing several centuries earlier (see figure).

Seedling establishment at these sites depends on the availability of decaying downed wood, or "nurse logs." The number of seedlings is greatest where there are canopy openings formed by fallen trees and where CWD loads are high. In recent surveys, we found mild to moderate defoliation in oval-leaf blueberry (*Vaccinium ovalifolium*) in at least 50% of the plots, presumably due to an outbreak of geometrid moths that had occurred within the last several years. We counted 32 taxa in the epiphytic lichen plots, most of which were characteristic of old-growth coastal forests and sensitive indicators of air quality. Lichen species of interest included *Hypogymnia duplicata*, a species of management concern in the Pacific Northwest and Gulf of Alaska (see photo below).

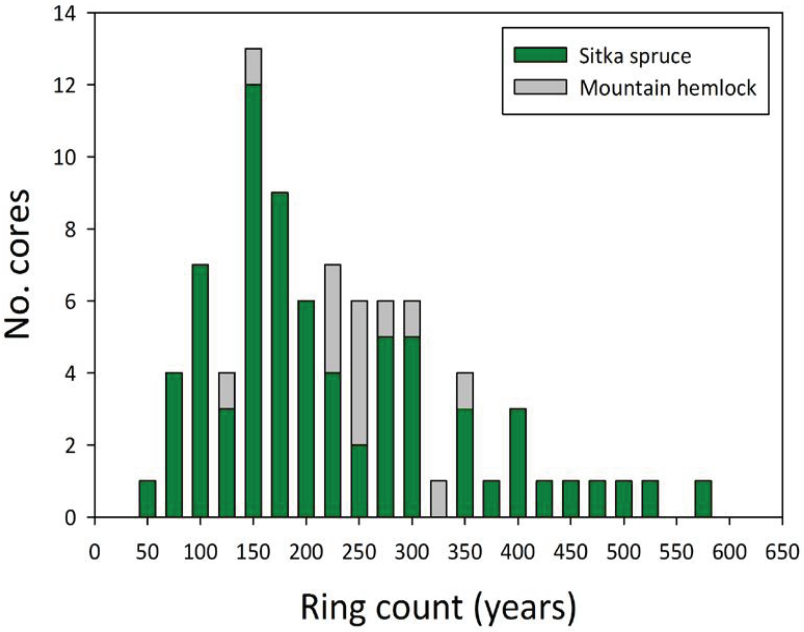


Figure. Composite frequency distribution for minimum ring counts on a representative subset of sampled live trees at KEFJ (n = 84). Approximately ten trees per plot of various diameter size classes were sampled. Ring counts on incomplete cores were included.

The duplicate tube lichen, *Hypogymnia duplicata*, observed at a single monitoring site. This Pacific Northwest endemic lichen displays a narrow ecological niche (high precipitation mature forests) and has a limited distribution. This lichen is a species of management concern under the Northwest Forest Plan of 1994.

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Photos: NPS/J. Walton

Miller, A. E. and J. K. Walton. 2014. Vegetation monitoring – Southwest Alaska Network: 2013 Annual report – Baseline sampling in coastal forests of Kenai Fjords. Natural Resource Data Series NPS/SWAN/NRDS—2014/675. National Park Service, Fort Collins, Colorado.

March 2016

Brief designed by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Lichens

Lichens are everywhere in Kenai Fjords National Park. They can be found in intertidal zones, the tops of mountains, and even on *nunataks* (the exposed rock outcrops of icefields). They grow on soil, rock, bark and wood, even on barnacles and buildings. Lichens are a major component of high-latitude ecosystems and contribute significantly to the biological diversity of the region. They are highly sensitive to environmental conditions including airborne contaminants, substrate chemistry, and climate; are ecologically important as food, shelter, and nesting material for wildlife; and play important roles in mineral and hydrological cycles, notably nitrogen fixation.

The very common (A) coral lichen (*Sphaerophorus tuckermanii*) and (B) yellow witch's hair lichen (*Alectoria sarmentosa* var. *sarmentosa*) were found at all eleven FIA lichen survey sites. Two rare to uncommon Kenai Peninsula coastal forest lichens, the (C) lettuce lichen (*Lobaria oregana*), and the (D) Pacific Northwest endemic tube lichen (*Hypogymnia duplicata*), were observed at only one survey site each.

Management Needs

Kenai Fjords National Park was created, in part, to preserve in perpetuity its unique fjord and rainforest ecosystems. Central to achieving this goal is an improved understanding of the lichen flora through the completion of an inventory and through monitoring of rare species and those that can indicate environmental change. The potential for new resource development in southwest and southcentral Alaska is expected to result in increased pollutant loads and increases in temperature regionally. This underscores the need for baseline data on lichen occurrences in the park. Because of their unique physiology, lichen communities are highly sensitive to their surroundings, making them ideal bioindicators for climate and environmental change.

Inventory

In 2015, a team of lichenologists from North America and Europe began to inventory and catalogue the lichens of Kenai Fjords under the guidance of Oregon State University and the National Park Service. To date, the team has surveyed lichens in the old-growth forests, riparian areas, and rocky shorelines of Nuka Bay and McCarty Fjord, Harris Bay and Granite Passage, Aialik Bay, and in the alpine ecosystems near Exit Glacier. Future visits are planned to coastal alpine areas and nunatak sites in the Harding Icefield. Already one lichen species new to North America has been identified: *Ephebe multispora*, a dark filamentous species found growing on seepage boulders in Coleman Bay. Previously it was known only from Greenland and northern Sweden. Additionally, *Ameliella andreaeicola*, a rare lichen known to grow only on a certain genus of moss, was recorded as new to the United States. It was discovered along the Harding Icefield trail near

NPS/James Walton

Surveying sloping peatland ecosystems in Kenai Fjords National Park for lichens (depicted in photos above and below).

NPS/James Walton

Exit Glacier. Lichenologists are in the process of curating and identifying collections from Kenai Fjords, and many more exciting discoveries are expected. Final products from this inventory will include a comprehensive voucher-based lichen species list and accompanying database for the park, as well as a peer-reviewed paper describing inventory findings. Specimens collected during the course of the inventory will be provided on loan to the University of Alaska, Museum of the North Herbarium and several other institutions where they will be available for research and educational purposes.

Monitoring

Southcentral Alaska hosts diverse and abundant lichen communities that are faced with a rapidly changing environment, moreso than those in southerly latitudes. Because of their unique physiology, lichens make ideal bioindicators due to their sensitivity to climate as well as a number of atmospheric pollutants, including sulfur dioxide, and nitrogen- and sulfur-containing compounds. During August 2012, the NPS established eleven lichen community monitoring plots in mature, low-elevation Sitka spruce-mountain hemlock forests. This forest type was chosen to monitor because it is some of the oldest and most commonly encountered along the Kenai Fjords coastline. Researchers used a lichen survey method developed by the Forest Inventory and Analysis (FIA) Program of the U.S. Forest Service which allows assessment of several key questions concerning natural resource contamination, biodiversity, and the ability to provide ecosystem services. Because this FIA lichen survey method is used throughout western North America, data from Kenai Fjords will be used to support large-scale tracking efforts of climate and environmental change. Initial baseline findings in Kenai Fjords revealed that the epiphytic lichen communities of these forests included several species sensitive to airborne pollutants such that their presence indicates unimpaired air quality. Prominence of these pollution-sensitive species, and a low abundance of nitrophilous species, is due in part to low nitrogen deposition throughout most of the region. Lichen community monitoring plots will be resampled every ten years to re-evaluate any change in condition.

NPS/James Walton

In 2015, new records were made in Kenai Fjords of the rare amphi-beringian lichen *Stereocaulon saviczii*.

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Alagnak Aniakchak **Katmai** **Kenai Fjords** **Lake Clark**

Lichen Inventory

Lichens are an important component of biological diversity and are sensitive indicators of air quality and climate. Despite their ecological importance in southwest Alaska, there is a general lack of information regarding lichen occurrence in the Southwest Alaska Inventory and Monitoring Network (SWAN) parks. To address this information need, the SWAN has partnered with Oregon State University (OSU) to conduct a lichen inventory of its three largest parks: Katmai, Lake Clark, and Kenai Fjords.

NPS/James Walton

Lichenologists take a closer look at Katmai National Park's lichens.

Preliminary Results

Under the guidance of OSU and the NPS, a team of lichenologists from North America and Europe visited Katmai in 2013, Lake Clark in 2014, and Kenai Fjords in 2015. They surveyed sites throughout each park that were selected by NPS botanists to span a range of rich lichen habitats, including coastal rock outcrops and forests, large interior lakes, river and forest systems, and interior and coastal alpine zones. Researchers observed a lichen flora with an interesting mix of arctic-alpine, boreal, and coastal elements. The Beringian element that is evident on the Seward Peninsula and Aleutian Islands did not appear to be prominent in SWAN parks. A number of oceanic forest species were found at low-elevation, moist forest sites.

Certain species groups or genera common to the alpine were surprisingly rare in Katmai. These included the alpine ground-dwelling *Rinodina* species, ground-dwelling *Hypogymnia*, and *Dactylina*. These genera were somewhat more abundant in Lake Clark than in Katmai, but still not as abundant as in more continental climates.

Nitrophilous species (e.g., *Caloplaca*, *Xanthoria*) do not appear to be abundant in any park, suggesting low levels of nitrogenous pollutants. Few calciphiles were encountered, owing to the predominantly acidic rocks in all parks. Although the team was unable to sample on limestone or dolomite in Katmai or Kenai Fjords, they did visit one site with marble on the shore of Lake Clark. Species found at that site differed from those occupying more acidic rock in surrounding areas.

At present, several notable lichen collections have been made, including the discovery of three species new to science, *Rinodina pallidescens* Sheard and Tønsberg, *Parvoplaca nigroblastidiata* Arup, Halıcı, and Vondák and *Rinodina incurva* Sheard (awaiting publication). Additionally, new populations of the globally endangered lichen, *Erioderma pedicillatum* (Hue) P. M. Jørg., were discovered in both Katmai and Lake Clark. Many other interesting finds were made, including new records for North America and Alaska, plus one or more additional new species.

Lichenologists are continuing the process of curating and identifying collections from Katmai, Lake Clark, and Kenai Fjords. Final products will include a comprehensive voucher-based lichen species list and accompanying database for each of the three parks. Specimens collected during the course of the inventory will be provided on loan to the University of Alaska, Museum of the North Herbarium and several other institutions, where they will be available for research and educational purposes.

Bald Eagles

Southwest Alaska parks support large populations of bald eagles. Bald eagles were once listed as an endangered species in the contiguous 48 states, but have since recovered and were delisted in 2007. As top predators, bald eagles can serve as indicators of the overall health of local ecosystems. Their breeding success is influenced by food availability and spring weather conditions, among other factors. Understanding the status and trends of local populations can assist park managers address concerns related to the impacts of human-caused disturbances, such as oil spills.

NPS/Kaiti Chritz

NPS

Bald eagles at Kenai Fjords National Park.

Improving Survey Methods

Assessing abundance (to estimate population size) is an important tool to monitor the condition of wildlife populations, especially during species recovery. Because it is often difficult to conduct a complete count by observation, modeling techniques and estimates are used.

In 2014, ecologists discovered a key weakness of the bald eagle monitoring methods that led to biased estimates of bald eagle nest occupancy in parks. The bias arises when the true status of a nest (initiated or empty) is ambiguous during observational nest surveys (Wilson et al. 2014). For example, in a single survey, it is impossible to know if an empty nest is truly empty, or if the eagles are just not in the nest during the time of the survey. Conducting two surveys can be used to correct bias from this ambiguous status.

National Park Service ecologists are finalizing the official monitoring plan and standard operating procedures for bald eagle monitoring in southwest Alaska parks. The protocol features important advancements in data collection and analysis that address imperfect detection at multiple levels.

Three bald eagle chicks observed in a nest during aerial surveys in Katmai National Park and Preserve. A clutch of three chicks, while predicted by models, is rarely observed.

NPS

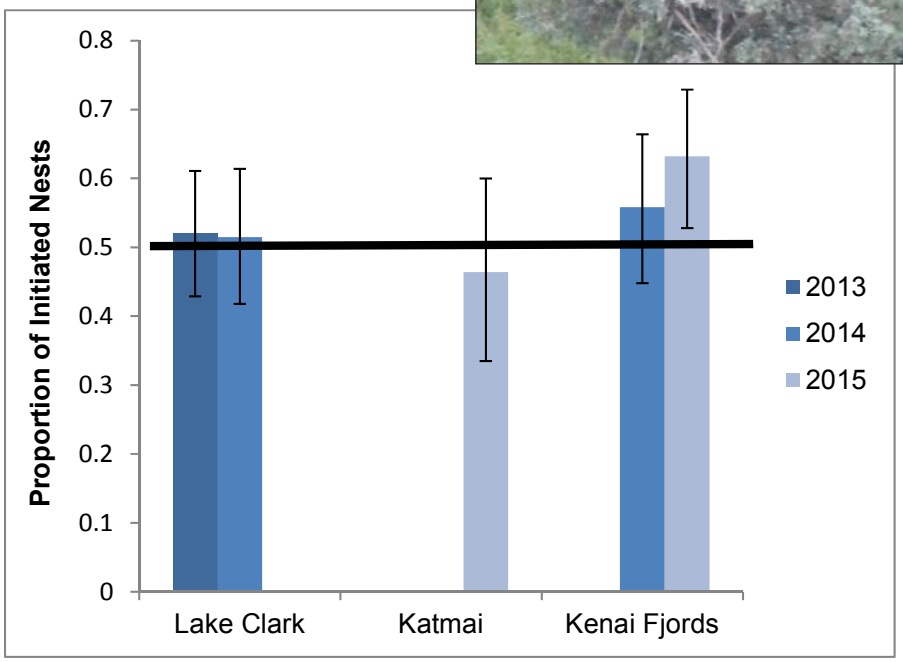

Figure 1. Bald eagle nest initiation in three southwest Alaska parks, 2013-2015. The solid bar indicates the 0.50 threshold at which bald eagle populations are considered stable.

