Alaska Park Science

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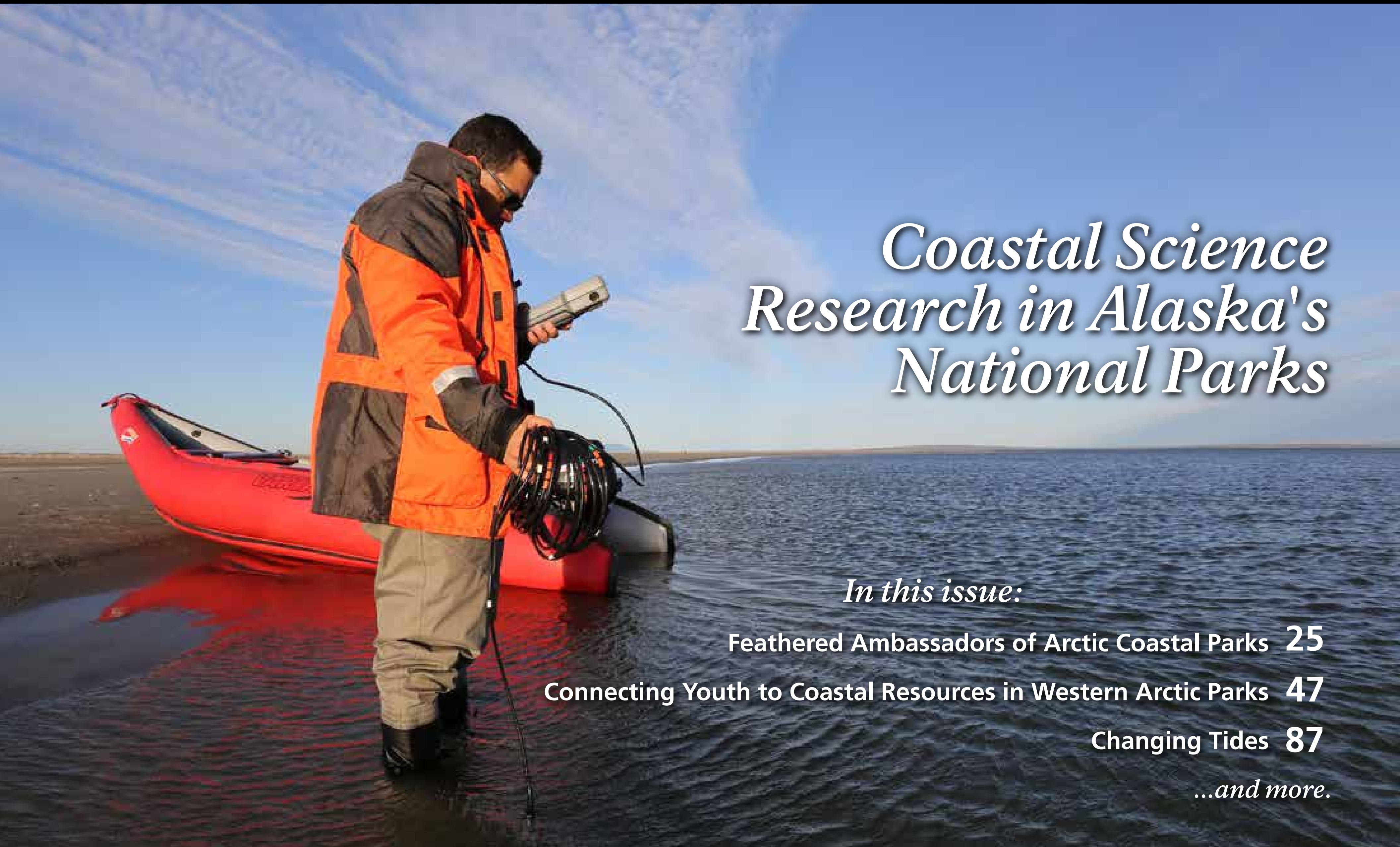

Coastal Science Research in Alaska's National Parks

In this issue:

...and more.

Volume 15, Issue 1

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Cover photo: Tahzay Jones uses a water quality sonde to measure dissolved oxygen, pH, conductivity, temperature, and turbidity at Ikpek Lagoon in Bering Land Bridge National Preserve.

NPS photo courtesy of Jim Pfeiffenberger

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Long-term monitoring of coastal resources is critical to detecting trends and changes.

NPS photo courtesy of Jim Pfeiffenberger

A Brief History of Coastal Marine Grant Projects

By Benjamin Pister

In 1999, the National Park Foundation, a nonprofit partner of the National Park Service (NPS), received settlement money from lawsuits against cruise ships for pollution and impact-related incidents in several locations, including Glacier Bay National Park in Alaska.

The money was designated for the scientific study and protection of National Park Service marine ecosystems and for the benefit of Alaskans and all visitors to Alaska's national parks. Activities included scientific research, long-term monitoring, restoration, education, public outreach, and enforcement.

The National Park Foundation invested the settlement money. Beginning in 2004, the earnings were used to support the Coastal Marine Grant Program for small marine projects (about $10,000 each) that didn't fit the requirements of other funding opportunities available to parks. Since only the earnings were being spent, these investment accounts weathered the Great Recession without losing value over the long-term; however, annual distributions declined for several years. Beginning in 2006, the Ocean Alaska Science and Learning Center (OASLC), an NPS entity devoted to the facilitation and communication of ocean science in Alaska's national parks, supplemented funding to the annual grant. The combined result was $928,000 awarded to 103 projects across 10 Alaska park units and involving 24 different partners. In 2014, a decision was made to expend the balance of funds (around $3.3 million) on worthy projects that address some of the many marine issues facing Alaska's national parks. This article highlights a small sample from ten years of small Coastal Marine Grants (2004-2013). A complete list is also included to highlight the broad spectrum of successful projects. Projects funded in 2014 are detailed in the following articles found throughout this issue of *Alaska Park Science*:

- Promoting spill preparedness in the western Arctic parks with the community integrated coastal response project
- Understanding the ecology of Arctic coastal lagoons through fisheries research and monitoring
- Feathered ambassadors of Arctic coastal parks
- The core of the matter: adventures in coastal geology at Kenai Fjords National Park
- Changing Tides project
- Whales, seals and vessels: Investigating the acoustic ecology of underwater Glacier Bay
- Removing marine debris from Alaskan coastal parks with numerous partners

NPS photo courtesy fo Jim Pfeiffenberger

Figure 2. Harbor seals haul out in Kenai Fjords National Park.

Harbor Seals in Glacier Bay and Kenai Fjords National Parks

With large soulful eyes and furry bodies juxtaposed on cold blue icebergs, harbor seals (*Phoca vitulina*) are one of the most abundant and most photographed marine mammals in the Gulf of Alaska. Large, seasonal aggregations of harbor seals are found in tidewater glacial fjords in Glacier Bay, Kenai Fjords, and Wrangell-St. Elias national parks (*Figure 2*). Such fjords are popular destinations for tour boats and cruise ships, and visitors love seeing harbor seals. But climate change and other factors affect glacial activity, including the icebergs that some seals use to haul out. Declines in the number of harbor seals have been documented in Glacier Bay and Kenai Fjords national parks (*Mathews and Pendleton 2006; Womble et al. 2010; Hoover-Miller et al. 2011*); however, the reasons for the declines remain elusive.

Figure 1. Hubbard Glacier, in Wrangell-St. Elias National Park, threatens to advance and close off Russell Fjord in the background. Such an event has far reaching consequences for marine creatures in the fjord and the residents of Yakutat, Alaska. The park used a Coastal Marine Grant to study the bathymetry around the glacier terminus.

NPS photo courtesy of Benjamin Pister

Figure 3. Biologists wait patiently to capture harbor seals for study in Glacier Bay National Park and Preserve. A net hangs suspended in the water column between the buoys. The pink float line allows researchers to know instantly when a seal is caught and to react quickly to capture them without harm.

In Glacier Bay, funding was used to develop an understanding of harbor seal post-breeding season movements, diving and foraging behavior, and habitat use (*Figure 3*). Another award was used to analyze harbor seal blood and fecal samples for evidence of exposure to pathogens (*Hueffer et al. 2011; 2013*). Interestingly, harbor seals were found to travel widely outside of Glacier Bay during the post-breeding season (September-April), but most returned to Glacier Bay the following breeding season (*Womble and Gende 2013*). Two implications of this finding are that harbor seals may be susceptible to impacts both within and outside of the park, and that the park is a good place to rear pups. Even more interestingly, harbor seals using glacial ice as haul outs dove deeper, travelled farther, and spent less time on the bottom in search of food than did seals hauling out on land (*Womble et al. 2014*). In essence, seals hauling out on ice may be working hard to forage. So why bother hauling out on ice? One idea is that glacial ice may offer a refuge from predators, such as orcas (*Orcinus orca*), and also provide a stable resting place for nursing young (*Womble et al. 2014; Pettit et al. 2015*).

In Kenai Fjords National Park, funding was used by the Alaska SeaLife Center to set up remote cameras to observe harbor seals using ice habitat in Aialik Bay and Northwestern Fiord. Using these cameras, former Alaska SeaLife Center researcher Anne Hoover-Miller examined how often kayaks or tour boats disturbed seals, as both are popular means of exploring the park. Most park employees assumed the larger, noisier tour boats would cause more disturbances for seals, but the data showed the opposite was true: Kayakers disturbed the seals far more often than the tour boats (*Hoover-Miller*

Photo courtesy of John Loughlin

Figure 4. Sea Train students engage Woody, a massive male Steller sea lion at the Alaska SeaLife Center.

et al. 2013). One potential reason is that kayakers have an ability to approach seals much more quietly and surprise seals at close distance, whereas tour boats are not as stealthy. Also, harbor seals were hunted from kayaks not so long ago, but not from tour boats. Although highly speculative, it seems plausible that harbor seals could be instinctually wary of kayaks. These kinds of scientific studies are extremely useful when parks work with local tour operators and guides to use the area responsibly, especially when they challenge assumptions and lead to more effective decisions. Fortunately, Hoover-Miller et al.'s study also showed that voluntary changes to viewing guidelines on the part of both tour operators and kayak guides led to less harbor seal disturbances.

Although we may not yet fully understand the reasons for the decrease in Alaska's most abundant marine mammal, these and ongoing studies definitely help fill in the pieces to the puzzle.

The Sea Train

The true value of education-enrichment projects is often difficult to quantify. Lessons and experiences often bury themselves deep in the psyche of students, only to resurface years, and even decades, later in a sudden "Aha!" moment. Nevertheless, experiential lessons can have a strong influence on who children become, and how they may act as stewards of our parks and our society.

If the random anecdotes heard from parents are any indication, Sea Train was just such an experience. On more than one occasion I heard the comment from parents: "My son/daughter took the train to Seward and learned SO MUCH on that trip to the SeaLife Center!" Sea Train was a collaboration between the Alaska SeaLife Center, the Anchorage School District, and the Alaska Railroad Corporation with participation from the NPS and the U.S. Forest Service. The Sea Train program was designed to provide a science-based field learning experience for Anchorage students using Alaska Railroad cars as mobile classrooms. The trip from Anchorage to Seward and back culminated with several hands-on activities at the Alaska SeaLife Center (*Figure 4*). Students engaged invertebrates and vertebrates alike in the "touch tanks" and through underwater viewing areas of the aquarium, and learned multiple lessons about Alaska's marine ecosystems.

Almost 1,500 students participated in Sea Train during 2007, most from Title I schools (which include high percentages of students from low income families) or schools affiliated with military bases. These students comprised a diverse demographic, many of whom had never travelled to the Kenai Peninsula or experienced the ocean, despite living in a coastal city. Funding provided through the coastal marine grant was used to offset costs for the railroad charter. The Sea Train program ran from 2005 through 2008.

NPS photo courtesy of Jim Pfeiffenberger

Figure 5. Dr. Bruce Molnia and a colleague search for the same spot Grant and Higgins used to photograph Holgate Glacier in Kenai Fjords National Park.

Grant and Higgins Repeat Photography

There is nothing quite like repeat photography to illustrate changes in our environment. U. S. Grant and D. F. Higgins were geologists with the U.S. Geological Survey (USGS). On a mineral surveying field trip in 1909, they surveyed and photographed dozens of glaciers in what would eventually become Kenai Fjords National Park. Although documenting glaciers was not the primary purpose of their trip, it is clear from their records that Grant and Higgins viewed their glacier photographs as important. Their prescience has paid off handsomely in our present-day bank of knowledge.

In 2004 and 2005, Dr. Bruce Molnia, also a USGS geologist, followed in their footsteps to repeat their effort (*Figure 5*). He used money from a coastal marine grant to help fund one of his trips to locate the exact spots they used to photograph the park's glaciers and retake photos from those locations to understand the changes over the last 100 years (*Figure 6*). One of the goals of the project was to document the process scientists go through while studying glaciers. The resulting series of photographs are a powerful interpretive tool to illustrate the effects of climate change. The NPS continues to repeat these photographs annually to further document the changes occurring in Kenai Fjords National Park. These repeat photographs are used extensively in ranger talks, presentations, park movies, and interpretive signage to illustrate the dramatic changes in our local environment and to engage visitors in the complexities of climate change.

Photos courtesy of U.S. Grant (1909) and Bruce Molnia (2005)

Figure 6. Bear Glacier in Kenai Fjords National Park retreated considerably between 1909 and 2005.

NPS photo courtesy of Leslie Witter

Figure 7. National Park Service biologist Lisa Schomaker performs regular maintenance on the video weir on Silver Salmon Creek. The fence on the right forces salmon through a chute in front of an underwater camera. The camera is powered by solar panels and controlled by the electronics in the foreground.

Silver Salmon Creek Fish Counts

Decades ago, the fishing lore on the Kenai Peninsula included tales of Silver Salmon Creek in Lake Clark National Park, where the fishing was so good you could catch a silver salmon on every cast when the fish were running. The Alaska Department of Fish and Game (ADFG) estimated the average annual harvest of silver salmon (*Oncorhynchus kisutch*) from Silver Salmon Creek to be about 1,000 fish per year, with a range of 356 in 2008 and 2,269 in 2003. However, their estimates came from statewide mail-in harvest surveys, which generally have wide margins of error and tend to overestimate harvests when compared to other methods. Silver Salmon Creek is a mile-long stream flowing between a series of small lakes and the ocean. It's narrow enough that most people could throw a rock across it without too much trouble. Silver salmon tend to have smaller runs, unlike the hundreds of thousands of pinks and red salmon common to the Alaska Peninsula and the Kenai Peninsula. On streams the size of Silver Salmon Creek, the silver run may only be a thousand fish per year, and no one knew for sure what it actually was. If fishers harvested 1,000 fish per year, they could potentially wipe out the run in a few years. And of course, bears and other wildlife also fish for salmon in this creek. Without more precise data, it is difficult to estimate the size of the run or how many salmon were really being harvested from this stream.

Dan Young, an NPS fisheries biologist, used a coastal marine grant to fund a project from 2011-2013 designed to determine the average run size, and count how many fish were being caught. To answer the first question, he built a video weir (*Figure 7*). Dan installed a fence across the river near the lake's mouth that forced the salmon to swim through a narrow channel. Then he put an underwater camera in a windowed box filled with crystal-clear fresh water. The box was submerged right next to the channel in the fence. The camera was attached to a motion detector, so whenever a salmon swam through, the camera turned on for five seconds. Thus, the salmon could be counted on the video, without generating weeks of video footage. In the end, the run size turned out to be between 6,000 and 9,000 fish, depending on the year.

To answer the second question, Dan and his assistants conducted a creel survey in 2013. A creel is a wooden basket anglers used to use to hold their catch. A creel survey simply asks fishermen what they have caught each day at the place they are fishing. Dan and his team interviewed nearly all of the fishermen in the area during the prime fishing season. It turned out the harvest in 2013 was around 200 fish, much less than the ADFG estimate from their statewide surveys. Estimates from other years ranged between 500 and 1,000 fish. The number of fish taken each year was an acceptable percentage of the total run size. Silver salmon were not the only things to swim through the weir. Aside from the occasional muskrat, the video camera recorded Dolly Varden (*Salvelinus malma*) along with a few chum (*Oncorhynchus keta*), pink (*Oncorhynchus gorbuscha*), and red salmon (*Oncorhynchus nerka*).

Seward Elementary School's Plankton Comparison Study

In 2006 and 2007, Bob Barnwell, a 6th grade teacher at Seward Elementary School, used a Coastal Marine Grant to fund a plankton comparison study for his students. During field trips inside Resurrection Bay and Kachemak Bay, the students gained basic knowledge of the plankton species that occurred in their local waters (*Figure 8*). They then studied the entire food web the plankton community

Photo courtesy of Bob Barnwell

Figure 8. Mr. Barnwell's 6th grade students from Seward Elementary school explore Kachemak Bay in their pursuit of knowledge in 2007.

supports to better understand the trophic links within the ecosystem. Along the way, they collaborated with local scientists to understand what was known and unknown about their local plankton.

One of the greatest challenges in teaching students about how ecosystems work is getting them to visualize and understand the monumental role that microscopic organisms play in our environment. This project opened the students' eyes to the microscopic world of plankton and educated them about the agencies and scientists working on ocean issues in their community.

Conclusion

From studying resource allocation in the sugar kelp (*Saccharina latissima*) to installing collection stations for discarded monofilament, to "Tidepooling for Tots," many successful projects ultimately fulfilled the full breadth of the original purposes envisioned for the money funded through these coastal marine grants. Although most of the available funds for these projects have now been expended, the long list of what has been accomplished will surely inspire many to continue to study the ocean and its resources.

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NPS photo courtesy of Katie Thoresen

Harbor seals' use of glacier ice habitat was a focus of OASLC-supported studies in both Glacier Bay and Kenai Fjords National Parks.

List of Coastal Marine Grant Projects, 2004-2013

Projects Funded in 2004

- Identifying Habitat Use by a Declining Harbor Seal Population in Glacier Bay
- The Life of a Glacier – An Exhibit
- Improvement of Research Collections for Coastal Archaeological Studies
- Shishmaref Subsistence Area Clean Up
- Cruise Ship Sound Measurements Enable Marine Mammal Protection in Alaska Coastal Waters
- Digital Coastwalking at Glacier Bay National Park, and Klondike Gold Rush and Sitka National Historical Parks: Limited Seasonal Technician Support for Completion of Coastal Resources Inventory and Mapping Databases
- Marine Education in Coastal Villages
- Partners for Leave No Trace
- Establishing Monitoring Protocol for Western Toads in the Southeast Alaska National Parks: Documenting Regional Distribution and Habitat Occupancy; Baselines for Detection of Future Change

Projects Funded in 2005

- Complete Digital Coastwalking
- Backcountry Human Waste Management
- Current Research Coastal River Otters
- Designing Monitoring Protocol for Kittlitz's Murrelets
- From the River to Classroom to Sea and Back
- Hubbard Glacier Closing
- Incorporating Coastal Marine Science in NPS-Alaska
- In the Wake Footsteps of Grant and Higgins
- Land/Water Appreciation Lectures Shishmaref
- Obtain Baseline East Alsek Water Quality
- Quantifying Coastal Vegetative Succession
- Tikigaq Townsite Re-visited - Point Hope
- Vessel Grounding Training
- Yakutat Beluga Whales Traditional Ecological Knowledge

Projects Funded in 2006

- Arranged for Change Educational Display Coastal Implications Climate Change
- Efficacy of Temporary Electric Fencing to Deter Brown Bears
- Facilitating Remote Bear Viewing at Pratt Museum in Homer
- Documenting Tlingit Traditional Ecological Knowledge Coastal Areas
- Short- and Long-Term Coastal Erosion Arctic Network Inventory and Monitoring Program
- Outreach Kayakers Marine Mammal Protection and Bear Safety
- Silver Salmon Creek Coho Population Estimate Harvest
- Is the Declining Population of Kittlitz's Murrelets Experiencing Low Productivity?
- Alaska Sea Kayaking Symposium
- Educating Public About Wild Birds and Coastal Habitat
- Determining Visitor Bear Use Patterns in Geographic Harbor
- Multimedia Glacial Change Landscape Evolution Website
- Identifying Critical Foraging Habitat of a Declining Harbor Seal Population
- Opening Our Ears to Underwater Sound in Glacier Bay to Protect Marine Mammals

Projects Funded in 2007

- Publication of Marine-Focused Issues of the Alaska Park Science Journal
- The Sea Train: Coastal Education in Motion
- Characterization of Viral Immune Response in Alaska's Sea Ducks
- Evaluating Nutrient Acquisition and Allocation in Captive Breeding Spectacled Eiders (*Somateria fischeri*) Using Stable Isotope Analyses
- Seward Area Coastal Observation and Seabird Team Science Program
- Best Practices in Marine Wildlife Viewing
- Connecting Youth of Upper Copper River Watershed with the Coastal Marine Ecosystem Through the Copper River and the Copper River Delta Through First-hand Field Experience
- Invasive Plant Control in Coastal Glacier Bay National Park and Preserve
- Comparing Primary Vegetation Succession in Two Recently Deglaciated Environments: Identifying Differences in Successional Pathways in Glacier Bay and Kenai Fjords
- Seward Elementary School's Plankton Comparison Study Between Resurrection Bay and Kachemak Bay
- Understanding Successional Dynamics in Streams in Glacier Bay National Park
- Assessing Contaminant Loads and Health Status in a Declining Harbor Seal Population Glacier Bay National Park
- Opening Our Ears to Underwater Sound in Glacier Bay to Protect Marine Mammals
- Facilitating Remote Bear Viewing at the Pratt Museum in Homer, Alaska
- Reprint Alaska Region Bear Safety Brochure for Visitors and Resource Protection

Projects Funded in 2008

- Seward Elementary School's Plankton Comparison Study Between Resurrection Bay and Kachemak Bay
- Enhancing Stewardship of Marine and Coastal Resources Through Ocean-based Community Education Programs
- Evaluating Nutrient Acquisition and Allocation in Captive Breeding Spectacled Eiders (*Somateria fischeri*) Using Stable Isotope Analyses: Phase 2 of an M.S. Thesis
- Understanding the Impacts of Cruise Ships to Coastal Ecosystems and Communities: A Seminar Series
- Observance Without Disturbance

List of Coastal Marine Grant Projects, 2004-2013

- Protecting Sensitive Coastal Resources from Backcountry Visitor Impacts
- Digitization of Video Archive from Aialik Bay, Kenai Fjords National Park
- Resource Allocation in Sugar Kelp (*Saccharina latissima*) Under Varying Environmental Conditions in Kachemak Bay, Alaska
- Workshop to Identify Harding Icefield Research and Management Priorities
- Monitoring Trends in a Declining Harbor Seal Population in Glacier Bay National Park and Preserve

Projects Funded in 2009

- Resource Allocation In Sugar Kelp
- Archaeological Survey of the Southern Coast of Adak Island
- Increase Technical Capacity to Conduct Coastal Campsite Impact Assessments
- Seward Monofilament Line Collection Project
- Monitoring for Invasive Species at the Gateway to Kenai Fjords National Park
- Collect and Analyze Sediment Samples for Geomorphic Timeline on the Coast of Lake Clark National Park and Preserve
- Using Fatty Acids to Infer Diets of Threatened Spectacled Eiders in Alaska
- Purchase Glacier Mass Balance Monitoring Supplies
- Cetacean Sighting Network

Projects Funded in 2010

- Seabirds and Rats: Interpretive Exhibit
- Host a Cruise Ship Science Meeting for Determining Criteria and Impacts to Marine Resources in Glacier Bay
- Seward Storm Drain Stenciling Project
- Marine Observational Surveys in the Kenai
- Time-Lapse Photography of Coastal Resources
- Prey Availability and Seabird Productivity: Missing Links in the Kenai Fjords
- Identifying Local Whales: Public Education and Enhancement of the Viewing Experience
- Identifying Indicators of Visitor Experience and Resource Conditions to Protect Sensitive Coastal Resources in Kenai Fjords National Park
- Updating the Resource Guide for Coastal Backcountry Users in Kenai Fjords National Park
- Winter and Nest Distribution of Black Oystercatchers Along Coastal Waters Near the Yakutat Ranger District, Alaska

Projects Funded in 2011

- Measuring Change in Estuarine Acidification and Consequences for Native Olympia Oysters
- Estimating Coho Salmon Escapement and Harvest at Silver Salmon
- Mapping Social Values of Marine Wildlife
- Ocean and Climate Change Teacher to Ranger to Teacher Program
- Provide Publicly Available Weather Data for Aialik Bay

Projects Funded in 2012

- Annual Resurrection Bay Conservation Alliance Watershed and Beach Cleanup
- Evaluation of Ashy Storm-Petrels at Bird Rock, Point Reyes National Seashore
- Support Development of a Long-Term Monitoring Protocol for Bald Eagles Nesting in Kenai Fjords National Park
- Monitoring Beluga Whales in Yakutat Bay and the Waters of Wrangell-St. Elias National Park
- Determination of Standards of Resource and Visitor Experience Conditions to Protect Sensitive Coastal Resources in Kenai Fjords National Park
- Whales in Kodiak
- Channel Islands National Park Marine Protected Area Education Resources Development
- Foraging Ecology of Black Oystercatchers (*Haematopus bachmani*) in Alaska: Then and Now
- Mentoring Ocean Connections

Projects Funded in 2013

- Determining Seasonal Arctic Lagoon Biophysical Dynamics
- Monitoring Ocean Acidification in Southwest Alaska
- Nearshore Ecology of Juvenile Salmon in Katmai National Park and Preserve
- Estimate Coho Salmon Escapement at Silver Salmon Creek
- Annual Resurrection Bay Conservation Alliance Watershed and Beach Cleanup
- Mentoring Ocean Connections 2 – A Growing Cohort
- Development of Aerial Observers Guide to North American Waterfowl
- Impressions of the Arctic: A Coastal Photographic Journey

The Vulnerabilities of Cultural and Paleontological Resources to Coastal Climate Change Processes in Northwest Alaska

By Michael J. Holt, Louise Farquharson, Thomas Urban, and Dael Devenport

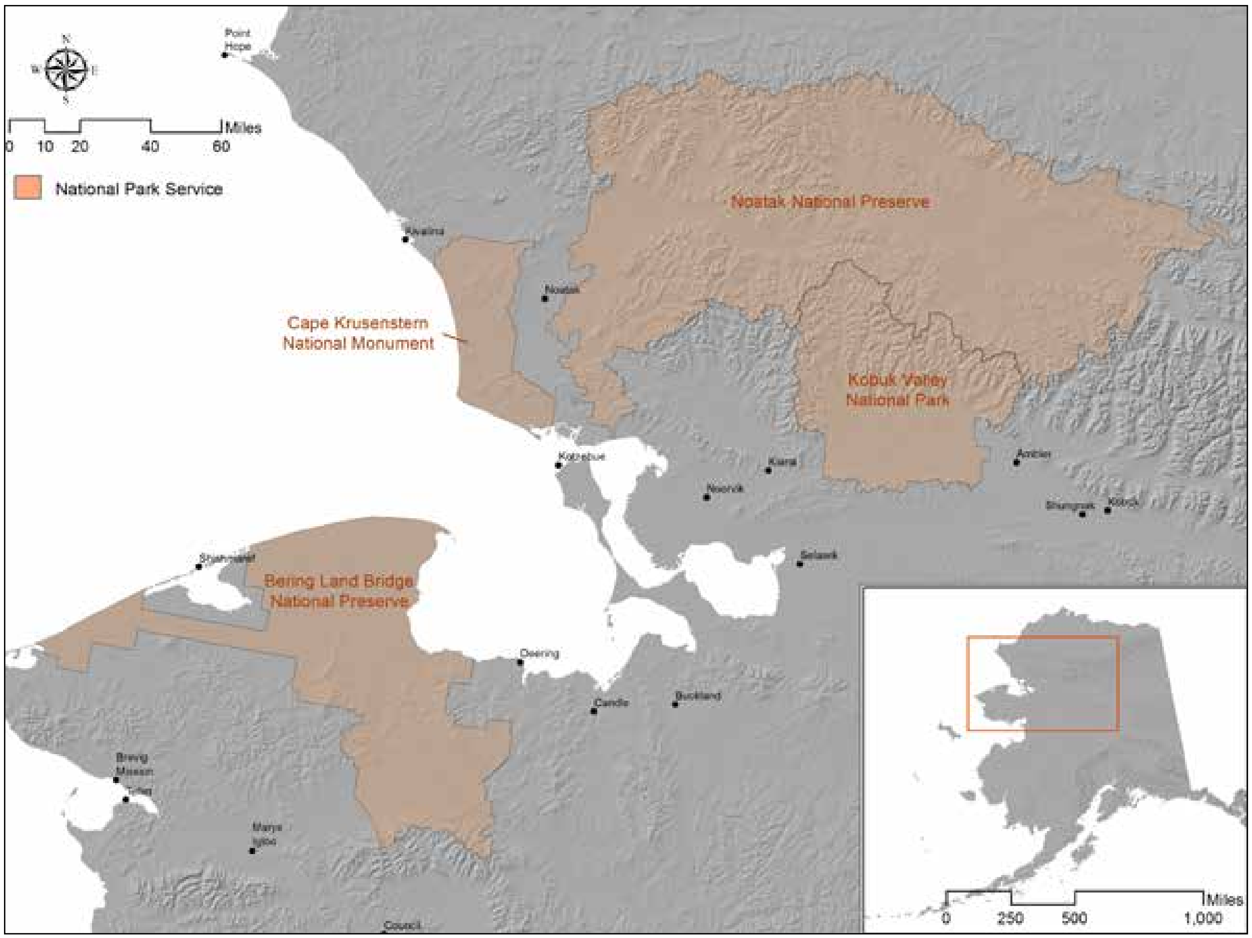

Figure 2 (left). Vicinity map.

