Coastal Lagoon Monitoring in the Southern Chukchi Sea National Park Units

Fieldwork Summary

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A report led by Wildlife Conservation Society, in partnership with US National Park Service, Native Village of Kotzebue, and University of Alaska, Fairbanks, submitted to US National Park Service Arctic Network.

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EXECUTIVE SUMMARY

Wildlife Conservation Society (WCS) works with the National Park Service to design and implement the Coastal Lagoon Vital Sign component of the Inventory and Monitoring Program. This program is intended to establish biotic and abiotic reference conditions for assessing long-term changes in the coastal lagoons of Cape Krusenstern National Monument and Bering Land Bridge National Preserve. The vital signs program focuses on monitoring both the structure and ecological function of lagoons, as well as the fish resources used for subsistence by coastal communities. A standardized Vital Sign Protocol was developed for these coastal lagoons, informed by our field efforts throughout 2015, 2016, and 2017. Our 2018 vital sign field efforts, supplemented by funding from the National Park Foundation in support of a project called "Kotzebue Sound Whitefish Ecology and Seasonal Dynamics," sought to build upon the pre-existing database of in-depth temporal and spatial information on lagoon ecology.

There are nine coastal lagoons described in the boundary of Cape Krusenstern National Monument – Aukulak, Imik, Ipiavik, Kotlik, Krusenstern, Port, Sisualik, Tasaycheck, and Atilagauraq. We collected seasonal physical and biological data at three Cape Krusenstern lagoons including Kotlik, Krusenstern and Aukulak. We collected information of physciochemcal water properties and performed zooplankton community sampling as well a primary productivity assessment at all three lagoons. We sampled community composition, seasonal and spatial patterns of lagoon use, trophic dynamics, and fish health taking otolith, fin clip samples and muscle plugs from captured specimens. Additionally, we conducted sampling in the Tukrok River, a marsh and riverine matrix which acts as the connection between Krusenstern Lagoon and the Chukchi Sea, with the outlet to the marine environment located 15 km away from the main body of the lagoon. Given the significant distance between the two sampling locations we treated the Tukrok channel as an entirely different sampling site than Krusenstern lagoon.

While ease of access and logistics allowed for frequent sampling at Cape Krusenstern, the need for floats (unavailable locally so cost preclusive) or a helicopter (no permits approved from Bering Land Bridge) prevented sampling effort at the Bering Land Bridge lagoons during the 2018 field season.

We generally accessed the various Park unit lagoons via fixed-wing plane equipped with tundra tires. Within each visited lagoon, we used a small inflatable boat equipped with a 9.9 horsepower outboard motor. Four long-term (Center, Outflow, Inflow, and Adjacent-to-the-Ocean stations) and three random sampling stations where sampled at each lagoon. At each station we collected data on primary productivity (YSI Sonde instrumentation) and fish population (beach seine, fyke net, gillnet, minnow trap). Additionally, certain stations were sampled for zooplankton abundance (Wisconsin plankton tow net), while opportunistic observations of avifauna and animal communities surrounding the lagoons were collected when possible.

Preliminary results from data gathered during the 2018 field season are synthesized in this report. The data compiled in this report reflect findings from sample efforts which included a total of 7 beach seine sets, 4 fyke net sets and 40 gillnet sets. These will supplement results from in-depth laboratory analyses of zooplankton and fish samples in collaboration with the University of Alaska, Fairbanks and Juneau.

Lagoons vary in their seasonal connectivity with the ocean. Initial analysis of water quality data indicates that physical water properties varied by lagoon and season. Seasonal salinity levels appear to be related to a lagoon's connection with the marine environment; the more directly connected the lagoon is to the Chukchi Sea, the higher its salinity. All lagoons were open to the marine environment during the first round of sampling and closed during the second round of sampling. Salinity levels at Aukulak were higher than the 2017 season, but lower than both the 2016 and 2015 mean salinity levels. Salinity levels at both Krusenstern and Kotlik lagoons were comparable to previous field seasons. Temperature at all three lagoons decreased over the course of the field season. Average temperature at Krusenstern lagoons was 2.5 °C higher that previously recorded.

Species richness of fishes and their abundance in lagoons fluctuated during the course of each field season with population composition and relative abundance varying between both season and lagoon. We

recorded a total of 22 different fish species, including several key forage and important subsistence species. We found higher overall richness than the 2017 field season wherein 19 species were caught. Species richness was highest at Aukulak Lagoon with 18 different species. We discovered lower overall species diversity in the Tukrok river channel during the 2018 season.

Otoliths were extracted from a total of 176 individuals of five species including: humpback whitefish, Being cisco, least cisco, Pacific herring and sheefish. We collected a total of 228 fin clip samples with the majority of samples taken from Krusenstern Lagoon. Muscle plugs were taken at Aukulak Lagoon exclusively, with a total of 30 samples taken from humpback whitefish, least cisco, Pacific herring and sheefish.

Our research included collaboration with members of the local community who shared their Traditional Ecological Knowledge with the lagoons field crew and provided insight into their comprehensive understanding of our study sites. Traditional knowledge of local ecosystems is a vital component of this monitoring system that supplements our scientific data collection. Many residents of the areas surrounding Cape Krusenstern, who rely on the lagoons for subsistence purposes, have observed a range of significant changes to these resources, potentially linked to climate change. In our efforts to construct a thorough and comprehensive picture of lagoon ecology and the subsistence resources the lagoons provide, we include these first-hand accounts from local communities. Our primary interaction with Kotzebue residents included a single informal meeting and brief interview with a member of the nearby village.

Overall, our research builds on prior traditional knowledge and scientific research, providing ecological information vital for understanding long-term change, monitoring and managing Arctic lagoons of these Park units, helps prioritize spill contingency planning (by establishing the most productive lagoons), and will continue to inform a comprehensive understanding of the *Story of the Lagoons* – a key priority for the Native Village of Kotzebue, Wildlife Conservation Society, and the National Park Service.

INTRODUCTION

In order to fulfill the National Park Service (NPS) mission of conserving parks unimpaired, National Park Managers are directed by federal law and NPS policies and guidance to know the status and trends in the condition of natural resources under their stewardship. The 2006, NPS Management Policies specifically directed the NPS to inventory and monitor natural systems. NPS has used the term "vital signs monitoring" since the early 1980s to refer to a relatively small set of information-rich attributes. This subset of physical, chemical, and biological elements and processes of park ecosystems are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. Vital signs can provide managers with an early warning of situations that require intervention in National Parks. The mission of the NPS Arctic Network (ARCN) Inventory and Monitoring Program includes monitoring 28 specific vital signs in the five northern Alaska park units, including the coastal lagoons of Cape Krusenstern and Bering Land Bridge (Lawler et al., 2009).

In 2007, the Arctic Network Inventory and Monitoring Program began developing a monitoring protocol for coastal lagoons located in Cape Krusenstern. Using monitoring data to inform management decisions is clearly outlined in both the General Management Plan (GMP) for Cape Krusenstern National Monument (NPS, 1986a): "…monitoring will be conducted so that thorough information about the condition of resources will be available to monument managers," and Bering Land Bridge National Preserve (NPS, 1986b) which notes the: "positive effects on natural and cultural resources within the preserve as a result of natural resource research and monitoring." More specifically, the Cape Krusenstern National Monument GMP states the importance of monitoring water quality within the monument. The National Park Service will establish a monitoring program: "…to provide baseline data on water quality of the monument against which future sampling can be compared."