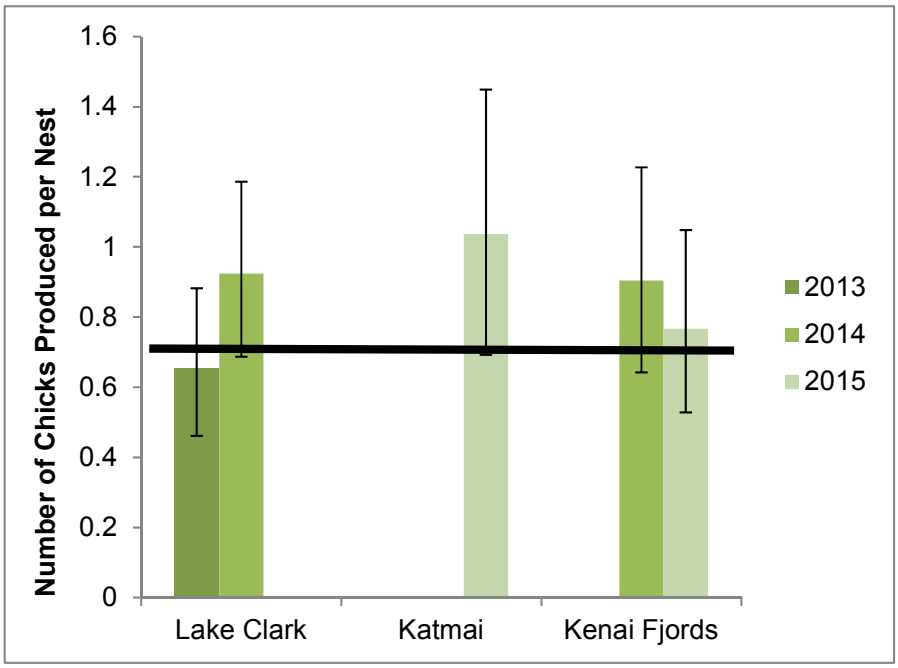

Figure 2. Bald eagle productivity in three southwest Alaska parks, 2013-2015. The solid bar indicates the 0.70 threshold at which bald eagle populations are considered stable.

Results Using New Methods

Bald eagle reproductive success is largely based on two components: nest initiation and nest productivity.

Nest initiation (that is, the number of nests where eagles attempt to breed in a given year) is important because it provides the context necessary for understanding the total population of breeding eagles, and number of chicks produced. Bald eagle populaitons are considered stable if nest initiation rates are greater than 0.50. Parks in southwest Alaska appear to have stable populations (Figure 1).

Bald eagle nest productivity is the average number of chicks produced for each nest in a given year. Bald eagle populations are considered stable if the average number of chicks produced for each nest is greater than 0.70. Again, the data show that bald eagle populations are stable in southwest Alaska parks (Figure 2).

The confidence intervals for each estimate (Figures 1 and 2) are depicted by brackets. In Bayesian statistics, the 95% credible interval means one can be 95% certain that the interval contains the true value.

Reference

Wilson, T. L., J. H. Schmidt, W. L. Thompson, and L. M. Phillips. 2014. Using double-observer aerial surveys to monitor nesting bald eagles in Alaska: are all nests available for detection? *Journal of Wildlife Management* 78(6):1096-1103.

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Bald Eagle Survey Methods

Importance

All three Southwest Alaska Network (SWAN) park units support large populations of bald eagles. Bald eagles were once listed as an endangered species in the contiguous 48 states due to human-caused declines. Populations have since recovered, and bald eagles were delisted in 2007. As top predators, bald eagles can serve as indicators of the overall health of local ecosystems. Their breeding success is influenced by food availability and spring weather conditions. Understanding the status and trends of local populations can assist managers in addressing future questions on the impacts of visitor access or other human caused disturbances, such as oil spills.

NPS photo/K. Chritz

Findings

Bald eagle nest monitoring continues to improve at SWAN parks. In 2014, ecologists discovered a key weakness of the bald eagle monitoring protocol that could lead to biased estimates of bald eagle nest occupancy in parks. The bias arises when the true status of a nest (initiated or empty) is ambiguous during observational nest surveys. For example, in a single survey, it is impossible to know if an empty nest is truly empty, or if the eagles are not in the nest during the survey. Two surveys can be used to correct any bias from this ambiguous status.

This bias is shown for the 2014 surveys in Lake Clark National Park and Preserve (see figure). Bald eagle populations are considered to be stable if nest initiation rates are greater than 0.5. The results from one survey is shown by the green circle. The curved line demonstrates what the bias-corrected results look like when two nest surveys are completed. From this figure, it is clear that one nest survey does not result in the most accurate information on eagle nests.

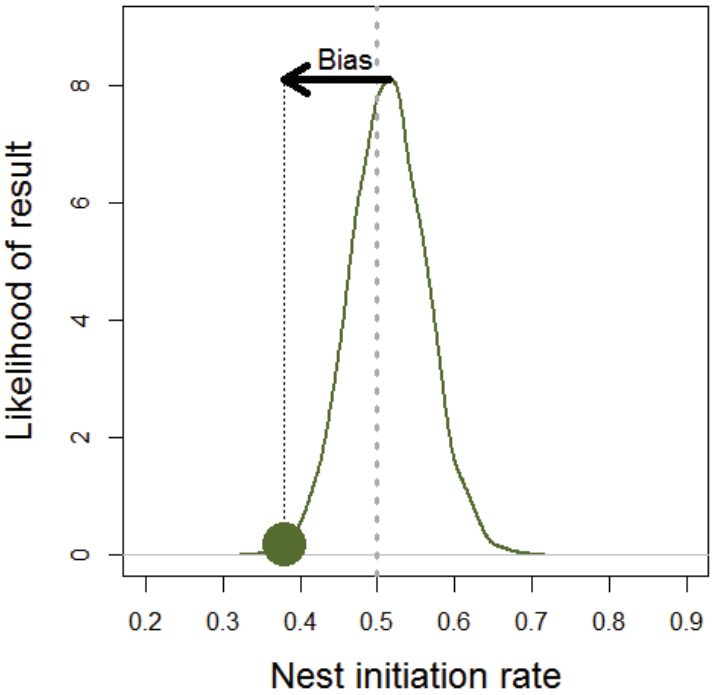

Figure of the bias-corrected (curve) and apparent (green circle) bald eagle nest initiation rates at Lake Clark National Park and Preserve.

Results of our recent analyses confirm that a negative bias in nest initiation rates is present in most cases. Biased estimates can be problematic for wildlife managers because they could lead to incorrect management actions. To correct for bias in nest monitoring, it is recommended that parks conduct two occupancy surveys during the nest initiation period in May.

Status

Bald eagle nest productivity in Katmai National Park and Preserve (NPP), Kenai Fjords National Park (NP), and Lake Clark National Park and Preserve (NPP) are shown in the table below. SWAN's new double occupancy survey model improves how productivity data are analyzed.

Park	Year	Productivity	Lower 95% confidence interval	Upper 95% confidence interval
Katmai NPP	**2015**	**1.04**	**0.68**	**1.46**
Kenai Fjords NP	**2014**	**0.90**	**0.64**	**1.23**
Kenai Fjords NP	**2015**	**0.77**	**0.53**	**1.05**
Lake Clark NPP	**2013**	**0.67**	**0.46**	**0.88**
Lake Clark NPP	2014	0.92	0.69	1.19

NPS photo/P. Calamari

Discussion

Ecologists at SWAN and SWAN parks are finalizing the official monitoring plan and standard operating procedures. These protocols feature important advancements in data collection and analysis. Look for it on IRMA prior to the onset of field sampling in May.

Bald eagles often have more than one nest in their territories. A recent study by Watts (2015) analyzed the value of protecting alternate nests from both a biological and economic perspective. The study found that alternate nests have a 70% chance of surviving to the next year, compared to 90% of primary nests. Further, the probability that a nest or nest tree would be reused or rebuilt (if lost) by the resident pair declined with the amount of time since the last nest was used. This decline in probability of nest reuse meant that the cost-to-benefit ratio of protecting alternate nests does not extend beyond three years post-abandonment.

Watts, B.D. 2015. Estimating the residual value of alternate bald eagle nests: implications for nest protection standards. The Journal of Wildlife Management 79:776-784.

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March 2016

Brief created by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Black Oystercatchers

Importance

The black oystercatcher is a common and conspicuous member of rocky intertidal marine communities and is thought to be important in structuring nearshore ecosystems. Black oystercatchers are completely dependent on nearshore marine habitats for all critical parts of their life cycle including foraging, breeding, chick-rearing and resting. Because of their complete reliance on nearshore marine habitats, they are also highly susceptible to human disturbance. The black oystercatcher is considered a Management Indicator Species by the Chugach National Forest and a species of concern by the Alaska Shorebird Working Group. It is widely recognized as a species representative of nearshore habitats and therefore particularly amenable to long term monitoring.

Monitoring Approach

Southwest Alaska Network (SWAN) staff and partners have been monitoring black oystercatchers annually in Katmai National Park and Preserve (NPP) since 2006, annually in Kenai Fjords National Park (NP) since 2007 and in western Prince William Sound (WPWS) since 2007, with annual sampling in WPWS starting in 2010. Boat-based surveys are conducted in early summer to determine breeding density. Nests are located on foot and examined for presence of chicks and/or eggs to determine productivity. Prey remains are collected and identified to species to determine chick provisioning habits.

Examining prey remains collected near black oystercatcher nests. NPS photo

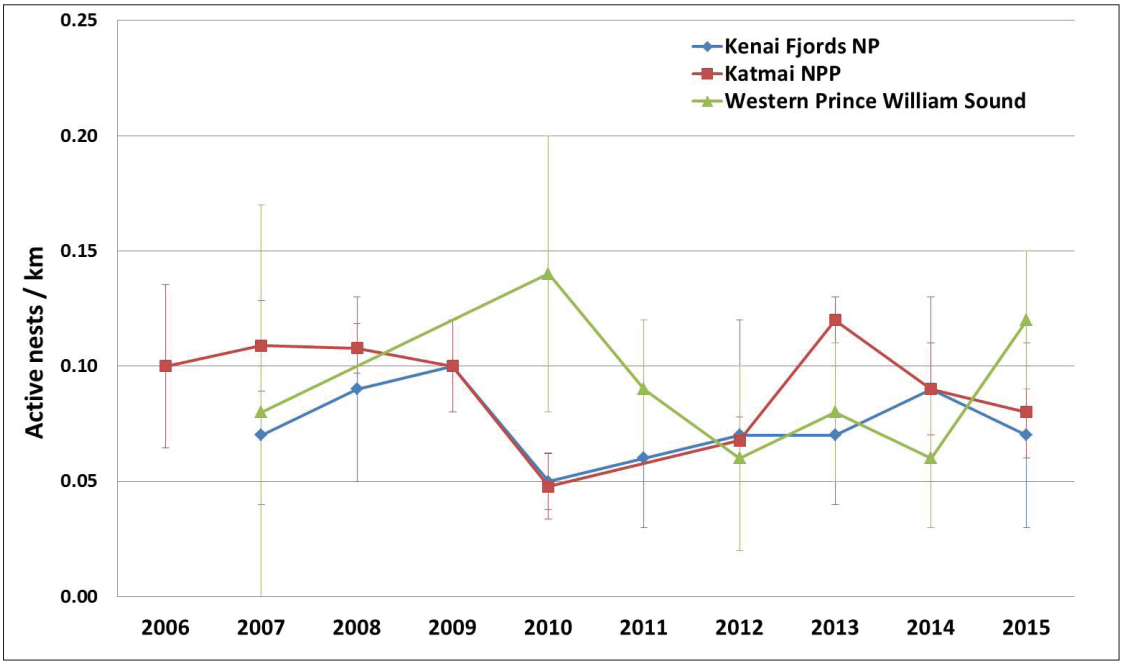
Black oystercatcher (top) and a clutch of three black oystercatcher eggs (bottom). NPS photos/K. Chritz

Findings to date

Active nest density continues to be similar across time with little evidence of a trend in all three regions (Figure 1). However, productivity (the number of eggs and chicks per nest) tends to be highly variable across all regions. Because we only visit a nest once per year in our monitoring program, results reflect productivity at the time of the survey, adding to the variability in the results.