The National Park Service (NPS) stewards roughly 1,000 miles (1,600 kilometers) of coastal landforms in Northwest Alaska (*Figure 1*). Bering Land Bridge National Preserve and Cape Krusenstern National Monument exhibit a wide variety of coastal landforms including barrier lagoons, tundra bluffs, accreting spits, and beach ridge complexes; all home to vulnerable fauna, flora, and avian communities; internationally significant archaeological, historic, and ethnographic resources; and unique paleoecological and fossil records Coastal landform erosion and its impact on cultural resources in Northwest Alaska has been a focal study area since the 1980s (*Jordan 1988; Mason 1995; Jordan and Mason 1999*) (*Figure 2*). Recent geomorphological studies, however, show that landscape erosion have intensified since 1980s, erasing the evidence of human adaptation to the coast at unprecedented rates (*ACIA 2004; Manley 2007*). To address this significant issue an interdisciplinary team of researchers comprised of archaeologists and geologists led by NPS and its research partners are updating perceptions about how these dynamic earth processes are impacting vulnerable cultural and paleontological resources on the coast (*Figure 3*).

Figure 1 (opposite). NPS staff and volunteers battled an almost endless barrage of inclement weather during archaeological fieldwork at Cape Krusenstern National Monument in summer 2015. Base camp was a welcome respite from the weather and mosquitoes.

Photo courtesy of Brooke Luokkala

Photo courtesy of Brooke Luokkala

Figure 3. Crew members uncover two chert lance points associated with the Choris culture (2,750-2,250 years years ago) of the Arctic Small Tool tradition in 2015. The artifacts were found by volunteers (Brooke Luokkala and Mariama Dryak) investigating a house pit previously excavated by Giddings and Anderson in the 1960s at Cape Krusenstern National Monument.

Ice Age Natural History

Archetypal Ice Age fossils such as the woolly mammoth (*Mammuthus primigenius*), steppe bison (*Bison priscus*), and wild horse (*Equus* sp.) (*Hopkins 1982; Guthrie 2003, 2006; Höfle 2000; Hardes 2014*) roamed Beringia until the end of the Ice Age when climatic amelioration ended a 75,000-year glacial period. This general warming trend (termed "Holocene") began roughly 12,000 years ago, sparking dramatic shifts in ancient Beringian biomes (*Bigelow 2003; Bird 2009; Calkin 1998; Jacoby 1999; Mann 2002*), as melting ice sheets and glaciers steadily raised global sea levels to current levels by the mid-Holocene (7,000 to 5,000 years ago) inundating the Bering Land Bridge (*Manley 2002; NOAA 2008*). Fossils and sediments preserving a record of ancient flora and fauna during the terminal end of our last great Ice Age are being destroyed by powerful Earth processes along coastal peat bluffs.

Tradition	Cultural Sequence	Approximate Age Range (cal BP) Max	min
	Paleoarctic	11000	6000
	Northern Archaic	6000	3000
Arctic Small Tool	Denbigh	4500	2750
	Choris	2750	2250
	Norton	2250	1350
	Ipiutak	1750	1150
Northern Maritime	Birnirk	1350	750
	Western Thule	1000	550
	Arctic Woodland	750	250
	Kotzebue Period	550	250
Ethnohistoric	Historic & Contemporary Iñupiat Lifeways	165	0

Figure 4. Coastal cultural sequence model

Cultural History and Climate Change

Cultural resources (i.e., archaeological, historic and ethnographic evidence) are the physical expression of past and present human land uses; a testament of how people adapt to their dynamic surroundings. As global temperatures and sea levels fluctuated throughout the Holocene, altering coastal landforms and biota (*Bigelow 2003; Bird 2009; Calkin 1998; Jacoby 1999; Mann 2002*), humans adapted unique lifeways in order to take full advantage of the world around them. This fundamental interaction between humans and their surroundings is called human-behavioral ecology, and is the theoretical perspective archaeologists use to study the enigmatic behaviors of our prehistoric forbearers (*Cronk 1991*).

Archaeological evidence can be used to demonstrate humankind's connection with the region's coast for almost 12 millennia starting with Paleoarctic (11,000 to 6,000 years ago) and Northern Archaic (6,000 to 3,000 years ago) foraging groups (*Giddings and Anderson 1986; Anderson 1988; Schaaf 1988*). These earlier groups may have taken advantage of opportunities along the coast, or simply passed through. It was, however, not until the late Holocene (a period spanning the last 5,000 years) that humans would develop lifeways and cultural identities centered on marine resources in the region (*Giddings and Anderson 1986*); (*Figure 4*).

Neoglaciation marks the start of the late Holocene, coinciding with the formation of the beach ridges and barrier island landforms in the region. This dramatic shift from warming, ca. 9,000 to 5,000 years ago to cooler global temperatures, and subsequent changes in biomes and resources likely compelled humans to focus more intensively on coastal environments and resources. These coastal landforms provided ideal conditions for human foraging groups focused on marine resources to support larger populations and influenced sociocultural complexity (*Giddings and Anderson 1986; Schaaf 1988; Jordan and Mason 1999; Freeburg and Anderson 2012*). Barrier islands and beach ridges are incredibly vulnerable to the ravages of climate change in the region, and are being erased at unprecedented rates (*ACIA 2004; Manley 2007*)—destroying an important record of human land use throughout the late Holocene.

There is no better example of the interaction between human foraging groups and the environment than at the Cape Krusenstern and Cape Espenberg (Bering Land Bridge) beach ridge complexes, where horizontal beach ridge building occurred in synchronicity with human occupation (*Gidding and Anderson 1986; Darwent 2013*). Louis Giddings, pioneer archaeologist, developed a coarse grained model of cultural change based on the sequential formation of beach ridges, using horizontal stratigraphy as a way to reconstruct regional culture histories or "beach-ridge archaeology" (*Giddings 1967; Giddings and Anderson 1986*).

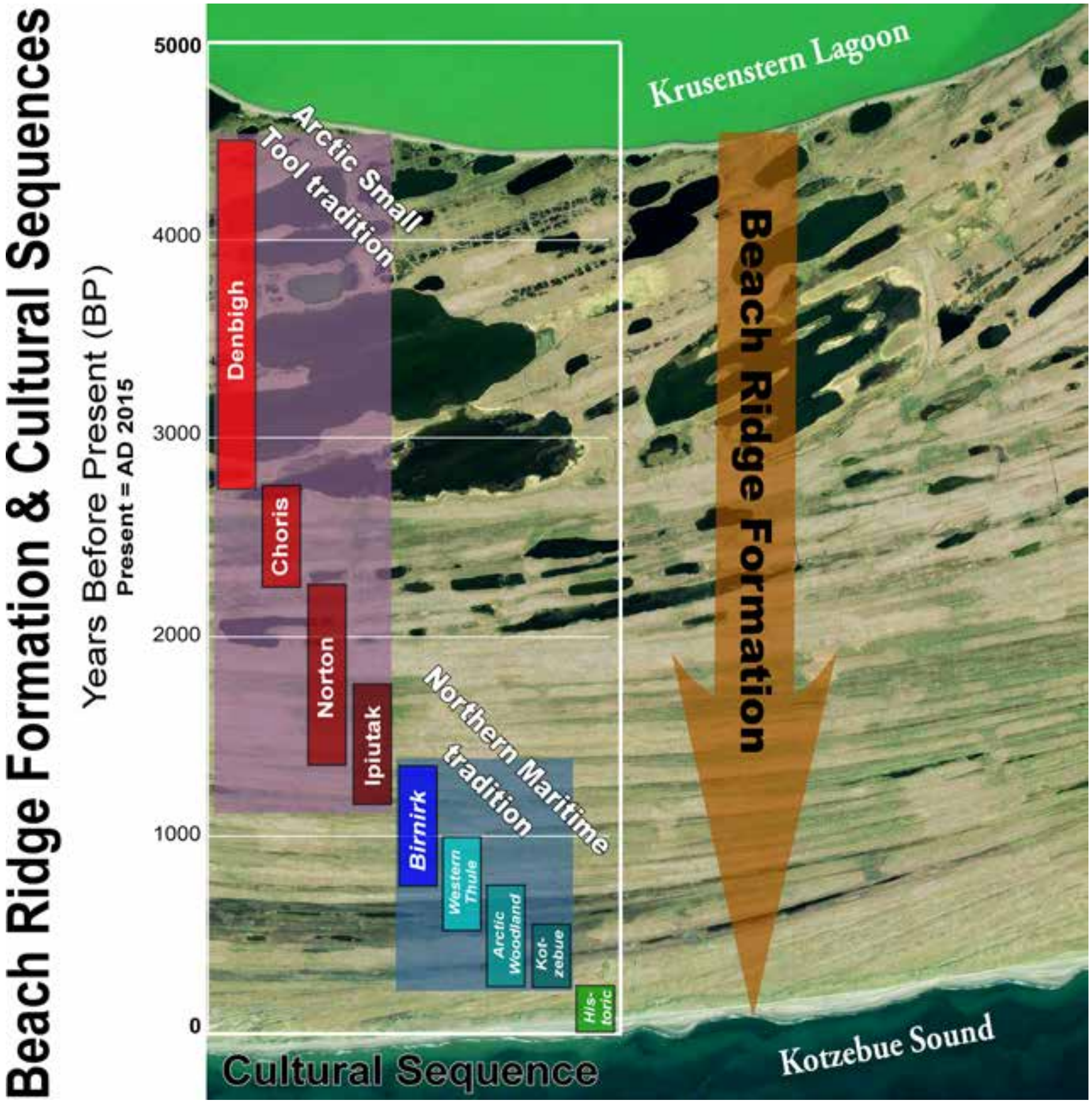

Figure 5. This model of "beach-ridge archaeology" has been simplified to demonstrate the synchronicity of beach ridge formation (orange) and human occupation throughout the Late Holocene. Typically, beach ridges formed horizontally from Krusenstern Lagoon to Kotzebue Sound at an average annual rate of 1.41 feet (0.43 meters) over a span of 5,000 years, with intermittent periods of erasure as evinced by truncated beach ridges. Cultures occupied beaches contemporaneous to their time as well as those formed during previous beach ridge building episodes.

Perhaps the earliest evidence of a coast-adapted lifeway derive from minute traces of small seasonal camps and artifact scatters deposited 4,500 to 2,750 years ago (Denbigh Flint complex); this evidence found within paleosols (ancient soil) along the oldest beach ridges, marked the beginning of the Arctic Small Tool tradition (ASTt) (*Giddings and Anderson 1986; Tremayne 2014*). The presence of semi-subterranean sod houses as well as pottery and complex tool assemblages are indicative of more sedentary lifeways focused on the coast during the Choris cultural period (2,750 to 2,250 BP) and subsequent Norton cultural period (2,250 to 1,350 BP) (*Giddings and Anderson 1986*). Human occupation of the coast during the ASTt reached its zenith during the Ipiutak culture (1,750 to 1,150 BP), marked by evidence of increased settlement, technological innovation, and growing sociopolitical complexity (*Larsen and Rainey 1948; Anderson 1962; Giddings and Anderson 1986; Schaaf 1988; Bowers 2006*) (*Figure 5*).

There is overlap between ASTt and Northern Maritime tradition (NMt) between 1,350 and 1,150 years ago (*Giddings and Anderson 1986; Schaaf 1988*), sparking a cultural transition which was heavily influenced by the Medieval Warm Period in Alaska (1,200 to 800 years ago) (*Hu 2001*). Iñupiat people living in Northwest Alaska today are directly descended from the NMt, which dominates the archaeological record on the region's coast. It was during NMt people permanently occupied and adapted to the coast, experienced a florescence in population, increased sociopolitical complexity, managed extensive trade networks and expansive territories, and developed large settlements and intricate tool assemblages. Material deposits and features derived from the Thule (950 to 550 years ago), Kotzebue cultures (550 to 250 years ago), and contemporary Iñupiat people within the last 1,000 years represent the most intensified human use of the coast (*Giddings and Anderson 1986; Schaaf 1988; Anderson 2013*). Arctic Woodland culture

Photo courtesy of NPS Shorezone Mapping Project

Figure 6. Oblique view of Kivalina.

Photo courtesy of NPS Shorezone Mapping Project

Figure 7. Oblique view of Shishmaref.

likely represents an expansion of Thule and Kotzebue cultures into interior watersheds between 750 to 250 years ago (*Giddings 1952; Giddings and Anderson 1986*). Climate amelioration sparked a 300-year global cooling trend called the Little Ice Age beginning 500 years ago, which once again influenced a regional shift in settlement and subsistence patterns as human foraging groups moved away from sea mammal-based lifeways to those centered around fishing, as evinced by advanced fishing tools and modified land use patterns (*Giddings and Anderson 1986*).

The historic period in the region began circa 1950s and ended 1965 (165 to 50 BP), representing a period of significant cultural and technological change for the region's indigenous people. While the Iñupiat had very limited interface with outsiders prior to this time (often termed "contact era"), the region was eventually exposed to the Euro-American fur trade industry, exploration, and subsequent distribution of firearms and other technological advances. A well-documented caribou famine in the 1890s served as the impetus for introducing reindeer herding in Northwest Alaska. By the early Twentieth Century, church missions established the current village centers in the region, contributing to a more sedentary lifeway (*Ray 1975; Burch 1998, 2006*).

Contemporary Iñupiat societies and their ancestors have relied on land and resources in the region since time immemorial, developing unique ways in which to thrive and adapt to arctic coastal environments (*Ray 1975; Burch 1998, 2006*). These distinctive lifeways are imperiled in places like the Native Villages of Kivalina (*Figure 6*) and Shishmaref (*Figure 7*) where the effects of climate change are exacting a direct and unprecedented impact on food security and cultural identity (*Druckenmiller 2011; Willis 2004; Sackur 2013*).

The archaeological survey crew at Cape Krusenstern National Monument in 2015 (pictured from left to right, Greg Luna Golya, Mariama Dryak, Brooke Luokkala, Justin Eichelberger, Becky DeAngelo, and Michael Holt).

Figure 8. Polygonal ice wedge formation and bluff erosion at Bering Land Bridge National Preserve. Polygonal wedges forming on the tundra-backed coastal bluffs and plains are indicative of acute permafrost melt. This process further exacerbates erosion along the bluffs and is evinced by severe sloughing.

Figure 9. Example of lagoon breaching in Cape Krusenstern National Monument in 2013.

Processes of Coastal Change in the Arctic

Coastal erosion occurs through a number of processes including storm driven waves along the bluffs and low-lying barrier islands, tidal inlet migration, and sediment redistribution due to large overwash events. Storm events appear to be key drivers, greatly influencing rates of coastal erosion (*Figure 8*).

Unlike coastal systems in the lower latitudes, Bering Land Bridge and Cape Krusenstern coastlines are closely tied to the dynamics of sea ice. Sea ice exerts crucial control over coastal processes, and climate change is now altering the sea ice regime in the Bering and Chukchi Seas quickly and radically. Arctic sea ice extent and thickness has been declining more than 10 percent per decade since satellite observations began in 1981 (*Stroeve 2012*). Over the last 40 years, the duration of landfast (or shorefast) sea ice along the Beaufort Sea coast has declined by approximately one week per decade (Mahoney 2014). A summer ice-free Arctic ocean is expected by 2030 (*Overland and Wang 2013*).

Another unique feature of the Bering Land Bridge and Cape Krusenstern shorelines is the presence of permafrost-rich bluffs, which when thawed are susceptible to erosion during storm events. Current observations show widespread permafrost degradation adjacent to the shoreline and the development of thermoerosion gullies draining onto the beach. In some cases, the process causes lagoons to breach (*Figure 9*).

Coastal Permafrost Dynamics

Cape Krusenstern exhibits a number of typical thermokarst features such as ice-wedge polygons and shallow lakes situated among a series of ancient beach ridges. Permafrost thawing occurs as average temperatures in May rise above freezing, reaching its maximum active thawing depth by the end of summer. This process reverses in early fall as average temperatures drop below 0°C (32°F) and the ground once again freezes. Depth of the active thawing layer is driven by variability in seasonal climate and impacted by both unseasonably long summers and higher-than-average temperatures. The rate of active thawing influences stability of the underlying permafrost layer. Permafrost changes can therefore be expected with a warming regional climate, particularly with warmer-than-average summers and longer seasonal timeframes when the average temperature remains above freezing (*Figure 10*).

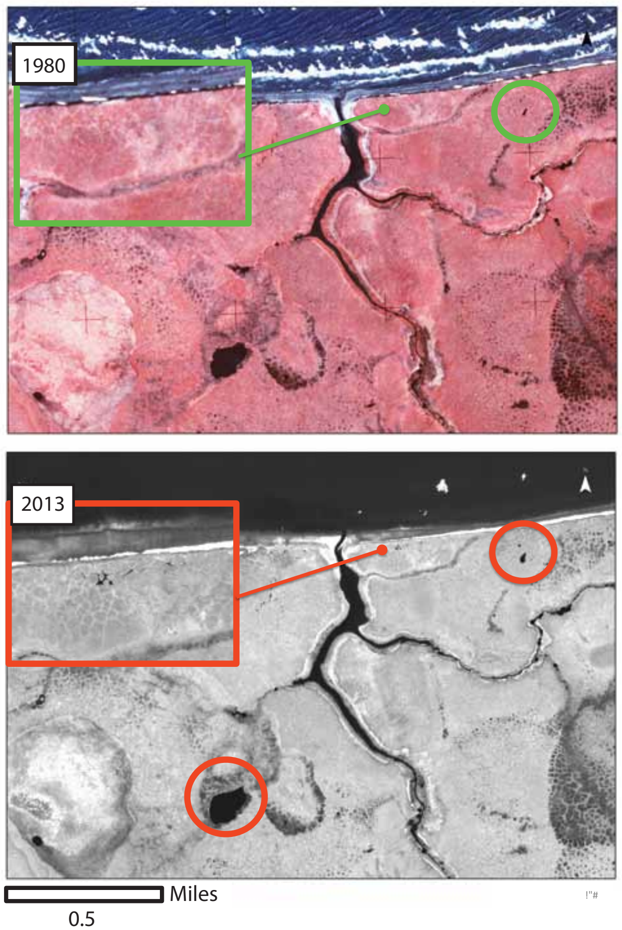

Figure 10. Comparison of ice-wedge polygon degradation between 1980 and 2013.

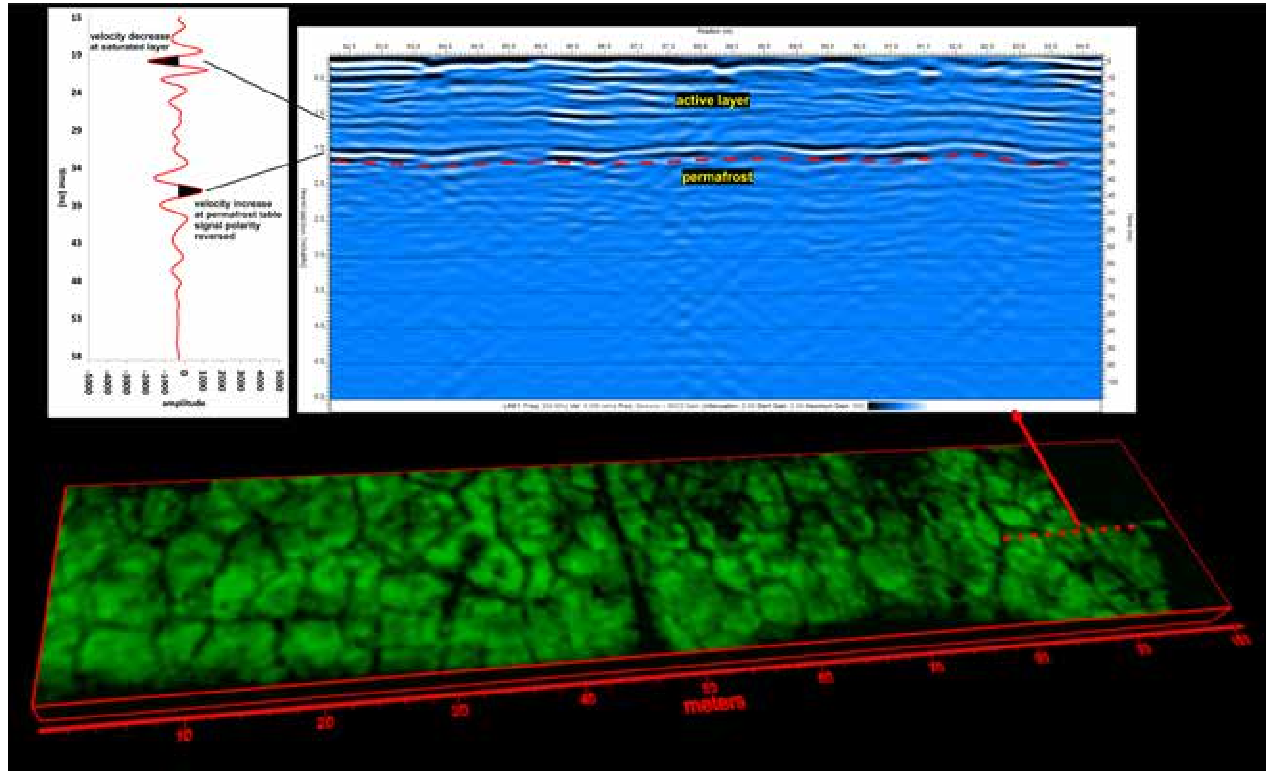

Figure 11. Example of ground-penetrating radar (GPR) used to monitor thawing from year to year at Cape Krusenstern. The lower portion shows the active layer at 50-60 cm deep with a typical network of patterns generated by the freeze-thaw cycle, while the extracted cross-section above shows the reflection from the frozen layer. Monitoring underway since 2011 with GPR has shown that the peak depth to the permafrost table in late summer is predictably effected by early summer warming. A longer summer time-window results in a thicker active layer by late summer.

Permafrost contains substantial frozen organic material and thawing can lead to decomposition of this material and the associated release of greenhouse gasses, such as methane. For this reason, permafrost loss is considered a global environmental threat. Locally, permafrost changes threaten infrastructure, ecology, and cultural resources by altering the dynamics of the shallow subsurface. This can result in accelerated erosion, vertical transport of artifacts, and general distortion of features within the archaeological record, thereby destroying or complicating contextual relationships. Archaeological sites in low-lying coastal areas of Bering Land Bridge and Cape Krusenstern are further exposed to salt water inundation in the wake of permafrost failure (*Figure 11*).

NPS photo courtesy of Jim Pfeiffenberger

Complex, low-lying barrier island, lagoon, and tidal inlet systems can shift and change rapidly, particularly with increasing storm surges that result from lack of sea ice.

A 2011 geophysical investigation of the Old Whaling archaeological site (Cape Krusenstern) revealed a late-summer permafrost table deeper than had been noted in previous archaeological investigations in the 1950s and even as recently as the early 2000s (*Wolff and Urban 2013*). The thickness of the active layer in a 100-meter stretch between two excavations was determined with ground-penetrating radar (GPR) in 2011, and then re-collected at the same location in 2013 and 2015. With GPR, the frozen layer is distinguished as a subsurface interface of abruptly increasing velocity in comparison to the lower velocity active layer. The velocity change occurs because frozen ground has different electrical properties than thawed ground. This results in a reflection from the frozen layer. Velocity estimates of the active layer using hyperbolic curves generated by frost cracks in the subsurface are then used to convert the two-way travel time of the radar signal into a depth representing the permafrost table.

Geochronology of Coastal Change

Changes in coastal geomorphology occur at many different time scales. Glacial-interglacial cycles operate over tens of thousands of years and cause fluctuations in sea level influenced by the accumulation and release of water for ice sheet growth and decay. As a result of fluctuating sea level, the shoreline moves either further inland or offshore. The modern day shorelines of Bering Land Bridge and Cape Krusenstern have evolved over the last 10,000 (during the Holocene) years as sea level rose from its ice age low and has fluctuated around its current level (*Carter and Woodroffe 1997*). Permafrost bluff sediment and ice accumulated over tens of thousands of

Photo courtesy of NPS Shorezone Mapping Project

Figure 12. Increased storm surge intensity and frequency have washed away the remnants of the Kitluk Village site (an important ethnohistoric Iñupiat settlement). Bluff erosion, permafrost melt, and dune deflation at the site have been intensively investigated by archaeologists and geomorphologists since the 1980s. During the recent assessment in 2015 there were no distinguishable features identified, and scant evidence of material culture was found within a highly disturbed context (i.e., on the beach or eroding bluff face).

years due to the continuous deposit of silt by wind and snow processes during the late Pleistocene (*Figure 12*).