Coastal lagoons are a dominant landscape feature of the Arctic coastline; over a third (37%) of the coastline between Wales and the Canadian border is adjacent to coastal lagoon habitat (Figure 1, Appendix 1). The coastal lagoons of the NPS Arctic Network represent a critically important ecosystem in the region, and are vulnerable to both climatic change and development impacts. They are also highly dynamic, with both intra- and inter-lagoon dynamics poorly understood. From a climate change perspective, increased coastal erosion and ocean acidification has the potential to profoundly alter the physical and biological dynamics of the lagoons. New dynamics of lagoon breaching will alter fish community patterns and the availability of important subsistence fish species. Projected changes in pH are projected to be most drastic in Arctic surface waters (Steinacher et al., 2009). This projected acidification has the potential to have a strong negative impact to calcifying organisms including mollusks and phytoplankton (Comeau et al., 2009). 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. Lagoon Vital Sign efforts address the need for baseline information about the structure and function of lagoons, as well as the dearth of information about the local fish resources utilized for subsistence (Lentz et al., 2001). Without a clear understanding of baseline conditions in the lagoons, including the seasonality and inter-annual variability of physical and biotic components, and relative productivity, it is impossible for managers to detect long-term changes that result from climate change, to quantify the impacts of accidents, or develop appropriate management plans (including prioritization of sites) that protect the key functions that these lagoons have on local ecosystems and subsistence economy.

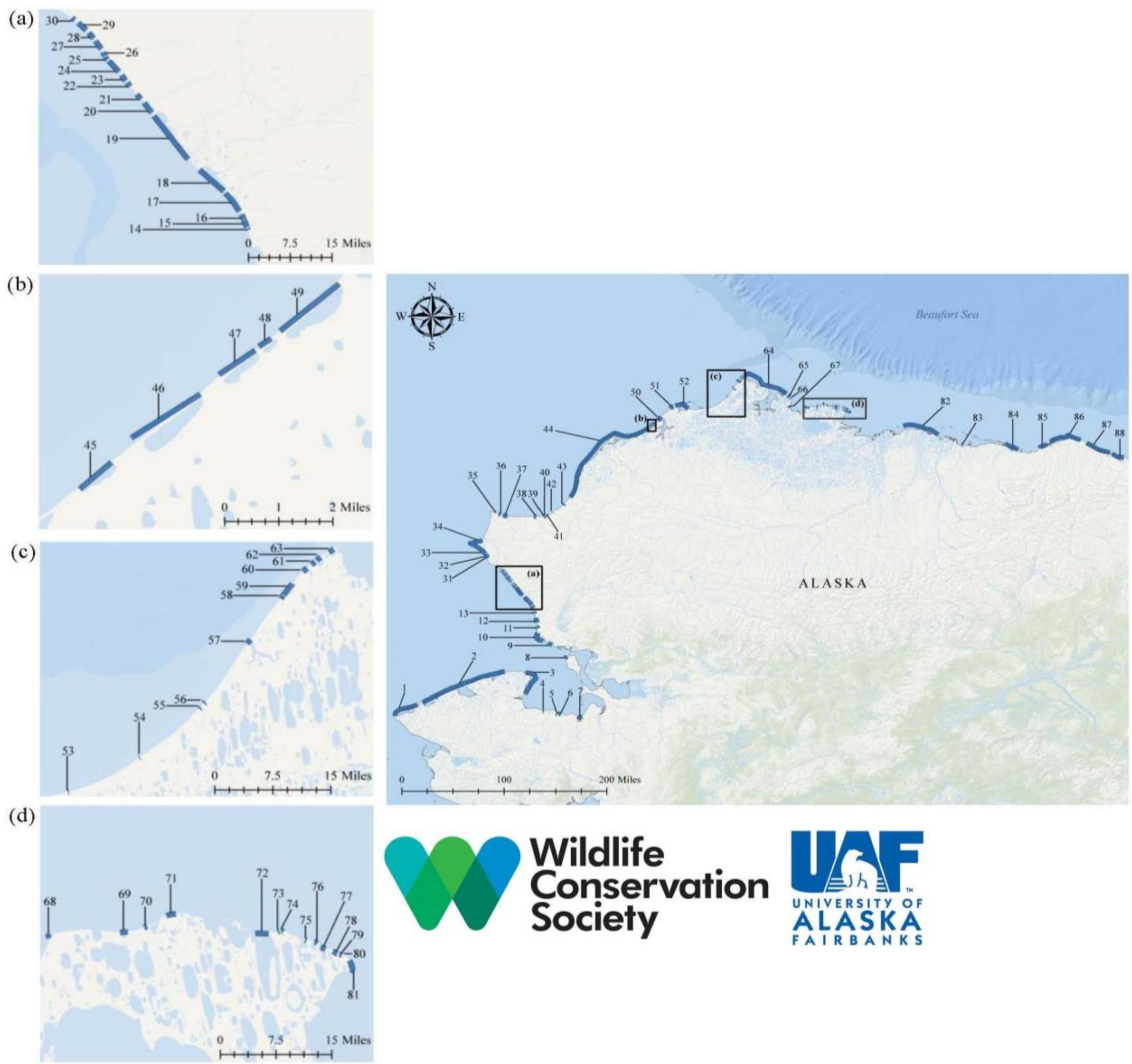

Figure 1: Map of the coastal lagoon habitat found in Alaska from Wales to the Canadian border. Coastline adjacent to lagoons is shown in blue, which amounts to 37% of the total coastline length.

Coastal Lagoons in Northern Alaska

Lagoons on the northern Chukchi and Beaufort Sea coastlines have been more comprehensively studied due to the relatively greater interest as part of oil and gas environmental assessment activities. Common to all the more northern studies is the significant interannual, seasonal, and geographical differences in physical conditions and fish catches. Lagoon conditions can vary from fresh to saline, sometimes within a season dependent on connectivity with the Beaufort Sea. Jarvela and Thorsteinson (1999) found Arctic cod, capelin, and liparids (snailfish) to be the most abundant marine fishes in catches, while arctic cisco was the only abundant diadromous (life cycles in fresh water and in marine water) freshwater species. Johnson et al. (2010) found capelin, Arctic cod, juvenile pricklebacks and juvenile sculpins to be the most common taxa in the Beaufort Sea around Cooper Island. In Elson Lagoon (Beaufort Sea coast), least cisco and juvenile sculpin were most common. Johnson et al. (2010) also concluded that species occupying coastal waters of the Beaufort Sea remained relatively unchanged over the past 25 years. Currently, Kevin Boswell, Brenda Norcross, Ron Heintz and colleagues are conducting a multi-year project funded by North Pacific Research Board looking at fish species composition and physical conditions in Kasegaluk

Lagoon and Peard Bay on the northern Chukchi Coast. A new Long-Term Ecological Monitoring (LTER) effort was also initiated in 2017 for the coastal Beaufort led by Dr. Ken Dunton – "The Beaufort Lagoon LTER and Arctic Coastal Ecosystem in Transition."

Between the North Slope efforts and the Cape Krusenstern and Bering Land Bridge NPS units, the most significant lagoon research efforts have been between Kivalina and Cape Thompson in the 1950s as part of the Project Chariot environmental assessment (Johnson, 1961; Willimovsky and Wolfe, 1966; Tash and Armitage, 1967; Tash, 1971) and at Port Lagoon just to the south of Kivalina as part of the Environmental Assessment for the Red Dog Mine port facility.

Within the focal National Park Service land units, there are nine coastal lagoons described within the boundary of Cape Krusenstern National Monument – Aukulak, Imik, Ipiavik, Kotlik, Krusenstern, Port, Sisualik, Tasaycheck, and Atilagauraq; and four coastal lagoons within the boundary of Bering Land Bridge National Preserve – Espenberg, Kupik, Shishmaref, and Ikpek (Table 1). We note that Sisualik and Espenberg may not fulfill all the requirements of being classed as lagoons, being more of a fully marine embayment or estuary (Durr et. al., 2011; Tagliapietra et. al., 2009).