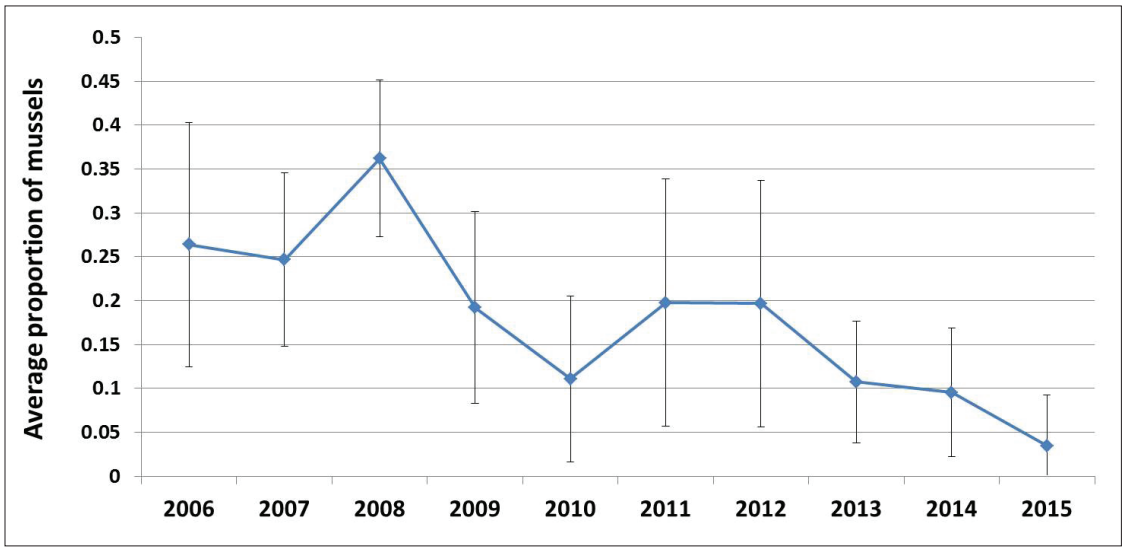
Prey remains collected from nests indicate that limpets (predominantly *Lottia* sp.) and mussels (*Mytilus trossulus*) continue to be the dominant food source for black oystercatchers in all three regions. However, we observed a decrease in the proportion of mussels in black oystercatcher diet over time (Figure 2), concurrent with changes in mussel availability (see mussel resource brief). Changes in prey abundance and how those changes potentially affect black oystercatcher populations is a question our long-term monitoring data is designed to answer.

Figure 1



Number of active black oystercatcher nests found per kilometer along shorelines in Kenai Fjords NP, Katmai NP, and western Prince William Sound. Error bars represent +/-1 standard error.

Figure 2



The average proportion of mussels in black oystercatcher diets through time. Diet remains were collected from nest sites within the study regions. Error bars represent +/-1 standard error.

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Nearshore web site at http://science.nature.nps.gov/im/units/swan/monitor/nearshore.cfm

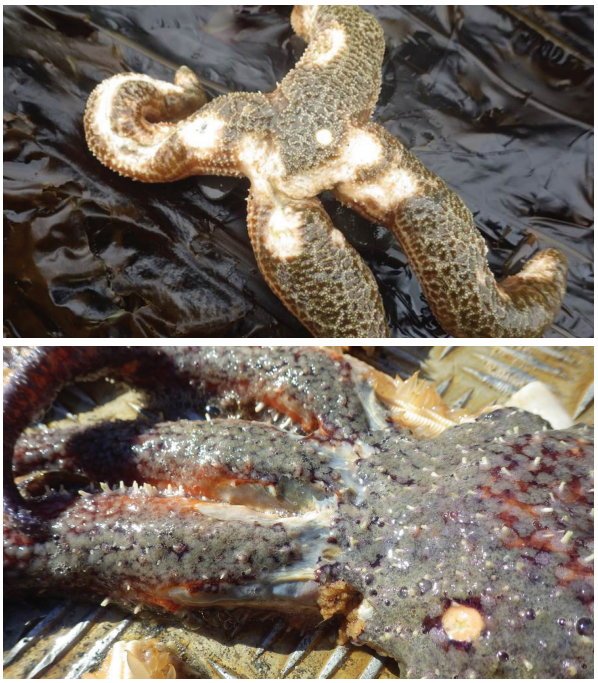
April 2016

Brief designed by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Sea Star Wasting Disease

Importance

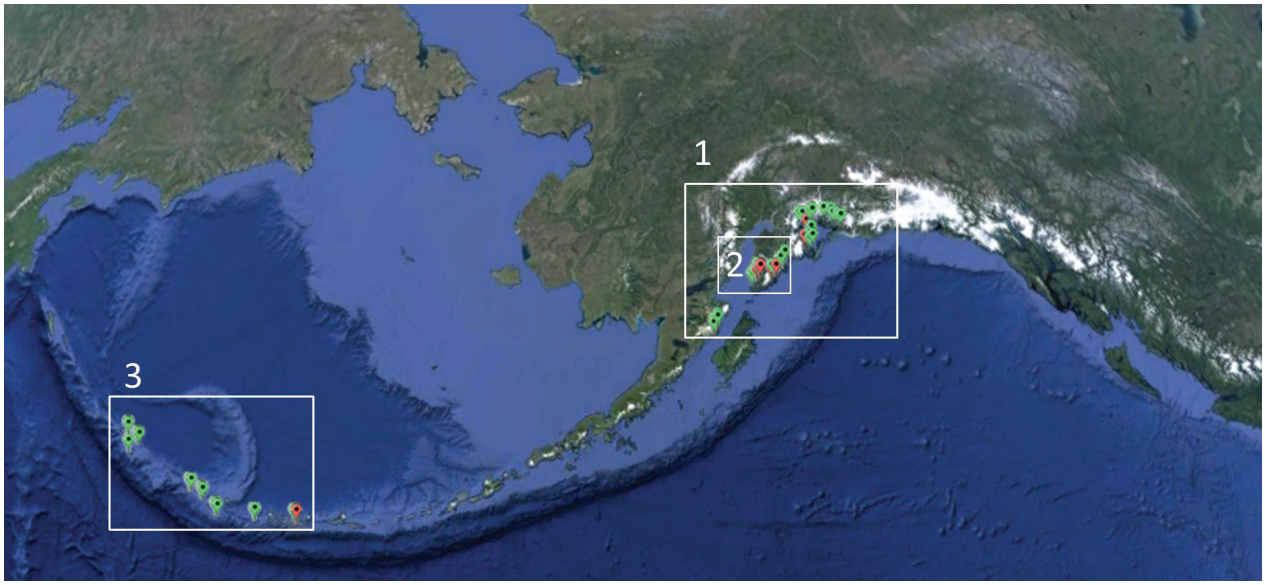
Sea stars play a vital ecological role as top level predators shaping nearshore ecosystems. The absence of sea stars can enable other organisms that sea stars eat, like mussels, to multiply and drive out other nearshore inhabitants. An epidemic wasting disease began in 2013, affecting sea stars from Alaska to Baja California, Mexico. The epidemic affects at least 20 sea star species, and sea star populations along the west coast of the U.S. have experienced very high levels of death. As the disease progresses, sea stars often lose arms and can have a jelly-like appearance. Death can occur within a few days of the initial signs of infection. This disease has been observed in several locations in southeast Alaska, and more recently in Western Prince William Sound and Kachemak Bay.



Images of lesions and unnatural body twisting typical of sea star wasting disease. Top image of a mottled star (*Evasterias troscheli*), and bottom image of a sunflower star (*Pycnopodia helianthoides*). Photos courtesy of K. Iken.

Methods

The National Park Service, in partnership with the U.S. Geological Survey, the University of Alaska, Fairbanks (UAF), the National Oceanic Atmospheric Administration (NOAA), and GulfWatch Alaska began a concerted effort to look for the disease in southcentral Alaska starting in 2014. Researchers from various institutions searched for the disease at long-term GulfWatch Alaska monitoring sites in Prince William Sound[1], Kenai Fjords National Park[1], Katmai National Park and Preserve,[1] and in Kachemak Bay[2]. GulfWatch Alaska collaborators from UAF also investigated sites in the Western Aleutian Islands[3], outside the scope of this long-term monitoring program.



Sites that were surveyed in Prince William Sound[1] and National Parks that border the Northern Gulf of Alaska[1], Kachemak Bay[2], and the Western Aleutian Islands[3].

Preliminary Findings

Infected sea stars that were found in survey locations are shown by red pins, and survey locations without infected sea stars are shown by green pins.

In 2014, only nine sea stars out of 1,588 observed across 30 sites were found infected (0.6% prevalence), and these nine sea stars were all found in Kenai Fjords National Park (McCarty Fjord and Nuka Passage).

In 2015, we found 69 infected sea stars out of 2,016 sea stars observed (3.4% prevalence). Almost all of these sea stars (67) were observed in Kachemak Bay, and additional information is needed to determine why this was the case.

Although there was a slight increase in disease prevalence in 2015, the occurrence of diseased stars is still low compared to southeast Alaska and the lower 48. However, occurrences may be underestimated due to the limited area of Alaska's coastline that had been sampled.

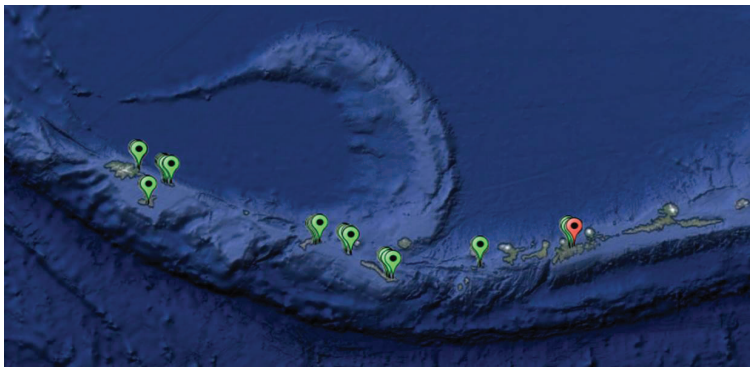
How you can help

Many sea stars can exhibit bodily damage, due to impact injuries from boulders moved by large waves, exposure to freshwater, and predators. These injuries can be confused with wasting disease, but you can visit **seastarwasting.org** for comprehensive identification guides. We encourage the use of citizen science in collecting data on diseased sea stars. If you observe a sea star that exhibits signs of this disease, please take a photograph, note the location and date, and send to: mandy.lindeberg@noaa.gov, kbiken@alaska.edu, or bhkonar@alaska.edu.

GulfWatch Alaska long-term monitoring sites[1]. Kenai Fjords National Park surveyed in 2014, Prince William Sound surveyed in 2015

Kachemak Bay[2] surveyed in 2015

Western Aleutian Islands[3] surveyed in 2015



Courtesy K. Iken

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Sea star wasting disease at www.seastarwasting.org

March 2016

Brief designed by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Sea Otters

Importance

Sea otters (*Enhydra lutris*) are known as a keystone species. A keystone species dramatically affects the structure and complexity of their environment. For example, when sea otters are present in rocky habitats, they eat sea urchins and urchin density decreases as a result. Lower urchin density reduces grazing pressure on kelps, resulting in a more diverse nearshore ecosystem[1]. In 2005, sea otter populations in the southwest Alaska population segment (which includes coastal habitat of Katmai National Park and Preserve) were listed as threatened under the Endangered Species Act. Further, the U.S. Fish and Wildlife Service designated almost 6,000 miles of coastline in southwest Alaska as critical habitat for the northern sea otter. Critical habitat is habitat that is deemed essential for the conservation of a threatened (or endangered) species. Monitoring sea otter populations, as well as other components related to sea otter status, in nearshore ecosystems will result in important information to better understand population trajectories.

Methods

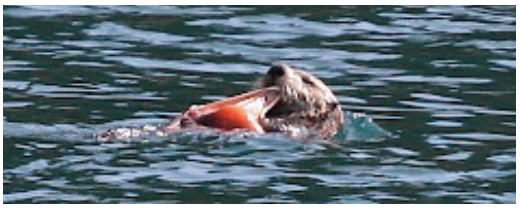
There are three different ways sea otter data are collected: fly aerial surveys to estimate abundance, conduct foraging observations to estimate energy recovery rates, and collect carcasses to estimate the age-class distribution of the dying otters.

Aerial surveys are conducted in order to calculate sea otter abundance. Surveys were flown in Katmai National Park and Preserve (NPP) in 2008, 2012, and 2015; Kenai Fjords National Park (NP) in 2007 and 2010; and western Prince William Sound annually from 1993 through 2005, 2007 through 2009, and 2011 through 2013.

Sea otter foraging data are collected annually in these areas to estimate energy recovery rates (kcal/min). These rates are used to indicate population status relative to a food-limited carrying capacity. In biology, carrying capacity is the maximum population size of a particular species that the environment can sustain indefinitely given the food, habitat, and other necessary environmental resources.

A biologist observes feeding behavior of sea otters in Kenai Fjords NP. Collected data include the type, size, and numbers of species consumed by otters, as well as how much time sea otters spend diving and at the surface. This data helps biologists calculate energy recovery rates of sea otters. NPS photo.