Impacts of Coastal Change

Over the last two years we have conducted a combination of field and remote sensing-based investigations looking into whether the coastlines of Bering Land Bridge and Cape Krusenstern have begun to change more rapidly due to loss of sea ice and warming air and ocean temperatures. Building on previous work by Manley (*2010*), measuring rates of change over two time periods (1950-1980, and 1980-2003), current data extends these observations to 2014. Our measurements show an increase in rates of coastal erosion along the Bering Land Bridge and Cape Krusenstern coastlines since 2003. Between 1980 and 2003, rates of coastal change along the Bering Land Bridge shoreline averaged .03 feet/year (0.01 meter/year) while Cape Krusenstern was found to be on average gaining land at 0.23 feet/year (0.07 meters/year) Bering Land Bridge's coastline is now eroding at an average rate of 2.82 feet/year (0.86 meters/

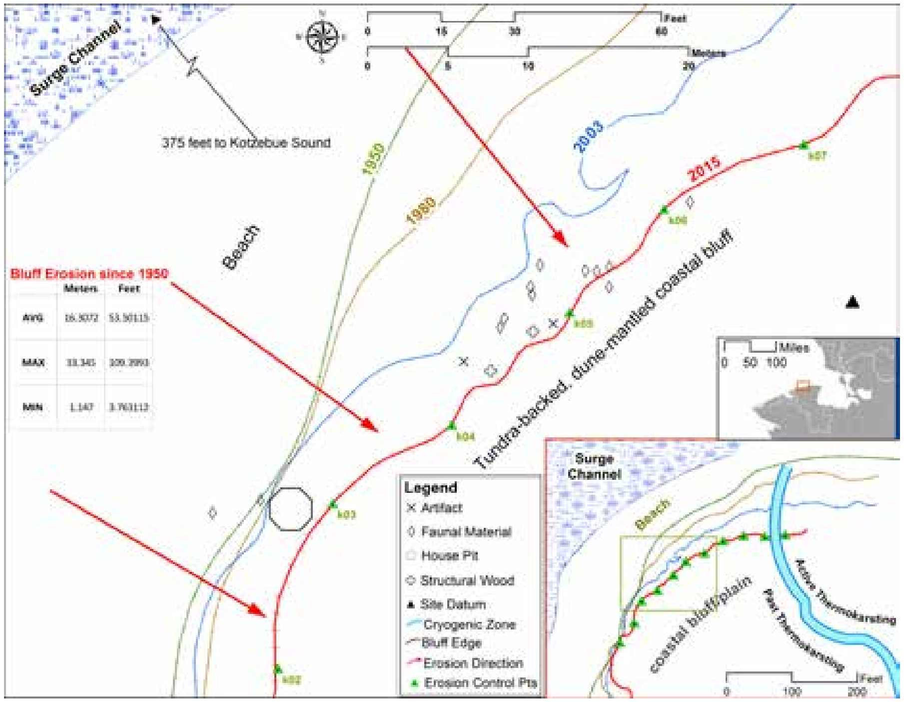

Figure 13. Bluff erosion at Kitluk River archaeological site between 1950 and 2015.

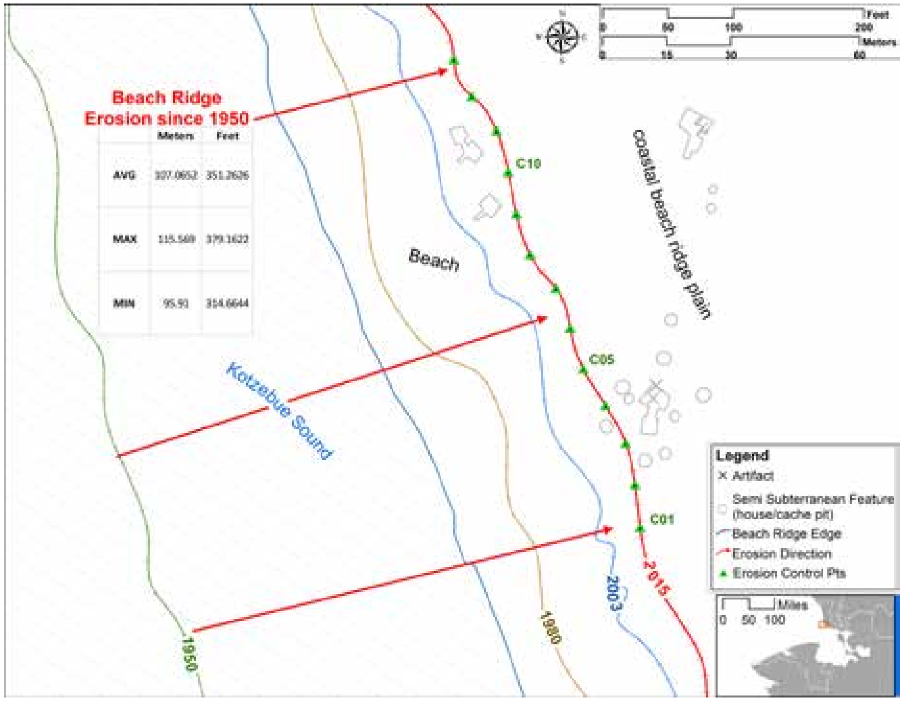

Figure 14. Beach ridge erosion at Cape Krusenstern National Monument between 1950 and 2015 (projected from 2010 satellite imagery).

year) and Cape Krusenstern's 2.26 feet/year (0.69 meters/year). This increase in erosion rates also coincides with a significant decrease in the duration and extent of sea ice in the Arctic.

Shrinking sea ice increases wave action, which provides more energy for coastal erosion (*Overeem 2011*) and barrier island inundation and sediment redistribution during storm events. The effects of changing sea ice condition are made even greater by the presence of extensive sections of ice-rich, permafrost bluffs. This makes the western Arctic coastline particularly vulnerable to the increasing temperatures of both the ocean and air as icy sediments thaw more rapidly.

Bluff erosion at Kitluk River ethnohistoric Iñupiat settlement (Bering Land Bridge) (*Figure 13*) has been the focus of past shoreline attrition studies (*Jordan 1988*). Fossils are commonly found exposed on the beach to the east of the settlement, eroding from bus-sized blocks of peat that had been preserved in Pleistocene ice and sediments. In 2015 a NPS survey team revisited the historic site to assess its continued vulnerability to coastal processes. Bounded by the Chukchi Sea (to the north) and storm surge channel along Kitluk River (to the west), the bluffs are continually battered by storms and the erosion impact is amplified by active thermokarsting. Landform erosion was measured using orthorectified historic aerial photogrammetric techniques (*Manley 2010*) to reconstruct bluff edges from 1950, 1980, and 2003 in addition to GPS data collected in 2015 by NPS archaeological survey crew. Eleven control points were arrayed along the 2015 bluff edge, spaced apart at 10-meter intervals to measure minimum, maximum, and average erosion from 1950 to 2015. Since 1950 there has been an average bluff loss of 53.5 feet (16.3 meters), ranging between 3.8 feet (1.1 meters) and 109.4 feet (33.3 meters). This is indicative of moderate-to-heavy annual erosion rates between 0.1 feet/year (0.02 meters/year) and 1.7 feet/year (0.51 meters/year). The components formerly contributing to the significance of Kitluk River site have been lost to the ravages of an unrelenting Chukchi Sea (*Figure 14*).

Photo courtesy of Gregory Luna Golya

Figure 15. Intensified storms occurr more frequently and shorefast ice recedes earlier than in the recent past, contributing to severe erosion along the coastal bluffs in the Bering Land Bridge National Preserve. High water surge events scour the bluffs, exposing permafrost and expediting melt-further compounding bluff erosion.

Perhaps the most vulnerable coastal landform in Northwest Alaska is the internationally significant Cape Krusenstern beach ridge complex. The storm battered fore-ridges have shown the most severe attrition since 1950 while the back-ridges are extremely susceptible to the impacts of melting permafrost in the form of frost-cracking and changing water tables, which amplify the effect of eolian erosion. As in the Kitluk River example, orthorectified historic aerial photogrammetric techniques (*Manly 2010*) aided in reconstructing fore-ridge edges in 1950, 1980, and 2003. Fore-ridge reconstruction for 2015 is a projection based on 2010 satellite imagery and average rates of erosion between 1950 and 2003. Thirteen control points were arrayed along the projected 2015 fore-ridge edge, spaced at 10-meter intervals to measure minimum, maximum, and average erosion between 1950 and 2015. Since 1950 there has been an average fore-ridge loss of 351.3 feet (107.1 meters), ranging between 314.7 feet (95.9 meters) and 379.2 feet (115.6 meters). This equates to severe annual erosion rates between 4.8 feet/year (1.5 meters/year) and 5.8 feet/year (1.8 meters/year). This pattern of erosion occurs throughout the Cape Krusenstern beach ridge complex, as cryogenic and eolian processes continue to impact the older ridges at unprecedented rates (*Figure 15*).

GIS Modeling

A Geographic Information Systems (GIS)-based predictive model was created to assist archaeologists in locating and documenting sites before they are lost to the effects of a changing climate. The predictive model is composed of two components: the first is a deductive model identifying parts of the coast subject to erosion, and the second is an inductive model identifying areas of the coast likely to contain an archaeological site. The two pieces were then added together to highlight the areas of the coast that are both likely to erode and to contain an archaeological site. The raster can then be used to prioritize areas for archaeological study.

Progress Report

Since 2012, the NPS has administered a vulnerability assessment program to identify our most significant and at-risk cultural and paleontological resources on the western Arctic coast (*Anderson 2015*). A vulnerability prioritization matrix was developed in cooperation with Portland State University (*Anderson 2015*) and further refined by the NPS to aid in the prioritization process. The matrix serves as a tool providing resource managers and researchers with consistent measures to assess the vulnerabilities of our affected resources. It does so by quantifying the product of four values including significance/data potential, condition/integrity, impact severity, and immediacy of threat. Significant/data potential is the antecedent value factored to the sum of the other values and based on the resource's potential to contribute to our understanding of past human adaptations and natural histories. Condition/integrity is determined by the integrity or quality of the significant components of a resource. Impact severity is used to determine how climate change or other impact agents have affected the significant components of a resource. Immediacy of threat is a chronological estimation of when an impact is expected to adversely affect the significant components of a resource.

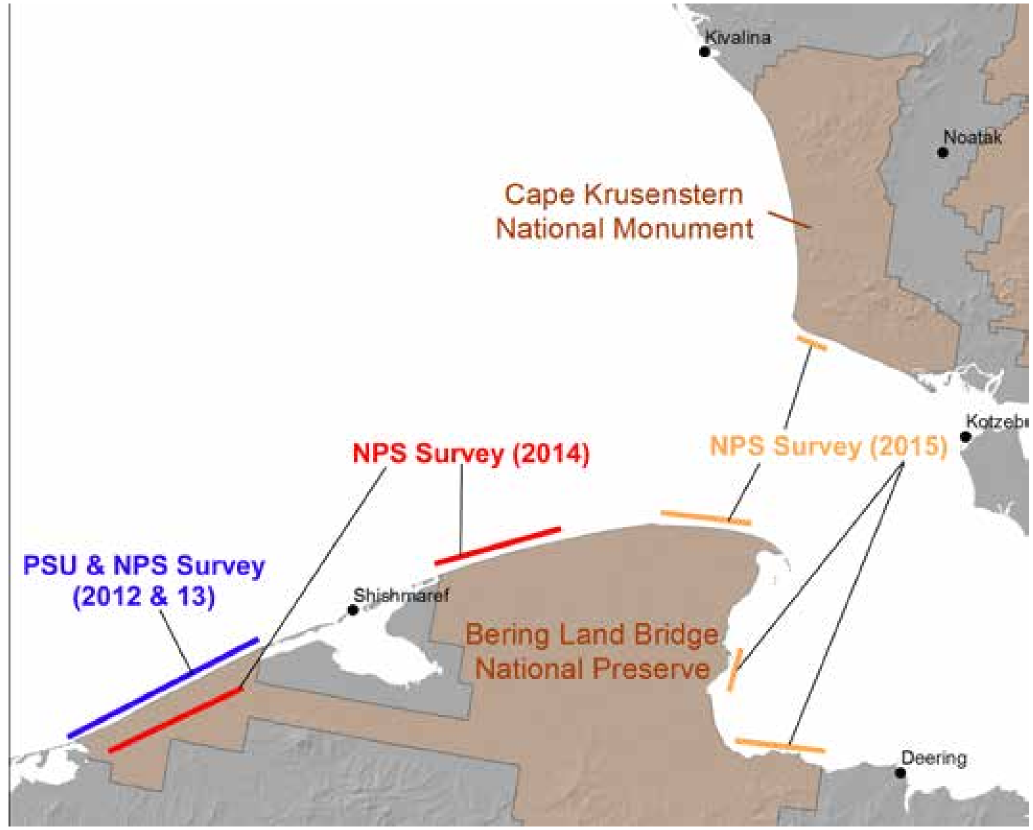

Figure 16. Map of coastal areas surveyed and prioritized for treatment by 2015.

The GIS model was tested with survey data collected by Portland State University in 2013 (*Anderson 2015*). The GIS predictive model has proven to be a useful tool for identifying our most significant and at-risk resources on the coast, further aiding in our efforts to understand and triage the impacts of climate change.

The NPS and our research partners have thus far succeeded in assessing vulnerabilities of cultural and paleontological resources along approximately 180 miles (289.7 kilometers) of coastline. The vulnerability matrix has been applied to 192 cultural and paleontological resources, resulting in a prioritized list for the treatment of our most significant and at-risk resources. The first phase of cultural and paleontological resources inventory and prioritization will continue in 2016 and 2017. Treatment and excavation (data recovery) for the next phase is planned subsequent to completion of survey and prioritization efforts, beginning in 2018 (*Figure 16*).

Concluding Remarks

Though Earth processes have continually shaped the region's coastal landforms and ecosystems since the onset of the Holocene, current data suggests rising global temperatures and sea level are amplifying the effects of coastal landform erosion at unprecedented rates, leaving them more vulnerable than ever. Storm surges previously buffered by shore-fast ice and resilient permafrost are battering the coast at unparalleled intensity and frequency. Diminished annual snow cover, permafrost melt, and changing vegetation are exposing the region's sand dunes to eolian erosion.

Understanding how permafrost responds to seasonal temperatures and monitoring significant changes at key locations such as Cape Krusenstern could aid in the future management of these resources. Our results at Cape Krusenstern have shown that the permafrost responds predictably to temperature increases and decreases from season to season. New permafrost monitoring stations were established in 2015 at the location of an eroding paleontological site at Imik Lagoon (Cape Krusenstern) and at an eroding archaeological site at Bering Land Bridge, to allow for future monitoring.

The irreversible impact of powerful Earth processes on cultural and paleontological resources is a key concern for NPS and our preservation partners. These fragile resources represent a moment frozen in time, giving us insight as to how our enigmatic predecessors adapted to past episodes of climatic amelioration. As bus-sized blocks of peat spill into the sea at unprecedented rates, paleontologists are rapidly losing evidence with which to study the movement and behaviors of the quintessential fauna roaming Beringia prior to global extinction at the end of our last great Ice Age. The most imminent concerns are those centering around the region's coastal communities and uniquely adapted societies, as contemporary climate change related issues severely impact home and food security, and threaten independence and cultural identity. The NPS, with help from interdisciplinary research partners and traditional knowledge experts, are studying climate change related processes and how they threaten our most significant and at-risk cultural and paleontological resources. Finally, research resulting from this program is contributing substantially to our understanding of past and present human-environment dynamics in the region; a fascinating tale of survival, adaptation and the enduring human spirit.

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Feathered Ambassadors of Arctic Coastal Parks

By Stacia Backensto, Jeremy Mizel, Audrey Taylor, Megan Boldenow and Martin Robards

At whatever moments you read these words, day or night, there are birds aloft in the skies of the Western Hemisphere, migrating.
-- Scott Weidensaul

Early March on the coast of New Zealand, a Bar-tailed Godwit (*Limosa lapponica*) gorges endlessly on mollusks to fatten up for its 7,000-mile (11,270 kilometers), non-stop flight to Alaska. In April, a Pacific Golden Plover (*Pluvialis fulva*) is also feeding constantly in preparation for its long journey from Hawaii to Alaska. Each spring, shorebirds—the long-distance athletes of the animal world—make marathon flights between hemispheres to remote areas in Alaska where they nest and raise young. Migratory birds are the feathered ambassadors of our planet; they connect water, land, air, and us to other people, cultures, and countries far away.

Coastal areas in the Bering and Chukchi Seas are increasingly vulnerable to heightened industrial activity and a rapidly changing climate. Despite the vulnerability of these areas to the potentially grave impacts of an oil spill from the increasing number of ships that now ply Arctic waters, little is known regarding abundance, species composition, or distribution of shorebirds during fall migration in this region. Without such information, it will be impossible to prioritize effective spill response to the most critical areas if such a disaster does occur or to manage restoration activities after an incident. Degradation or loss of stopover sites used during migration in Bering Land Bridge National Preserve and Cape Krusenstern National Monument may have significant impacts to migratory populations on a global scale.

The coastlines of Bering Land Bridge and Cape Krusenstern hold 1,000 miles (1,600 kilometers) of low, sandy beaches, extensive and shallow lagoons, vast and estuaries, mudflats, salt marshes, the occasional cliff habitat, and shallow nearshore environments with extensive barrier islands and sandbars. Bering Land Bridge's enabling legislation specifically establishes this national preserve to, among other values, "protect habitat for internationally significant populations of migratory birds." Likewise, Cape Krusenstern's enabling legislation establishes this national monument to, among other mandates, "protect habitat for and populations of birds and other wildlife." To that end, we work with collaborators to understand shorebird use of coastal areas in these parks during migration.

Stepping Back in Time

Our ability to manage habitat for birds within both parks is constrained without an understanding of the historical status and variability of waterbird populations. We recently collaborated with Wildlife Conservation Society's Arctic Beringia Program to assess the historical status of bird species in Bering Land Bridge and Cape Krusenstern, as well as elsewhere in the transboundary landscape of Beringia. Understanding what species are and have been present in Kotzebue Sound provides us with a tool for understanding future changes to the region.

The birds of Kotzebue Sound have been periodically studied since the late 1800s. Joseph Grinnell produced the first thorough survey of the birds of the region from the summer of 1898 to the following summer of 1899 (*Grinnell 1900*). Periodic, natural history surveys took place through the first half of the twentieth century before being replaced by site- and species-specific work in the late twentieth century. Site-specific studies such as Schamel and Tracy's *Environmental Assessment of the Alaskan Continental Shelf (1979)*, and Wright's graduate thesis, *Reindeer Grazing in Relation to Bird Nesting on the Northern Seward Peninsula (1979)*, also provided detailed species lists and encounter histories in their reports. Recent studies conducted during the twenty-first century were varied in this regard. Between 1951 and 2000, natural historians and researchers collectively recorded 159 species, in comparison to 126 species recorded between 2001 and 2012. The vast majority of these species are migratory, with only 30 recorded wintering in northwest Alaska. Fewer records of species made during recent times may be an artifact of the shift from natural history record keeping to more quantitative approaches.

Figure 1. Bar-tailed Godwit (*Limosa lapponica*), famous in the bird world for its incredible migration between Western Alaska and New Zealand which, in the fall, is done in a single nonstop flight across the Pacific Ocean.

NPS photo courtesy of Jared Hughey

East Asian-Australasian Flyway Partnership (www.eaaflyway.net)

Figure 2. East Asian - Australasian Flyway

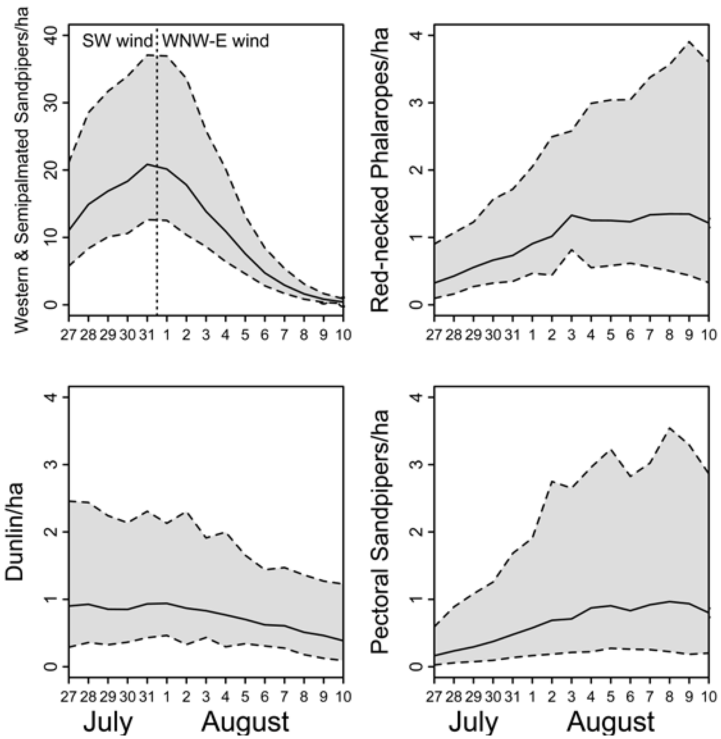

Figure 3. Temporal variation in post-breeding shorebird density in low marsh on Ikpek and Arctic Lagoon barrier island strip, Bering Land Bridge National Preserve (2013). The solid line represents the mean (expected) count per hectare for each day from July 27 to August 10. The dotted line and shaded region represent the 95 percent credible interval. The vertical line in upper left figure indicates the point at which winds shifted from southwest to northerly (varying WNW-E).

Shorebird Migration in Bering Land Bridge and Cape Krusenstern

Alaska's nearshore environments are staging areas for many Arctic breeding shorebirds making trips between their overwintering areas and breeding grounds. More shorebird species breed in Alaska than in any other state in the U.S. Thirty-seven species, including several unique Beringian species and Old World subspecies, regularly breed in the region (*Alaska Shorebird Group 2008*). The extensive saltmarsh and tidal flat habitat of the Chukchi coastline lies at the convergence of three major migration flyways: The East Asian-Australasian (*Figure 2*), Central Pacific, and Pacific Americas. As a result, birds from five of the seven continents may converge here.

Migration is a dangerous undertaking, and birds face numerous threats throughout their journeys. Frequent population trends for migratory shorebirds show a global pattern of decline (*Bart et al. 2007*). Their vulnerability is due in part to their frequent dependence on intact networks of coastal and wetland habitats during their long-distance migrations, since these habitats serve as important places to rest and refuel. Addressing the conservation needs of migratory shorebirds involves understanding habitat use and connectivity on a scale that spans wintering areas, migration routes, and breeding grounds Bentzen et al. 2016 (*Gratto-Trevor et al. 2012*). To understand the use of coastal areas by shorebirds during migration in Bering Land Bridge and Cape Krusenstern, we collaborated with shorebird biologists from the University of Alaska-Anchorage (UAA) and University of Alaska-Fairbanks (UAF) beginning in 2012.

Surveying the Salt Marsh

In late July through early August of 2013, three biologists and one intern investigated shorebird use of coastal salt marsh habitat along the barrier island at Ikpek and Arctic Lagoons in Bering Land Bridge. We found that roughly 3,400 Western Sandpipers (*Calidris mauri*) and Semipalmated Sandpipers (*Calidris pusilla*) used this 1.15-square-mile (3-square-kilometer) patch of saltmarsh each day, approximately double that reported by Connors and Connors (*1985*) along the Beaufort and southern Chukchi Sea coasts during the same time period. These results suggest that these lagoons are important stop-over sites for these species. Other shorebirds like Dunlin (*Calidris alpina*), Pectoral Sandpiper (*Calidris melanotos*), and Red-necked Phalarope (*Phalaropus lobatus*) were found in relatively low numbers throughout the survey period (*Figure 3*). Overall shorebird density peaked at 20.1 shorebirds/hectare on July 31. We observed a total of 20 shorebird species.

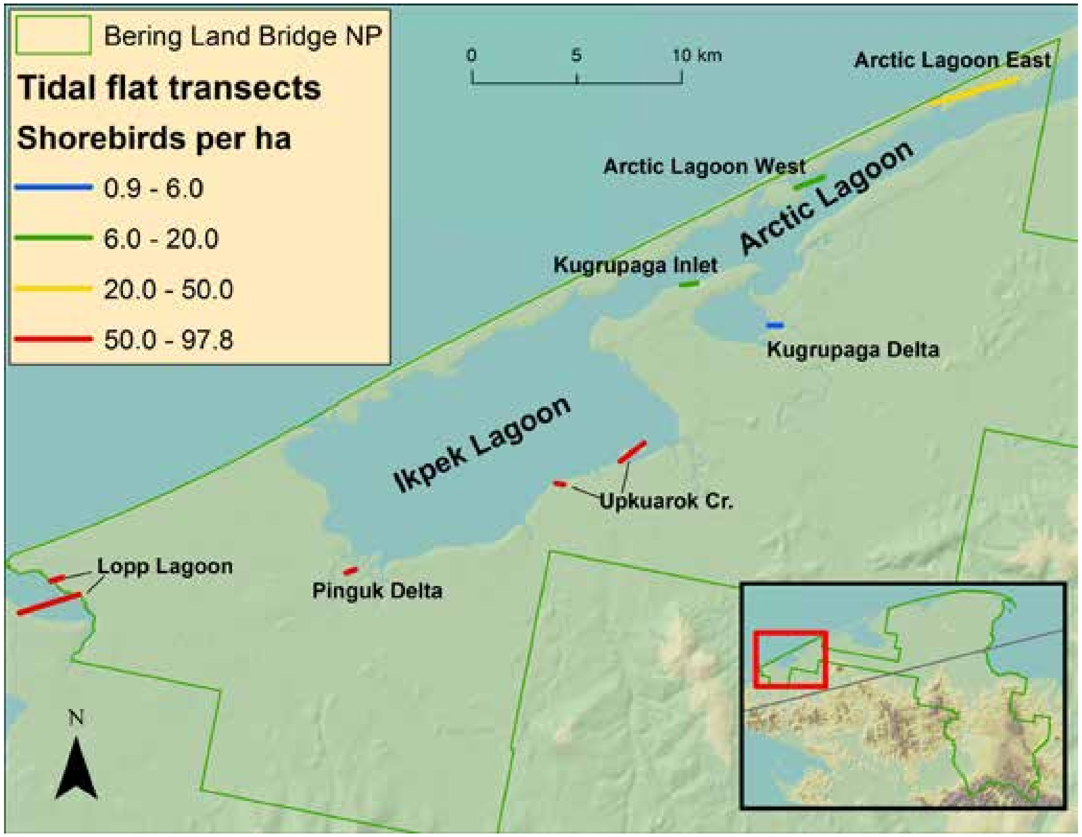

Figure 4. Spatial variation in post-breeding shorebird density on transects flown over tidal flats along the western coastline of Bering Land Bridge National Preserve (2014). Densities (per hectare) correspond to the mean across all transects within a site.