Villages in proximity to Cape Krusenstern National Monument include the Native villages of Kivalina (17 km northwest of the monument boundary), Noatak (13 km east of the monument boundary), and Kotzebue (15 km southeast of the monument boundary). For Bering Land Bridge National Preserve, proximal villages include the Native villages of Deering (20 km east of the preserve boundary), Shishmaref (surrounded by the preserve at a distance of about 20-30 km), and Wales (36 km southwest of the preserve boundary). Many residents of these villages use camps along the coastline, including around several of these lagoons. Red Dog Mine, one of the world's largest lead and zinc mines is located just north of Cape Krusenstern's boundary.

Of the lagoons in Cape Krusenstern, Atilagauraq is the smallest (<0.5 km^2) and Krusenstern Lagoon is the largest (56 km^2). Lagoons vary in the amount of water exchange with the surrounding marine environment. Aukulak, Krusenstern, and Sisualik are connected to Kotzebue Sound and Imik, Ipiavik, Kotlik, Tasaycheck, Atilagauraq and Port are connected to the more open Chukchi Sea. Aukulak, Imik, Kotlik, and Port are all intermittently open. Krusenstern, Atilagauraq, and Tasaycheck lagoons are typically seasonally closed. Krusenstern Lagoon is connected to the ocean at the mouth of the Tukrok River, which is 15 km away from the main body of the lagoon itself. The mouth of the Tukrok opens in springtime as a result of snow and ice breakup in the rivers and lagoons feeding the river, which builds pressure at the beachhead, and ultimately in some years breaking through (sometimes helped by local fishermen who recognize that the opening of the lagoons allows fish to enter (and grow). The mouth of the Tukrok River routinely closes in mid to late summer as gravel is pushed up by wave action resulting from strong storms. Sisualik, and Ipiavik are open year-round.

Prior Coastal Lagoon Research in ARCN National Park Units and Overall Picture of Lagoons
There have been a number of prior research efforts investigating the ARCN national park units that include this report's study areas. Throughout the 1970's, reports outlined avifaunal community composition and behavior surrounding the lagoons at Cape Krusenstern and Bering Land Bridge National Park. Additional insight from these predominantly avian studies included information on zooplankton community composition, which was found to be less diverse inside rather than outside the lagoons (Connors and Risebrough, 1977, 1978).

During the 1980's several reports were compiled that explored basic physical water quality parameters and fish and invertebrate community composition as well as fish abundance and size at study sites at Cape Krusenstern, Kotzebue Sound and the Tukrok River Channel (Raymond et al., 1984; Dames and Moore, 1983: Baylock and Erikson, 1983). Additional areas explored in these and associated reports included lagoon epibenthic regions, which were discovered to be highly variable and attributed to specific lagoon assemblages, timing, and location within lagoons by Blaylock and Erikson (1983). Findings from reports completed during this time period also suggested greater fish species diversity occur in lagoons open to marine environments rather than those closed off (Dames and Moore, 1983).

Research and data collection at lagoons in northwest Alaska National Park units continued into the 1990's, with one major study conducted at Krusentern Lagoon by Schizas and Shirley (1994). This study was in conjunction with a larger survey on benthic and epibenthic invertebrates of lagoons in Cape Krusenstern, and identified a new species of harpacticoid copepod (*Onychocamptus krusensterni)* among the benthic community at Krusenstern lagoon.

During the early 2000's, additional information on physiochemical (e.g. nutrients) and biological (e.g. zooplankton, epibenthos and fish) parameters was collected at six of the eight coastal lagoons located in Cape Krusenstern (Imik, Kotlik, Krusenstern, Aukulak, Sisualik,) (Reynolds et al., 2005). However, determining the general status and trends in conditions for these lagoons, in a manner comparable with future years, was not a feasible product of these studies, which acknowledged the absence of comprehensive baseline data for many coastal lagoons in the southern Chukchi Sea (Reynolds, 2012). A more limited sampling effort for the Cape Krusenstern National Monument Lagoons in 2009 was conducted utilizing preexisting sampling sites with the intent of utilizing this in addition to data collected by Reynolds et al. (2005) to act as baseline information for Cape Krusenstern lagoons. Reynolds had sought to monitor coastal lagoons of Cape Krusenstern National Monument to document the long-term status and trends of physical, chemical, and biological components. In order to achieve that objective, Reynolds planned to collect: 1) physicochemical data in the five lagoons, 2) nutrient and chlorophyll A samples in five lagoons, 3) zooplankton samples in five lagoons, 4) benthic samples in three lagoons (Kotlik, Krusenstern, and Sisualik), 5) pelagic fish species in three lagoons (Kotlik, Krusenstern, and Sisualik), and 6) geomorphological data in five lagoons. These data, along with those previously collected (Reynolds et al. 2005), were intended to contribute to baseline water quality and species data for the five coastal lagoons in Cape Krusenstern. Additionally, field efforts during this sampling period were to be used to determine the feasibility of field-sampling methods for long-term sampling of these remote lagoon ecosystems (i.e., to develop a vital sign protocol).

Reynolds' efforts to seasonally sample multiple lagoons were ambitious given their remote nature and profound variability. While providing some valuable baseline data on basic conditions, a greater focus was still needed on a few lagoons to understand their temporal and spatial variability. Reynolds' protocols were not fully operationalized, and efforts to conduct in–field monitoring were thwarted by challenging logistics, creating a need and opportunity for NPS and Wildlife Conservation Society to collaborate towards common objectives and derive mutual benefit.

The Wildlife Conservation Society led field efforts have taken place over the course of the 2012, 2015, 2016 and 2017 seasons. This report builds on information collected from these prior field efforts, which include baseline information for physiochemical water properties, primary productivity, zooplankton abundance and fish community dynamics. Results from these previous efforts indicate that both physical and biological dynamics vary greatly between both lagoon and season. Water quality parameters fluctuate in response to connectivity with the ocean; with salinity, temperature and dissolved oxygen levels varying across each season. In some cases, the synthesis of results from data collection indicate common trends as a result of this closure with both salinity levels and temperature decreasing over the course of the season in several cases. Fish communities were also highly variable with species abundance changing both across and between seasons. Results from fishing efforts indicate that seasonal dynamics of fish community composition change as the physical dynamics and characteristics of the lagoons undergo seasonal changes. Catches of migratory species (e.g. sheefish, humpback whitefish) generally decreased towards the 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.

During the 2015 to 2018 period, Marguerite Tibbles used data collection from these lagoons in summer and winter, as well as remote sensing to inform her MSc research at University of Alaska, Fairbanks

(Tibbles and Robards, 2018; Tibbles et. al., 2018; Tibbles, 2018).

Traditional knowledge of local lagoon ecosystems has developed from a long history of subsistence fishing and is a vital monitoring system that supplements scientific data collection. Many residents of areas surrounding Cape Krusenstern rely on the lagoons for subsistence purposes, and have observed a range of significant changes to these resources linked to climate change (Moerlein et. al., 2015; Jones, A., 2006). These observations work to emphasize the importance of scientifically evaluating ecological functionality and health of lagoon systems, and incorporating local observations and expertise into these efforts. As Boswell et al. (2012) highlight for lagoons on the North Chukchi Sea coast, there is great importance in "developing a firm understanding of the value and role of these sensitive habitats with respect to fisheries productivity in the Arctic and their function as sources of nutrition and refuge for important fish, birds and mammals is imperative, especially in context of climate and environmental change."