Carcass surveys also occur annually. To date, very few carcasses have been found in Kenai Fjord NP, presumably because of the relatively low density of sea otters in the area and the lack of low sloping beaches that could act as repositories for carcasses. Carcasses are collected every year from Katmai NPP and western Prince William Sound.



Sea otter feeding on an octopus (left) and grooming (right). NPS photos.

Findings to date

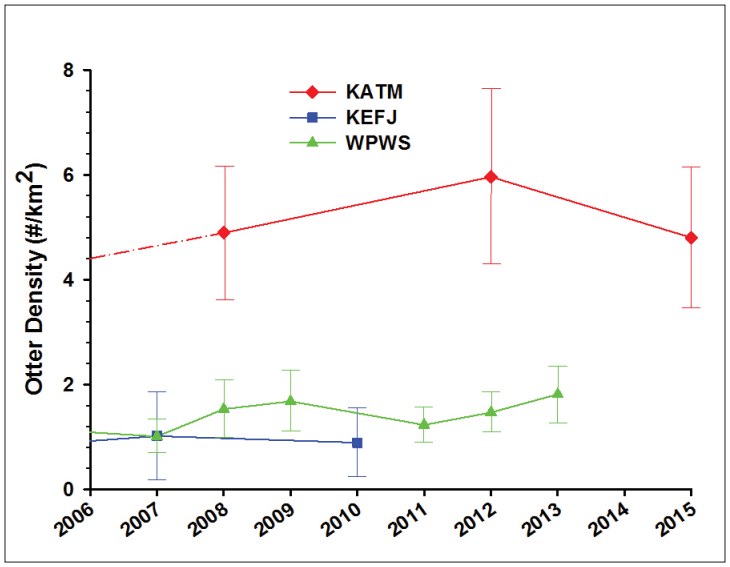
In Katmai NPP, our data suggest that sea otter numbers increased substantially since the early 1990's and have been at high and stable densities in recent years (see Figure 1). This corresponds with declining energy recovery rates, suggesting that otters have reached a food-limited state (see Figure 2).

Densities of otters in Kenai Fjords NP, while relatively low, have been stable since 2002 (see Figure 1) with stable energy recovery rates (see Figure 2), indicating a population at carrying capacity with low food availability in comparison to Katmai NPP. Unlike Katmai NPP, which has extensive shallow soft-sediment habitats ideal for clams, Kenai Fjords NP is predominately a glacial fjord ecosystem. Its "steep and deep" characteristics can be unfavorable for clams. The low availability of clams likely contributes to the lower density of otters in Kenai Fjords NP.

Initially, in western Prince William Sound, food was not a limiting factor in sea otter recovery from the *Exxon Valdez* oil spill. More recently we have observed a moderate increase in sea otter population density, with a subsequent decline in energy recovery rates. This indicates that the population may be reaching its carrying capacity for this region (see Figures 1 and 2)[2].

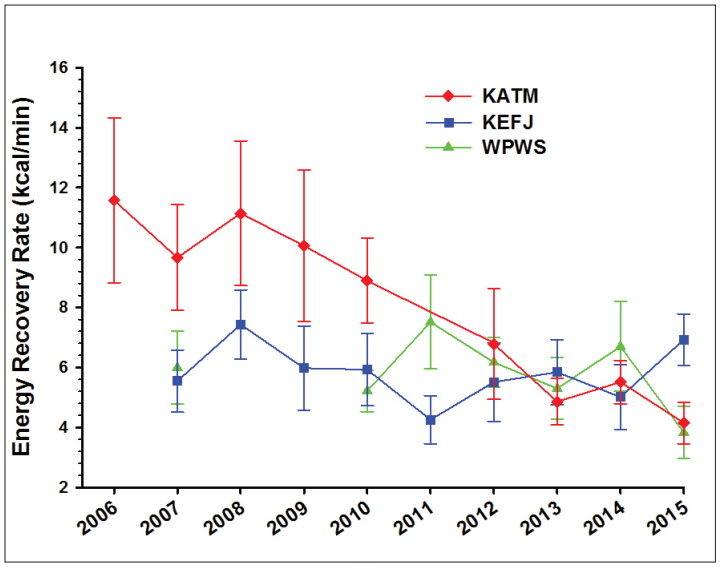
The design and coordination of our monitoring program allows the National Park Service to infer potential causes and spatial extent of the observed changes in abundance that have occurred through time.

Figure 1



Estimated mean density of sea otters occupying suitable habitat in Katmai NPP (KATM), Kenai Fjords NP (KEFJ), and western Prince William Sound (WPWS). Error bars represent 95% confidence intervals.

Figure 2



Energy recovery rates (measured as kilocalories gained per minute, kcal/m) for sea otters foraging in Katmai NPP (KATM), Kenai Fjords NP (KEFJ), and western Prince William Sound (WPWS). Error bars represent 95% confidence intervals.

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2. Coletti, H.A., J.L. Bodkin, D.H. Monson, B.E. Ballachey and T.A. Dean. Ecosphere. Detecting and inferring cause of change in an Alaska nearshore marine ecosystem. *In review*.

April 2016

Brief designed by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Mussels

Importance

Pacific blue mussels (*Mytilus trossulus*) are common and abundant in shallow nearshore marine waters. They often form dense stands of individuals, commonly called mussel beds. They are a valued food for humans. In the nearshore, they are consumed by many predators including sea otters, black oystercatchers, and several species of sea ducks and sea stars. Because of their ecological and cultural value, mussels are an important part of our nearshore monitoring in the Gulf of Alaska.

Monitoring mussel beds.
NPS photo/P. Calamari

Findings

Beginning in 2008, we have been monitoring mussel beds at sites in Katmai National Park and Preserve (NPP), Kenai Fjords National Park (NP), and western Prince William Sound (WPWS). When we began sampling, beds were largest in Kenai Fjords NP, averaging about 5,000 m^2. In Katmai NPP and WPWS, beds averaged about 2,000 m^2 (Figure 1).

Interestingly, mussel populations have declined throughout the Gulf of Alaska. Average mussel bed size declined by about half, and some beds essentially vanished by 2012 or 2013 (see photo 2 in Kaflia Bay time series, taken in Katmai NPP). Since then, we have monitored mussel recovery to their initial bed sizes at most sites (10 out of 15, see photo 3). The largest beds in Kenai Fjords NP, mostly found on unconsolidated sediments, have not recovered, resulting in the patterns shown in Figure 1.

PHOTO 1 **Kaflia Bay in 2008**

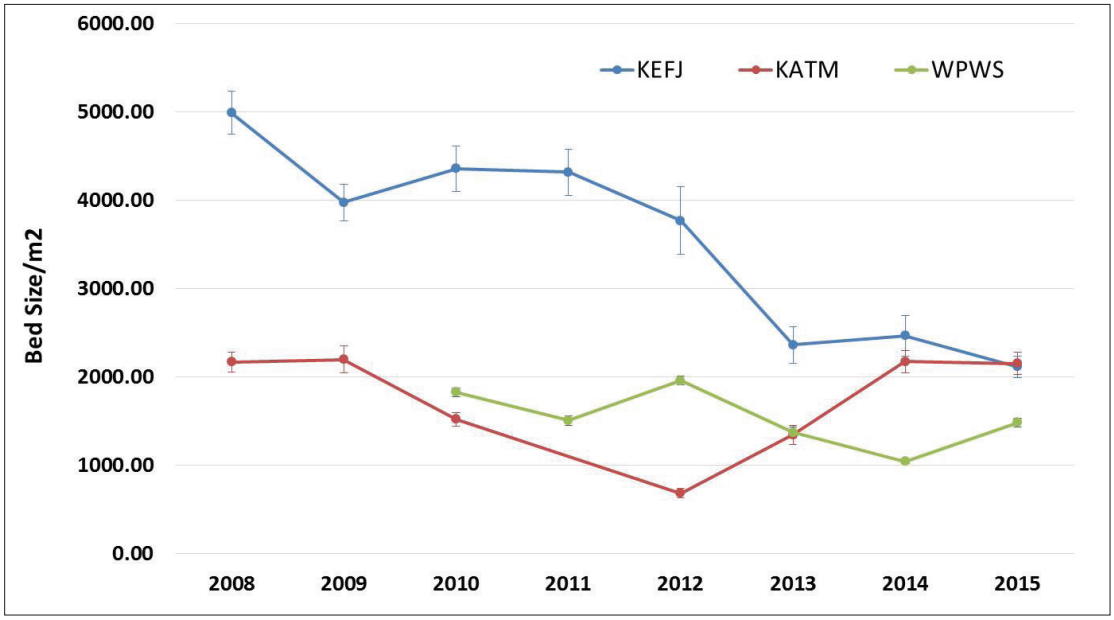
PHOTO 2 **Kaflia Bay in 2012**

PHOTO 3 **Kaflia Bay in 2015**

Densities of large mussels (those preferred by some predators) show the same patterns of decline and recovery as bed size. We see similar patterns of large mussel abundance across the Gulf of Alaska, with average densities declining by 50-90% and then increasing at most sites. We also monitor the abundance of small mussels to see how recruitment of juvenile mussels will eventually affect bed size. We see similar patterns of small mussel abundance across the Gulf of Alaska, with average densities at Kenai Fjords NP (about 25,000 m^2) more than five times the average than in other areas (Figure 2). However, the densities of small mussels do not show the same pattern of decline and recovery observed in bed size or large mussel abundance.

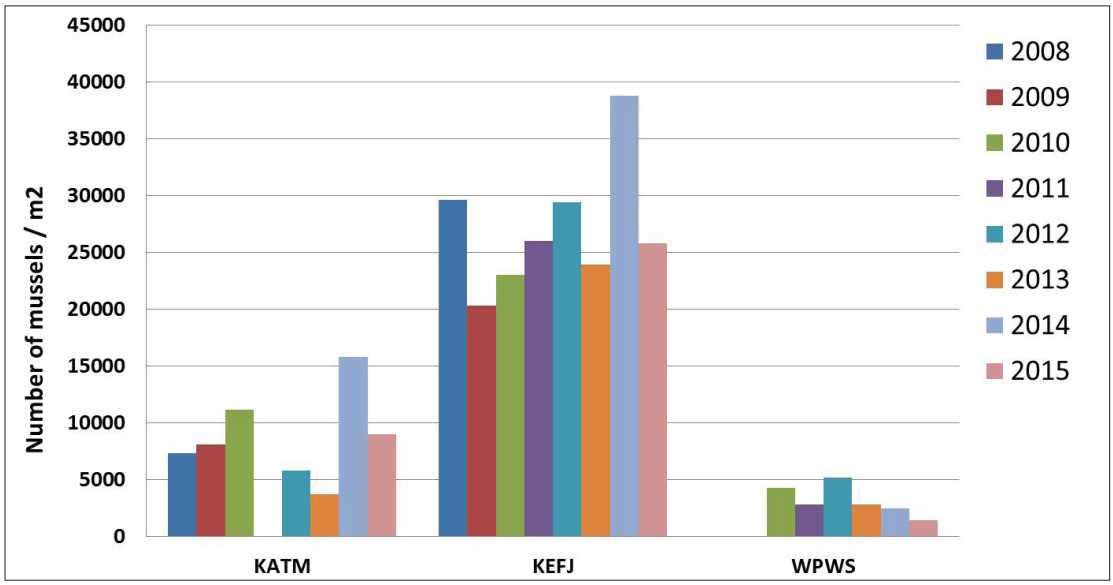
Instead we see much more consistent densities of small mussels across years (Figure 2), despite the reductions of large mussels and observed bed size. It appears as though settlement of juvenile mussels occurs on a frequency and magnitude likely sufficient to support the losses of adult mussels. It also appears that survival of those recent recruits may be highly variable, possibly leading to the longer term patterns of mussel bed declines and recovery (Figure 1). Understanding how and why mussel populations vary over time will aid management and conservation of not only mussels, but also of the many consumers that rely on this important bivalve for food.

Figure 1



Mussel bed size across three regions in the Gulf of Alaska. Kenai Fjords NP (KEFJ), Katmai NPP (KATM)--not sampled in 2011, and western Prince William Sound (WPWS)--not sampled in 2008 or 2009. Error bars indicate standard error.

Figure 2



Density of small mussels across three regions in the Gulf of Alaska. Kenai Fjords NP (KEFJ), Katmai NPP (KATM), and western Prince William Sound (WPWS).

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Nearshore web site at http://science.nature.nps.gov/im/units/swan/monitor/nearshore.cfm

April 2016

Brief designed by: Erin Kunisch
www.nps.gov/rlc/oceanalaska/index.htm

Marine Birds

Importance

Many marine birds rely heavily on habitats and prey associated with the marine nearshore ecosystem of park coastlines. These species are top-level consumers of fish and marine invertebrates, such as mussels, clams, snails, and limpets. Because of these characteristics, these birds are good indicators of change in the marine ecosystem. Monitoring focuses on birds that are trophically linked to the nearshore food web such as sea ducks (harlequins, Barrow's goldeneye, mergansers, and scoters) and black oystercatchers as well as various guilds of other marine birds (e.g., pigeon guillemots, blacklegged kittiwakes, and cormorants) that occupy other food webs or habitats.