Surveying Mudflats from Above

In order to describe shorebird use of coastal areas at a much larger scale, and to identify potential hotspots for staging or migrating shorebirds, we took to the air. In late July and early August of 2014, Dr. Audrey Taylor (UAA) conducted aerial surveys along a random sample of transects in mudflat habitat to count shorebirds. We counted over 26,000 shorebirds from the aircraft between July 28 and August 13. Estimates of shorebird densities were highest for Ikpek and Lopp Lagoons (*Figure 4*), followed by Shishmaref Lagoon and Cape Espenberg. Shorebird densities were highest during the first half of the survey period with as many as 100 shorebirds per hectare. By the end of the surveys, densities varied between 0 and 60 birds per hectare – a pattern likely due to pulses of shorebirds waiting in these areas to depart with favorable winds.

Species Composition at Sisualik and Cape Krusenstern National Monument

During the same time Dr. Taylor surveyed mudflats from the air, UAF graduate student Megan Boldenow staged at Sisualik Spit at the southern edge of Cape Krusenstern. Her field crew observed 19 shorebird species (on average 11 species per day) stopping over on migration. Approximately 10,300 shorebirds out of 14,482 waterbirds were counted. Western Sandpiper, Semipalmated Sandpiper, Dunlin, and Red-necked Phalarope were the most abundant species, with at least 500 observations made during roughly two weeks. Least Sandpiper (*Calidris minutilla*), Pectoral Sandpiper, and Long-billed Dowitcher (*Limnodromus scolopaceus*) were the most common (greater than 100 individuals observed over the course of the season). They even recorded the Stilt Sandpiper (*Calidris himantopus*), an uncommon migrant along the Chukchi Sea coast that breeds on the North Slope.

Conclusion

From our recent work with collaborators, we gained new insights into shorebird use of coastal areas in Bering Land Bridge and Cape Krusenstern during migration. Tens of thousands of shorebirds use the lagoons and large mudflats of Bering Land Bridge during their post-breeding migrations; most are western and semipalmated sandpipers. These same species are also the most abundant shorebirds stopping over at Sisualik Spit in Cape Krusenstern. The occurrence of an oil or industrial spill near lagoons and mudflats along the coast of these parks during late July through the middle of August would likely affect upwards of 20 shorebird species and at a minimum, several thousand individuals; particularly Western and Semipalmated Sandpipers.

We still need to conduct additional aerial and ground-based surveys along the coasts of both parks to determine peak densities of shorebirds at lagoons and mudflats during the post-breeding period. Longer studies over multiple years will also be necessary to understand the timing of migration on an annual basis. For example, weather conditions in a given year can have a large effect on migration. During our ground surveys at Ikpek Lagoon in 2013, a shift in wind direction precipitated significant declines in the numbers of western and semipalmated sandpipers using salt marsh habitat. It seemed that the birds took advantage of favorable wind conditions to continue their southbound journeys and left the survey area. Without multiple years of information, we cannot identify peak migration periods or know which areas support the highest number of birds. Moreover, the lack of this information will impede our ability to prioritize coastal areas for spill response.

Acknowledgments

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Photo courtesy of Ken Stenek

Semi-palmated Plover at Sarichef Island near Bering Land Bridge National Preserve during spring migration.

Understanding the Ecology of Arctic Coastal Lagoons through Fisheries Research and Monitoring

By Trevor Haynes, Tahzay Jones, Martin Robards, Jim Lawler, Alex Whiting, Marguerite Tibbles, Mark Wipfli and Peter Neitlich

Within the western Arctic parks, there are seven coastal lagoons described within the boundary of Cape Krusenstern National Monument—Aukulak, Imik, Ipiavik, Kotlik, Krusenstern, Port, and Sisualik; and four coastal lagoons within the boundary of Bering Land Bridge National Preserve—Lopp, Kupik, Shishmaref, and Ikpek. Sediment transport is beginning to form a fifth lagoon in the shallow, protected waters behind Cape Espenberg. These shallow, dynamic coastal lagoons represent a critically important ecosystem in the region, supporting avian, fish, and invertebrate populations, in addition to being used by both terrestrial and marine mammals.

The western Arctic lagoons are found at the nexus of both the North American and Asian avian flyways, with habitat that supports migratory seabird, shorebird, and waterfowl populations resident to northern and southern hemisphere Asian and American continental avian populations. They support seasonal subsistence activities and are used as navigational pathways throughout the year by local village residents. These subsistence practices have continued for thousands of years, attested to by rich cultural and archaeological sites found in immediate proximity to the lagoons.

The lagoons are extremely vulnerable to both climate change and human impacts from increased activities in and around the region. The lagoons in Cape Krusenstern can seasonally open and close to the ocean with seasonal storm events, and Bering Land Bridge lagoons have seen significant changes in the erosion and deposition of sediments along the exterior barrier islands and particularly within the lagoon inlets.

Challenged by remote access, and encumbered with extremely difficult logistics, studies of this area have been few. While there have been multiple attempts since the 1970s to study these coastal areas with some success, the study purpose, and temporal and spatial separations of these studies has made developing a cohesive reference condition understanding of the biological and physical characteristics of these lagoons nearly impossible.

Initial work in the area prior to the establishment of the western Arctic parks focused on avian fauna with limited lower trophic information collected on planktonic communities (*Conners and Conners 1982; Connors and Risebrough 1977, 1978*). Raymond et al. (*1984*) collected some limited basic physical water quality, fish, and invertebrate composition in lower Cape Krusenstern lagoons. The Red Dog Mine environmental studies (*Dames and Moore 1983; Blaylock and Erikson 1983; and Blaylock and Houghton 1983*) were fairly thorough during their two years, and collected avian fauna information along with physical water quality parameters, fish, and invertebrate data. However, the Red Dog environmental studies program focused only on lagoons in northern Cape Krusenstern as part of the environmental studies necessary to site the Red Dog port facilities for the development of the Red Dog Mine, haul road, and port. They did provide some insight into the ecological functioning of the lagoons, indicating that while the lagoons were open, they provided a greater degree of species diversity than when they were closed to the ocean.

Limited scientific studies outside of avifauna were completed in the lagoons following the Red Dog environmental studies, until the NPS Arctic Inventory and Monitoring Network was established. The Arctic Network focuses ecosystem monitoring in five northern Alaska parks, including the coastal lagoons of Cape Krusenstern and Bering Land Bridge (*Lawler et al. 2009*). In 2007, the Arctic Network began developing a protocol for western

Figure 1. Marguerite Tibbles, graduate student at the University of Alaska Fairbanks, with a sheefish (*Stenodus nelma*) in Cape Krusenstern National Monument.

Photo courtesy of T. Haynes

Arctic coastal lagoons to support informed management decisions as outlined in the parks' General Management Plans (*NPS 1986a and 1986b*).

Lagoon Protocol Development

Lagoon monitoring efforts are intended to address the need for reference conditions followed by standardized monitoring of the structure and function of lagoons, as well as local fish resources used for subsistence (*Lenz et al. 2001*). Without a clear understanding of reference conditions in the lagoons, including the seasonality and inter-annual variability of physical and biotic components, it's impossible to detect long-term changes, quantify accident/incident impacts, or even develop appropriate management plans designed to protect key functions of these lagoons for local ecosystem services and subsistence economies.

Reynolds et al. (*2005*) conducted physicochemical (including nutrients) and biological (zooplankton, epibenthos, and fish) sampling in five of the seven Cape Krusenstern coastal lagoons (Imik, Kotlik, Krusenstern, Aqulaaq, and Sisualik); they were the basis for her PhD dissertation (*Reynolds 2012*).

Supported by the Arctic Network during 2009, Reynolds sought to effectively survey and develop a monitoring protocol for coastal lagoons in Cape Krusenstern to document the long-term status and trends of physical, chemical, and biological components. Reynolds' efforts provided reference condition data of water quality and some zooplankton information for the lagoons, but additional work was still needed to better understand temporal and spatial variability. Because of the variability seen in the data, there was not enough data collected for reliable conclusions about seasonal or interannual variability, particularly for lagoons only sampled once. In 2012, Robards (*2014*) conducted biological and physical study of lagoons in Cape Krusenstern and Bering Land Bridge to assist NPS with the design and implementation

Photo courtesy of M. Tibbles

Photo courtesy of M. Tibbles

Photo courtesy of R. Sherman

Figure 2. Photographs of the three major sampling techniques employed, including beach seine (top left), gill net (top right), and fyke net (bottom). Gill nets were either set at shore (shown here) or away from shore.

of the Coastal Lagoon Vital Signs program. This research broadened our understanding of the physical dynamics of lagoons and the spatial distribution of the fish communities across lagoons.

Methods and Results

Through a collaborative effort between the Wildlife Conservation Society, the Native Village of Kotzebue, and NPS, we expanded on the research of Robards (*2014*) to aid in Vital Signs protocol development for coastal lagoons. During the ice-free season of 2015, we sampled fish communities and water quality of three lagoons (Aukulak, Krusenstern, and Kotlik) in Cape Krusenstern and two lagoons (Kupik and Ikpek) in Bering Land Bridge. Our objectives for fisheries data collection in 2015 were to:

- Document fish community composition and patterns of use in the coastal lagoons. Lagoons in these parks range in size, connectivity, and saltwater influence, allowing us to sample fish distributions, abundance, and community composition through the season and across selected environmental gradients.
- Examine trophic structure of lagoons by sampling fish diets. Examining fish diets establishes key trophic linkages among species and begin to develop a broader understanding of Arctic lagoon food webs.
- Measure fish growth rates for resident and migratory species. Documenting fish growth rates will be used to monitor long-term changes in fish condition, and ultimately changes to the lagoon conditions that affect fish growth.

Photo courtesy of M. Tibbles

Figure 3. Measuring water chemistry (e.g., salinity, temperature, dissolved oxygen) at Aukulak Lagoon, Cape Krusenstern National Monument.

Using several fishing methods (*Table 1, Figure 2*), we sampled lagoons for fish community composition, seasonal and spatial patterns of use, trophic dynamics, and health. Building on previous work, we documented 26 fish species total, five of which have not been recorded in any of these lagoons before and 33 instances where species were new to specific lagoons (*Table 2*). We monitored water quality through the season (three to five times total per lagoon) at the three lagoons in Cape Krusenstern, and once for the two lagoons in Bering Land Bridge (*Table 3, Figure 3*). We also attempted to sample water quality in the protected waters behind Cape Espenberg; however, extremely shallow water throughout (less than 0.98 feet [30 centimeters]) prevented us from collecting data.

For the lagoons that we were able to sample, water quality appeared to be affected by lagoon connectivity to the marine environment and the amount of freshwater input. Fish community composition correlated with the physical dynamics and characteristics of the lagoons. Variation in lagoon connectivity to the Chukchi Sea also affected the timing and duration for which lagoons were accessible to marine species. Catches of migratory species (e.g., sheefish [*Stenodus nelma*], humpback whitefish [*Coregonus pidschian*]) generally decreased towards the

Table 1: Fishing effort over the season using three methods. Fishing hours for beach seine is not displayed as this is an active-sampling method (each seine replicate takes approximately 15 minutes to set).

Number of Replicates (Fishing Hours)

Method	July	August	September	Total
Beach seine	9	11	18	38
Fyke net	4 (18:32)	1 (3:35)	2 (4:50)	7 (26:57)
Gill net	26 (48:03)	19 (26:58)	22 (43:45)	67 (118:46)

Table 2: New species caught in each lagoon in the 2015 field season.

Aukulak	Krusenstern	Kotlik	Kupik	Ikpek
Arctic flounder (*Liopsetta glacialis*)	Saffron cod (*Eleginus gracilis*)	Arctic flounder (*Liopsetta glacialis*)	Arctic flounder (*Liopsetta glacialis*)	Arctic flounder (*Liopsetta glacialis*)
Pacific herring (*Clupea pallasii*)	Dolly varden (*Salvelinus malma*)	Least cisco (*Coregonus sardinella*)	Fourhorn sculpin (*Myoxocephalus quadricornis*)	Fourhorn sculpin (*Myoxocephalus quadricornis*)
Longhead dab (*Limanda proboscidea*)+	Fourhorn sculpin (*Myoxocephalus quadricornis*)	Pink salmon (*Oncorhynchus gorbuscha*)	Pond smelt (*Hypomesus olidus*)+	Pacific herring (*Clupea pallasii*)
Rainbow smelt (*Osmerus mordax*)	Pink salmon (*Oncorhynchus gorbuscha*)	Rainbow smelt (*Osmerus mordax*)	Rainbow smelt (*Osmerus mordax*)	Ninespine stickleback (*Pungitius pungitius*)
Saffron cod (*Eleginus gracilis*)	Pond smelt (*Hypomesus olidus*)+	Pacific sand lance (*Ammodytes hexapterus*)+	Starry flounder (*Platichthys stellatus*)	Pond smelt (*Hypomesus olidus*)+
Starry flounder (*Platichthys stellatus*)		Sheefish (*Stenodus nelma*)		Saffron cod (*Stenodus nelma*)
		Tubenose poacher (*Pallasina barbata barbata*)+		
		Unidentified Sculpin*+		

*We are currently confirming the identification of 3 sculpin species we captured in this lagoon.

+Species that have not been recorded in any of the 5 lagoons in previous research.

end of the season as fish left the lagoons, likely in response to the potential loss of connectivity to overwintering habitat as freeze-up approached. Traditional knowledge and past research suggest that fish likely move back into river systems to overwinter. Our preliminary observations of fish diets suggest that mysids (*Mysid* spp.) and ninespine stickleback (*Pungitius pungitius*) are critical for transferring energy from secondary producers to top predators. Mysid densities in the lagoons were remarkable, and this was reflected in the diets of fish. Mysids were present in the stomachs of almost every species we sampled for diet, and many species fed on mysids almost exclusively. However, ninespine stickleback, which were also highly abundant in the lagoons, were fed on heavily by pisciviorous fish (e.g., sheefish; *Figure 4*) and birds (e.g., Arctic terns [*Sterna paradisaea*]).

We collected fish length data and otolith data to examine fish growth rates for resident and migratory species. We gathered length-weight measurements and otoliths from pond smelt (*Hypomesus olidus*), a poorly studied species, which was identified in lagoons for the first time this

Photo courtesy of M. Robards

Figure 4. Trevor Haynes and Marguerite Tibbles, University of Alaska Fairbanks, gastric lavage a sheefish (*Stenodus nelma*) at Krusenstern Lagoon to obtain a diet sample.

Table 3: Mean water quality parameters for the sample sites in each lagoon in July 2012 (Robards 2014) and 2015.

Lagoon	Year	Temperature °C	Dissolved O_2 (mg/L)	pH	Salinity (PSU)†	Turbidity (NTU)‡
Kotlik	2015	15.57	9.45	8.12	22.18	3.55
	2012	12.39	10.93	8.84	17.61	41.89
Krusenstern	2015	13.96	11.53	8.82	1.48	8.39
	2012	12.58	12.71	9.77	4.03	56.9
Aukulak	2015	17.49	-	8.1	20.04	8.32
	2012	12.29	11.6	8.87	4.03	35.9
Kupik	2015	14.99	10.93	8.55	26.6	2.65
	2012	14.74	11.22	9.12	20.65	2.83
Espenberg	2015	13.82	-	7.88	31.9	0.7
Ikpek	2015	15.77	11.04	8.37	27.8	1.64
	2012	13.67	12.79	9.2	22.53	1.37

† Salinity is measured in Practical Salinity Units, which is a unit based on the properties of seawater conductivity.

‡ Turbidity is measured in Nephelometric Turbidity Units, which is a unit based on the propensity of particles to scatter a light beam.

Table 4: Number of contaminants samples collected per species for each lagoon in Cape Krusenstern National Monument.

	Contaminant Samples Collected		
Species	Krusenstern	Aukulak	Kotlik
Bering Cisco (*Coregonus laurettae*)	5	0	0
Fourhorn Sculpin (*Myoxocephalus quadricornis*)	2	0	5
Humpback Whitefish (*Coregonus pidschian*)	6	4	0
Least Cisco (*Coregonus sardinella*)	3	2	0
Ninespine Stickleback (*Pungitius pungitius*)	5	0	0
Pacific Herring (*Clupea pallasii*)	5	0	0
Saffron Cod (*Eleginus gracilis*)	0	5	5
Sheefish (*Stenodus nelma*)	3	0	0
Starry Flounder (*Platichthys stellatus*)	5	4	5

season. Smelt were locally abundant and consequently may play an important role in the trophic dynamics in certain lagoons. To examine fish health, we are partnering with the State of Alaska to analyze contaminants in nine species, collected from several lagoons (*Table 4*). Data we collected in 2015 builds on prior traditional knowledge and research, provides ecological information vital for monitoring and managing Arctic lagoons of these parks, and will continue to inform a comprehensive understanding of the *Story of the Lagoons*—a key publication priority for the Native Village of Kotzebue, the Wildlife Conservation Society, and the National Park Service.

Conclusions

From a climate change perspective, increased coastal erosion has the potential to profoundly alter the physical, chemical, and biological dynamics of the lagoons. New dynamics of lagoon breaching will affect salinity, prey resources, and alter fish community patterns and the availability of important subsistence fish species. Coastal lagoons are also facing potential threats from increased development in the Arctic including potential oil and gas development in the northern Chukchi Sea, deep-water ports in the northern Bering Sea, and increased international shipping along the Northern Sea Route above Siberia. This project will foster a better understanding of the long-term threats to fisheries resources of coastal lagoons in the western Arctic and helps disentangle the role of climate change influences from other potential impacts. Our research activities will also illuminate how to prioritize protections across the wide number of lagoons along the northwest Alaska coast. Specifically, we are using these field efforts to: (a) provide a summary of reference conditions in the lagoons of western Arctic parks; (b) continue development of the Arctic Network monitoring program, (c) frame more in-depth assessments to place long-term monitoring in the context of seasonal variability, (d) complement new subsistence fisheries research we are conducting in collaboration with the Native Village of Kotzebue to better understand the management needs for whitefish in these coastal lagoons, and (e) begin to assess prioritization of coastal lagoons for protection from oil spills based on their ecological or subsistence contribution.

This season's work provides a valuable advance in our understanding of the aquatic ecology of Arctic coastal lagoons, which will be key in managing these habitats into the future. However, the high number of instances where we discovered species new to specific lagoons demonstrates that we are still capturing baseline fisheries information for these dynamic systems, and more research is necessary. Our plans to collect further fish data will be paired with parallel efforts we are undertaking to understand subsistence fishing harvest and lagoon physical dynamics, such as coastline change, water quality, ice formation, and water balance. We expect our sampling in the summers of 2016-2017, as well as our planned winter sampling, will not only establish the strong baselines necessary for monitoring programs to detect change, but also uncover important aspects of the aquatic ecology necessary for management of the Arctic lagoons .

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Photo courtesy of ShoreZone

The lagoon systems along the coast of Bering Land Bridge National Preserve are little-studied, but are believed to be important habitat for juvenile fishes.


GARMIN

Promoting Spill Preparedness in Western Arctic Parks with the Community Integrated Coastal Response Project

By Tahzay Jones, Peter Neitlich, and Paul Burger

On August 7, 2011, a tanker laden with fuel oil crashed into the rocky reefs of Little Diomede Island in the Bering Strait in Northwest Alaska, spilling 400,000 of gallons of IFO 180 fuel oil (a type of intermediate fuel oil) adjacent to Bering Land Bridge National Preserve. This was the scenario for a planning exercise in late 2011 sponsored by the U.S. Coast Guard (USCG) and supported by the State of Alaska Department of Environmental Conservation (ADEC) and National Oceanic and Atmospheric Administration (NOAA) Office of Restoration and Response (ORR) to understand the potential ecological impacts from a spill in the Bering Strait region of Northwest Alaska (*Aurand and Essex 2012*).

With continued sea ice extent reductions, the Bering Strait is poised to become a crucial marine transport waterway for the world. Connecting the Bering Sea to the Chukchi Sea, the Bering Strait is the only marine connection from the Pacific Ocean into Arctic waters; thus, all Pacific marine traffic to or from the Arctic Ocean must pass through the Bering Strait (*Figure 2*). Because of continuing reductions in summer Arctic sea ice extent from historical averages, the northern passage shipping routes (the Northern Sea Route above Siberia and the Northwest Passage through the Canadian Archipelago) are now in use or proposed for use by cargo ships, fuel tankers, tourism vessels, and others (*Figure 3*). Using the Northern Sea Route reduces both transit time and distance to Europe and North America from Asia compared to some Suez and Panama Canal routes. The Northwest Passage is still too ice-choked for commercial routes and is

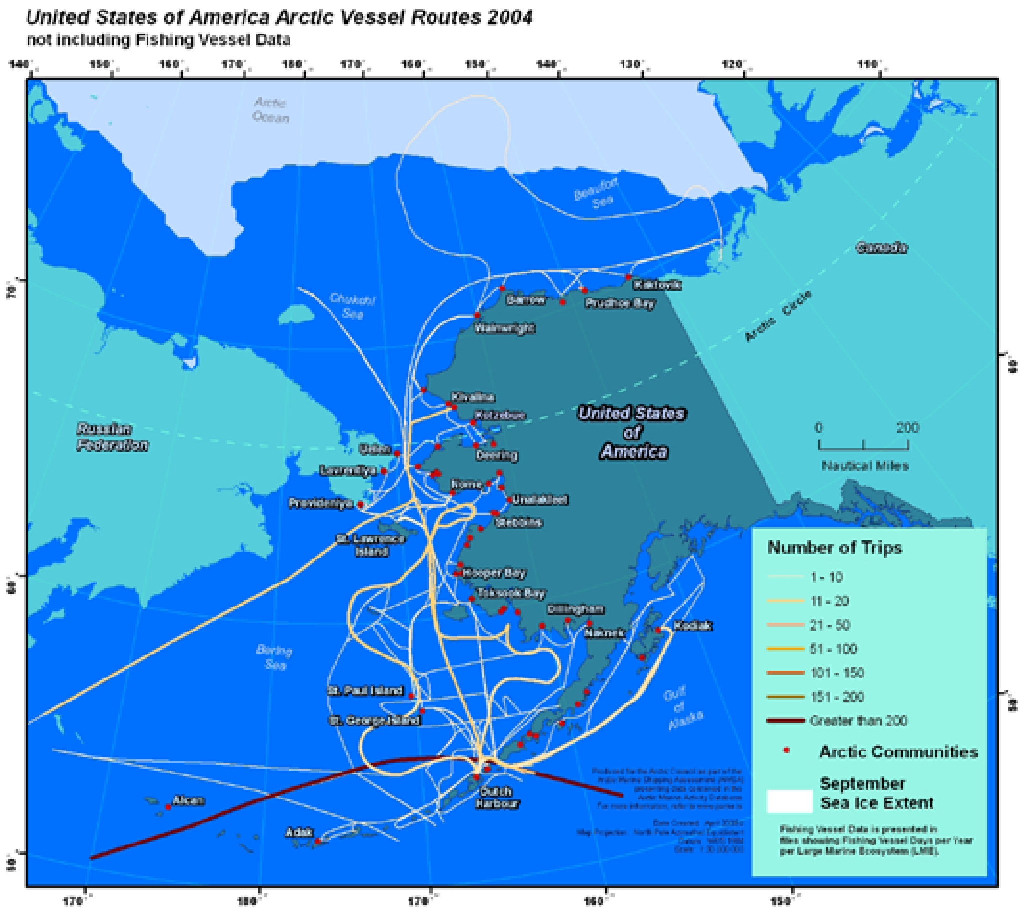
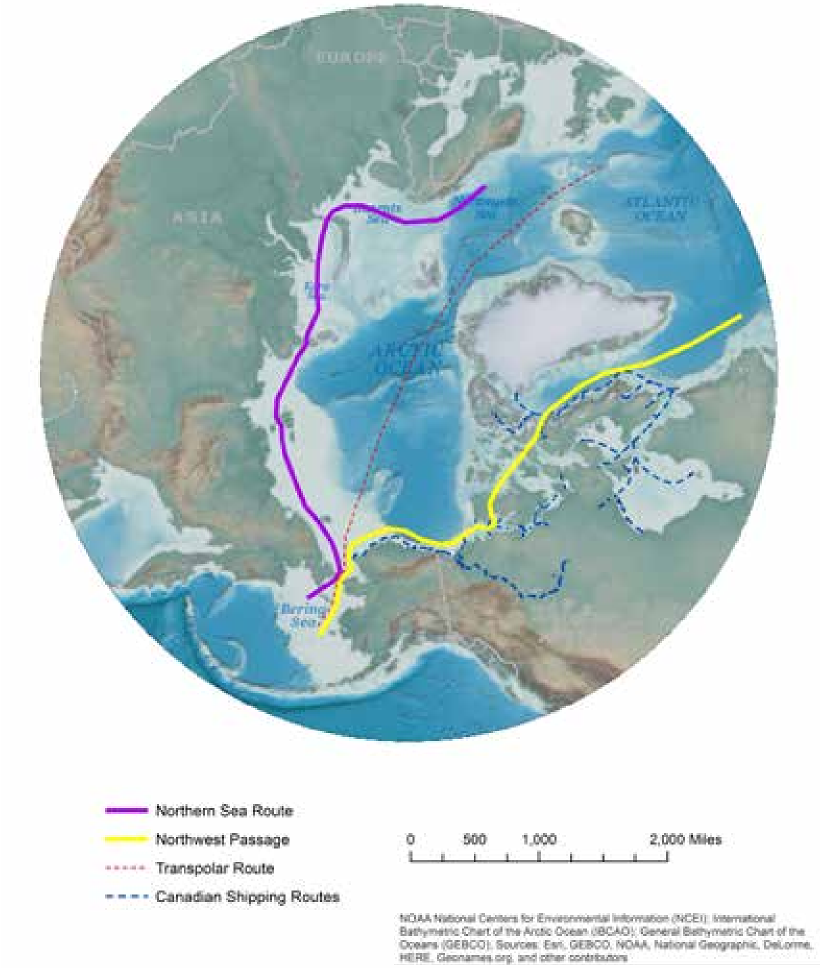


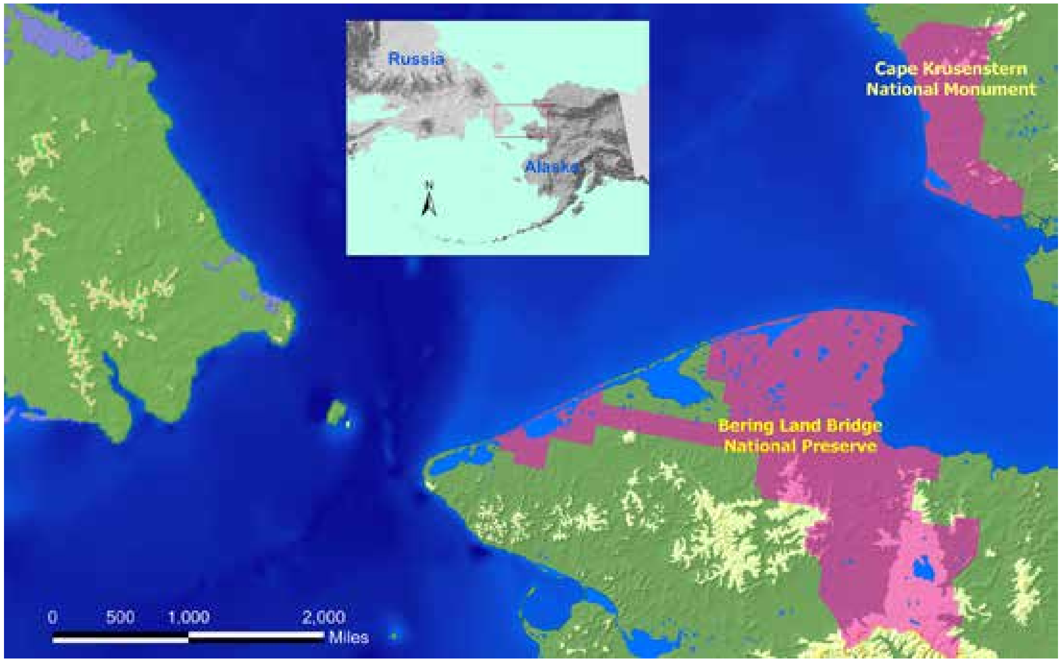
Figure 2. 2004 United States Arctic Vessel Routes from 2004. Data from Arctic Marine Shipping Assessment 2009 Report, *Arctic Council, April 2009.*

infrequently used, but shipping traffic is likely to increase as ice continues to withdraw. Daily traffic rates through the Bering Strait are projected to increase by as much as 500 percent by 2025 (*Azzara et al. 2015*). The increasing maritime importance of the Bering Strait is expected to outpace infrastructure development to protect this coastal region (*US CMTS 2013*).