Ultimately, the development of a workable protocol and recommendations for conservation are beneficial for land management agencies. For example, lagoons and their marsh areas are particularly sensitive to climate change or oil that once entrained in the lagoon system would be very difficult to remediate; so, assessing the ecological or subsistence value of different lagoons supports both an understanding of change in lagoons as well as prioritized contingency planning in the case of an oil spill. This report will contribute to the pre-existing body of information on Cape Krusenstern lagoons and will help to inform the ongoing development of sampling protocols and monitoring measures for Arctic lagoons.

2018 FIELD EFFORT

Objectives

The objectives of the Wildlife Conservation Society-led activities throughout the 2018 field season include the following:

1. Test the viability of the National Park Service Coastal Lagoons Vital Signs Monitoring Protocol for the Arctic Network developed based on WCS led research efforts from the 2012, 2015, 2016, and 2017 field seasons;
    a. Streamline logistics and provide feedback on standardized sampling protocol;
    b. Update sampling protocols and objectives to reflect in-the-field experiences during the 2018 field season;
    c. Report findings from 2018 field season and incorporate data into comprehensive Arctic Lagoons monitoring database;
2. Collect data from lagoon sites in Cape Krusenstern National monument and Bering Land Bridge National Preserve including;
    a. Water quality parameters: temperature, pH, salinity, dissolved oxygen, turbidity, and specific conductivity;
    b. Primary Productivity including blue green algae and chorophyll concentrations;
    c. Zooplankton abundance and community composition;
    d. Fish distributions, abundance, community composition, life history, genetic information and mercury levels;
    e. Species composition and behavior of animal communities interacting with lagoon ecosystems.

Study Design

The NPS sampling protocol was followed closely to test for viability in the field.

Field Methodologies

Water Quality

Sampling methods used to collect physicochemical data were based on the Environmental Protection Agency (EPA) National Coastal Assessment Field Operations Manual (U.S. EPA 2001). At each sampling point (7 sites per lagoon per month) and at a depth of 50 cm, the following core water quality parameters were measured in situ using a YSI EXO 2 multiparameter sonde: water temperature, dissolved oxygen, salinity, specific conductivity, turbidity, and pH. Water depth was measured with a hand-held depth sounder. Grab samples were also taken at each water quality station and frozen to be analyzed for total nitrogen, nitrate, phosphate, and total alkalinity.

Primary Production

Primary production was estimated using the YSI EXO 2 sonde to measure chlorophyll and blue-green algae in the lagoons during the 2017 season. Reynolds (2012) and Robards et al. (2014) had used laboratory analysis for chlorophyll. However, the expenses for conducting this work are preclusive for a long-term monitoring project, particularly given the large number of below-detection samples over the course of the season.

Zooplankton

Using an 150µm mesh Wisconsin plankton net with a mouth diameter of 50 cm we sampled each lagoon one time during the sample period. When possible, we collected samples in the area around fresh water inlets. We measured flow rate during sample collection using a General Oceanics Flow Meter Model 2030 series, standard model attached to zooplankton net at opening. Flow rate data will be used to calculate volume of water filtered/distance traveled during tow for data quality assurance purposes.

Standard sampling procedure is as follows:

1) Rinse plankton net and collection cup in ambient water

2) Attach collection cup. Record numerical value displayed on flow meter on data sheet under "flow start".

3) Throw the net from a stationary point and tow the net slowly behind a boat or, if performing a nearshore walking tow sample, behind body for 50m (aim for obtaining a sample size of ~ 5-10 cubic meters of water, distance can be measured with GPS unit). Prevent the net from coming in contact with the bottom, particularly when sampling from shore. Care needs to be taken that flow meter does not turn backwards while conducting the tow. Make sure the net is constantly moving through the water without pauses when collecting sample; the recommended tow speed is 0.75-1 m.

4) Pull net from water in one motion, shake out excess water and drain the sample into collection bottle using squirt bottle filled with filtered water to remove any sample remaining in collection cup. Samples should have an approximate volume of 16 oz including lagoon water.

5) Record information on data sheet including: date, time, location, sample name and flow meter numerical value at end of tow.

6) Samples should be preserved in 5-10% formaldehyde/(sea) water solution. For a 16 oz sample, add 50 ml of 40% formaldehyde using syringe. Invert container to mix thoroughly. Write sample number information on piece of write in the rain paper (with pencil), add label to the bottle along with sample.

7) Store sample in a cool, dark place, such as a cooler.

8) Perform 3-5 sample tows per lagoon to account for spatial variation.

While we performed zooplankton sampling during the 2018 field season it should be noted that future field efforts should aim to sample several times throughout the open water the field season with the objective of creating a more complete picture of zooplankton activity throughout the summer. Additionally, a protocol should be developed to investigate diurnal zooplankton activity within these lagoons. All these factors will need to be incorporated if results are to be compared over seasonal, annual and decadal time scales.

Fish Sampling
We sampled fish in all lagoons using a beach seine, fyke net and experimental gill nets.

The 3.1x15 m beach seine was used to sample fish at any location where beaches allowed for deployment (e.g., sandy with no protruding rocks). We walked the net out to about 20m into the water then drew it parallel to shore the retrieved the net in a symmetrical manner with people drawing the wing lines attached to the net's ends simultaneously at a constant rate (per Robards et al., 1999).

We used fyke nets to collect larger volumes of fish in locations where the depth and substrate were favorable. Our fyke net was constructed with 3.1 mm stretch mesh, a 91.5 x 122 cm frame made of two rectangular conduit frames, 5 steel hoops, 2 throats, and a 15.2 m lead. The wings were anchored using rebar with the main line attached perpendicular to shore and the wings set at approximately 45˚. Set time for fyke nets was more standardized than scientific gillnets throughout the three field seasons, however soak time still varied between sets to avoid mortality where catches were large. Mean set time for fyke net sets during the 2018 season was 2.93 hours.

Experimental gill nets consisted of 5 panels, each 25ft in length, for a total net length of 125ft. Stretch measurement of the individual panels were: 1 inch, 1.5 inch, 2 inch, 3 inch, and 4 inch. Set sites were selected in areas near the inflow/outflow (regardless of whether the connection was open or closed), and points next to water quality sample points through the lagoon (e.g., central, marine edge). Soaking nets are monitored in order to minimize risk of a) birds or other unintended animals being caught, and b) unnecessarily heavy fish mortalities. Mean set time for gillnets during the 2018 field season was 1.47

hours.

We identified all fish to species and measured each individual to fork length. We collected otoliths, fin clip samples and muscle tissue samples from the larger whitefish species Salmon species and Pacific Herring. Otoliths were extracted and placed in a small coin envelope, labelled and stored in a dry case. We took one fin clip from each individual (right pelvic fin) and placed the sample in a 1.8 mL cryo tube containing desiccant beads for storage. Muscle tissue samples were taken using a sterile biopsy punch. We harvested three 6mm samples from the side of each fish at the thickest part of the body. Samples were weighed and placed small coin envelopes. We stored envelopes in a large dry case lined with desiccant beads.

Traditional Ecological Knowledge Surveys
Informal interactions occur in the field with local experts when, while collecting data, we encounter members of the local community. These encounters are documented in the sampling descriptions below.

Implementation
We spent the field season sampling lagoons located in Cape Krusenstern due to the simplified field logistics of using the NPS Ranger Station at Anigaaq as a base for a field camp. With our field camp at Anigaaq we were able to store and secure food and gear, operate a propane freezer for biological samples throughout the season, make quick commutes to Kotzebue and, have access to outhouse, cooking, and sleeping facilities. Lagoons sampled in Cape Krusenstern included Krusenstern, Aukulak, and Kotlik. We did not visit Bering Land Bridge lagoons during the 2018 field season due to unresolved flight logistic challenges (lack of float plane available for work and no permits provided to support helicopter access).