Conducting nearshore surveys in Katmai NPP. NPS photo/J.Walton

Monitoring these various guilds simultaneously improves our ability to discriminate among potential causes of change in seabird populations and the nearshore ecosystem. For example, some of the species we monitor were impacted by the *Exxon Valdez* oil spill, and exhibited protracted recovery periods as a consequence of lingering oil in nearshore habitats. Public concern exists for the welfare of marine birds because they are currently affected by human activities like pollution and commercial fishing.

Methods

In Katmai National Park and Preserve (NPP) and Kenai Fjords National Park (NP), ecologists conduct shoreline skiff-based surveys along coastal (nearshore) habitats. We collect data that provides baseline information on species composition, distribution, and density for populations of marine bird and mammals that occur in the nearshore waters of Katmai NPP and Kenai Fjords NP.

Summer surveys are conducted annually and winter surveys are conducted in each park in alternate years as weather permits. Marine bird surveys have been conducted in Katmai NPP and Kenai Fjords NP since 2006 and 2007, respectively.

Fresh common murre carcass that was sent to the U.S. Geological Survey's National Wildlife Health Center for analysis (top, NPS photo/E. Kunisch). Collecting a wing from a dead murre to analyze the feathers for nutritional stress (right, NPS photo/J. Walton).

Findings to date

During the summer of 2015, we observed large increases in common murres compared to previous years. This increase was particularly evident in Katmai NPP (Figure 1) where there are no murre colonies and densities of murres are generally low. This increase in numbers is most likely a function of changed distribution. In poor conditions, these long-lived birds will readily defer breeding; therefore they are not tied to colonies and thus ended up nearshore, likely searching for food.

Although Kenai Fjords NP does have common murre colonies, we still have evidence of an increase of these birds moving into coastal areas not associated with colonies (Figure 2). Our documentation of unusual murre distributions correspond to observations of large die-offs of murres throughout the North Pacific Ocean in winter 2015-2016. We speculate that high water temperature may have disrupted prey abundance and/or availability, leading to changes in murre distribution, behavior, condition, and mortality rates. Our results contribute to observations across the Gulf of Alaska that demonstrates that 2015 was an anomalous year.

In response to this yearlong widespread common murre die-off along the Pacific Coast and the northern Gulf of Alaska, National Park Service, along with agency partners (U.S. Fish and Wildlife Service and U.S. Geological Survey) conducted a winter marine bird and mammal survey in Katmai NPP in March 2016. We also surveyed 19 segments of beaches by foot (a combined total of ~12 linear miles) and two offshore islands, and found evidence of the die-off everywhere we looked. We counted over 2000 seabird carcasses (1,988 murres, 16 crested auklets, 2 least auklets, 1 marbled murrelet, 1 glaucous-winged gull, 2 black-legged kittiwakes, 2 cormorants, and 23 unidentified small alcids). Nearly all carcasses were estimated to be on the beach for over 1.5 months, heavily scavenged, and found further inland on the beaches.

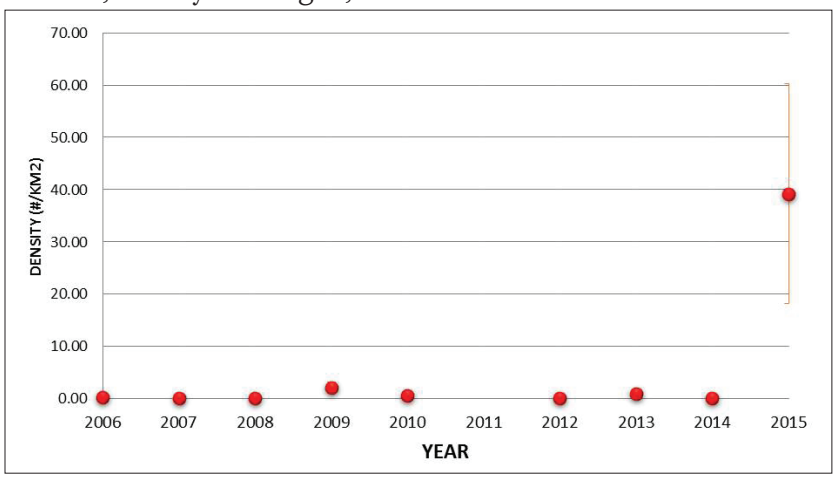

Figure 1. Common murre density estimates in Katmai NPP from 2006 through 2015 (2011 was not surveyed). Error bars equal standard error.

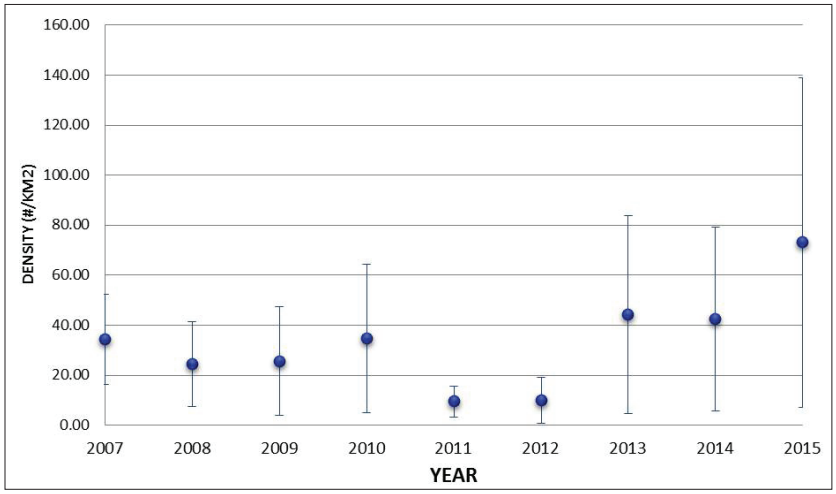

Figure 2. Common murre density estimates in Kenai Fjords NP from 2007 through 2015. Error bars equal standard error.

Common murre with winter plumage found near the coastline of Katmai NPP during the most recent winter survey in March 2016 (top). Starting a nearshore marine bird transect (bottom). NPS photos/E. Kunisch

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SWAN web site at http://science.nature.nps.gov/im/units/swan/

Water Quality

Lakes integrate water, energy, nutrients, sediments, and pollutants from the surrounding land and air. Therefore, lake water quality can be a useful indicator of broad scale stressors, such as climate change. High-latitude lakes are projected to become not only warmer as a result of climate change, but also more turbid, more enriched in nutrients and organic matter, and more productive (Wrona et al. 2005). These changes have the potential to impact the growth, survival, and reproduction of aquatic organisms, such as salmon, and also the terrestrial organisms that rely on them. The Southwest Alaska Network (SWAN) monitors several lake water quality parameters, including temperature, pH, conductivity, and dissolved oxygen. Of these parameters, temperature is particularly important because all the other parameters are directly related to it.

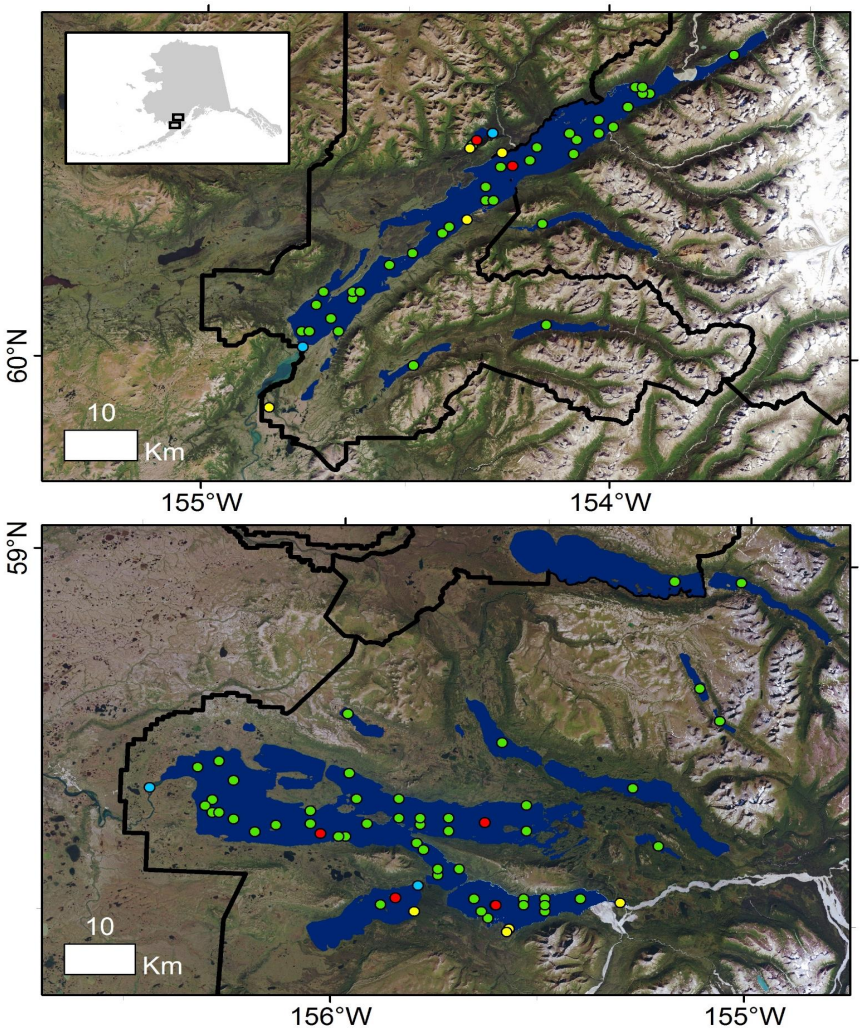

Figure 1. SWAN water temperature monitoring sites in Lake Clark NPP (upper) and Katmai NPP (lower). Red dots indicate mid-lake sites where temperature arrays are deployed continuously; green dots signify mid-lake sites where sondes are used annually; blue dots represent lake outlet sites where sondes and other types of temperature sensors are deployed seasonally or longer; and yellow dots indicate lake shore or tributary sites where various types of temperature sensors are deployed continuously. Park boundaries are depicted in black. (Some outlying sites in each park unit are not shown.)

Findings

SWAN monitors water temperature hourly, year-round in four lakes: Naknek Lake and Lake Brooks in Katmai National Park and Preserve (NPP), and Lake Clark and Kijik Lake in Lake Clark NPP (Figure 1). This monitoring relies on the use of programmable data loggers attached at various depths, from 1 to 100 m, on moored vertical lines called "temperature arrays." Recent results from the Lake Clark and Naknek Lake arrays are summarized in Figure 2. Variability is evident both between years in a given lake and between lakes in a given year. Average daily temperatures depicted in Figure 2 rarely exceed the state's water quality threshold of 15°C, for the migration routes and rearing areas of fish. However, the fact that this threshold is crossed at a depth of 5 meters mid-lake warrants concern, given that temperatures at the surface and lake edges are likely warmer. Moreover, average surface temperatures during July are projected

NPS/E Booher

Hydrological technician, Jeff Nelson, samples water quality with a multi-parameter sonde in Hallo Glacier Lake, Katmai NPP.

to increase 3 to 6°C by the year 2100 in six nearby lakes, including Naknek Lake and Lake Brooks (Jones and Arp 2014).

Methods

SWAN uses several approaches to monitor water temperature, ranging from year-round measurements at targeted locations to once-a-year measurements at randomly selected sites. These measurements rely on various types of equipment. For example, temperature arrays are deployed at a six sites continuously; multi-parameter sondes are deployed at two sites seasonally and are used at an additional hundred or more sites annually (Figure 1).

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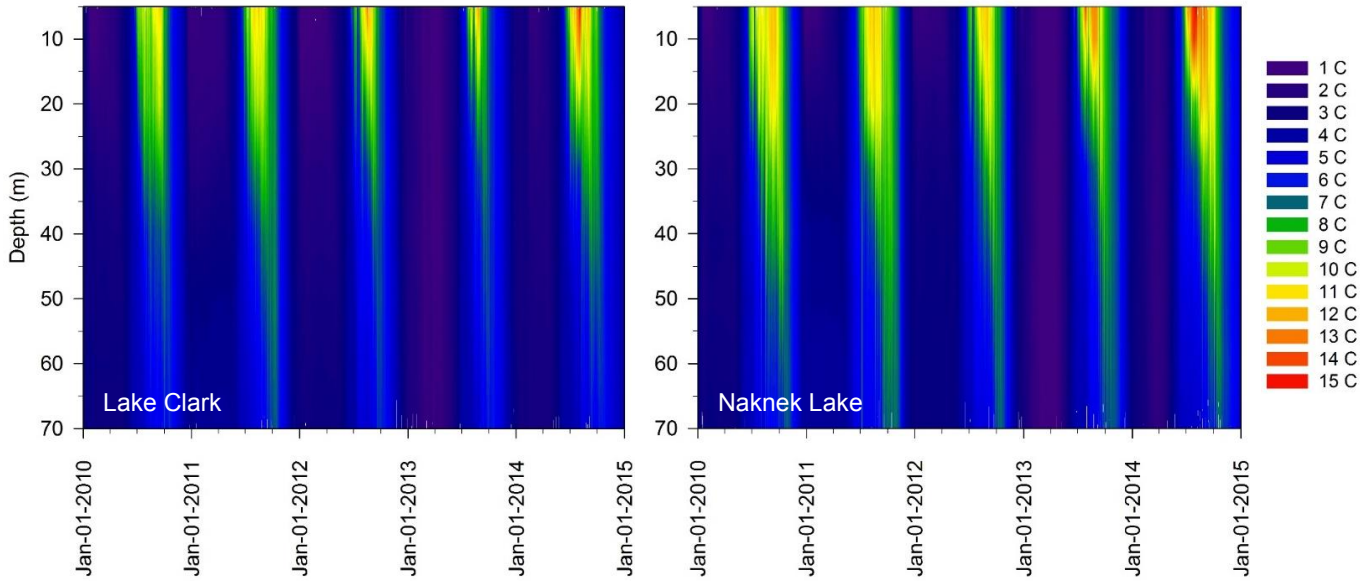

Figure 2. Average daily water temperatures (°C) from 5 to 70 m depth in Lake Clark and the North Arm of Naknek Lake, based on temperature array data from 2010 to 2015. According to the State of Alaska's water quality standards (http://dec.alaska.gov/commish/regulations/pdfs/18%20AAC%2070.pdf), the upper temperature limit for fish migration and rearing habitat is 15°C.