Figure 1. Hydrologist Paul Burger (NPS) conducting a lagoon survey as part of the GRS testing project at Aukulak Lagoon, Cape Krusenstern National Monument.

NPS photo courtesy of Tahzay Jones





[Left] Figure 3. Northern Passage shipping routes from the Pacific Ocean, through the Bering Strait, and to the Atlantic Ocean. Data from NOAA.

[Above] Figure 4. The Alaska Northwest Arctic including the Seward Peninsula with Bering Land Bridge National Preserve and Cape Krusenstern National Monument.

Arctic shipping transits through the Bering Strait are immediately adjacent to the western Arctic parks of Bering Land Bridge National Preserve and Cape Krusenstern National Monument (*Figures 3 and 4*). Significant concerns from the increasing risk of spills and vessel incidents have made preparing for a coastal incident one of the highest priorities for park management of both parks. Reductions in sea ice leave the northern sea routes open to vessel traffic later into the fall, increasing shipping vulnerability due to several factors including late fall storms. Marine transportation is increasing along northern shipping lanes to support oil development and exploration, industrial development and expansion, and growing communities in northern Alaska (*US CMTS 2013*).

Fuel is transported by fuel barges navigating and anchoring in shallow waters near shore. The Red Dog Mine uses a port site located on Native Corporation lands surrounded by monument lands and currently barges in over 20 million gallons of diesel fuel per year along the coast, and plans to operate for 50 more years.

The western Arctic region is extremely remote with only eight coastal villages between Nome and Kivalina, an extent of over 750 coastal miles (1,207 kilometers). Comparatively, a similar coastal extent along the Gulf of Mexico coast stretches from Panama City, Florida, to Marsh Island, Louisiana, and includes New Orleans, Mobile, Gulfport, Biloxi, and Pensacola. In Alaska, the nearest Coast Guard vessel station is on Kodiak Island (1,400 miles [2,253 kilometers] away by sea) and the nearest Coast Guard aircraft station is in Anchorage (650 miles [1,046 kilometers] by air). The scenario of a Bering

NPS photos courtesy of Tahzay Jones

Figure 5. Cultural and natural resources in Bering Land Bridge National Preserve. (Top): A historic bidarka, a small hunting kayak, lies exposed on the coast. (Bottom): Sensitive salt marsh habitat of the Nugnugaluktuk River (Lane River).

Strait incident, with Coast Guard vessels in home port, is roughly akin to a shipwreck occurring in Portland, Maine, and the Coast Guard sending a plane from Raleigh, North Carolina to assess, and using a vessel from Miami, Florida, to respond.

Fortunately, the key industrial stakeholders have some response capability in place partnering with Alaska Chaddux, a response consortium that provides rapid, early response. Alaska Chaddux participated in spill response workshops in Kotzebue and Nome this year and reported that they now have response equipment staged at the Ted Stevens Anchorage International Airport that can be deployed by a C130 aircraft statewide immediately following a spill. Chaddux is a nonprofit, member-driven spill-response organization whose members include many of the fuel providers in northwest Alaska, the Red Dog Mine, and other fishing and industrial enterprises (*Alaska Chaddux 2015*). Chaddux's services are excellent to provide initial response capability, but in a larger incident, these services would need to be followed by a significant response presence coordinated by USCG and ADEC.

The communities in this area depend heavily on coastal natural resources for survival. In addition, subsistence practices are integral to the cultural identity and cultural practices of village residents. Approximately 84 percent of the subsistence harvest of the 12 coastal communities in the Bering Strait region consisted of marine mammals (predominantly ice seals, whales, and walruses) and fish (*Arctic Council 2009*). Ongoing support and protection of subsistence activities within National Park Service (NPS) jurisdiction is a part of the mandate for these parks under the Alaska National Interest Lands Conservation Act, or ANILCA (Public Law 96–487). The natural and cultural resources along this coast are unparalleled (*Figure 5*), containing some of the oldest archaeological sites in North America, as well as some of the best examples of unaltered naturally functioning coastal barrier islands and marsh habitat in North America (*Dr. John Harper/Shorezone, pers.*). It is only through preparation that the NPS can maintain and uphold the purposes for which these parks were designated.

Protection of these coastal resources is of the highest importance for the NPS and is written into the enabling legislation of both western Arctic park units. Relevant to the project at hand, Cape Krusenstern's enabling legislation includes "to protect habitat for seals and other marine mammals; to protect habitat for, and populations of, birds, and other wildlife, and fish resources; and to protect the viability of subsistence resources." Enabling legislation for Bering Land Bridge includes "to protect and interpret . . . coastal formations; . . . to protect habitat for internationally significant populations of migratory birds; to provide for archaeological and paleontological study, in cooperation with Native Alaskans, of the process of plant and animal migration, including man, between North America and the Asian Continent; to protect habitat for, and populations of, fish and wildlife including, but not limited to, marine mammals; . . . and to protect the viability of subsistence resources."

NPS resource managers lack reference condition data to adequately assess potential impacts from marine

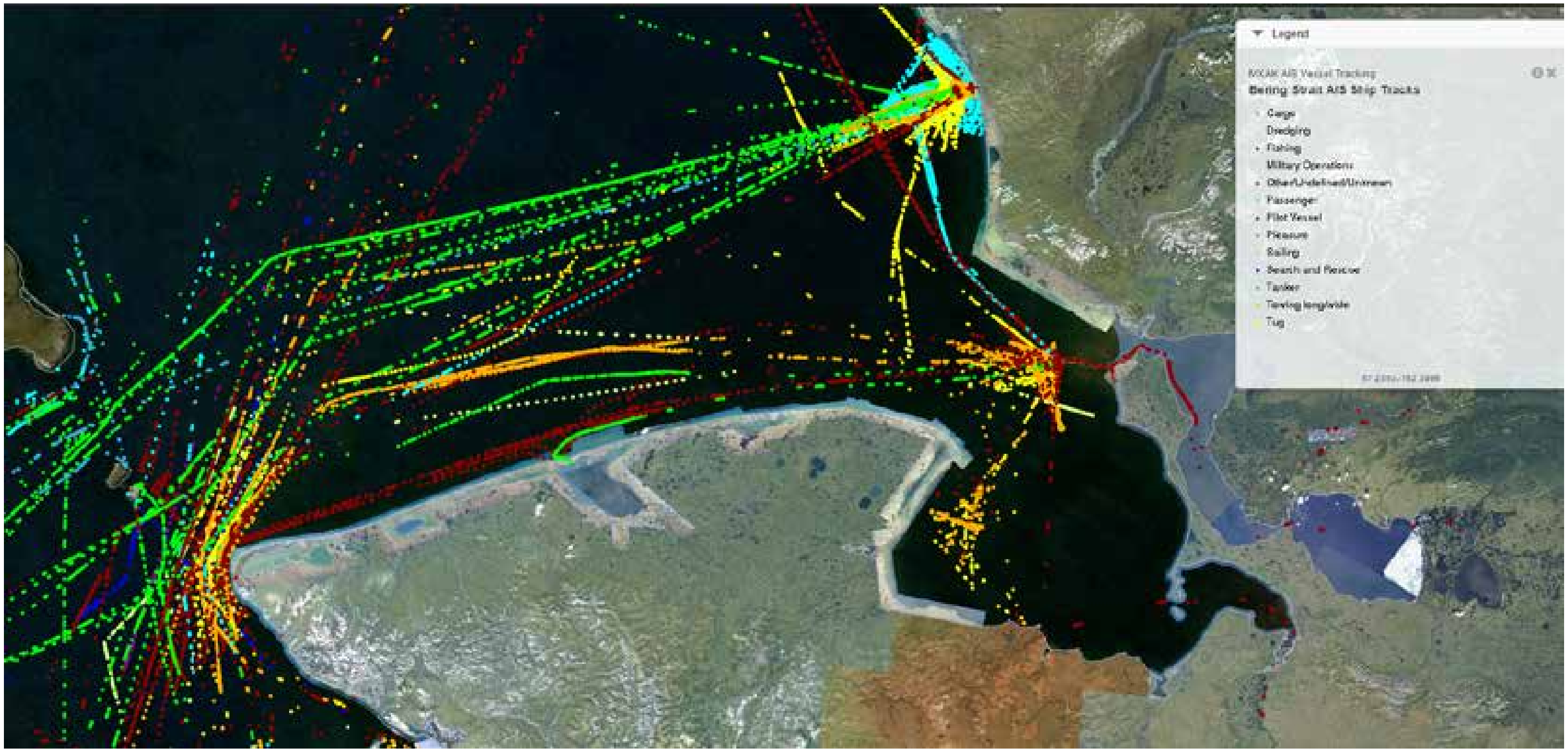


Figure 6. Automatic Identification System documentation of vessel transits through the Bering Strait in July of 2015. Data from the Marine Exchange of Alaska.

incidents. This lack of knowledge severely limits the ability of park management to fulfill resource stewardship requirements, including mandated requirements (i.e., enabling legislation, compliance with Endangered Species Act, Migratory Bird Act, Marine Mammal Protection Act, and others) within the designated national preserve and national monument.

Ongoing studies and efforts are quickly filling in many of the gaps. Both parks are actively engaged in learning from local residents and involving them in planning for protection and response. Local communities in this area are extremely interested in all activities that occur in the region, and are willing to participate in ongoing actions that support and protect their homelands. Protection of resources is in the interest of both the communities and the local federal agencies operating in the area; therefore, this is an ideal opportunity to bring all interests together for resource protection throughout the area.

Supporting the understanding of current response plans to marine incidents, and projections of marine traffic in the future, the NPS was able to obtain funding for a project focused on addressing three components of understanding resource risk and incident response preparation.

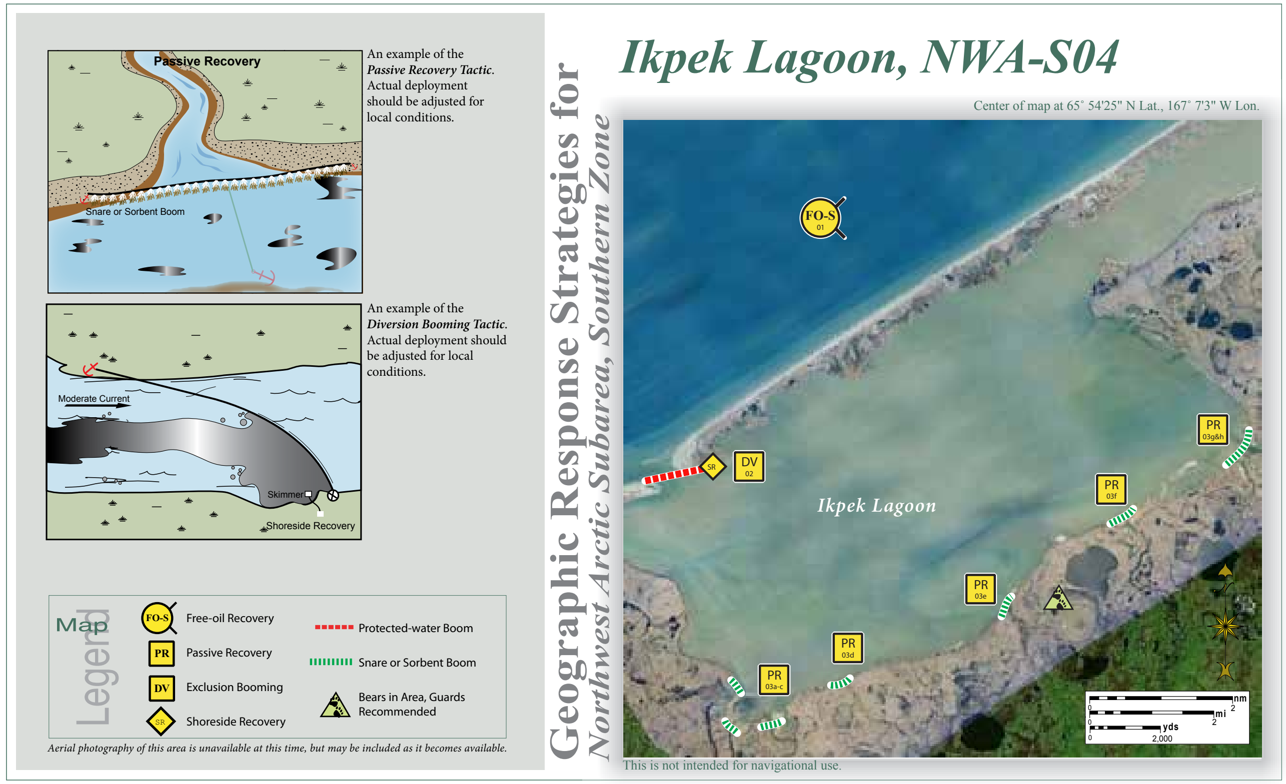
The three components of this work are field studies of shipping traffic modeling, community response training, and geographic response strategies.

Shipping Traffic Modeling —This project seeks to better understand the risks (and spill threat) associated with projected increases in shipping through the Bering Strait. We are developing a vessel traffic simulation model based on commercially available AIS (Automatic Information System) ship data for ship type, location, and timing through the U.S. Arctic, including the Bering Strait region (*Figure 6*). Once the simulation model is completed, the model will incorporate assessed projections of future traffic scenarios to understand the projected extent of shipping impact to western Arctic parks.

Shipping modeling is under development with several key components completed. The extent of the model includes ships moving through the Aleutians, the Bering Sea, and the Bering Strait. This is important because these are key transit areas to understand how shipping lanes approach the Bering Strait. With the help of the U.S. Fish and Wildlife Service and the Wildlife Conservation Society, we have identified shipping lanes based on AIS data.

NPS photo courtesy of P. Neitlich

Figure 7. Deployment of boom during a Geographic Response Strategies testing exercise, June 2015 in Kotzebue, Alaska.



June 28, 2011 DRAFT This tactic map is a working draft being used to develop a Geographic Response Strategy at this location. The tactics represented here have not been approved by the Subarea Committee and should not be considered final. If you have questions or comments please contact us by email at contact@nukaresearch.com. NUKA Research & Planning Group, LLC.

Figure 8. Ikpek Lagoon Geographic Response Strategy. Modified from Alaska Department of Environmental Conservation, developed by Nuka Research Inc. Accessible at http://dec.alaska.gov/spar/PPR/grs/nwa/NWAS04IkpekLagoon.pdf.

Community Response Training — Community response training includes an introduction to the Incident Command System specifically designed to inform and engage local communities in what would happen in the event a spill response situation in their area. The goal is to enable communities to better prepare for and support large response operations to protect local resources. A HAZWOPER class (Hazardous Waste Operations and Emergency Response) may also be held in conjunction with these trainings to enable more residents to participate in spill response planning. The sessions will also serve as a forum to encourage local boat captains to apply to participate in the USCG's "Vessel of Opportunity" program, which pays captains for logistical support in a response. The USCG has already conducted training sessions in Nome and Kotzebue focused on the ongoing development of the subarea contingency plans (*Figure 7*).

Geographic Response Strategies — ADEC and USCG oversee Geographic Response Strategy (GRS) development to protect sensitive areas in the event of a spill (*Figure 8*). These strategies detail tactical response operation (e.g., booms, skimmers) recommendations likely appropriate on a fine scale within the sensitive area. Our project assesses the physical limitations for implementation of current GRSs within Bering Land Bridge and Cape Krusenstern, and some of the physical dynamics of the system including the water velocities and bathymetry of the GRS locations and the surrounding areas (*Figure 8*). Surrounding areas are surveyed to generate documentation of physical dynamics in the event that recommendations for alterations to the Geographic Response Strategies are required. This information will be given to ADEC and USCG to use for consideration in revising the local GRSs. The ultimate management objective is to collect the data required to determine necessary updates to the GRSs to better protect the parks from a spill.

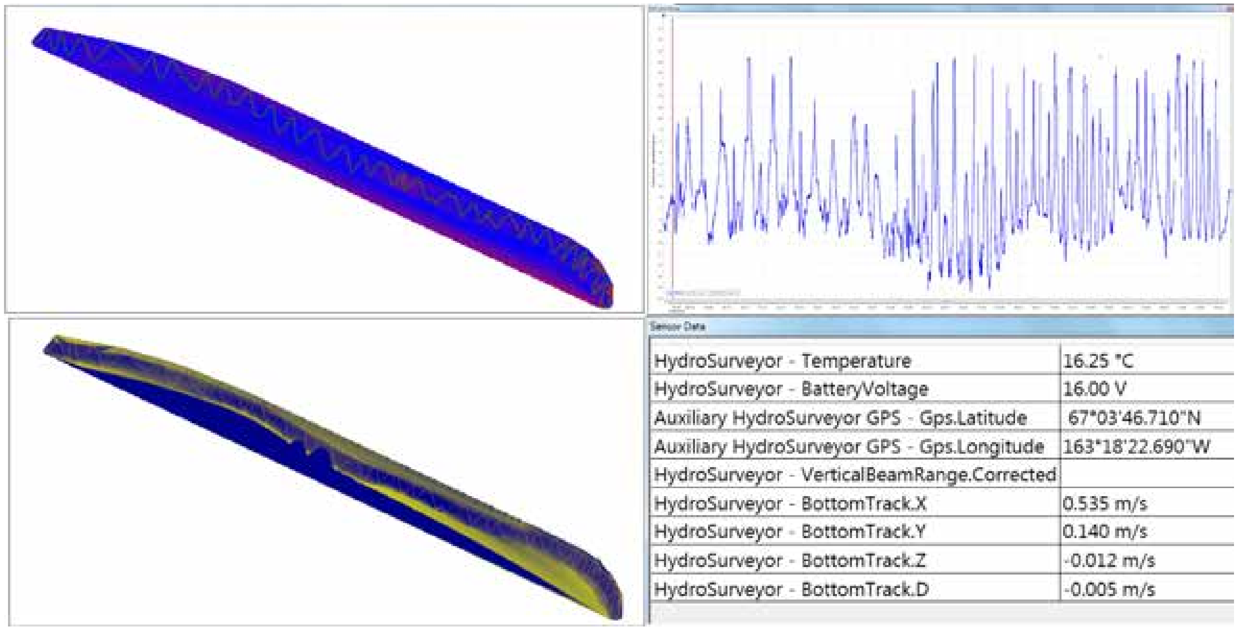


Figure 9. Hydrosurveyor output of surveys on the Tukrok River, Cape Krusenstern National Monument. Clockwise from top left; extrapolated water velocity, bottom depth, instrument sensor readings, and extrapolated bathymetry (blue is deeper, yellow is more shallow).

We conducted GRS physical limitations studies in three GRS sites in each park (Bering Land Bridge and Cape Krusenstern) in July 2015, with additional sites planned in 2016. Cape Krusenstern sites included Jade Creek, Tukrok River, and Aukulak Lagoon (*Figure 9*). An overflight in June 2015 confirmed that several of the lagoons had their outlets closed to the ocean by winter storms. This is a relatively common occurrence, but it did prevent the team from surveying at these sites. We found that Aukulak Lagoon, the only lagoon in Cape Krusenstern surveyed for flow and bathymetry, was relatively shallow (less than 1.09 yards [1 meter]) over the vast majority of the area. From a response standpoint, operations in this area would require a vessel with a very shallow draft. Additionally, access to the site in the back of the lagoon is in water that is approximately 1 foot (0.3 meters) in depth. This shallow water would require additional consideration to access in a response.

The sites in Bering Land Bridge were different in form, but still present significant physical limitations. Sites surveyed in the preserve included the Goodhope River, Kitluk River, Lane River, Kupik Lagoon, and Ikpek Lagoon (*Figure 10*). We found the offshore areas were extremely shallow and require some degree of knowledge to safely approach the coast without grounding the vessel. Low tide in the nearshore area of Goodhope River was frequently less than 1.5 feet (0.5 meters), and, while not specifically measured, there was a barrier sand bar offshore from the Espenberg River that was less than 1 foot (0.3 meters) deep (instrumentation does not accurately measure depths less than 1 foot depth). Equally challenging was the interior of Kupik Lagoon. Tactical strategies in the back of the lagoon are surrounded by extremely shallow waters of 1 to 1.5 feet (0.3 to 0.5 meters) in depth, as are the approaches to these areas. The inlet of the lagoon, while much deeper, produces high water velocities that would need to be considered in the event of boom deployment.

As the western Arctic parks continue to address concerns regarding the changes coming to the Arctic, coastal concerns remain high on the radar. With these remote areas and the limited resources available, concern

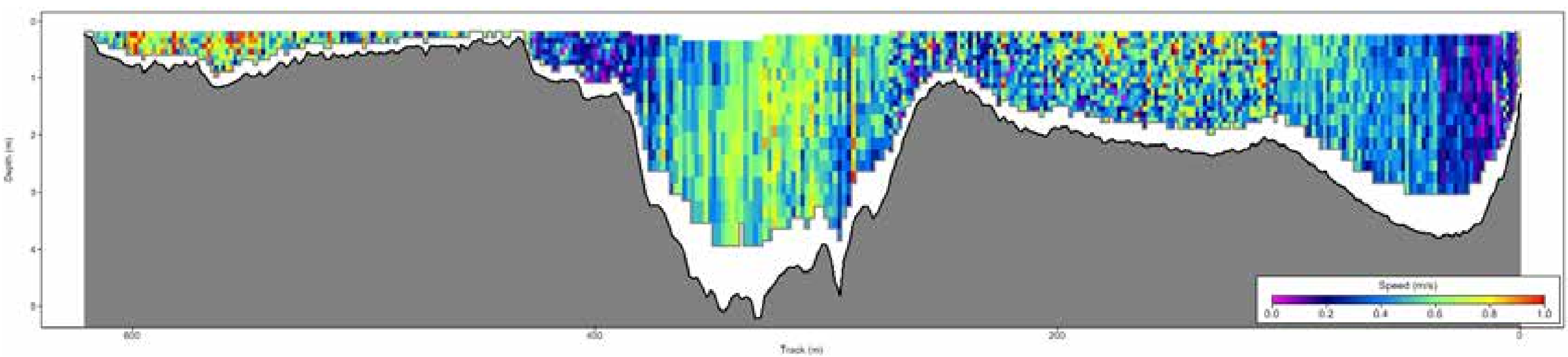


Figure 10. Riversurveyor output showing the bottom profile of the south inlet to Ikpek Lagoon, Bering Land Bridge National Preserve. Colors indicate water velocity.


NPS photo courtesy of Tahzay Jones

Figure 11. Preparing for a Geographic Response Strategies tactics survey at Lane River (Nugnugaluktuk River), Bering Land Bridge National Preserve.

about how to best prepare for a marine incident remains prominent. By updating the geographic response strategies, there is hope that precious time will be saved by avoiding the deployment of vessels into unworkable environments and by incorporating tactics designed around the physical dynamics of these systems. While the GRS of any given area is not an exact prescription for how to respond, it does provide an excellent blueprint to shape strategic thinking, and the more effective this blueprint is, the more efficient and effective our response efforts can be. Furthermore, the development of traffic simulations will aid park managers in visualizing the projections of increasing vessel traffic. Finally, spreading information about how responses are structured will strengthen the local capacity to support a response operation, ultimately protecting these unique and vulnerable places.

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КАМЧАТКА
МАЛКИНСКОЕ
МЕСТОРОЖДЕНИЕ

Connecting Youth to Coastal Resources in Western Arctic Parks

By Stacia Backensto, Dev Dharm Khalsa, and Melanie Flamme

Reaching next-generation scientists, policy makers, teachers, storytellers, and resource stewards is critical to resource conservation and an important National Park Service (NPS) mission. It is imperative that our children value resource stewardship to "preserve unimpaired the natural and cultural resources of our parks...for the enjoyment, education, and inspiration of this and future generations." To foster this sense of stewardship and scientific scholarship in youth, we provide diverse park experiences that create deep connections between the younger generation and parks. In collaboration with education partners, we hope to create new generations of citizen scientists and future stewards (*NPS 2015*).

We added youth-related initiatives to three science projects in western Arctic parks: (1) Yellow-billed Loon youth videography (2013, 2014), (2) shorebird migration at Sarichef/Shishmaref (2015); and (3) marine debris clean-up (2015). In doing so, we provided opportunities for Alaska youth to participate in NPS science, promoted cultural and social exchanges between rural and urban youth, shared their story through digital media, and removed marine debris scattered along the coasts of Bering Land Bridge National Preserve and Cape Krusenstern National Monument. We relied heavily on our committed collaborators to make these experiences happen: Wildlife Conservation Society, Alaska Geographic, Alaska Teen Media Institute, Shishmaref School, Effie Kokrine Early College Charter School, and Student Conservation Association.

NPS photo courtesy of Dev Dharm Khalsa

Figure 2. Sam Tocktoo (Shishmaref School, Shishmaref, Alaska) readies his camera to film yellow-billed loons at the Helmericks homestead on the Colville River. Sam participated in both years of video production, experienced contaminants sampling of loon eggs in Bering Land Bridge National Preserve with NPS and USFWS biologists and witnessed the North Slope Oil Fields juxtaposed with homesteading life at the Helmericks.