To reach Krusenstern Lagoon, we boated up the Tukrok River and through the adjacent wetland. We found two navigable routes through the network of waterways, islands, shallows that made up the wetland. Both routes were accessible all season and were approximately equal in travel time; however, as the season proceeded, aquatic vegetation increased and slowed travel by fouling the propeller of the 9.9 hp outboard engine. To reach Aukulak, we boated from Anigaaq Ranger Station to the mouth of the Tukrok River, then approximately 2.5 km SE along the Chukchi coast. Because Aukulak was not open to the Chukchi, we portaged the boat and gear across the marine edge berm into the lagoon. Due to its location 50 km north of Anigaaq ranger station, we accessed Kotlik Lagoon by fixed wing plane. While Kotlik Lagoon is close enough to access by four-wheeler from Anigaaq ranger station, exposed beach below the high-water mark does not consistently occur throughout the route, making safe travel along the coast ephemeral. Furthermore, some of the route requires transit over private lands which was not authorized for this project at this time. While visiting Kotlik we set up camp and staged gear on the terrestrial edge of the lagoon. Sampling for the Tukrok River was performed directly from our base at the ranger station.

Throughout the 2018 field season, our team partnered with several individuals based in Kotzebue village representing different organizations and agencies. We collaborated with Alex Whiting of the Native Village of Kotzebue, who provided extensive information on local fishing practices, logistical assistance and insight into our study sites. Additionally, Bill Carter of the Department of Fish and Wildlife Service's Selawik National Wildlife Refuge Office provided general logistical support as well as knowledge on and information about subsistence whitefish species included in our research. Collaboration was further supplemented by in-the-field interviews with members of the local community who provided traditional ecological and subsistence knowledge to guide our research. These interactions are touched upon in the following reporting.

Field Notes for Sampled Lagoons

Kotlik

July 9th, 10th, 11th

We arrived at Kotlik on the morning of the 9th July, the lagoon was open to the ocean. We conducted water quality data collection and three zooplankton tows. That same day we set a gillnet at camp which soaked for three hours total and was checked at one-hour intervals. We caught mostly starry flounder and humpback whitefish. The following day we set a total of three gillnets and conducted two beach seine pulls. We caught a large number of juvenile sculpin as well as starry flounder. Rain in the morning gave way to sunshine in the afternoon. Fishing efforts at the mouth revealed relatively low abundance compared to previous years. The lagoon was open to the ocean during the July sampling period. On the morning of the 11th July it was raining. We fished near camp, setting two gillnets and catching humpback whitefish and starry flounder. We observed a group of 5-7 female common eiders on the marine edge of the lagoon.

August 28th, 29th, 30th

We arrived at Kotlik to sample for the second time on August 28th and the lagoon had closed to the ocean. We completed half of the water quality data collection that evening, but winds picked up and we were not able to complete data collection. Weather cleared the next morning and we completed water quality and conducted four zooplankton tows. We set six gillnets total catching humpback whitefish, least cisco, starry flounder and saffron cod. While fishing at the mouth of the lagoon we observed a large group of schooling fish jumping at the surface of the water, but were unable to identify them to species. The following day we set a fyke net in the main body of the lagoon, but had to reset the net in the channel of lagoon due to high concentrations of algae fouling the net. A fyke net set in the channel soaked for two hours and caught mostly ninespine stickleback, juvenile Pacific herring, and juvenile flounder as well as several humpback whitefish. We set two gillnets in the channel of lagoon and caught a spawning chum salmon.

Krusenstern

July 2nd, 3rd, 4th, 7th

We sampled Krusenstern for the first time in 2018 on July 2nd. Upon arriving at the lagoon, the area that, in the past several field seasons has been the opening between the main body of the lagoon and the Tukrok River channel was blocked by a gravel berm, making boating straight into the lagoon impossible. We portaged the gear and boat over the berm and fished right inside what has historically been the mouth. We set a total of two gillnets and performed one beach seine pull catching mostly Pacific herring. We found a dead scaup on a gravel bar just inside the lagoon which we collected for necropsy by the National Park Service. The following day we returned to Krusenstern and set a fyke net near to what has historically been the mouth of the lagoon. While the fyke net soaked we set two gillnets, one nearshore and one further offshore catching mostly Pacific herring and humpback whitefish. After a three-hour soak time we pulled the fyke net which had caught mostly smaller forage fish, including juvenile Pacific herring, ninespine stickleback and pond smelt. We observed Arctic terns fishing around the mouth of the lagoon as well as Sabine's gulls and three female common eiders. On the 4th July we collected water quality data throughout the lagoon and conducted five zooplankton tows. On the gravel bar close to the fresh water inlet we encountered a female plover, which we think was a lesser sand plover, and several chicks as well as a female Arctic tern and chicks. On the 7th July we returned to Krusenstern and fished near the mouth of the lagoon setting a total of three gillnets and catching primarily humpback whitefish. While traveling to the lagoon we observed a gyre falcon and long billed dowitcher as well as several parasitic jaegers.

August 22nd, 25th, 27th

We revisited Krusenstern for the second round of sampling on August 22nd. Upon our first trip to the Krusenstern we discovered an alternate opening from the lagoon to the Tukrok channel. A breach in the berm separating the lagoon from the river had occurred further west, connecting a wetland associated with the river to the lagoon and we were able to boat through this area due to high water levels. Having observed this breach during a flight over the area while in transit to Kotlik lagoon, we believe this opening to have existed during our first sampling session as well. We set the fyke net to soak for a total of 3 hours. We set four gillnets near the open mouth of the lagoon and caught primarily humpback whitefish and Pacific herring. The fyke net caught a relatively low diversity of species, but with high abundance of juvenile herring (over 6,000 individuals) in addition to a large number of pond smelt. We fished at Krusenstern again on the 25th August, setting four gillnets at the open mouth of the lagoon and catching humpback whitefish, least cisco and one coho salmon. We attempted to collect water quality data, but were only able to visit three sites and collect two zooplankton samples before experiencing technical difficulties with our boat engine. We completed water quality data collected on the 27th August as well as performing another two zooplankton tows.

Aukulak

July 5th

We traveled to Aukulak Lagoon on the morning of July 5th. We boated out the Tukrok channel and down the coast to the lagoon, which was open to the Chukchi Sea but had a strong current flowing out of the lagoon making passing through the mouth by boat unsafe. We portaged the boat and gear over the berm further northwest from the mouth and fished just off the marine edge of the lagoon. We set a total of two gill nets and conducted two beach seine pulls. The beach seine pulls caught juvenile flounder, several larger whitefish (least cisco) and smaller forage fish (pond smelt and threespine stickleback). We collected water quality data and conducted three zooplankton tows. On our return journey to Anigaaq ranger cabin, we met Cyrus Harris, a member of the local Kotzebue community, who helped with gear portage and spoke to us about fishing success and lagoon breaching events. Cyrus described a large storm that occurred in November of the previous year that blew gravel from the beach up onto the land, affecting many of the local camps in the areas around the lagoons. Additionally, he mentioned visiting Krusenstern Lagoon that spring and noticing the change to the opening of the main body of the lagoon and attributed this change to the November storm event.

August 21st, 23rd, 26th

We traveled to Aukulak Lagoon on the 21st of August and the mouth of the lagoon had closed. The weather was clear and we collected water quality data and conducted four zooplankton tows. We conducted two beach seine pulls catching juvenile Pacific herring and juvenile flounder. We set two gillnets catching humpback whitefish, saffron cod, sheefish and several other species. We returned to Aukulak Lagoon on the 23rd, setting a fyke net for four hours in addition to two gillnets. We caught mostly humpback whitefish and least cisco in the two gillnets. The fyke net caught primarily forage fish, including rainbow smelt, pond smelt and stickleback as well as some whitefish species. The fyke net also caught a large number of juvenile Coho Salmon. We sampled Aukulak for the final time during the 2018 field season on August 26th. We traveled to Aukulak late in the morning via four-wheeler, the weather was rainy and windy. We set one gillnet off the shore of the marine side of the lagoon catching mostly sheefish and least cisco.