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Resident Lake Fish

Resident (non-migratory) lake fish are key indicators of ecosystem health in southwest Alaska. They are also important to recreational and subsistence fisheries. Understanding what controls their contaminant levels, therefore, is crucial. Many contaminants accumulate over time in fish tissue, especially in long-lived piscivorous species like lake trout (*Salvelinus namaycush*). When contaminant levels reach certain thresholds, fish consumption can be harmful and safety advisories can be issued for particular lakes or species. Consequently, elevated contaminant levels have human health ramifications, as well as broader ecological consequences.

NPS/S Huffman

Lake trout collected for mercury analysis.

Findings

The National Park Service (NPS) has sampled more than 300 fish, representing 9 species from 13 lakes in 2 park units since 2005. These samples indicate that some resident fish species in southwest Alaska lakes have elevated concentrations of mercury, the majority of which is methylmercury, a potent neurotoxin. Why do these fish, which inhabit some of the most pristine and remote waters in North America, have such elevated mercury levels? And what accounts for differences in fish mercury levels among lakes? Factors driving fish mercury levels can be grouped into

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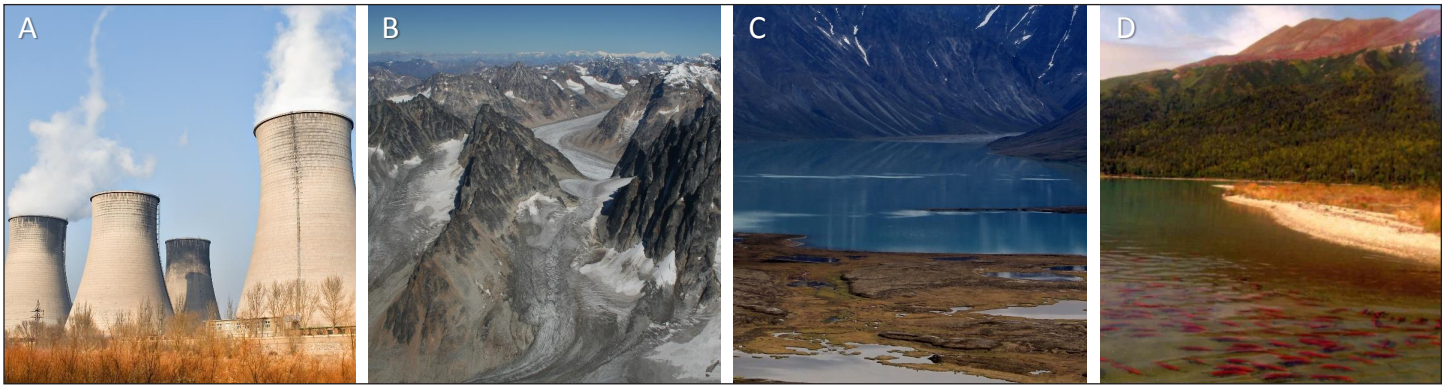


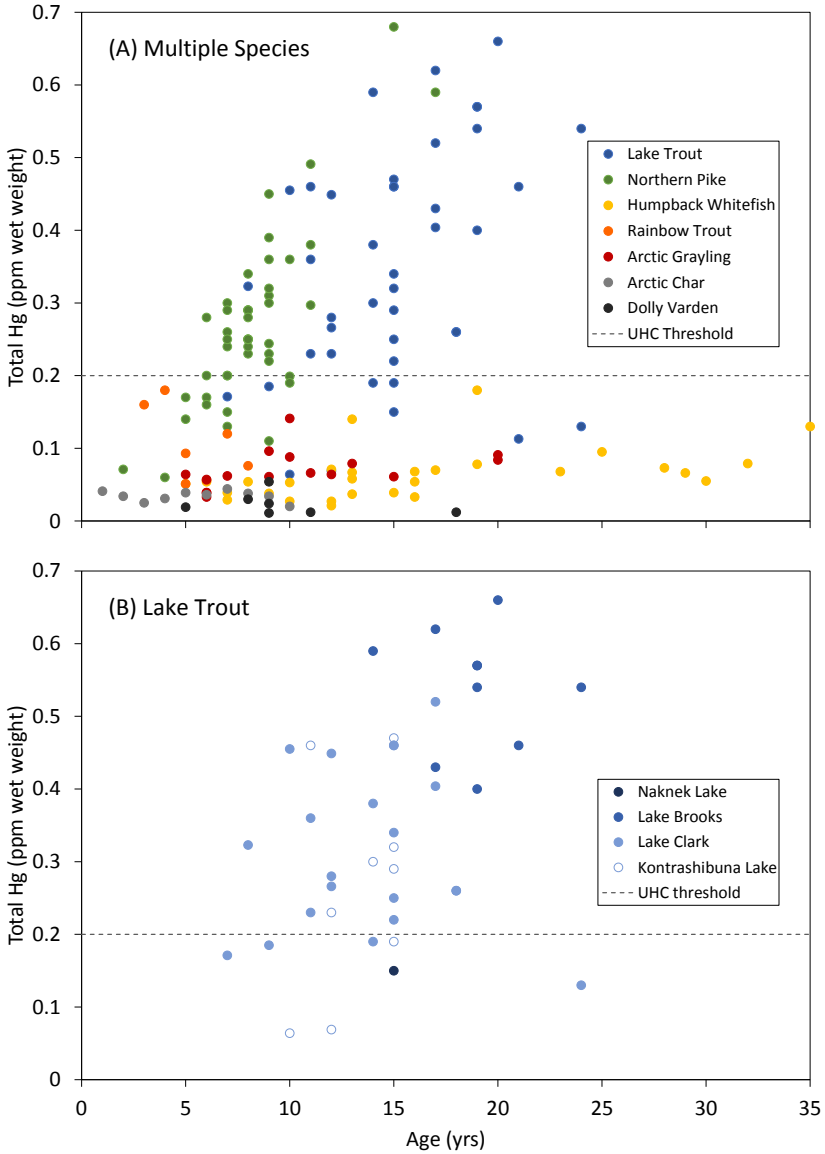
NPS/C Lindsay, E Booher, D Young

Drivers of mercury levels in resident lake fish include distant and local factors. Distant factors are predominantly atmospheric emissions (A). Local factors include melting glaciers, which contain latent reservoirs of atmospherically deposited mercury (B); nearby wetlands, which convert atmospherically deposited mercury to methylmercury through bacterial respiration (C); and spawning salmon, which import methylmercury acquired while at sea (D).

two broad categories: distant and local. Distant factors are atmospheric emissions (notably from coal burning), and subsequent long-range transport and deposition. Local factors, such as glaciers, wetlands, and salmon, influence the distribution of distantly derived mercury (Nagorski et al. 2014). Fish age and species also help determine mercury concentrations, in that older top predators tend to have higher concentrations. Understanding the interplay of each of these factors will help make sense of the observed pattern in the mercury levels of fish (see figure, right).

Methods

This year, the NPS will be working with the U.S. Geological Survey (USGS) to better understand the factors controlling mercury levels in lake trout from Katmai and Lake Clark National Parks and Preserves. Together, the NPS and USGS will collect water, plankton, and fish samples from 12 lakes with a range of glacier, wetland, and salmon influences. Samples will be tested for mercury, methylmercury, and other analytes including stable isotopes of mercury, carbon, and nitrogen. The goal of this work is to identify where the mercury is originating and how it is reaching lake trout in these park units.



Total mercury levels in resident lake fish samples are determined partly by fish age and species (A). Even when age and species are accounted for, however, variability in mercury levels exists among lakes (B). In both graphs, the dashed line represents the upper limit for unlimited human consumption (UHC) of Alaska-caught fish, specifically for women of childbearing age, nursing mothers, and children under the age of 12 (0.20 parts per million (ppm); Hamade 2014).

Collecting fish samples from Hammersly Lake in Katmai National Park and Preserve (below).

NPS\E Booher

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Recent Trends in Southwest Alaska Salmon Stocks

Each year, millions of sockeye salmon (*Oncorhynchus nerka*) return to Bristol Bay, infusing life into the culture, economy, and ecosystem at large. Sockeye salmon have sustained people living in the region and provided for the majority of their subsistence diet for hundreds of years. In addition to the sockeye caught by local residents, the Bristol Bay commercial fleet harvests around 20 million sockeye salmon valued at more than $100 million annually, making it the world's largest and most valuable commercial sockeye fishery. Ecologically, sockeye salmon returning from the sea provide energy and nutrients vital to the freshwater ecosystems in which they spawn, as well as the neighboring riparian and terrestrial ecosystems. This is apparent each fall when rivers and lakes become hubs of activity with bears, wolves, eagles, and trout feasting on spawning salmon and their eggs.

NPS/Dan Young

NPS/Dan Young

Sockeye salmon return to natal waters to spawn and die, providing important resources for aquatic and terrestrial ecosystems. Escapement data are critical for the sustainable management of commercial, subsistence, and recreational fisheries.

Findings—Bristol Bay

The number of migrating adult salmon that "escape" the commercial fishery to spawn in their native stream is commonly referred to as *escapement*. According to the Alaska Department of Fish and Game (ADFG), the annual escapement of sockeye salmon to Bristol Bay in 2015 was 22,366,676 fish. An additional 35,672,859 sockeye salmon were harvested, yielding a total run of 58,039,535 fish, the largest run since 1995.

Findings—Katmai

The estimated annual escapement of sockeye salmon for the Naknek River in 2015 was 1,920,954 fish, or 13% above the average escapement from 2000 to 2014 (1,698,635 fish; Figure 1). The timing of the return in 2015 was six days later than the average for recent years (Figure 1).

Findings—Lake Clark

The estimated annual escapement of sockeye salmon for the Kvichak River in 2015 was 7,341,612 fish and 730,338 fish for the Newhalen River (Figure 1). For both rivers, escapement in 2015 was more than twice the average from 2000 to 2014 (2,748,012 and 358,717 fish for the Kvichak and Newhalen, respectively). Salmon counted in the Newhalen River are a subset of those counted in the Kvichak River further downstream, thus the smaller size and later timing of the Newhalen peaks in daily escapement (Figure 1).

Monitoring Approach

Counting towers are one of several methods for monitoring escapement. ADFG currently operates counting towers on the Naknek River downstream of the Katmai boundary and on the Kvichak River downstream of the Lake Clark boundary (Figure 2). NPS staff operate counting towers on the Newhalen River, upstream of ADFG's Kvichak towers, but downstream of the Lake Clark boundary (Figure 2). At each tower, observers count migrating salmon for a portion of every hour from approximately mid-June to mid-August. Counts are multiplied to yield hourly estimates, and then summed to arrive at daily or annual escapement. Other methods for monitoring escapement include aerial surveys, weirs, and sonar. ADFG escapement data using these methods are available for the Alagnak River, Crescent River (Lake Clark), and Delight and Desire Lakes (Kenai Fjords).