Yellow-billed Loon Conservation Through Videography

In 2013 and 2014, we brought together youth from rural and urban Alaska and a Student Conservation Association Media Intern to (1) experience firsthand the conservation efforts and scientific research on yellow-billed loons (*Gavia adamsii*) in northern Alaska and (2) use digital media—the hallmark of today's youth—to share their experience. The group produced two videos that are available on the AlaskaNPS YouTube channel. *Alaska's Yellow-billed Loons* highlights the long-term monitoring of the species, including conservation issues and concerns, and *Telling a Loon story: An Alaskan Youth Filming Expedition in Bering Land Bridge National Preserve* (2013, http://youtu.be/EbRmNLWNvAc) depicts the students' experiences. Both videos were shown in 2015, the first in January on the Alaska Ocean Observing System website and the second in February at the Alaska Forum on the Environment Film Festival. A third video, *Filming Alaska's Yellow-billed Loons: A Youth Experience*, about the 2014 outing, is also available on the AlaskaNPS YouTube channel.

In June 2013, 18-year-old Max Dan of Anchorage and 14-year-old Sam Tocktoo of Shishmaref travelled to Bering Land Bridge to film Yellow-billed Loons and NPS efforts to monitor the population. Unfortunately, that year's late thaw of lakes on the Seward Peninsula and poor weather in Kotzebue hampered the pair's videography efforts. Despite these limitations, the pair produced a story using the video footage they were able to collect. Spirit of Youth Radio interviewed Dan and Tocktoo about their experience in 2013. Listen to their interview at www.spiritofyouth.org.

In 2014, the young filmmakers fared better. Sam Bernitz (Alaska Teen Media Institute, Anchorage) and Sam Tocktoo (Shishmaref School, *Figure 2*) traveled to Kotzebue to connect with biologists Angela Matz (USFWS) and film contaminants sampling at study plots in Bering Land Bridge and Cape Krusenstern. While they filmed Yellow-billed Loons at these plots, they also observed scientists swab eggs in nests for DNA samples and place minnow traps. At the Bureau of Land Management bunkhouse in Kotzebue, both students were engaged in other methods of field science: sample preparation and storage. Meanwhile, Dev Dharm Khalsa (Student Conservation Association Media Intern) traveled

Figure 1. Erin Kunisch (NPS Science Communicator) holds a dirty bottle of Kamchatka spring water. Many of these bottles were found during the cleanup along the coastline of Cape Espenberg, Bering Land Bridge National Preserve.

NPS photo courtesy of Dev Dharm Khalsa

to Inigok Field Facility in the National Petroleum Reserve-Alaska to film Yellow-billed Loon aerial surveys conducted by Debbie Nigro (Bureau of Land Management).

A few weeks later, we added Andrew Kennedy (Effie Kokrine Early College Charter, Fairbanks) to the film crew and he traveled to the Helmericks Homestead, an island on the Colville River Delta where the Helmericks family has lived for more than 70 years. Up to this point, the youth film crew had struggled with acquiring close-up video of the loons. With easy access to a lake where seven Yellow-billed Loons congregated and 24 hours of daylight, the crew succeeded in getting close-ups of the birds and other species inhabiting the island. The experience was further enriched by the storytelling and sharing of ecological knowledge by Teena and Jim Helmericks.

NPS photo courtesy of Stacia Backensto

Figure 3. Ken Stenek, Shishmaref School science teacher, is an avid and skilled birder. He maintains a Facebook page, "The Birds of Shishmaref," that provides a way to receive updates and track migration of birds he observes at Sarichef Island.

The weather doesn't look so good up there. Inigok's webcam is fogged over and looks as if the camp was hit by a Category 4 hurricane. My heart sank. Trips always seemed to start out with bad weather. Three duffels, two pelican cases, two backpacks, one massive 50-pound tripod and a GoPro bag later (that's just my stuff), we're off to catch our flight with 45 minutes to spare. Soon we are soaring above the dark, ominous storm clouds cloaking Fairbanks. The clouds break as we pass over the Brooks Range to the north. Then the mountains drop away and a single, thick pancake cloud blankets the land as far as the eye can see. We dip lower and lower—the altimeter reads 1200, 1000, then 800. For minutes, I can see nothing. Then, a lake becomes visible, and another. As we dip below the last layer of fog, I see many small lakes dotting the land all around us. We have reached the North Slope.

~Dev Dharm Khalsa, field notes from Inigok, National Petroleum Reserve-Alaska.

Shishmaref Shorebirds

During the summer of 2015, we worked with Shishmaref School science teacher Ken Stenek and a small group of high-school students to document timing of spring and fall bird migration (with particular focus on shorebirds) at Sarichef Island using time-lapse cameras.

Two years earlier, during a phone conversation with Stenek about shorebirds, we realized that there was a serious and skilled birder living in Shishmaref a coastal village bordered by Bering Land Bridge (*Figure 3*). Shortly thereafter, we began collaboration with Shishmaref

NPS photo courtesy of Ken Stenek

Figure 4. Ken Stenek and his students set up time-lapse cameras to record bird migration at Sarichef Island.

School to help us document shorebird migration near the preserve. After all, collecting information about shorebirds that are migrating along the park's coastline is complicated and logistically difficult. Moreover, what better way to integrate science and digital media with education?

Time-lapse photography is a useful, non-invasive method for studying certain aspects of wildlife biology. Eight cameras were deployed across the island during late spring migration (May 25-June 10) and a portion of post-breeding migration (August to mid-September). Stenek and his students monitored and managed the cameras and storage of images (*Figure 4*). Three cameras disappeared because of either storm surges or disturbance by wildlife. Initial review of the images indicates that this technique can provide descriptive information about the migration phenology for groups of birds in discrete locations. Citizen science in this way helps us learn more about shorebird migration where three major flyways converge while providing opportunities for Shishmaref youth to participate in the project and learn about bird migration.

Documenting and Cleaning up Marine Debris: A Videographer's Reflections

By Dev Dharm Khalsa

This summer I had the opportunity to assist with an NPS sponsored marine debris cleanup initiative in Bering Land Bridge National Preserve. This cleanup was part of a larger project involving several agencies and partners all along Alaska's coastline. For me, the highlight of the trip was working with Sam Bernitz and Brian Britt—two highly skilled youth videographers from the Alaska Teen Media Institute in Anchorage, a nonprofit organization devoted to giving teens the opportunity to learn and use media skills in a professional setting. Not only did we pick up a lot of trash, but we had a lot of fun. Cooking group meals and sharing in the dishwashing and other camp duties is what really bonds people together and results in a great and unique experience on the job.

NPS photo courtesy of Dev Dharm Khalsa

Figure 5. Brian Britt holds up an abandoned fishing net taken from the coast of Bering Land Bridge National Preserve in Northwest Alaska.

Did we make a dent? There is only so much a team of just a dozen or so people with a boat and a few all-terrain vehicles can accomplish in one week. Nevertheless, I learned that it takes a lot of effort to make this kind of trip happen, and it was rewarding on a personal level. I think the best thing we did was to open the eyes of Alaska youth to what is happening to our Alaska coastline, and maybe this will encourage young people and the NPS to continue with the goal of making Alaska a better, cleaner, and more conscientious place in the future—because that's what stewardship is all about.

This week we are at Cape Espenberg, off the coast of Bering Land Bridge National Preserve. As we venture down the windblown coast, bear tracks the size of small frying pans sometimes crisscross our own steps across the sandy beach. I look up at the bluff, expecting to see a giant grizzly peering down at us, sniffing the air for our human scent. But we did not see any giant bears the entire time!

The evening light spills golden hues across the sand...the soft light and gentle breeze make it feel more like a tropical beach than Arctic Alaska. I close my eyes and can almost imagine myself in Waikiki. That is, until I look at my watch that told me it was 2 a.m. and still sunny outside.

NPS photo courtesy of Dev Dharm Khalsa

Figure 6. Evening light spills across the coast of Bering Land Bridge National Preserve.

We finish the day with a dozen or so large garbage bags full of plastic, scrap metal, water bottles, ramen packages, and various unique objects that one could only guess at how they ended up there. The majority of the items found were of Japanese or Russian origin, but there were a few local items in the mix as well."

~Dev Dharm Khalsa, Field notes from Bering Land Bridge National Preserve

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A Tale of Two Skeletons: Rearticulating Whale Bones from Glacier Bay

By Christine Gabriele and Melissa Senac

All photos provided by the National Park Service. Identification photos of Whale #68 (Snow) taken under authority of National Marine Fisheries Service scientific research permits.

When a dead whale washes up on a beach in a national park, it is definitely not cause for celebration. On the contrary, there is anguish, worry, and a flurry of activity to investigate, especially if mortality may have been caused by human factors. On the bright side, people are fascinated by whales, thus a stranding provides a rare opportunity for a close look at a wild, ocean-dwelling animal whose body can usually only be glimpsed as it surfaces for air. A dead whale is also a treasure trove of biological information, especially in the case of identified individuals whose life history is known.

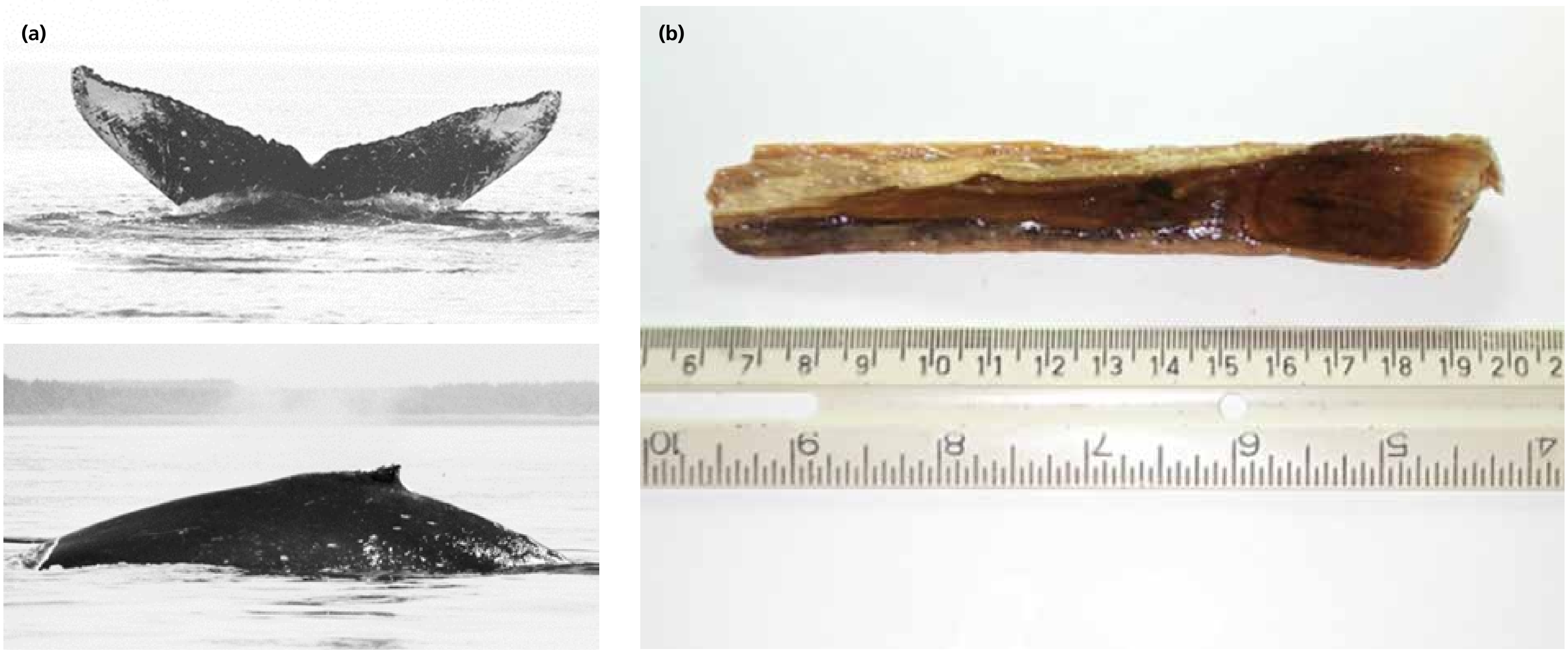
In this project, supported by a Coastal Marine Grant administered by the National Park Foundation, we learned that by preparing two spectacular and beautiful whale skeletons for display, it is possible to turn the tragic death of a magnificent animal into an inspiring educational opportunity. This is a story of two whales: an adult female humpback whale known as "Snow" whose Tlingit name is Tsalx̱aan Tayee Yáay, which translates as "Whale Beneath Mount Fairweather," and a juvenile female killer whale whose Tlingit name is Keet'k', meaning "Little Killer Whale." Read on to learn how these whales, and the people who worked with them, provide an opportunity for people to think about the lives of whales and their ocean ecosystems.

Snow

Glacier Bay National Park biologist Janet Neilson found the floating body of a humpback whale near the mouth of Glacier Bay on the way home from a whale monitoring survey on July 16, 2001. Park staff secured the carcass and towed it to shore the next day for veterinary examination to determine the cause of death. Dr. Francis Gulland of The Marine Mammal Center Sausalito, California, led a necropsy which revealed a fractured skull and blunt trauma. The trauma was pinpointed to a ship strike that was reported by an observer on July 13, 2001—three days before the body was found. Ship strikes are a real danger for whales and occur fairly often in Alaska (108 documented between 1978 and 2011) most commonly when a whale fails to get out of the path of a fast-traveling vessel.

Snow is the second-largest humpback whale skeleton on exhibit in the world, and there are only about eight complete killer whale skeleton displays in the U.S.

Photo courtesy of NPS



Natural markings on a humpback whale's (*Megaptera novaeangliae*) tail and flanks are used to identify individuals (a). The markings on the tail flukes allowed identification of this whale as catalog #68, also known as "Snow." We know that Snow was a mature female, weighed approximately 70,000 pounds, was 45.5 feet in length, and was pregnant when her body was found. Southeast Alaska's humpback whales are baleen whales that feed in rich, high-latitude waters and migrate to wintering grounds in Hawaii for mating and calving. Glacier Bay's humpback whale monitoring program maintains sighting histories of numerous whales who were first sighted as a calf and return annually to feed, socialize, and raise their young in Glacier Bay and Icy Strait within Glacier Bay National Park. Identification photos of Whale #68 (Snow) taken under authority of National Marine Fisheries Service scientific research permits.

By counting the growth layers in Snow's ear plug, we learned that she was born around 1957 (b). One growth-layer is added per year on these ear plugs and help us understand the lifespan of humpback whales. Typically, humpback whales live to be around 60 years old, but the oldest known whale was 96 years, and Snow was 45 when she died.

A charter vessel reported a dead killer whale on the beach in lower Glacier Bay on August 26, 2005. Park staff responded immediately to assess the situation and retrieve the carcass for veterinary examination. It is believed that the dead killer whale came from AF or AG pod (a resident pod), but it is not known for sure. The little killer whale, Keet'k', was a juvenile female about 18 months old and still being weaned from nursing. She weighed about 600-800 pounds and was 11.7 feet long.

It was immediately obvious that Keet'k' had ingested fishing gear, but unknown whether it was the cause of death. A necropsy completed by Dr. Pam Tuomi of the Alaska SeaLife Center revealed a fish hook had pierced the back of her throat; she died of pneumonia and blood poisoning and was also malnourished. Blubber analysis reported high levels of flame retardants, DDT, and other contaminants.

Some toothed whales, including killer whales, have learned to take fish off of commercial or sport fishermens' lines (known as depredation). Two varieties of fishing gear were found in Keet'k's body—light, trolling gear and long-line gangion were hanging from her mouth, and a J-hook and circle hook with gangion and snap were found in her stomach.

Preparing Whale Bones is a Dirty Job

Park staff, students, and local volunteers worked together to retrieve the whale skeletons and baleen. Whale bones are notoriously oily: the larger they are, the more oil they contain. The bones were subjected to many cleaning treatments, including (a) soaking in seawater (b), heating to release oil, (c) pressure-washing, (d) whitening with peroxide, and (e) burial in compost.

Killer Whale Articulation
After making a complete inventory of the bones—250 in all and weighing 96 pounds, we hired articulation expert Lee Post (shown at right) to come to Gustavus for two weeks to work with our education specialists, local residents, and students in putting the killer whale skeleton together.

Humpback Whale Articulation
The expert crew at Whales and Nails, LLC, led by Dan DenDanto (left with Chris Gabriele), shipped the entire skeleton to their workshop in Maine, where they finished cleaning the 161 humpback whale bones (weighing over 5,000 pounds), repaired damaged bones, fabricated realistic replicas to replace missing bones, and designed a support system with a graceful posture that brings the whale to life.

Installation, Dedication and Education

The articulation of Keet'k', the little killer whale, brought a small Alaska town together to work, learn, and play while creating a beautiful exhibit for people to enjoy at the Gustavus Public Library (above) starting in February 2014.

At the humpback whale exhibit grand opening in June 2014, a Hoonah Tlingit spirit ceremony gave Snow a new name: Tsalxaan Tayee Yáay—Whale Beneath Mount Fairweather.

The story of these whales and the people who worked together to bring their stories to life is even bigger than the bones themselves. Together these unique exhibits provide people with the opportunity to pause and think about the toughness and fragile beauty of a whale's life and the ocean environment in which they live.

Education specialists Melissa Senac (left) and Kelly VandenBerg (right), won the National Freeman Tilden Award in 2014 for coordinating Glacier Bay National Park's efforts to create the humpback and killer whale exhibits and accompanying educational curriculum that brought together kids and adults alike to help prepare and assemble the skeletons.

Fact	Humpback Whale	Killer Whale
Date Found	July 16, 2001	August 26, 2005
Species and Stock	North Pacific humpback whale (*Megaptera novaeangliae*)	Killer whale (*Orcinus orca*) of the Resident ecotype, from AF or AG pod
Length	45.5 feet	11.7 feet
Age Class	Pregnant sexually mature female. Vertebral growth plates were fused in all bones of the spine, indicating that this whale had reached her full length (physical maturity).	Juvenile female killer whale, age believed to be about 18 months old, based on her length and growth layers in tooth. Milk was found in the stomach, indicating that she was partially weaned (a calf may nurse for 12 months and is typically weaned at 1-2 yrs).
Estimated Body Weight	About 70,000 pounds	600 – 800 pounds (about 300-400 pounds at birth)
Skeleton Weight	3,718 pounds	70 pounds
Skull Weight Including Jaws	1,322 pounds	26 pounds
Number of Bones	161 bones	250 bones (including all growth plates)
Feeding Apparatus	over 600 baleen plates	48 teeth
Scientific Documentation	Each bone was weighed and photographed prior to articulation. The Idaho Virtualization Laboratory made a three-dimensional scan of every bone to be publicly available in their research reference collection.	The skeleton was weighed and each bone photographed prior to articulation.
Cause of Death	Necropsy led by Dr. Frances Gulland, DVM of The Marine Mammal Center revealed a fractured skull and blunt trauma caused by a ship strike that had been reported by an observer on July 13, 2001.	Necropsy led by Dr.Pam Tuomi, DVM of the Alaska SeaLife Center revealed a fish hook had pierced the back of her throat (oropharynx). She died of pneumonia and septicemia (blood poisoning) with underlying malnutrition.
Biological Findings	Counts of growth-layers in her earplug revealed that Snow was born around 1957, confirming that one growth-layer is added per year, helping to resolve a long-standing controversy about the lifespan of humpback whales (now known to be typically about 60 years, with the oldest known to be 96 years).	Blubber analysis reported high levels of flame retardants (PBDE's), DDT, and other contaminants.
Marine Conservation Issue	Ship strikes and how to avoid them are important global issues.	Some toothed-whale species have learned to take fish off of commercial or sport fishermens' lines (known as depredation) to make a living. Two varieties of fishing gear were found in this whale's body: light trolling gear and long-line gangion were hanging from her mouth, and a J-hook and a circle hook with gangion and snap was found in her stomach.
Skeleton Articulation Expert	Dan DenDanto, Whales & Nails LLC, Seal Cove, Maine	Lee Post, The Boneman, Homer, Alaska
Exhibit Grand Opening Date	June 25, 2014	February 25, 2014
Hidden Facts About the Display	The skull was greatly damaged by the ship strike and several bones were missing when NPS collected the skeleton 15 months after the whale was towed ashore. Thus, several bones were repaired by Whales and Nails, and three cervical as well as two caudal vertebrae were borrowed from other humpback whales that stranded in Southeast Alaska.	The 48 teeth on display are cast replicas of the real teeth, which have been preserved for educational use.

Photo courtesy of Jim Pfeiffenberger

There are two main social groups or ecotypes of killer whales, residents and transients. Transient pods are generally made up of a female and two or three of her offspring and hunt marine mammals for food. Resident pods are made up of stable family groups including both sexes and primarily eat salmon and other fish.

Photo courtesy of Jim Pfeiffenberger

Individual humpback whales can be identified by markings on their tail flukes.

Whales, Seals, and Vessels: Investigating the Acoustic Ecology of Underwater Glacier Bay

By Christine Gabriele, Michelle Fournet, and Leanna Matthews

It takes two to speak the truth—one to speak and another to hear.

-- Henry David Thoreau

Scientists in Glacier Bay National Park are studying marine mammals with their eyes closed. In 2015, with funding from a National Park Foundation Coastal Marine Grant, park scientists began an exciting new collaboration with researchers from Oregon State University and Syracuse University to document how harbor seals and humpback whales use sound in daily life, and to evaluate the extent to which man-made noise hinders successful communication (*Figure 2*). Building on the legacy of long-term studies of whales, seals, and underwater sound in Glacier Bay, this study will help scientists determine whether whales and seals alter their vocal behavior in response to vessel noise.

The Glacier Bay/Icy Strait area is the summer feeding range for nearly 250 humpback whales (*Megaptera novaeangliae*) and home to over 5,000 harbor seals (*Phoca vitulina richardsii*; Womble et al. 2010, Allen and Angliss 2015, Neilson et al. 2015; *Figure 3*). Because these acoustically adept mammals share their habitat with other sound sources such as vessels, wind, rain, melting ice, and calving glaciers, it stands to reason that understanding some of the basic truths about how marine mammals use sound requires researchers to *listen*. Passive listening with automated audio recording devices is a non-invasive way to track vocal animals and better understand their relationships to other sounds in their environment (also known as acoustic ecology).

Photo courtesy of NPS

Figure 2. The research team at Strawberry Island observed and enjoyed daily "drive-bys" of humpback whales feeding very close to shore. For two months in summer 2015, the team made visual observations of whale behavior that will be paired with underwater sound recordings to learn more about how humpback whales and harbor seals use underwater sound in their daily life.

In a nutshell, this study seeks to clarify the physical description and context of seal and whale vocal behavior. Understanding how marine mammals interact vocally with others of their species brings us closer to assessing the biological implications of human impacts on the underwater sound environment.

Photo courtesy of Janet Neilson

Figure 3. Harbor seal

Biological Context

Humpback whale and harbor seal vocalizations are well-adapted for the marine environment, but also overlap considerably with man-made sounds, including vessel noise (*Richardson et al. 1995; Fournet et al. 2015*).

Harbor seals rely heavily on acoustic communication for reproductive success, including passive listening to detect predators (*Deecke et al. 2002*), as well as vocalizing during the mating season. Harbor seals, like most seal species, mate underwater (*Van Parijs et al. 1997*). During the breeding season, male seals establish underwater territories and use acoustic signals, known as "roars," to defend these territories from intruder males and possibly to attract females (*Hanggi and Schusterman 1994; Hayes et al. 2004*). Harbor seals are found in a variety of habitats, including glacial ice floes, sand bars, and rocky beaches

Figure 1. Aerial survey photo of harbor seals hauled out at the Spider Island Reef Complex in the study area. Male harbor seals in the water offshore defend acoustic territories during the breeding season.

NPS photo courtesy of Jamie Womble

Study Questions

- How loud are harbor seal roars and humpback whale calls?
- How often do individual animals produce these calls?
- In what behavioral context are calls produced?
- Do other animals call or otherwise react to an individual's calls?
- Does loudness, calling rate, or behavior change in the presence of vessel noise?

(*Bigg 1981*). They return to the same breeding grounds every year to mate and give birth to pups (*Boness et al. 2006*). About 70 percent of the harbor seals in Glacier Bay occur at the primary glacial ice site in Johns Hopkins Inlet. For our study, we selected a site near the Spider Island Reef complex, where pupping occurs in late spring and over 700 seals haul out for molting in late summer (*Womble et al. 2015; Allen and Angliss 2015*).

Humpback whales are probably best known for the males' long, complex songs produced mainly in sub-tropical breeding grounds (*Payne and McVay 1971*), but also in Alaska (*Gabriele and Frankel 2002*). They produce a wide variety of non-song calls in Southeast Alaska (*D'Vincent et al. 1985; Wild and Gabriele 2014; Fournet et al. 2015*) for which the exact functions are unknown. Humpback whales are long-lived social baleen whales that maintain complex multi-year social bonds (*Baker 1985; Ramp et al. 2010; Hanser 2009; Sharpe et al. 2013; Pierszalowski et al., in review*), thus in general their calls likely play a critical role in maintaining these bonds over space and time. Some of the calls produced in Glacier Bay, including a commonly heard "whup" call, may act as a contact call (*Wild and Gabriele 2014*), while others may be linked to foraging behaviors (*D'Vincent et al. 1985*) or facilitate social interactions (*Fournet 2014*).

The story of underwater sound monitoring in the park centers on a long-standing concern that the presence of vessel-generated noise has the potential to disturb marine mammals and other wildlife. In Glacier Bay, the study of acoustic ecology dates back to landmark projects in the 1980s that quantified the underwater soundscape and demonstrated that humpback whales in Glacier Bay change their behavior in the presence of vessels (*Malme et al. 1982; Baker 1985*). Park scientists began regular monitoring of ambient underwater noise in 2000. Vessel noise contributes dramatically to the park's underwater soundscape (*Kipple and Gabriele 2004; McKenna et al. in review; and Gabriele et al. 2015*) and reduces the communication space available for whales and seals (*Clark et al. 2009; Gabriele et al. 2010, 2015*). However, several important questions remain about acoustic behavior in harbor seals and humpback whales. Which brings us back to listening. . .

Field Season 2015

In late May 2015, we started listening. The research team chartered a vessel to deploy the hydrophone array that lies at the heart of this project. The array consists of four underwater microphones (hydrophones) with electronics to record audio continuously in the waters of Beardslee Entrance in Lower Glacier Bay. This site was chosen because it is near the large harbor seal haul-out at Spider Island Reef and is a place where humpback whales are known to feed in spring through fall. We chose each hydrophone's location carefully, crossed our fingers for luck, and left them to do their work until October. In mid-June, the visual observers arrived and set up camp overlooking the hydrophone array.

From their tents on Strawberry Island, the five-person field team could hear the sniffs of harbor seals in the intertidal, and feel the vibrating boom of humpback

Figure 4. For the past 30 years, the Glacier Bay National Park and Preserve humpback whale monitoring program has maintained an extensive life history database based on identifying individuals by their natural markings. If you look closely, you can see that this is the same whale as in Figure 2. Whale #1302 is a mature female who was first sighted as a calf in 1992, making her 23 years old in 2015. Photos taken under National Marine Fisheries permits.