Tukrok River Channel

July 6th

We sampled the Tukrok River channel by the ranger station on July 6th. We set one gillnet from shore and caught mostly starry flounder, humpback whitefish and threespine stickleback. The weather was warm and sunny. We traveled up the Tukrok channel to clear creek to collect fresh water and observed a large flock of tundra swans.

August 24th

We fished the Tukrok River channel on August 24th and the mouth of the channel had been closed by a large gravel berm. We fished using a gillnet set from shore for a total of two hours. We caught humpback whitefish, starry flounder and Pacific herring as well as one spawning pink salmon.

RESULTS AND DISCUSSION

Water Quality

Temperature and Salinity

Physiochemical properties varied between lagoons. All lagoons were open to the marine environment during the first round of sampling and closed during the second round of sampling. While average salinity levels at Kotlik Lagoon dropped between the first and second sampling rounds (20.83 ±1.29 ppt down to 16.83 ±1.96 ppt), Aukulak Lagoon increased in average salinity throughout the season (11.86 ± 0.30 ppt to 12.48 ± 0.11 ppt). Krusenstern also increased in average salinity going from 3.65 ± 0.22 ppt in July to 4.30 ± 0.09 ppt in late August. Mean salinity level at Aukulak Lagoon during 2018 was significantly higher than the previous field season (12.17 ppt in 2018 versus 3.51 ppt in 2017). Aukulak Lagoon may not have had significant influx of saline water from the ocean side during the 2017 season based on being closed during our visits. In the past, when open to the marine environment, Aukulak has had relatively high mean salinity levels, and, while salinity levels recorded during 2018 are higher than the 2017 season, they remain lower than both the 2016 and 2015 mean salinity levels (25.37 ppt and 18.3 ppt, respectively). In the past, salinity levels at Krusenstern have always remained low, ranging from 2.1 ppt in 2015 to 4.7 ppt in 2016. Being that the main body of the lagoon is so far from its primary exchange with saline water from the ocean, which occurs only when salt water flows through the Tukrok channel from its opening at Anigaaq, it appears that mean salinity levels do not fluctuate as intensely as they do in Aukulak Lagoon. Mean salinity level at Kotlik Lagoon was comparable to historical values, resembling readings of the 2015 and 2016 seasons most closely (19.6 ppt and 22.58 ppt, respectively).

Temperature at all three lagoons decreased over the course of the season (Table 3.) Average decrease in temperature was 2.43 ± 1.12 °C. Average drop in temperature was smaller than previous seasons, with the most drastic temperature shift recorded in 2015 (-11.6 ± 1.6 ˚C from early July to early September). Average temperature at Krusenstern Lagoon was 2.5 °C higher that previously recorded (15.02 ± 1.51°C) with an average overall temperature from previous field seasons of 12.59 °C. Temperatures at Kotlik and Aukulak Lagoons were comparable to previous seasons (Table 2.)

Dissolved Oxygen/pH

Mean dissolved oxygen levels at all three lagoons were comparable to readings from the 2017 season with average overall concentrations ranging between 102.1 ± 2.12% and 108.57 ± 9.35% ODO (Table 2.). Dissolved oxygen readings were lower than those recorded during the 2016 when the mean dissolved oxygen level throughout all three Krusenstern lagoons was 119.91 ± 2.23% ODO.

Average pH was highest at Krusenstern Lagoon (9.15 ± 0.13) and lowest at Aukulak (8.05 ± 0.09). Mean pH values at Aukulak and Kotlik lagoons were within the range in values recorded during previous field seasons. However, mean pH at Krusenstern Lagoon was higher than previous seasons with average values ranging from 8.02 in 2015 to 8.79 in 2017.

Primary Production

Primary productivity was highest at Krusenstern Lagoon with a mean chlorophyll level of 27.12 ± 17.37 mg/L and mean blue green algae (BGA) reading of 181.76 ± 88.83 µg/L. Readings varied highly throughout the lagoon during both sampling sessions with no discernable pattern in primary productivity between the two sample periods. Primary productivity increased over the course of the season at Kotlik Lagoon with average chlorophyll levels growing from 0.74 (±0.35 mg/L) to 2.73 (±1.24 mg/L) and BGA increasing from 12.22 (± 2.80 µg/L) to 25.15 (±9.93 µg/L). Chlorophyll levels fell at Aukulak Lagoon from 9.03 (±2.58 mg/L) to 7.78 (±2.34 mg/L). BGA concentrations increased over the course of the season at Aukulak growing from 77.81 (±17.74 µg/L) to 92.59 (±26.60 µg/L).

We observed high concentrations of algae in the water column at Kotlik Lagoon during both sample sessions. During the July sampling we had several gillnets fouled by large amounts of algae. In August we were forced to move several nets set in the main body of the lagoon to the more sheltered channel due to algae fouling the net.

Zooplankton Sampling

Zooplankton surveys were performed at all lagoons, with 3-5 samples taken per lagoon. Samples were sent to University of Alaska facilities in Juneau for processing and will be analyzed for species composition.

Fish Sampling

Species Richness and Composition

Species richness and relative abundance in lagoons fluctuated during the course of each field season with population composition and density varying between both season and lagoon. We recorded a total of 22 different species including several key forage and important subsistence species, a higher overall richness than the 2017 field season when 19 species were encountered. Key forage fishes included ninespine stickleback, threespine stickleback, pond smelt, rainbow smelt, and Pacific herring. Important subsistence species included humpback whitefish, least cisco and sheefish. Species richness was highest at Aukulak Lagoon with 18 different species caught (Table 5.). Only 15 species were captured at both Kotlik Lagoon and the main body of Krusenstern Lagoon (Table 5.). Species richness at all three lagoons was higher than recorded during the 2017 season.

The Tukrok channel had a total species richness of 11 (Table 5.). Nine total species were found in common between the river channel and the main body of Krusenstern lagoon. Two species, including belligerent sculpin and pink salmon, were found only in the river channel. Six species were found only in the main body of Krusenstern, including Bering cisco, chum salmon, coho salmon, four-horned sculpin, ninespine stickleback and pond smelt (Figure 2.). Fishing during the 2017 field season produced a total of 14 different species in the channel of the Tukrok and only 11 in the main body of Krusenstern Lagoon suggesting frequent movement between the lagoon and the channel connecting the marine environment. Lower species diversity in the Tukrok during the 2018 season may suggest more limited movement between the main body of the lagoon and the mouth of the channel compared to the 2017 season, or relatively limited sampling missing movement events between the ocean and lagoon.

There were limited discernable trends in migratory fish catches throughout the season. Previous sampling efforts have revealed a noticeable decrease in catches of migratory species (e.g. sheefish, humpback whitefish) towards the 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. However, fishing during the 2018 field season produced comparable numbers of most migratory species throughout the course of the season with the exception of Pacific herring. August sampling of the Tukrok river channel caught over eight times the number of Pacific herring compared to the July sampling. Herring likely became aggregated at the outlet of the lagoon due to being unable to leave due to absence of connectivity to the Chukchi Sea. These results were similar to those of the 2017 season, when large schooling groups of fishes were observed at the mouth of the river channel during the final sampling effort of the season.

Laboratory Analysis

Samples taken during the 2018 field season will be evaluated for stable isotopes, mercury levels, genetic information, and life history. Using results from these analyses we hope to answer several questions including:

- How genetically related or distinct are fish from closely separated study sites?
- Do mercury levels in fishes vary between study sites?
- Do stable isotope values in whitefish vary with geographic region, age, sex and length?
- Do total mercury levels vary with the relative trophic position of the whitefish?