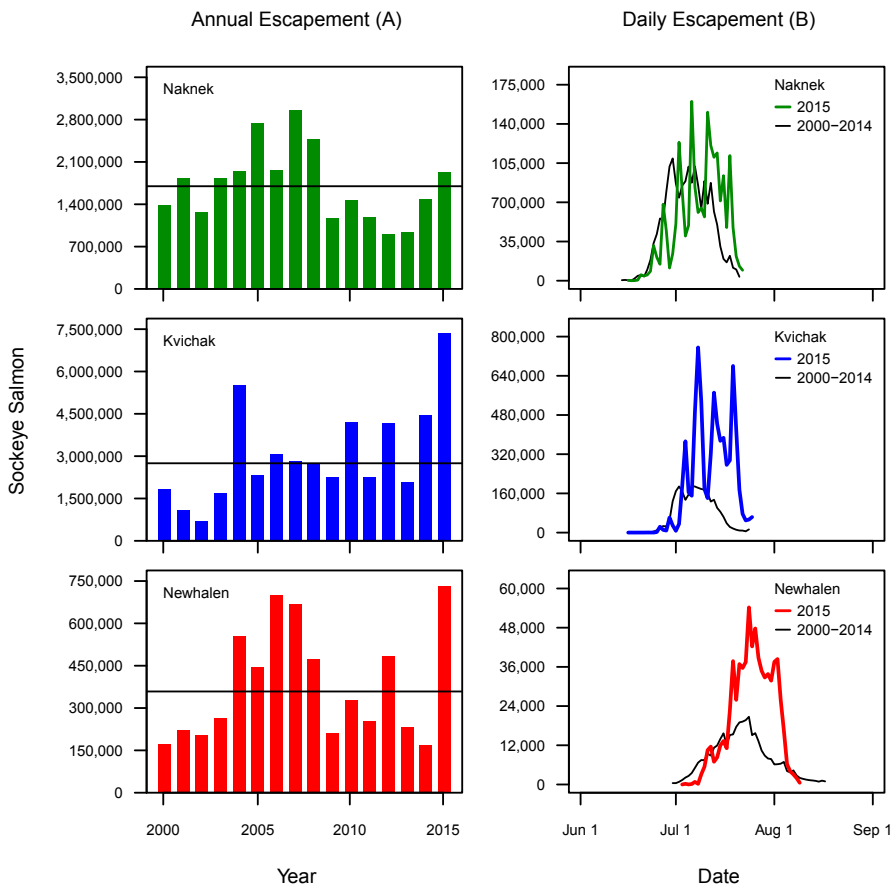

Figure 1. Sockeye salmon escapement estimated annually (A) and daily (B) at counting towers on the Naknek, Kvichak, and Newhalen Rivers. Black lines represent the average escapement for the years 2000-2014. Note the differences in y-axis scales among the graphs. Naknek and Kvichak data are from http://www.adfg.alaska.gov/.

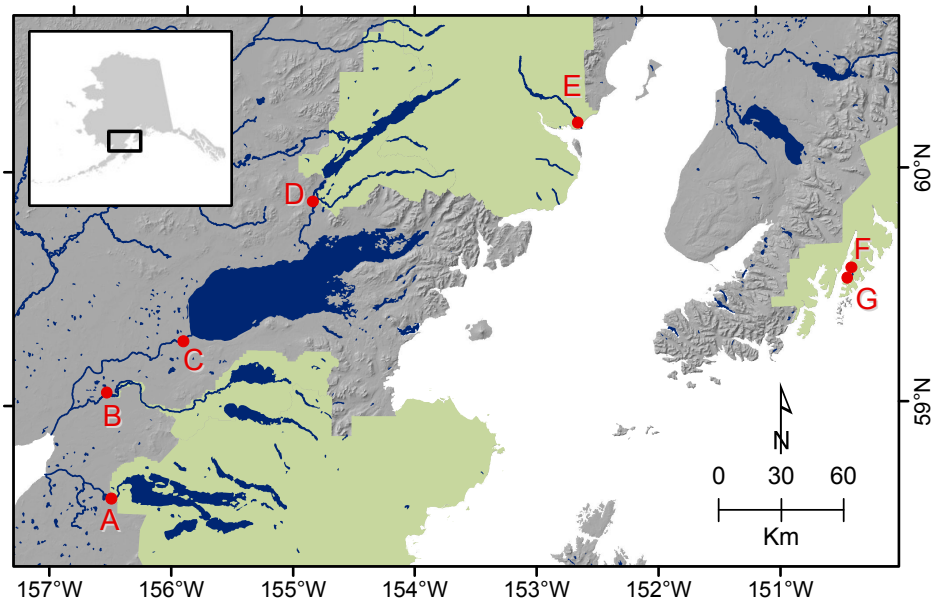

Figure 2. Sites where salmon escapement is monitored near southwest Alaska parks: Naknek (A), Alagnak (B), Kvichak (C), Newhalen (D), and Crescent (E) Rivers, and Desire (F) and Delight (G) Lakes.

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Visitor Use at Lake Clark NPP

Understanding visitor use patterns across the parks and over time allows park managers to assess where rangers and staff need to be stationed and where impacts to resources (such as trampling) may need to be monitored or mitigated in the future. Likewise, visitor use patterns may also inform commercial business operators (such as guides or air taxies) by providing insights to the areas currently visited and the timing of visits, details that are helpful when planning their services.

NPS/Rebekah Jones

Visitor watching bears at Chinitna Bay, Lake Clark National Park and Preserve.

Park Visitation Triples

Over the last nine years, the number of visitor use days reported by businesses operating in Lake Clark National Park and Preserve (NPP) has more than tripled from approximately 4,000 days to 13,000 days. Most of this increase has been on the Cook Inlet (coastal) side of the park. In 2015, Crescent Lake, Silver Salmon Creek, and Chinitna Bay were the most highly visited places in the park, together accounting for over 70% of visitation (over 10,000 days combined). Crescent Lake has seen a phenomenal growth in visitor use, increasing from less than 250 reported visitor use days in 2007 to approximately 3,900 in 2015, a fifteen-fold increase (Figure 1). Approximately two-thirds of the visitation occurs in July and August. In spite of the tripling of visitation over nine years, the timing of the visits has stayed about the same (Figure 2).

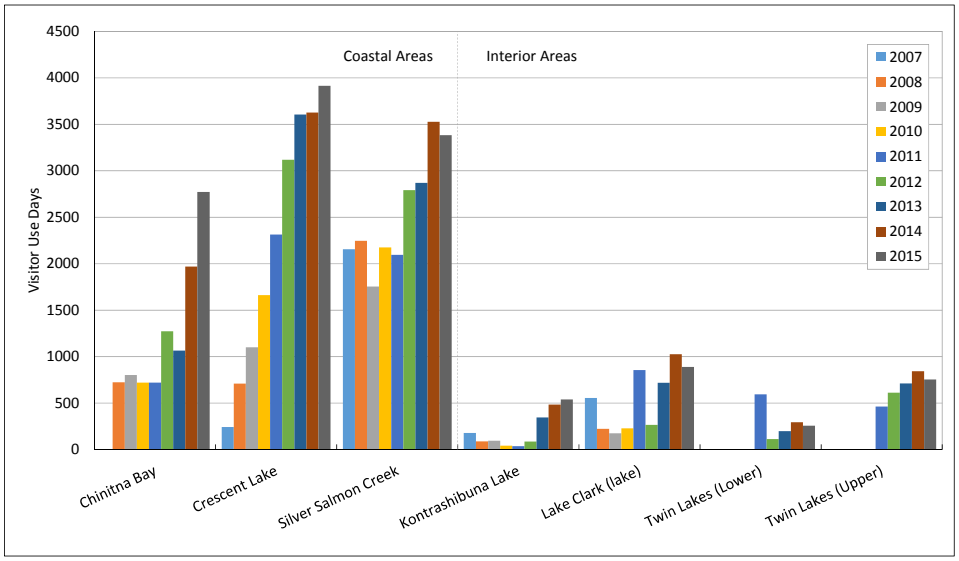

Figure 1. Crescent Lake, Silver Salmon Creek, and Chinitna Bay are the most-visited locations in Lake Clark NPP. This graph shows total visitor use days by location (2007-2015) for the three most-visited locations on the coast and the interior. Upper and Lower Twin Lakes were broken out separately starting in 2011 and thus data are shown only after 2011. [Data for all sites except Upper Twin Lakes from the Lake Clark NPP CUA database (3/9/16), and NPS data for Upper Twin Lakes.]

The three most popular activities at the park are bear viewing, sport fishing, and photography (Figure 3). There has been significant growth in the number of visitors coming to Lake Clark NPP to participate in these activities. The number of visitor use days reporting bear viewing as their main activity has

risen from approximately 1,000 people in 2007 to over 4,800 in 2015, a more than four-fold increase.

The number of reported user days focused on sport fishing and photography has more than doubled in this same period of time. The percentage of people that are either bear viewing or photographing in the park is approximately 54%, with 23% sport fishing. The number of reported visitor use days for all other activities has stayed relatively constant (Figure 3).

NPS/Megan Richotte

Sport fishing is popular at Crescent Lake, Lake Clark National Park and Preserve.

Methods

Remote Alaska parks do not have entrance stations to count people visiting the park, but the vast majority of visitors to Lake Clark NPP use a lodge, guiding service, or air taxi operator. These commercial operators pay a small fee for each visitor they bring to the park, and report back to the park the number of visitors, activities visitors are engaged in, and where within the park visitors go. Each park is divided into areas, roughly corresponding to watersheds. Areas with concentrated use have been sub-divided into smaller areas to provide more specificity. The data collected by commercial operators are the primary means to quantify and understand visitation patterns and public uses. NPS data collected at some sites supplement the commercial operators' data.

A "visitor use day" is defined as each day a visitor is at the park engaging in some activity. Visitors who spend several days in the park will be counted each day according to where they go and what they do. This information is valuable for understanding how visitors enjoy the park and to identify potential management issues.

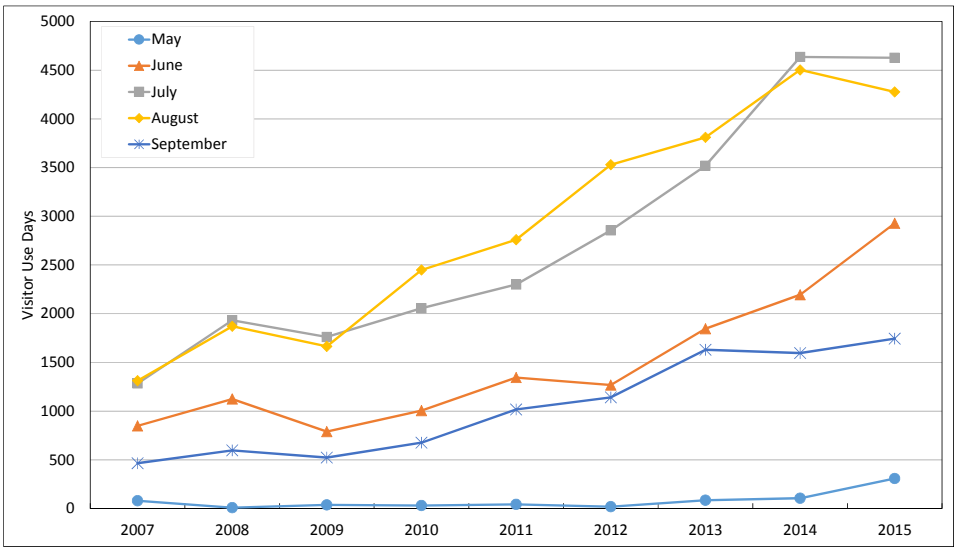

Figure 2. In 2014, July surpassed August as the month with most visitor use. The number of visitor use days for May-September for 2007-2015. [Data from the Lake Clark NPP CUA database 3/9/16.]

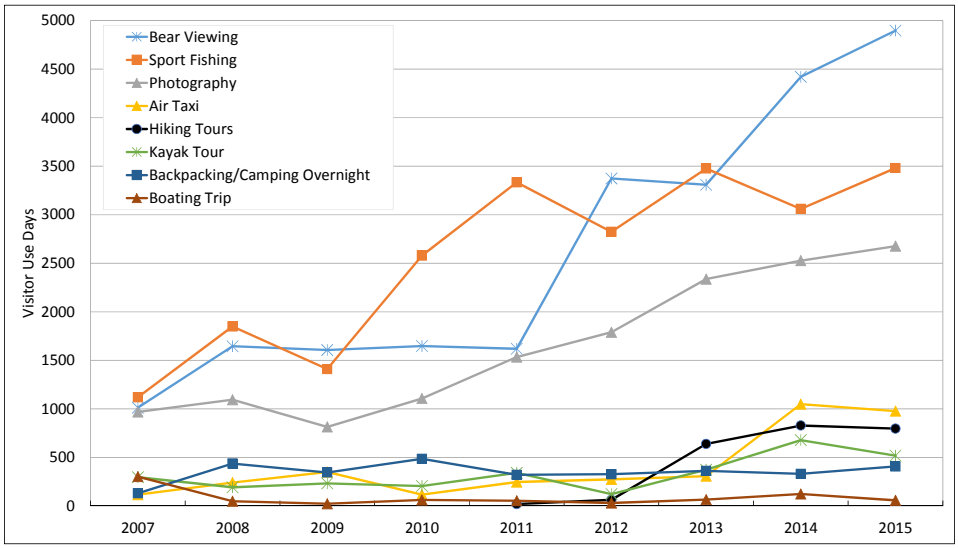

Figure 3. In recent years, bear viewing has surpassed sport fishing as the most popular activity. The number of visitor use days for each of the main activities in Lake Clark NPP from 2007-2015. [Data from the Lake Clark NPP CUA database 3/9/16.]

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Visitor Use at Katmai NPP

Understanding visitor use patterns across the parks and over time allows park managers to assess where rangers and staff need to be stationed and where impacts to resources (such as trampling) may need to be monitored or mitigated in the future. Likewise, visitor use patterns may also inform commercial business operators (such as guides or air taxies) by providing insights to the areas currently visited and the timing of visits, details that are helpful when planning their services.