Figure 5. Observation tower and beach theodolite.

whale breaches. From mid-June through mid-August, the team lived on the island collecting behavioral data from a peninsula that overlooked a seal haul-out and humpback whale foraging ground (*Figure 4*). Poised in an elevated hunter's blind and outfitted with binoculars and a surveyor's transit (*Figure 5*), the team conducted focal follows of humpback whales. They selected an individual whale and documented its every action, marking its location as it surfaced, dove, and moved through the survey area. Simultaneously, another pair of researchers on the beach with similar equipment marked the location of every visible whale and vessel, as well as photographing any seal or whale that came close enough to be identified based on individual markings. This combination of methods allowed us to document the fine-scale behavior of individual focal animals *in the context* of the other animals and vessels in the area, without becoming part of the scene. Identification photographs allow behavior to be interpreted in the context of age, sex, and reproductive status, using life history data from the Glacier Bay humpback whale monitoring program (*Neilson et al. 2015*).

Field Results 2015

At the time of this writing, the hydrophones are on land, but still wet: the research team successfully (and gratefully) retrieved all four recording units in late October 2015 (*Figure 6*). The unspoken truth is, when you put equipment in the ocean, there's always a possibility that you won't get it back! The electronics worked perfectly, and each of the four recording units has about 3,800 hours of audio data on it. Now the hard work begins. The recordings will be examined over the winter for seal and whale vocalizations as well as vessel noise and environmental noise.

With audio from the four hydrophones, we can use triangulation to locate the underwater positions of vocalizing whales and seals. By stringing a series of acoustic locations together, calling whales and seals can be "tracked" underwater; their calls can be classified and described, and calling rates can be calculated. Once the location has been determined of the calling animal, we can estimate the loudness of the call based on the known distance from the hydrophone and the physics of how sound travels underwater. Quantifying the variability in how loud the calls are gives an indication of how detectable these calls will be (to other whales or seals) when the underwater sound environment gets noisy. Understanding how often animals are calling provides clues into why the calls are produced and how these animals may adapt to noise from wind, rain, vessels, or any other sounds in their acoustic environment. Vessel noise was audible in air and underwater from the observation site, and will be quantified with audio data from the hydrophone array.

Over the eight-week field season, the Strawberry Island team conducted upward of 400 focal follows and over 500 scan point surveys. On average, there were six humpback whales sighted during each scan point survey, but on some days researchers documented as many as 24 whales spending time in the vicinity of the Beardslee Island

Figure 6. The authors (Gabriele, Fournet, and Matthews, left to right) aboard the *M/V Lite Weight*, celebrating the successful retrieval of the hydrophone audio recorders, October 29, 2015.

complex. Individual whales linger to feed in a given area for days or weeks at a time, so we don't know exactly how many different individuals were observed. Researchers are currently processing close to a thousand photographs taken of whales and seals in an effort to identify animals that may have known life histories.

Harbor seals were visually detected on every sampling day, and the observers grew very familiar with one "resident" harbor seal that was seen almost daily near their observation site. A number of seals are found in the water near the Spider Island Reef Complex, the largest terrestrial site for harbor seals in Glacier Bay. Results from the park's annual aerial survey in 2015 will provide an estimate of the number of harbor seals on shore during pupping (June) and molting (late July and August; *Womble et al. 2010, 2015*) to give context to our findings.

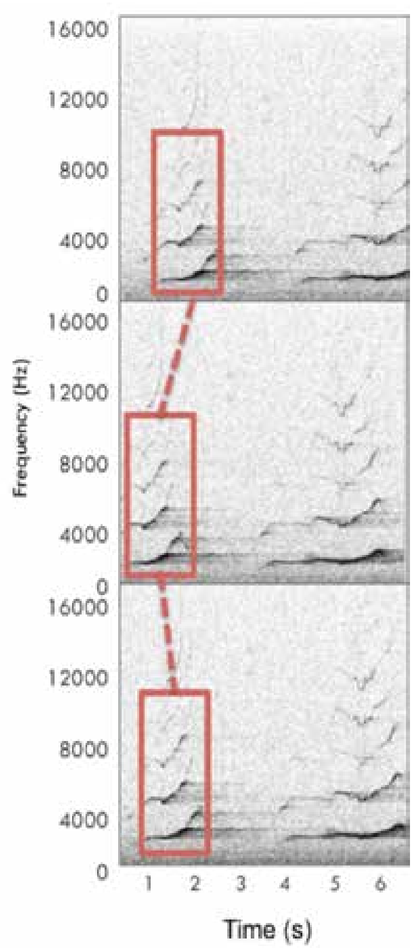


Figure 7. Researchers measure the exact time a sound reached each hydrophone. The sound will arrive at the closest hydrophone first. By measuring the difference in arrival times researchers can calculate the location of the sound source.

Insights and Discoveries

The best kind of research generates at least one new question for every answer it provides—such is the nature of human curiosity. A few tantalizing observations have already surfaced in this study. From previous ambient noise studies in Glacier Bay, we expected that we'd hear seals often, so it came as no surprise that harbor seal roars were detected every time the team listened from a kayak with a portable hydrophone (*Figure 7*). In fact, it was sometimes difficult for the listener to hear anything else with a seal roaring nearby, demonstrating that man-made noise is not the only factor that animals must accommodate in acoustic ecology. It was an unexpected and pleasant surprise to hear harbor seal roars as late as mid-August, since we presumed that seals would cease roaring at the end of the breeding season, presumably in July. This previously undescribed prolonged period of roaring may provide insight into the length of the breeding period of Glacier Bay harbor seals or suggest that roaring serves other purposes along with protecting breeding territories.

> Research is above all the great admission of not knowing. In Glacier Bay this not knowing is palpable and comfortable. It gives our team the chance not just to seek answers, but to seek questions.
> *~Michelle Fournet 2015 field notebook*

More discoveries will undoubtedly arise from such a rich visual and acoustic dataset. In addition, having a field team living so closely with their study species has already led to novel insights that are beyond the scope of the initial study design. For example, humpback whales in Glacier Bay are known to maximize foraging by taking advantage of tidal current patterns at headlands (*Chenoweth et al. 2011*). Anecdotally, researchers observed humpback whales in tidal headlands that appeared to be disturbing bottom substrate in shallow water (about 19.6 feet [6 meters]) and lunging toward the surface after small prey. If these disturbances are audible on the hydrophones (the sound of grinding gravel), our research may confirm that humpback whales are actively foraging in the benthos of the high intertidal zone. This hypothesis would not have been formulated if it were not for the ability to observe humpback whales closely and continuously in their environment without disturbing them (*Figure 8*).

Planning for 2016 and Beyond

In 2016, the hydrophones have been redeployed for several more months of acoustic data collection. The researchers are taking what they learned from acoustic tracking analysis and fine tuning the behavioral observation protocols. Data from this study will be a major component in the doctoral dissertations of Matthews and Fournet, and aspects of the study will be published in scientific journals and presented at scientific conferences. We'll be producing a short video to share with students and the general public. We will continue to update our

Photo courtesy of NPS

Figure 8. One of the four cylindrical autonomous underwater hydrophones deployed in May 2015, secured to the aluminum mooring with heavy concrete and metal footings. Using an acoustic release (yellow item near orange buoy), the entire mooring is retrieved at the end of the project, leaving nothing on the seafloor.

new *Currents: Ocean Science Hub* blog to share a variety of Glacier Bay ocean research projects with the maritime community. We'll expand upon these educational efforts in 2016.

In the end, we hope the most important outcomes will extend to the seals and whales themselves. They may not have noticed that we were there and were eavesdropping, but nevertheless, they stand to benefit from an improved understanding of how marine mammals interact with sounds in their underwater world.

Acknowledgements

Big thanks to the 2015 student field crew from Oregon State University (David Culp, Tom Plank, Lucas Williams, Kate Popisil). Installing and retrieving hydrophones was made easy by the *M/V Lite Weight* (Paul Weltzin, John Martin, and of course, Betty the dog). Huge thanks to the engineers at the National Oceanic and Atmospheric Administration-Pacific Marine Environmental Lab who built and outfitted the hydrophones, and trained our team, as well as all of the oceanographers and acousticians who we consulted on mooring design and deployment techniques. We also couldn't have done it without Glacier Bay National Park maintenance staff that specializes in fixing equipment and moving heavy things (Dustin Hazen, Jonathon Bier, Bruce McDonough, and others). Craig Murdoch was our fuel cell guru and Wes Bacon-Schulte helped us troubleshoot our surveyor's instrument. Todd Bruno of the *M/V Capelin* transported our team to and from Strawberry Island throughout the summer, and delivered a few much needed icebergs. Kayak training by Corey and Linsey Dusin helped keep us safe on the water and bear safety consultations by Christopher Behnke and Tania Lewis helped us keep a bear-free camp and sleep well at night. Lastly, thank you to Cheryl Cook and Kathy Hocker for the use of their cabin when the team needed a roof to sleep under. Funding for this study was provided by the Coastal Marine Grant administered by the National Park Foundation.

Photo courtesy of Michelle Fournet

Whale offshore of observation site.

Photo courtesy of Michelle Fournet

Listening from a kayak near Strawberry Island.

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Ocean Acidification in Glacier Bay

By Stacey Reisdorph

Since the start of the Industrial Revolution in the late eighteenth century, mankind has emitted a large volume of carbon dioxide (CO_2) into the atmosphere, primarily from the burning of fossil fuel (*Sabine et al. 2004*). This CO_2 is ultimately partitioned among the atmosphere, terrestrial, and marine ecosystems. When the marine ecosystem takes up CO_2 from the atmosphere, it causes the pH of the water to decrease, making it more acidic over time, and can lead to negative effects on some organisms within these waters. Approximately 46 percent of anthropogenic, or man-made, CO_2 remains in the atmosphere, while about 28 percent is taken up by the terrestrial biosphere, and the remaining 26 percent is absorbed by the ocean (*Sabine et al. 2004*). This increase in oceanic CO_2 has led to an increase in dissolved inorganic carbon (DIC) concentrations and a reduction in global ocean pH of approximately 0.1 units (*Feely et al. 2004*). However, the uptake of atmospheric CO_2 is not the only climate-induced phenomenon that can lead to a reduction of marine pH. The addition of freshwater, such as glacial melt, can also impact seawater chemistry and contribute to decreased pH.

Although Alaska's coasts contain more than 200 major fjords, few have been studied in detail (Etherington et al. 2007) and several receive large volumes of glacial runoff. Glacier Bay, within Glacier Bay National Park and Preserve, lies along the eastern coast of the Gulf of Alaska in Southeast Alaska (*Figure 2*) and is an example of a pristine tidewater glacial fjord ecosystem. It was once occupied by one large icefield, aptly named the Glacier Bay Icefield, which has experienced rapid deglaciation since the end of the Little Ice Age around AD1770 (*Johnson et al. 2013*). As a result of this deglaciation, Glacier Bay is now surrounded by a number of tidewater and alpine glaciers. The bay has experienced one of the most rapid deglaciations on record (*Pfeffer et al. 2000*), increasing the amount of freshwater runoff into the marine ecosystem and affecting the chemistry, biology, and flow dynamics of the bay (*Hill et al. 2009*).

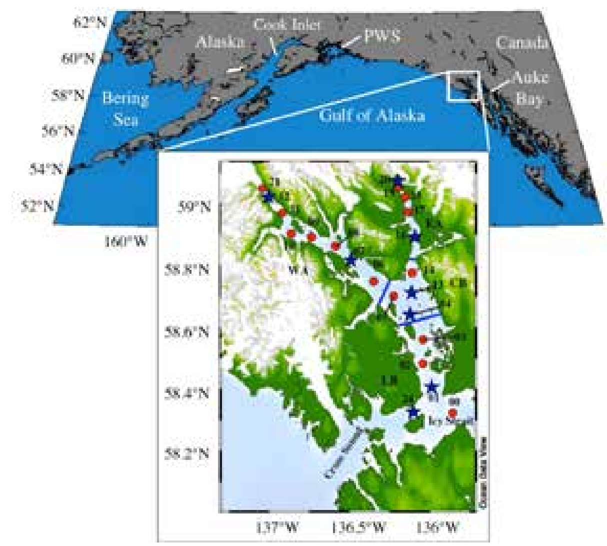

Figure 2. Glacier Bay, within Glacier Bay National Park and Preserve.

Freshwater, including glacial melt, has lower alkalinity than oceanic water. Alkalinity is a measure of the capacity of seawater to neutralize or "buffer" acids. When freshwater enters seawater, it dilutes the alkalinity in the seawater, making it less able to buffer against decreases in pH. When glacial melt enters the marine waters of Glacier Bay, it dilutes alkalinity, allowing the uptake of atmospheric CO_2 by the surface waters to more easily cause a decrease in pH, contributing to ocean acidification. The Glacier Bay marine ecosystem, along with similar fjord systems around the Gulf of Alaska, is highly influenced by freshwater runoff. Therefore, alkalinity must be taken into account when analyzing Glacier Bay's susceptibility to ocean acidification.

What is Ocean Acidification?

Ocean acidification (OA) refers to the increase in ocean acidity (decrease in ocean pH), typically caused by the dissolution of atmospheric CO_2 gas into seawater. When CO_2 is absorbed by seawater, chemical reactions occur that reduce seawater pH and calcium carbonate ($CaCO_3$) ion concentration. These chemical reactions are termed ocean acidification. Because the pH scale is logarithmic, the roughly 0.1 pH unit decrease in ocean water during the Industrial Revolution translates into a roughly 30 percent increase in acidity (*Frisch et al. 2015*).

Other factors can exacerbate the severity and duration of OA events. Freshwater inputs, such as glacial melt, are low in alkalinity. These additions "dilute" seawater, reducing its capacity to buffer against the reductions in pH

Figure 1. The sun starts to set as scientists wrap up a day of sampling in Glacier Bay.

Photo courtesy of Stacey Reisdorph

that are driven by the uptake of atmospheric CO_2. In this way, ocean waters receiving lots of glacial melt are more susceptible than usual to OA.

The severity of OA is assessed using saturation states. Saturations states act as a numerical index to describe the water chemistry in terms of the current degree of OA. They are calculated with respect to calcium carbonate minerals, such as aragonite, which are used by many marine organisms to build shells and skeletons. When the saturation state is greater than 1.0, waters are considered supersaturated with respect to calcium carbonate minerals. This means there is an abundant supply of these minerals available for use by calcifying organisms such as pteropods (tiny planktonic snails), clams, and crabs. However, OA can cause parts of the ocean to become undersaturated with respect to these minerals (saturation states less than 1.0), which likely impacts the ability of some organisms to produce and maintain their shells. This may lead to profound changes in marine ecosystems. Conversely, when organisms undergo photosynthesis, or primary production, they take up CO_2, the major constituent of DIC, from surface waters and can lead to an increase in surface water saturation states, mitigating some of the effects of reduced alkalinity.

Seasonal Ocean Acidification in Glacier Bay

We found that Glacier Bay waters experienced seasonal and regional ocean acidification events (i.e., times when saturations states were less than 1.0). During the spring, summer, and early fall seasons, primary production is at elevated levels, consuming DIC in the surface waters. This reduces DIC concentrations and results in increased saturations states. However, glacial melt is also higher during those same seasons. When glacial melt enters the surface waters it dilutes alkalinity and can lead to reduced saturation states.

Low-saturation states observed in Glacier Bay were well correlated with the timing of maximum glacial discharge events and were most prominent within the two arms

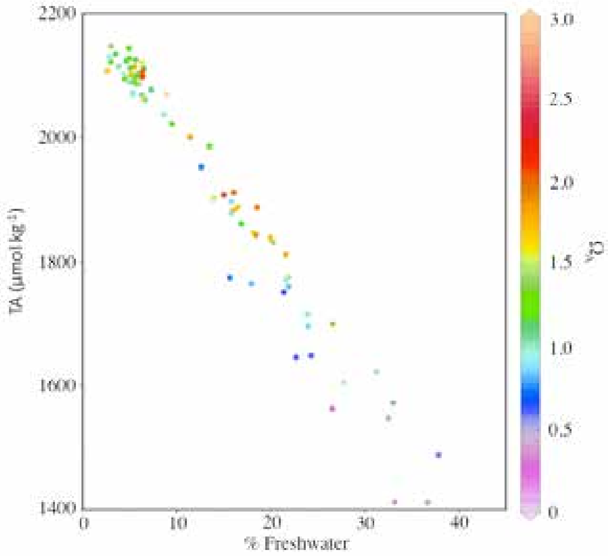

Figure 3. Surface samples collected between July 2011 and July 2012. The cooler colors (purple and blue) represent lower alkalinity saturation states, found in the regions with the most freshwater input, and the warmer colors (orange and red) represent higher alkalinity saturation states.

where glacial influence was greatest. *Figure 3* shows all surface samples collected between July 2011 and July 2012. It illustrates that the regions of the bay receiving the most freshwater input (the upper arms) also had the lowest alkalinity concentrations and saturation states. Saturation states reached a minimum of 0.40 at the surface during the summer of 2011. Saturation states increased from the upper to the lower bay as waters became less influenced by glacial runoff.

During the fall, all Glacier Bay surface waters had saturation states below 1.0. This may have been due to increased winds during fall that mixed DIC from depth back into the upper water column, while simultaneously enhancing atmospheric CO_2 uptake by the surface waters. The bay remained relatively well mixed throughout the

NPS photo courtesy of Faye Schaller

Figure 4. Stacey Reisdorph (University of Alaska-Fairbanks) prepares sampling equipment for deployment in the nearshore environment.

winter, with elevated concentrations of DIC and alkalinity as a result of low primary production, reduced glacial melt, and greater wind mixing.

Saturation states returned to supersaturated conditions (i.e., saturation states greater than 1.0) in the spring of 2012. During spring, increased primary production caused a reduction in DIC in the surface waters, initiating an increase in saturation states before glacial runoff peaked. Conditions in the upper arms became undersaturated once again during the summer, with increasing glacial runoff overwhelming any drawdown of DIC from primary production.

Impacts of Anthropogenic CO_2

The uptake of anthropogenic CO_2 has already lowered the average ocean pH by approximately 0.1 units, with a continued reduction of 0.1 to 0.5 units expected over the next 100 years (*Feely et al. 2004*). While most OA research to date has been conducted in the open ocean, few studies have focused on near-shore estuarine ecosystems (*Figure 4*). Unique coastal processes reduce salinity and alkalinity concentrations and dampen the buffering capacity of these waters, making them more susceptible to changes in pH than the open ocean (*Miller et al. 2009*). It is important to understand, however, that these waters also naturally have seasonally dynamic pH values that may not all directly reflect current anthropogenic influences.

Atmospheric CO_2 is made up of emissions from natural as well as anthropogenic sources, such as the burning of fossil fuels. While we cannot directly quantify the amount of anthropogenic CO_2 versus naturally occurring CO_2 in Glacier Bay, its effects on dissolved carbon concentrations in the bay can be estimated. To estimate these anthropogenic effects on OA in Glacier Bay, about 45 moles kg−1 were removed from the measured DIC values to represent pre-industrial conditions, while all remaining variables remained as observed (*Mathis and Questel 2013*). Saturation states were recalculated for each season using the seasonal pre-industrial DIC values. Although all saturation states increased with the removal of the anthropogenic CO_2 signal, the effect of anthropogenic CO_2 was most notable during the seasons with the lowest surface saturation states (i.e., summer and fall). During the summer seasons, the only samples that remained undersaturated after removing the anthropogenic signal were those of surface waters within the arms of the bay where glacial influence was greatest. While saturation states during the fall indicated that all surface waters, as well as several samples from deeper depths, were undersaturated, upon removal of the anthropogenic CO_2 signal, the fall samples from all depths became supersaturated. This simple approximation demonstrates the impact that anthropogenic CO_2 has on marine systems like Glacier Bay.

Potential Future Implications

As atmospheric CO_2 concentrations continue to rise, the anthropogenic signal in seawater will also increase. Wanninkhof et al. (2013) showed that the partial pressure of CO_2 (pCO_2) is increasing in the North Pacific by about 1.5 ppm per year, or about 75 ppm every 50 years. Using this rate of increasing pCO_2 along with data from our discrete measurements, we calculated that saturation states with respect to aragonite have the potential to decrease by an average of 0.16 throughout surface waters of Glacier Bay in the next 50 years, with the largest effects seen during the spring season. We also found that if atmospheric CO_2 trends continue at their current rate, the surface waters of the bay will become perennially undersaturated in aragonite in approximately 150 years. However, because the rate of CO_2 accumulation in the ocean is also increasing, it is likely that this is a conservative estimate and does not take into account the changes in pCO_2 due to potential seawater temperature changes in the bay as the climate warms. Additionally, this estimate does not include potential acidifying affects of increased freshwater and glacial inputs due to rising atmospheric temperatures, which will also increase pCO_2, and lower total alkalinity concentrations compared to pre-industrial values.

Summary

Glacier Bay experienced seasonal and regional ocean acidification events during 2011-2012, and we belive this is the usual pattern. Areas where OA conditions were most severe and prolonged correlated with regions of the bay that experienced the greatest degree of glacial influence (i.e., the east and west arms). Saturation states were lowest in the upper east and west arms during the summer seasons, and all surface waters were found to be undersaturated during the spring of 2011. Saturation states rebounded to greater than 1.0 across the bay during the winter, and waters remained supersaturated through the spring season as primary production reduced DIC concentrations in the surface waters.

When the anthropogenic CO_2 signal was removed from current seasonal conditions, saturation states increased and, in most cases, waters became supersaturated with respect to calcium carbonate minerals. However, waters nearest the glacial outflows in the upper arms remained undersaturated due to the influence of low-alkalinity meltwater. Estimations of future OA conditions show the potential for saturation states to decrease by 0.16 units over the next 50 years. Projecting these estimates farther into the future, we believe that surface waters throughout Glacier Bay have the potential to become undersaturated year-round within the next 150-200 years. However, these estimates are based on current DIC and alkalinity concentrations, as well as current rates of glacial runoff. More extensive study is necessary to understand how continued glacial retreat will impact future DIC and alkalinity concentrations in Glacier Bay.

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Further information available at:

NOAA-PMEL Ocean Acidification: http://oceanacidification.noaa.gov/

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NPS photos courtesy of Bruce Molnia

The discharge of freshwater from melting glaciers into the ocean makes places like Glacier Bay and Kenai Fjords more subject to impacts from ocean acidification.

A Partnership to Remove Marine Debris from Alaskan Coastal Parks

By Sharon Kim, Peter Neitlich, Carissa Turner, Miranda Terwilliger, Benjamin Pister, Tahzay Jones, Janet Bering, and Lori Polasek

Remote coastal beaches in Alaska wilderness surrounded by high, scenic mountains or vast coastal plains are often the last places that visitors expect to find man-made materials and trash. However, many of these remote beaches receive significant accumulations of marine debris due to ocean currents, vessel traffic, and storm surges (*Howell et al. 2012*).

For example, the deadly March 2011 Tōhoku earthquake resulted in a tsunami in Japan that generated approximately 1.5 million tons of floating debris. This detritus was transported across the North Pacific on ocean currents (*Government of Japan 2012; NOAA 2013*) and has been found on the west coast of North America, including Alaska (*NOAA 2013*). The arrival of the tsunami rubble brought immediate attention to the persistent marine debris issue in Alaska and across the United States. For the Northwest Arctic, marine debris concerns are also heightened by the decreasing extent of sea ice, which allows for more vessel traffic and increases the open-water period for debris to move into and throughout Arctic waters (*Arctic Council 2009*).

Under the 2006 Marine Debris Research, Prevention, and Reduction Act, marine debris is officially defined as "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment" (33 USC 1951 et seq. as amended by Title VI of Public Law 112-213). Marine debris includes fishing gear, plastic materials, building materials, and any other non-natural, solid materials that come onshore. These types of debris can affect marine mammals and birds directly through entanglement, strangulation, and digestive blockage (*reviewed by Derraik 2002, U.S. Environmental Protection Agency 2011, Ryan et al. 2009*). Marine debris can transport invasive marine organisms, which have the potential of causing ecological and economic impacts. In addition, marine debris is unsightly and can be a negative effect for visitor experience.

Plastics break down over time into microplastic particles that can more readily enter the food web and persist. Research has shown that bioaccumulative toxic substances adsorbed from the ocean by experimentally provided microplastics were readily transferred to fish in cages in the Pacific Ocean (*Rochman et al. 2013*), with the implication that large volumes of microplastics in the ocean are a mechanism for transferring toxic substances into the food web. For rural Alaska communities dependent on marine mammal subsistence harvest, the potential for bioaccumulation of toxic substances is of particular concern. To compound the potential, it has also recently been discovered that Arctic sea ice in remote locations contains concentrations of microplastics several orders of magnitude higher than those previously reported in highly contaminated surface waters such as those of the Pacific Gyre (*Obbard et al. 2014*).

In summer 2015, we conducted an extensive five-park, multi-partner project to remove marine debris from park beaches known to have high to moderate levels of marine debris accumulation. The five park units were Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Katmai National Park, Kenai Fjords National Park, and Wrangell-St. Elias National Park and Preserve. Beaches in these parks are not accessible by roads, which made debris removals logistically challenging and costly, but with numerous partners and good weather, we managed to successfully remove over 11 tons of marine debris from these remote beaches.

Figure 2. Map of the five parks from which researchers removed marine debris from beaches in 2015.

Methods and Findings

Marine debris was collected from 28 beaches in five National Park Service units between May 21 and July 22, 2015 (*Figure 2*). Beaches in each park were not randomly chosen, but specifically targeted for clean-up operations.

Figure 1. Kenai Fjords National Park staff bag marine debris at Black Bay, a "collector beach" in the park. The trash is loaded into large white super sacks to be lifted off the beach by helicopter later.

NPS photo courtesy of J. Bering

NPS photos courtesy of J. Bering (top four), Bailey (lower left), S. Schmidt (lower right)

Figure 3. Examples of various marine debris types found throughout the five parks. Upper left: plastic gas cans and other debris in Cape Krusenstern National Monument. Upper right: Fishing nets in Bering Land Bridge National Preserve. Middle left: typical large foam piece found in Kenai Fjords National Park. Middle right: a large pile of debris collected from a single beach by workers in Kenai Fjords National Park. Lower left: foam and floats in Katmai National Park and Preserve. Lower right: plastic bottles typical of marine debris, on Bering Land Bridge National Preserve.