Otoliths, Fin Clips and Muscle Plug Samples

Otoliths were extracted from a total of 176 individuals over five species including: humpback whitefish, Being cisco, least cisco, Pacific herring and sheefish. Microchemistry analysis of otoliths can provide key information on fish life history, age structure and migratory patterns. We collected a total of 228 fin clip samples with the majority of samples taken from Krusenstern lagoon. Genetic information derived from fin clip sample analysis will provide insight into the genetic relationship between fish from closely separated study sites. Muscle plugs were taken at Aukulak Lagoon exclusively, with a total of 30 samples taken from humpback whitefish, least cisco, Pacific herring and sheefish. Muscle plugs will be analyzed for total mercury levels. Samples will be analyzed for mercury content at the University of Alaska, Fairbanks. Samples taken by species and lagoon can be found in tables 6. through 8.

Traditional Ecological Knowledge

Traditional ecological knowledge was informally collected through chance encounters with members of the local community throughout the field season. While we have had the chance, during previous field seasons, to interview several local community members at length, we did not conduct any in depth interviews during the 2018 season. The single extended interaction with a local community member was our meeting with Cyrus Harris, who provided logistical support as our crew traveled back from Aukulak lagoon. Apart from discussing logistics with Cyrus, he told us about the trench fishing techniques he and his family would be using later on that season now that the channel to the Tukrok river had closed. These techniques include digging a trench into the gravel bar that separates the river from the ocean so that water flows out of river and towards the ocean, bringing the fish that congregate at the mouth of the river with it. Because the trench becomes gradually shallower, the fish are stuck on the gravel and fishermen can pick them as they become stranded on the gravel bar. Cyrus explained that the best time to trench fish was late in the season, around October. This way the desired species will have spent the summer feeding and growing inside the lagoon and will be large enough to dry and preserve for the winter. Cyrus discussed the importance of upholding traditional fishing practices and explained that knowledge of the dynamics and ecology of the lagoon help to understand the populations of species that are important for subsistence use.

Outputs

Media Outputs

Video by Eben Hobson illustrating sampling effort at Cape Krusenstern Lagoons:
https://vimeo.com/304516747?fbclid=IwAR1HYTecG4-VrtKn7bSmP5GayO8XjIHgkMl1yUc7ReBNlIhfOm57THdLvNA

Scientific Outputs

Tibbles, M., and M.D. Robards. 2018. Critical trophic links in southern Chukchi Sea lagoons. Food Webs 15. E00099.

Future Directions

Data compiled throughout the 2018 field season builds upon a database of baseline information compiled from previous field seasons. While our research encompasses many aspects of lagoon ecology and provides valuable insight into the complexity of these systems, there remain important knowledge gaps that we hope to address in future field efforts.

1. In an effort to continue to develop knowledge of feeding behavior and diet contents of fish species that exist in these lagoons, it is important to further expand our understanding of mysid abundance at our study sites. Preliminary analysis of diet contents indicates the significance of mysids in most species' diets. A more comprehensive understanding of the movement of mysid populations throughout the lagoons has the potential for providing further insight into feeding habits of major subsistence species that feed in these lagoons. While several mysid community sampling protocols have been tested since the inception of the lagoon research project, we have yet to identify a technique that works best for these purposes;
2. While we have acknowledged the importance of monitoring animal activity associated with the lagoons, a workable protocol has still not been developed. During the 2017 field season we compiled a preliminary list of bird species observed at study sites;

3. In the future we will continue to build on the preliminary profile of fish communities in the Tukrok River and the Chukchi Sea in order to establish a better understanding of movement of species between the marine and lagoon environment.
4. Detection of timing and location of seasonal berm breaching is a critical need given the importance for lagoon ecology. Efforts should continue to assess remote sensing techniques to confirm this facet of the annual cycle of lagoons.
5. Based on poor success with the Ponar Grab in past years, we did not attempt to sample the benthos during the 2018 field season. Benthic and epibenthic sampling is still of interest, but should be a collaboration with experts in this field.

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TABLES AND FIGURES

Table 1. Lagoon size, general salinity, and water exchange for southern Chukchi Sea lagoons (ordered north to south). Data from Reynolds, 2012; Blaylock and Houghton, 1983; Robards, 2014; current study.

NPS Unit	Lagoon	Size (km^2)[1]	Physical Tendency[2]	Connection
CAKR	Ipiavik	14	Fresh/Brackish	Open Channel
	Port	2	Fresh	Closed
	Imik[4]	5	?	Intermittently Open
	Kotlik	24	Brackish	Intermittently Open
	Tasaycheck	0.5	Fresh/Brackish	Intermittently Open
	Atilagauraq	< 0.5	Fresh/Brackish	Intermittently Open
	Krusenstern	56	Fresh	Seasonally-Closed
	Aukulak	6	Fresh/Brackish[3]	Intermittently Open
	Sisualik	34	Fresh	Open
	Espenberg	12	Marine	Open
	Kupik	109	Brackish	Open Channel
BELA	Shishmaref[4]	370	?	Open
	Arctic	430	Brackish	Open Channel
	Ikpek	128	Brackish	Open Channel
	Lopp	176	Brackish	Open Channel

[1] We recognize the subjectivity in describing boundaries– our estimates delineate the main water body (for example not including the long channel connecting Krusenstern Lagoon to the ocean).
[2] Based on average salinity within lagoon: <11 fresh; >11 - <30 brackish; >30 marine (see Table 3)
[3] Physical tendencies depend on the dynamics of the seasonal opening. In 2015, Aukulak was brackish due to an early season connection with the marine environment.
[4] Imik and Shishmaref lagoons have not been visited during any field season so far.

Table 2. Mean (standard deviation) water quality parameters at each lagoon during the 2018 field season

	Depth (m)	Temperature (°C)	SPC (mS/cm)	Salinity	ODO %	pH	Chlorophyll mg/L	BGA µg/L
Kotlik	1.36 (0.33)	13.19 (1.79)	27615.36 (9969.70)	18.90 (2.33)	102.98 (8.14)	8.38 (0.26)	1.64 (1.30)	17.88 (9.38)
Krusenstern	2.13 (0.17)	15.02 (1.51)	7109.08 (642.94)	3.94 (0.37)	108.57 (9.35)	9.15 (0.13)	27.12 (17.37)	181.76 (88.83)
Auluak	1.07 (0.25)	14.94 (0.68)	20417.58 (653.83)	12.17 (0.39)	102.10 (2.12)	8.05 (0.09)	8.41 (2.46)	84.80 (23.81)

Table 3. Mean (standard deviation) for salinity and temperature at each lagoon over the 2018 field season. Numbers proceeding lagoon names correspond with sample round where 1 = July sample effort and 2 = August sampling effort.

Lagoon	Salinity (ppt)		Temperature (°C)	
	AVG	SD	AVG	SD
Kotlik 1	20.83	1.29	14.55	0.46
Kotlik 2	16.83	1.96	11.25	0.45
Krusenstern 1	3.65	0.22	16.28	0.19
Krusenstern 2	4.30	0.09	13.45	0.64
Aukulak 1	11.86	0.30	15.53	0.42
Aukulak 2	12.48	0.11	14.36	0.13

Table 4. Number of gear sets (mean set time in hours) by type for each lagoon. Note: beach seine sampling is active and does not include allowing the net to soak for an extended period of time.

	Gear Type		
Lagoon	**Beach Seine**	**Gill Net**	**Fyke Net**
Kotlik	2	19 (1.14)	1 (2.2)
Krusenstern	1	14 (1.77)	2 (2.85)
Aukulak	4	7 (1.51)	1 (3.75)

Table 5. Species diversity by lagoon, x indicates species was experienced at corresponding lagoon.