NPS/

Visitors bear watching at Brooks Falls, Katmai National Park and Preserve.

Park Visitation

Over the last nine years, the number of visitor use days reported by businesses operating in Katmai National Park and Preserve (NPP) has fluctuated between 25,000 and 27,000 per year. Visitation patterns are affected not only by sport fishing and bear viewing opportunities, but also by national events. The economic downturn in late 2008 affected the number of visitors in the 2009 season. Visitation for Brooks Camp dropped by almost 2,000 visitor use days, and took three years to recover (Figure 1).

Hallo Bay, Geographic Harbor/Amalik Bay, Kukak Bay, and Swikshak Lagoon are some of the most visited locations on the Katmai coast, receiving over 5,000 visitor use days per year (Figure 1). Visitation to the other areas in the park's interior vary between years. This probably is due to the change in the timing and magnitude of salmon runs over different years, which are related to fishing and bear viewing opportunities.

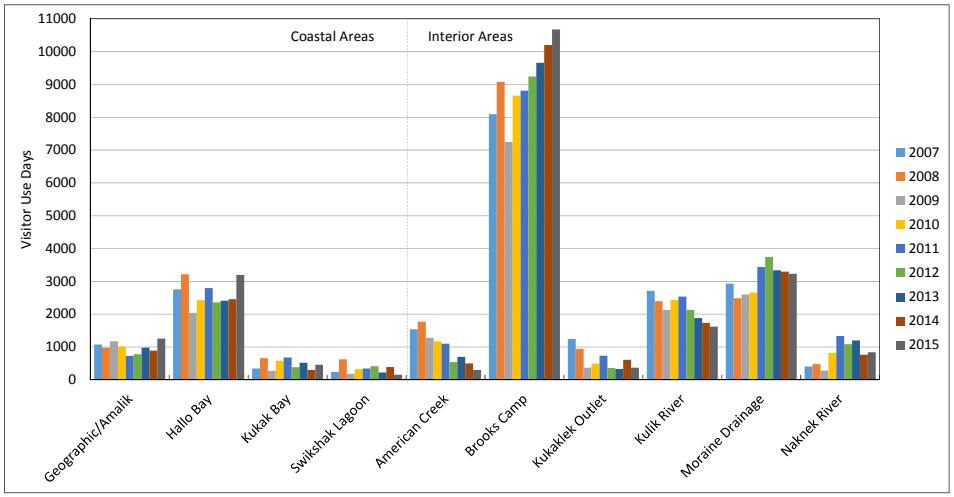

Figure 1. Bar graph by year of visitor use days by location (2007-2015) in Katmai NPP as reported by the commercial use operators. [Data from the Katmai NPP CUA database 03/30/16.]

Most of the visitation for Katmai NPP occurs in July and August. About 72% of the visitor use days occur in these two months (Figure 2). July visitation seems to be growing (almost 10,000 visitor use days in 2015), whereas visitation in June and September declined or remained flat over the 2007-2015 period (Figure 2). Data from 2015 provide a snapshot of where the visitation occurred in each

month. Brooks Camp is busy in July when the bear numbers on Brooks River are at their peak, and much less in the other months (Figure 3). Moraine Creek has over 1,500 visitor use days in August, 600 visitor use days in July, and 350 days in September (Figure 3).

The main three activities reported by commercial operators are sport fishing, bear viewing, and air taxi, and these activities are not mutually exclusive (Figure 4). Other reported activities, such as big game transporters, hiking tours, and photography, continue to make up a very small percentage of visitor use days (Figure 4).

Methods

Remote Alaska parks do not have entrance stations to count people visiting the park, but the vast majority of visitors to Katmai NPP use a lodge, guiding service, or air taxi operator. These commercial operators pay a small fee for each visitor they bring to the park, and report back to the park the number of visitors, activities visitors are engaged in, and where within the park visitors go. Each park is divided into areas, roughly corresponding to watersheds. Areas with concentrated use have been sub-divided into smaller areas to provide more specificity. The data collected by commercial operators are the primary means to quantify and understand visitation patterns and public uses.

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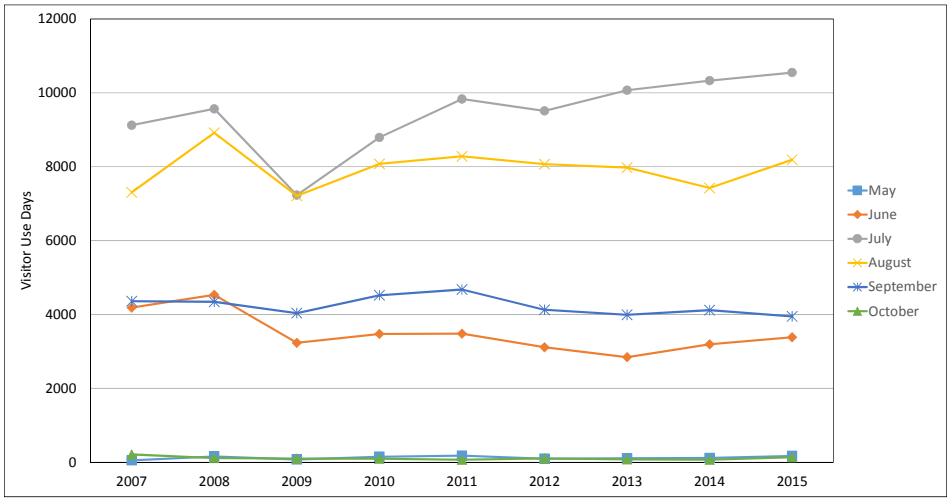

Figure 2. Line graph by month across the years of visitor use days for May through October for 2007-2015 for Katmai NPP. [Data from the Katmai NPP CUA database 03/30/16.]

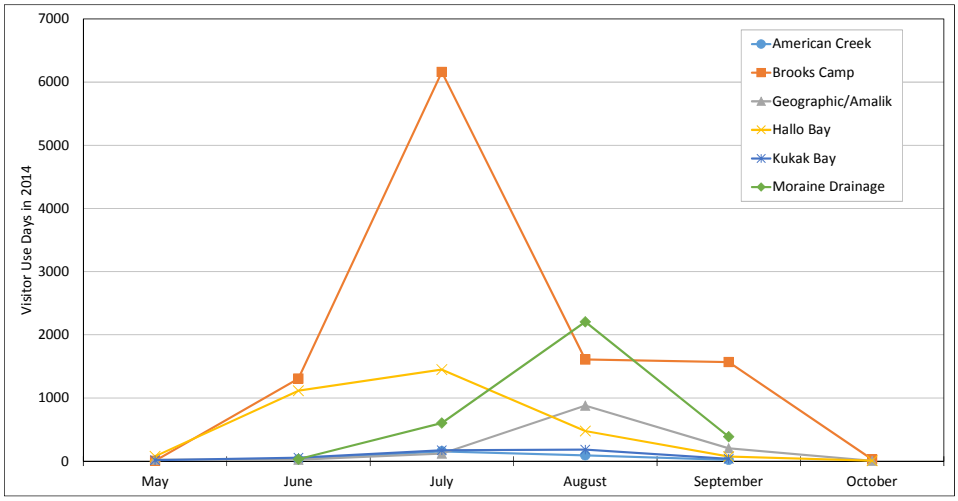

Figure 3. Use patterns across the season for 2015 for some of the most frequently visited locations in Katmai NPP. [Data from the Katmai NPP CUA database 03/30/16.]

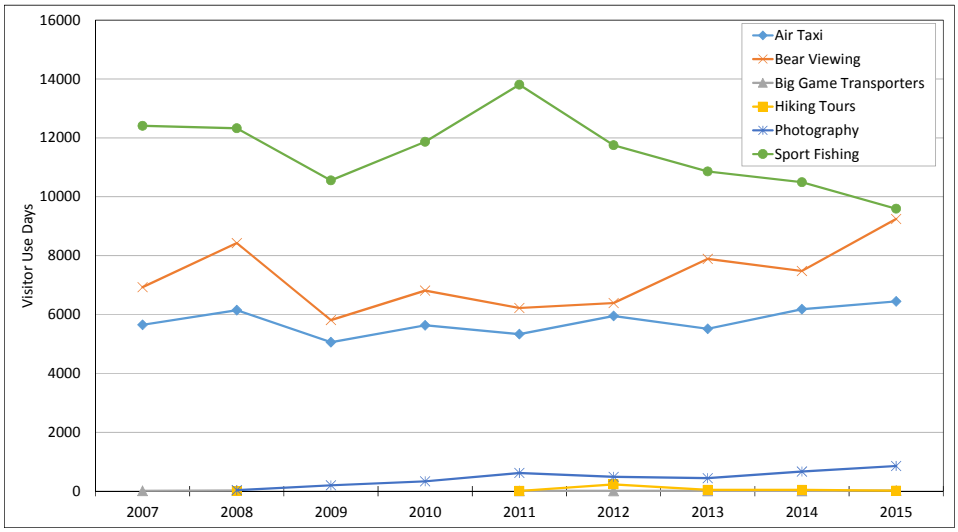

Figure 4. The number of visitors and their primary activities as reported by the commercial operators working in Katmai NPP, 2007-2015. Sport fishing, bear viewing, and air taxi services continue to be the most popular activities in Katmai. [Data from the Katmai NPP CUA database 03/30/16.]

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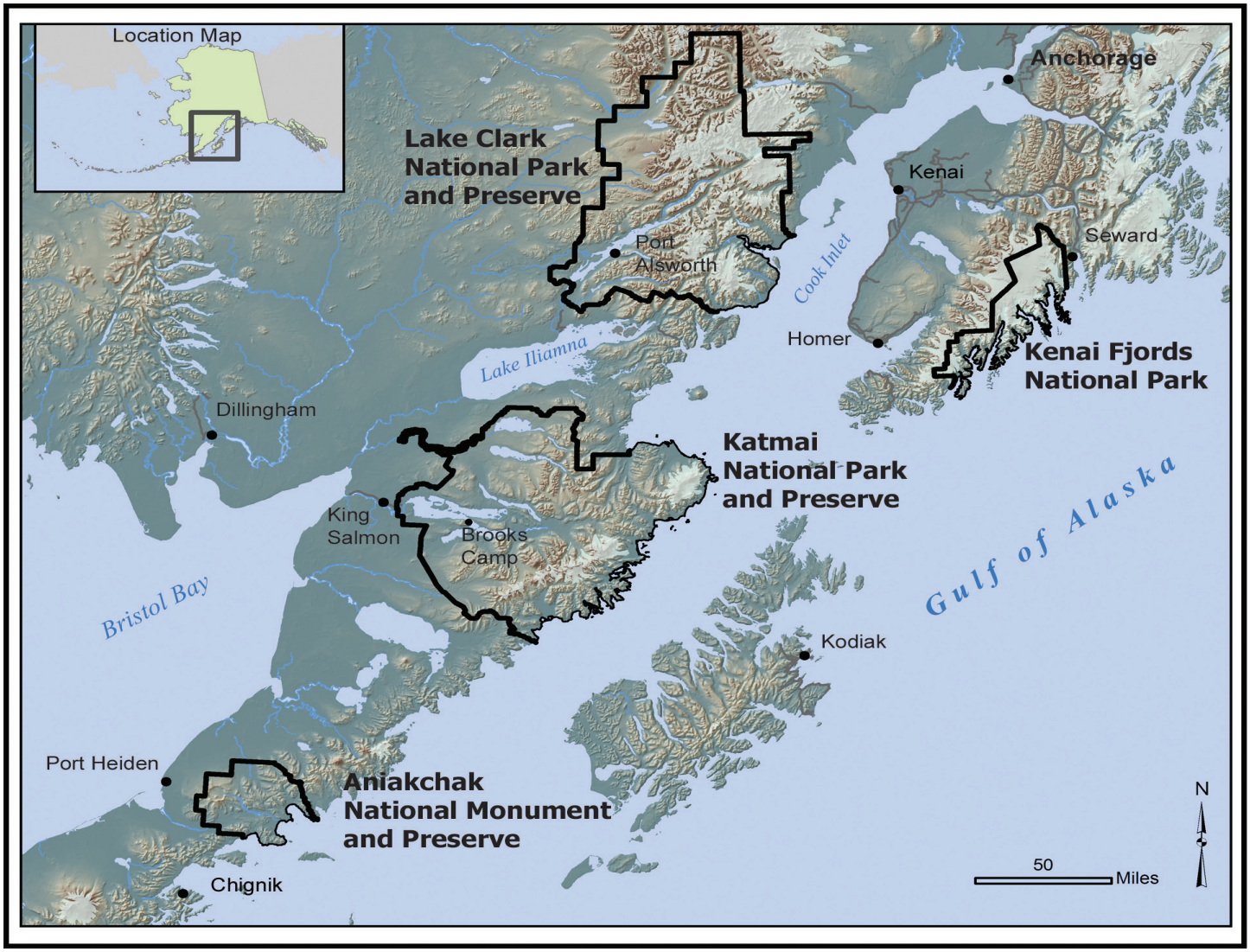
National Park Service
U.S. Department of the Interior

Alagnak Aniakchak Katmai Kenai Fjords Lake Clark



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