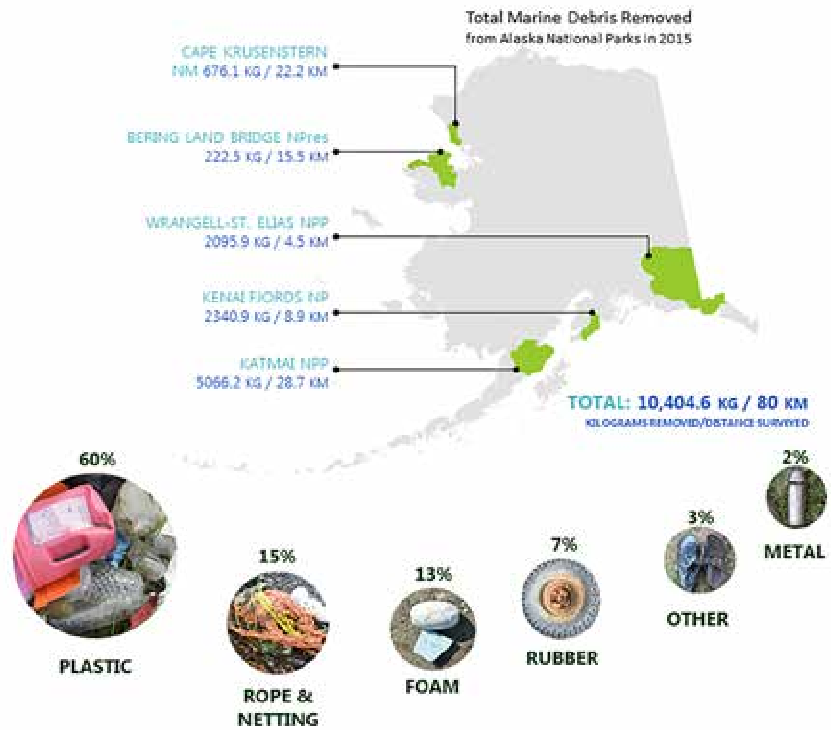

Figure 4. Marine debris removed from parks in 2015.

In each park, we walked the beach and collected all debris greater than 0.39 inches (10 millimeters) long from the waterline inshore to the highest strandline on the upper shore (smaller debris was collected if possible). We did not collect heavily buried debris, debris tangled or lodged in boulders or logs, glass, ferrous metals, or processed lumber. Our team weighed the debris according to six categories (examples shown in *Figure 3*): plastic, rubber, non-ferrous metal, rope and netting, foam, and other (e.g., ATVs, refrigerators).

We found marine debris on all beaches surveyed. The team found hard plastic on all 28 beaches, foam at 27 beaches, rope and netting on 23 beaches, non-ferrous metal on 19 beaches, and rubber at 18 beaches. Only 14 of the 28 beaches that we visited had items designated in the "other" category. Hard plastic was the most common debris item making up 60 percent of the total weight of all the debris we collected.

We tallied the total weight and distance surveyed for each park (*Figure 4*). The total volume of debris that we collected in Kenai Fjords was 5,330 pounds (2,717.7

NPS photo courtesy of Katie Nicolato

Figure 5. Researchers collect marine debris in Katmai National Park and Preserve.

NPS photo courtesy of DevDarma Khalsa

Figure 6. Researchers search for debris on a beach in Bering Land Bridge National Preserve.

Photo courtesy of Steve Baugh

Figure 7. Of the beaches cleaned, Cape Krusenstern National Monument had the highest percentage of rubber.

kilograms) with more than 60 percent plastic. We collected 5,316 pounds (2,411.4 kilograms) of debris from Wrangell-St. Elias and found more foam there than in any other park. In Katmai, we collected more debris than any other park with over 11,155 pounds (5,060.3 kilograms) of debris primarily comprised of hard plastics (not floats), rope, and netting (*Figure 5*). We collected the least debris in Bering Land Bridge: 497 pounds (225.5 kilograms). By proportion of beaches sampled, Bering Land Bridge had the highest amount of rope and netting, and it was the only park where we did not collect any rubber. Cape Krusenstern beaches had the second lowest amount with 1,464 pounds (664.1 kilograms) of debris and the lowest proportion of plastic compared to other parks. Unlike the Bering Land Bridge beaches (*Figure 6*), Cape Krusenstern beaches had the highest proportion of rubber (*Figure 7*).

Photo courtesy of NPS

Figure 8. Marine debris collected at Black Bay in Kenai Fjords National Park.

Our primary goal was debris removal and not quantification of debris found on beaches in park units. Furthermore, project beaches were not selected randomly with the goal of quantification, but were selected for management interest and logistical constraints. While it is difficult to compare across all of the parks because of these issues, the parks were located in two different regions of Alaska which appear to show different levels of debris overall: the Gulf of Alaska (Katmai, Kenai Fjords, and Wrangell-St. Elias) and the western Arctic (Bering Land Bridge and Cape Krusenstern). The Gulf of Alaska beaches had significantly more debris than the western Arctic beaches and the difference was likely driven by the much higher levels of plastic and foam in Gulf of Alaska parks (*Figure 8*). This difference may result from the physiographic constriction caused by the Bering Strait, the only connection of the Pacific to the Arctic Ocean, with oceanographic currents moving generally northward into the Arctic Ocean. The Bering Strait limits potential debris moving north from the Pacific Ocean to a 53-mile-wide gap, which affects how much debris reaches the western Arctic parks. Marine debris in the western Arctic parks seemed to be derived more from local terrestrial sources, such as coastal villages and numerous fishing camps, with light input from pan-Asian sources; previous surveys appeared to show that Cape Krusenstern debris sources derived more from local inputs while Bering Land Bridge's debris sources were more regional. In contrast, the Gulf of Alaska parks are closer in proximity to the north Pacific Gyre, which harbors significant amounts of marine debris from many sources. Accumulation on Gulf of Alaska beaches occurs primarily during winter storms with strong onshore winds (*Pallister and Gaudet 2011*).

These findings about marine debris are a snapshot in time, with results dependent on previous clean-up operations. Beaches with little or no clean-up history were expected to have a higher amount of debris than areas where recent clean-ups had occurred. Previous marine debris clean-up efforts in coastal Alaska were directly correlated with coastal accessibility. Between 2009 and 2014, Kenai Fjords and Resurrection Bay Conservation Alliance used boats to remove over 33,070 pounds (15 tons) of marine debris from 19 beaches (including the project beaches) within park boundaries; in 2014 alone, a half-ton of foam was removed from the project beaches during debris assessments to prevent foam disintegration. In June 2013, Katmai partnered with the Alaska SeaLife Center's Gyre project on a marine debris cleanup of Hallo Bay and removed over 4,409 pounds (2 tons) of debris from 3.3 miles (5.4 kilometers) of beach. In 2005, a large-scale cleanup occurred for Sisualik Spit in Cape Krusenstern, a heavily used area by Kotzebue residents for seasonal hunting and fishing camps, and in 1999, a large-scale clean-up operation occurred in Bering Land Bridge to remove all 55-gallon drums from the outer coast of the Seward Peninsula. The Malaspina Forelands in Wrangell-St. Elias have not had a focused marine debris removal effort.

Partners Involved in the Beach Cleanups

This marine debris removal project involved an extensive number of partners, with National Park Foundation and National Park Service (NPS) Water Resources Division providing significant amounts of funding. The NPS provided personnel in all parks for the clean-up and logistics operations and the Alaska SeaLife Center managed data collection across the parks. Alaska Airlines donated 10 round-trip tickets for fieldwork across the five parks, and consolidated debris removal was coordinated with a Gulf of Alaska Keepers-State of Alaska marine debris removal project.

NPS courtesy of Miranda Terwilliger

Figure 9. Marine debris is loaded into a plane in Wrangell-St. Elias National Park and Preserve.

Local park partners were extremely important in field clean-up efforts to collect and consolidate the marine debris. Wrangell-St. Elias worked closely with Yakutat Tlingit Tribe youth and interns from Youth Conservation Corps, Student Conservation Association, and Alaska Native Science and Engineering Program. Kenai Fjords worked with volunteers from Resurrection Bay Conservation Alliance. Port Graham Corporation, which owns various coastal lands within Kenai Fjords boundaries, was also a partner to ensure marine debris was removed from high-volume beaches. Katmai partnered with the Marine Vessels *Ursus* and *Waters* to help remove marine debris from Ninagiak Island. Bering Land Bridge and Cape Krusenstern partnered with the Boy Scouts of America, Alaska Teen Media Institute, Northwest Arctic Borough, and the Native Villages of Shishmaref, Wales, and Kotzebue.

Additional Partnering: Gulf of Alaska Keepers-State of Alaska Project

Along with the NPS debris removal operations, another large marine debris project coordinated by the Gulf of Alaska Keepers occurred simultaneously. The Gulf of Alaska Keepers conducted large-scale removal of marine debris across the Gulf of Alaska extending from Kodiak Island to British Columbia; it was originally funded by the Government of Japan through the State of Alaska Department of Environmental Conservation and the National Oceanic and Atmospheric Administration (NOAA). This project included transferring existing marine debris "super sack" caches onto a Waste Management, Inc. barge that moved across the Gulf of Alaska, starting from Kodiak Island and ending in Washington State. Super sacks are large mesh containers that hold approximately nine 55-gallon garbage bags full of debris to facilitate storage and transport using heavy equipment. Existing super sacks and had been amassed by Gulf of Alaska Keepers during previous years of marine debris clean-ups.

The Gulf of Alaska Keepers-State of Alaska project greatly facilitated removal of marine debris in Katmai, Kenai Fjords, and Wrangell-St. Elias by not only accepting Katmai debris onto the barge at Kodiak Island, but also having the barge make slight route deviations to retrieve our marine debris super sacks in Kenai Fjords and Wrangell-St. Elias. This partnership was also good for the State of Alaska and the NPS; instead of transporting debris to be buried in an Alaska landfill, the debris was removed to an out-of-state facility capable of recycling much of the debris. The barge ultimately transported all of the debris to a Waste Management, Inc. facility in Seattle, Washington, where it was sorted for recycling. Anything not recyclable was taken to a landfill in eastern Oregon (*Waste Management, pers. comm., January 2015*).

Marine Debris Monitoring

Prior to 2015, four of the five parks (Kenai Fjords, Katmai, Bering Land Bridge, and Cape Krusenstern) had initiated NOAA marine debris monitoring protocols (*Opfer et al. 2012; Lippiatt et al. 2013*) to assess marine debris stocks and refreshment rates. In Alaska, the NOAA protocols were modified to document the large amount of marine debris that gets pushed inshore beyond the initial beach berm to a second barrier (such as a lagoon) by highly dynamic winter storms (*P. Murphy and S. Lippiatt, pers. comm., February 2013*).

Two types of NOAA marine debris monitoring can be done: *accumulation surveys* completely remove the marine debris from the site and document what returns, while *standing stock surveys* leave the marine debris in place and document the change in debris. Many of our remote beaches are only accessible by small airplane or boat (*Figure 9*), which do not have the capacity to remove debris from the site, so standing stock surveys are more frequently used in these remote beaches.

In 2015 in Kenai Fjords, NOAA accumulation surveys continued at Bulldog Cove, Northwestern Spit, and near Pedersen Lagoon; this is the third consecutive year for Bulldog and Northwestern and the second consecutive year for Pedersen. At Katmai, NOAA standing stock surveys were conducted in 2015 at Dakavak Bay, Hallo Bay, and Swikshak Bay for the fourth consecutive year. At Bering Land Bridge, paired NOAA accumulation and standing stock surveys were completed in 2013 and 2014, and additional work is planned for 2016. All of these data were uploaded to the NOAA database for their national analyses. This five-park project enabled Wrangell-St. Elias to initiate NOAA standing stock surveys on the Malaspina Forelands for the first time.

Outreach

Unless marine debris can be prevented from entering the environment, marine debris will continue to accumulate on park beaches. Thus, education and outreach are a clear part of the solution for marine debris prevention. Both Katmai and Kenai Fjords have been working closely with local schools to provide hands-on field activities related to marine debris. Katmai worked closely with Bristol Bay schools in August 2015; Kenai Fjords created a marine debris curriculum for high-school students and started working with a Seward High School class in August 2015 to conduct NOAA marine debris monitoring surveys at an accessible local beach outside of the park. Park education staff trained the students to use the NOAA protocols in the field so students themselves could conduct monthly monitoring and data entry into the national database throughout the school year. This curriculum will be presented as part of the Kenai Fjords distance learning curriculum and will also be shared with other parks with marine debris issues. In the Wrangell-St. Elias and the western Arctic parks (Bering Land Bridge and Cape Krusenstern), youth videographers gathered content during the field season and are working on video production. In addition, Bering Land Bridge and Cape Krusenstern partnered with the Center for Alaskan Coastal Studies to present marine debris classes and clean-ups in five schools in the Kotzebue Sound and Southern Chukchi Sea regions during the spring and fall of 2016. Wrangell-St. Elias will use the curriculum developed by Kenai Fjords and adapt it for classrooms in Yakutat.

Future Direction

All of the five parks will continue partnership efforts to remove marine debris and monitor changes in debris accumulation over time. While it is unlikely that this level of funding will occur again for these parks, each park will continue to work with its partners to get additional funding to continue both marine debris removal and outreach and education efforts.

For the Gulf of Alaska, discussions have begun about how to make a project like this occur on a more regular basis, whether the interval would be every several, five, or ten years. In the Arctic, a partnership has been forged with the Northwest Arctic Borough for ongoing work around known source areas near Bering Land Bridge and Cape Krusenstern.

Marine debris projects are tangible efforts that the public can relate to and where there are clear results after the beach is cleaned. While volunteer efforts can be challenging to organize for these remote locations with difficult logistics, often gathering a large group of volunteers, students, and interns can be an investment for future efforts and garnish additional support. For all the parks, we hope to continue to augment this marine debris removal and outreach project with our numerous partners.

Conclusion

While single events such as the 2011 Japanese tsunami can generate extensive marine debris, marine debris in Alaska is usually caused by more routine and common means such as lost shipping containers, derelict fishing gear, upstream littering, and other human activity; the debris is then transported by winter storm events, ocean currents, and wind (*Howell et al. 2012*). In populated remote areas of Alaska such as the western Arctic, solid waste containment is a challenge for local communities and many coastlines are littered with plastics. Because marine debris is a regularly occurring problem, it is critical to combat it at the source through education and outreach. As a two-pronged effort to combat this long-term problem, our project combined the removal of existing marine debris that affects wildlife, subsistence resources, and recreation experiences on remote park beaches with education and outreach efforts. Our goal was to help the public and next generation prevent marine debris from entering the environment.

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The Core of the Matter: Adventures in Coastal Geology at Kenai Fjords National Park

By Christopher Maio, Richard Sullivan, and H. Sharon Kim

The rain pelted us as we moved heavy equipment from the deck of the *M/V Serac* into the two awaiting skiffs that sat rolling in the wind-driven chop. The eight-foot aluminum poles, inflatable pontoons, and other sediment-coring equipment quickly filled up the small skiffs. Launching into the open waters of the fjord, we carefully navigated over the kelp-laden shoals to avoid fouling the propeller and threaded our way to the entrance of the adjacent lagoon we sought to enter. After fighting against the outflowing tide and driving rain, we finally arrived on the protected and pristine shores of an inner lagoon in Kenai Fjords National Park.

Once on the beach, we worked together to assemble and launch the newly-built coring platform (*Figure 2*), and then figured out a way to anchor ourselves over the deepest portions of the lagoon to collect sediment cores from its depths (98.4 feet [30 meters]). Our coring sites were selected based on an acoustic sub-bottom seismic survey carried out during the previous day allowing us to peer into the depths of the lagoon's sediments. The seismic reflection profile had revealed a rich sedimentary archive contained within the deep basin of the lagoon. With the assistance of the National Park Service skiffs, three anchors were dropped from the coring platform into the lagoon and the raft triangulated in on the first coring target (*Figure 3*). The gravity corer, weighing 120 pounds, and topped with lead weights and a set of four stabilizer fins with a removable 6.5-foot (2-meter) stainless steel barrel

Photos courtesy of C. Maio

Figure 2. The cataraft coring platform is built on the beach of a small lagoon within Kenai Fjords National Park. Coring platform and NPS skiffs are set to cast off and head to the first coring target (top). Aluminum frame and 18-foot pontoons are assembled and inflated in preparation for launch (bottom left and right).

Figure 1. Inflatable sediment coring platform dwarfed by the dramatic topography of James Lagoon, Kenai Fjords National Park. Scientists supported by NPS staff seek to decipher the coastal evolution of James Lagoon using sediment cores collected from its depths. An extensive stand of "ghost" trees drowned during the 1964 earthquake seen along the shoreline and the Dinglestadt Glacier perched in the upper foreground attest to the dynamic nature of this environment.

NPS photo courtesy of J. Hardes

mounted on the bottom, was slowly lowered by hand using a block-and-tackle system until it sat 22.9 feet (7 meters) above the seafloor. Once in position, we released the line, sending the corer plummeting into the sediments. The corer was then laboriously hauled in with heavy anticipation. Once on the deck of the coring platform, the sediments were carefully extracted and we celebrated a well-preserved 5.2-foot (1.6-meter) sediment core. This was one day's adventure during 10 days of coastal geologic research within the park. Over the next two days we collected six more cores from our coring platform and two from the deck of the *Serac* totaling 39.7 feet (12 meters) of sediments.

This fieldwork represents a broader project deciphering the glacial and sea-level history of the fjords and coastal lagoons within Kenai Fjords. The seafloor sediments of deep coastal lagoons within the park could potentially provide a millennial-scale record of local environmental change and a timeline of catastrophic events such as volcanic eruptions, glacial advances, and tsunamis. Understanding how the park's coastline responded to past tectonic and climate-driven changes should provide valuable context to ongoing and future conditions.

Sediment grain size analysis coupled with radiometric dating of these cores is currently proceeding at the Alaska Coastal Geoscience Lab at the University of Alaska-Fairbanks. Preliminary results appear to be showing that McCarty Glacier may not have extended as far as many previous researchers surmised. We look forward to sharing results from this research in a future issue of *Alaska Park Science*.

We acknowledge the people who assisted us in this soil sediment endeavor: Melissa Knight (M/V *Serac* captain), Jennifer Pletz (M/V *Serac* deckhand), Dr. Aron Crowell, Jonathan Hardes, Ivana Ash, and Norma Johnson. We also thank the Woods Hole Oceanographic Institution Coastal Systems Group for providing the coring and seismic equipment.

NPS photos courtesy of J. Hardes (top), C. Maio (bottom left), R. Sullivan (bottom right)

Figure 3. Coring platform zeros in on first target. Cataraft shown with gravity corer hung on block and tackle system (top). NPS crew move one of three anchors into position (bottom left). Sediment sample extracted from gravity corer is held aloft in celebration (bottom right).


NPS photos courtesy of Doug Capra

The glaciers of Kenai Fjords National Park reveal not just land, but also more marine habitat as they recede in the face of climate change.

Changing Tides

By Heather Coletti, Grant Hilderbrand, and
Jim Pfeiffenberger

Southwest Alaska's coastal brown bears are the largest of their kind in the world, deriving much of their bulk from the abundant salmon resources that pulse into the rivers from the sea each summer. This age-old relationship between bear and fish has forged one of the most apparent and enduring links between the ecosystems of the land and the sea in coastal Alaska.

Less apparent, but perhaps no less important, is the connection between bears and intertidal resources such as clams and mussels. Along the shores of Lake Clark National Park and Preserve and Katmai National Park and Preserve, bears spend seemingly countless hours in the mudflats digging, chomping, slurping, and digging again. Their presence in these coastal areas is so regular and predictable that an industry in bear viewing has developed around them over the last couple of decades and continues to grow (*Figure 2*).

But just how critical are these shellfish to brown bears? How much nutrition do they actually provide? How healthy are the shellfish populations? Would it matter if these populations were impacted by human-caused changes such as increasing ocean acidity, overharvesting, or even another oil spill? At what point does human presence on these same beaches affect bear behavior and access to these food resources? And how can park managers best mitigate the impacts of human-caused changes in order to maintain healthy coastal ecosystems for bears and clams? These are some of the questions

Figure 2. Bear-viewing is an increasingly popular visitor activity along the coasts of Katmai and Lake Clark national parks.

Figure 1. Brown bears along the coast of Katmai and Lake Clark national parks exploit exposed mudflats during low tides to feed on razor clams.

Photo courtesy of © Debi Ropken

Figure 3. Scientists work rapidly to collect a variety of measurements from a tranquilized brown bear at Katmai National Park.

Figure 4. Graduate student Joy Erlenbach spent four months in the field at Katmai National Park observing brown bear behavior.

being investigated as part of the Changing Tides project, an ambitious three-year study that began in the summer of 2015.

Field work aimed at addressing these questions falls into two main components (1) brown bear fitness and use of marine resources and (2) the abundance, distribution, and health of clams and mussels. Within each component, a whole suite of data is being gathered by teams of collaborators from the National Park Service, the U.S. Geological Survey (USGS), the Alaska SeaLife Center, and various universities.

To gain a better understanding of brown bear use of mussels and clams, USGS biologist Grant Hilderbrand is leading an effort to put GPS collars on up to 12 bears each summer to track movements along the rugged coast of Katmai (*Figure 3*). "Part of what I think is fascinating about this study is that we just don't really know where all these bears go, what they do, or how they spend their year," Hilderbrand says. He and his team were able to collar nine bears in the first field season. Locations transmitted every hour revealed that all of the collared bears stayed along the coast all summer and occupied relatively distinct territories. Hilderbrand has just begun to analyze the data more closely to gain a better picture of how much time they spend in the intertidal zone.

What the bears are doing when they are in the intertidal zone and what food they are eating are questions that are being investigated in a couple different ways. For one, graduate student Joy Erlenbach from Washington State University spent the better part of four months in the field observing bears and recording their behavior (*Figure 4*). Through long days of cold, sideways rain, across miles of puddled mudflats, and occasionally even in bright summer sunshine, she squinted through her spotting scope, hoping to gain insight into what food resources and habitats are most important to these coastal bears. "Bears constantly surprise me with their different behaviors. I get to see little cubs riding on mom's backs, and bears mating, and wrestling, and chasing each other on the intertidal. It's pretty much always something new every day." Erlenbach speculates that intertidal resources may be particularly important during the springtime when the bears are first emerging from hibernation. "If other areas are still snow covered, they might not have access to vegetation in those areas, whereas coastal areas, and the intertidal specifically, are more likely to be snow free."

Another method that is helping us learn what the bears are doing is to add small video cameras to some of the GPS collars. Two bears donned such collars last summer, and the analysis of the many hours of video has just begun. A preliminary peek at some of the footage revealed that when bears dig in the mud, in addition to shellfish, they sometimes catch and devour small flounder that are nestled in the muck waiting for the tide to roll back in. Bears are opportunistic feeders, and the study has shown that in addition to salmon, they will also eat vegetation, clams, and seals.

NPS photo courtesy of Kaiti Chritz

Figure 5. The isotopes contained in a sliver of claw can provide important clues about a bear's diet.

NPS photo courtesy of Kara Lewandowski

Figure 6. A researcher digs in the mudflats along the coast of Lake Clark National Park to assess the distribution and abundance of razor clams.

This steady diet of marine resources provides energy for foraging, mating, and nursing; and also helps bears pack on the pounds needed to survive winter hibernation. "We're handling the bears three times a year…in the spring, the summer, and the fall," says Hilderbrand. Each time the bears are handled, they are weighed and measured. Several of them gained more than 88 pounds (40 kilograms) between May and July, and one of them gained a whopping 140 pounds (63 kilograms). Bears averaged around 15 percent body fat in May, but bulked up to just under 40 percent by fall. A blood sample, hair, and a sliver from the bear's claw are also collected when the bears are handled (*Figure 5*); chemical analyses of these samples provide clues about what the bears have been eating and can reveal shifts in diets over time.

The other major component of the project is looking directly at the bivalves that the bears are eating. Several species are thought to be potential prey, including blue mussels, razor clams, and butter clams. National Park Service biologist Heather Coletti is leading the effort to better understand these species. She explains "These invertebrates are critical prey resources for a variety of species. They are also considered indicators of the marine nearshore and are susceptible to changing ocean conditions. But they are difficult to measure in terms of health and abundance. Changing Tides is giving us an opportunity to fill that knowledge gap and create better tools to assess the health of these important species."

Clams and mussels were collected from the shores of both Katmai and Lake Clark national parks in 2015 (*Figure 6*). Some of the samples were kept alive in small aquarium-like containers and transported to the Alaska SeaLife Center in Seward where researchers could measure things such as shell weight, shell thickness, total weight, and overall dimensions. Individuals were placed in tanks with algae so their feeding rate could be calculated; the concentration of algae was measured at the beginning and then again three hours later. They also measured the production of byssal threads in blue mussels, the tiny strands they use to attach themselves firmly to the rocky shoreline. All of this information adds to the basic understanding of how these animals survive along the wild coasts of Alaska.

Other specimens were dissected and their tissues will be analyzed to provide clues to more specific questions, like how many calories a clam provides for a bear, or what certain protein and genetic markers in clams and mussels look like (*Figure 7 and 8*). These markers can show whether the bivalves have been exposed to environmental stress such as elevated temperatures, increased acidity, pollution, or disease. Measuring and describing the markers in these sample tissues gives researchers a tool that can help them compare the health of clam and mussel populations at different sites and assess their exposure to environmental stress.

NPS photo courtesy of Benjamin Pister

Figure 7. Alaska SeaLife Center scientist Katrina Counihan extracts hemolymph, the bivalve equivalent of blood, from mussel specimens collected near Lake Clark National Park.

NPS photo courtesy of Jim Pfeiffenberger

Figure 8. A technician measures the shell thickness of a razor clam at the Alaska SeaLife Center. A wide variety of measurements like this help assess the overall condition and health of the prey species that bears target in the intertidal zone.

Researchers also hope to gauge the abundance and distribution of marine bivalves as a part of this study (*Figure 9*)—in other words, to assess how much of this prey resource, particularly razor clams, is out there for bears to use. The question of how to measure razor clam abundance has puzzled both biologists and managers for decades. The current method used by state fisheries managers involves intensive sampling in relatively small areas on the east side of Cook Inlet where people typically dig for clams. While there is both commercial and personal harvest of clams along shores of Lake Clark National Park on Cook Inlet's west side, no abundance sampling has been done there. A team spent a week in the field during July 2015 slogging across the mudflats near Polly and Silver Salmon creeks, testing several different sampling methods. These included using photo sampling to document clam "shows," which are small holes in the sand from the clam's siphon; counting every clam "show" in defined areas; and doing some good old-fashioned digging as well. No method proved foolproof, and if nothing else, the effort confirmed that it is extremely challenging to accurately estimate clam populations over large areas.

All these efforts will combine to create not just a better understanding of how bears use specific intertidal resources, but also a broader understanding of how the sea is tied to the land, how the mysterious web of marine life is intertwined with the more familiar territory of forest, mammal, and solid ground. Ultimately, by understanding these connections, park managers will be better equipped to take actions to protect these unique ecosystems in the face of such stressors as increased human activities, changing ocean conditions, and potential disasters such as oil spills. If we don't know how the ecosystem functions, and where the critical connections lie, it is hard to know what parts to protect in the face of stressors such as increased human use, changing ocean conditions, or potential disasters like oil spills. The Changing Tides project is an important and ambitious step in protecting and preserving these resources for future generations.

NPS photo courtesy of Benjamin Pister

Figure 9. Scientists record information about clam abundance along the coast of Lake Clark National Park.

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