Species	Lagoon			
	Kotlik	Krusenstern	Aukulak	Tukrok Channel
Arctic Flounder	x	x	x	x
Belligerent Sculpin	x			x
Bering Cisco		x	x	
Chum Salmon	x	x		
Coho Salmon		x	x	
Fourhorned Sculpin		x	x	
Humpback Whitefish	x	x	x	x
Juvenile flounder	x		x	
Juvenile Sculpin	x		x	
Juvenile Smelt			x	
Least Cisco	x	x	x	x
Ninespine Stickleback	x	x	x	
Pacific Herring	x	x	x	x
Pink Salmon			x	x
Pond Smelt	x	x	x	
Rainbow Smelt		x	x	x
Saffron Cod	x	x	x	x
Sand Lance	x			
Sheefish		x	x	x
Starry Flounder	x	x	x	x
Threespine Stickleback	x	x	x	x
Tubenose Poacher	x			

Figure 2. Venn diagram showing species overlap between the Tukrok river channel and the main body of Krusenstern lagoon.

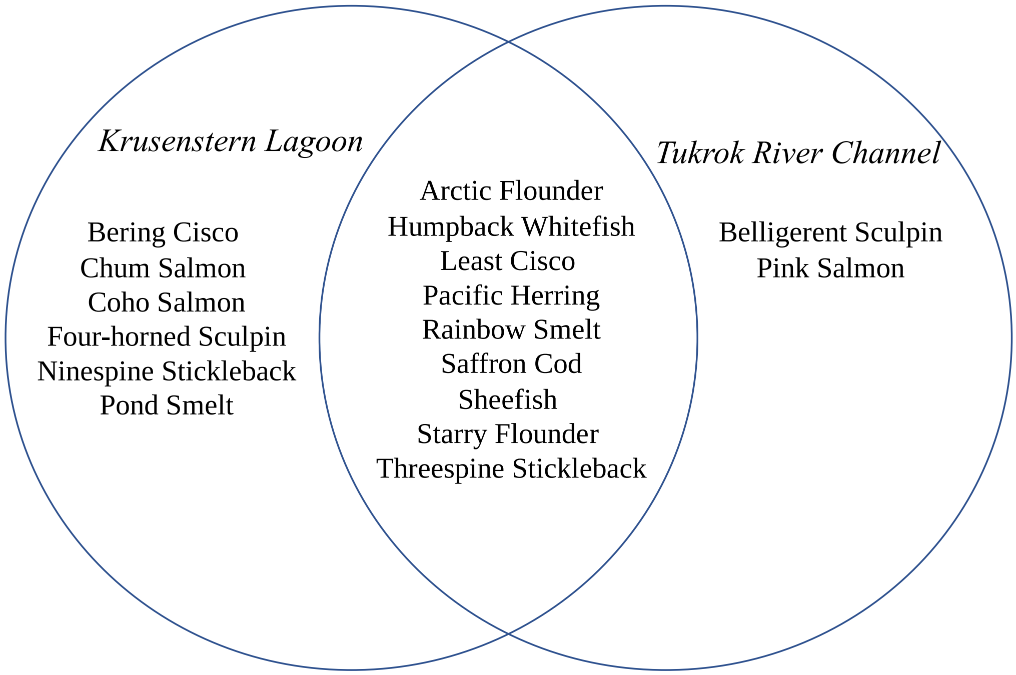

Table 6. Number of samples by species by type for Kotlik lagoon

Species	Otolith	Fin Clip	Muscle Plug
Humpback Whitefish	20	27	0
Least Cisco	6	6	0
Pacific Herring	1	1	0

Table 7. Number of samples by species by type for Krusenstern lagoon

Species	Otolith	Fin clip	Muscle Plug
Bering Cisco	2	2	0
Humpback Whitefish	21	41	0
Least Cisco	22	26	0
Pacific Herring	20	29	0
Sheefish	5	5	0

Table 8. Number of samples by species by type for Aukulak lagoon

Species	Otoliths	Fin Clip	Muscle Plug
Humpback Whitefish	26	32	13
Least Cisco	23	29	6
Pacific Herring	11	11	3
Sheefish	19	19	8

Table 9. Summary of zooplankton samples taken at Cape Krusenstern during the 2018 field season.

Date	Lagoon	Latitude	Longitude	Time	Flow Start	Flow Stop
7/4/18	Krusenstern	67.13139	-163.53567	12:01	029700	032115
7/4/18	Krusenstern	67.17374	-163.63779	13:53	034380	035730
7/4/18	Krusenstern	67.18892	-163.69072	14:47	035740	036443
7/4/18	Krusenstern	67.12388	-163.66975	15:56	036445	036921
7/4/18	Krusenstern	67.13158	-163.51047	16:59	038088	038395
7/5/18	Aukulak	67.05924	-163.26683	14:59	038430	039092
7/5/18	Aukulak	67.05737	-163.24327	15:16	039100	039853
7/5/18	Aukulak	67.05859	-163.25667	15:42	039899	040343
7/9/18	Kotlik	67.41596	-163.81339	14:30	040400	040485
7/9/18	Kotlik	67.38887	-163.84229	15:10	040500	NA
7/9/18	Kotlik	67.34601	-163.82133	16:50	041850	043474
8/21/18	Akulak	67.06067	-163.2507	11:12	080124	083011
8/21/18	Akulak	67.061	-163.229	11:32	083012	086129
8/21/18	Akulak	67.07	-163.239	11:49	086128	088330
8/21/18	Akulak	67.08062	-163.27019	12:15	088329	089761
8/25/18	Krusenstern	67.13033	-163.55359	12:44	089785	091048
8/25/18	Krusenstern	67.1413	-163.61739	13:08	091050	092758
8/27/18	Krusenstern	67.18741	-163.69881	10:35	092802	094400
8/27/18	Krusenstern	67.16864	-163.72028	10:54	094423	095722
8/28/18	Kotlik	67.34602	-163.81879	20:04	095749	097607
8/28/18	Kotlik	67.36555	-163.8205	20:17	097628	099239
8/29/18	Kotlik	6740087	-163.79193	11:26	100000	101501
8/29/18	Kotlik	67.3989	-163.82677	11:50	101514	103204

APPENDIX 1: Catalogue of Coastal Lagoons Including their Coastline Length, Latitude and Longitude

Appendix 1: Coastal lagoons located between Wales, Alaska and the Canadian border. Lagoons were characterized as coastal bodies of water that are separated from the ocean by barrier islands. Lagoons are typically parallel to shore, and are connected to the ocean, at a minimum, seasonally.

Lagoon Name	Adjacent coastline length	Centroid latitude (DD)	Centroid longitude (DD)	Notes
Lopp Lagoon	42	65.748483	-167.900311	
Ikpek	28.3	65.970459	-167.052476	
Arctic	29.4	66.125899	-166.53867	
Shishmaref	44.7	66.3373	-165.72313	
Kupik	36	66.480387	-165.070989	
Espenberg	52.4	66.444181	-163.661938	
NoName1	2.11	66.058733	-163.139605	
NoName2	2.15	66.042369	-162.645261	
NoName3	3.6	66.042214	-162.561935	
Kiwalik	7.66	66.023826	-161.840787	
Swan Lake	4.98	66.884352	-162.611331	
Aukulak	5.5	67.056001	-163.243076	
Krusenstern	18.4	67.108306	-163.700997	
Tasaychek	1.94	67.272593	-163.770781	
Kotlik	7.88	67.379310	-163.844472	
Imik	3.77	67.489363	-163.951627	
NoName4	0.66	67.552509	-164.024668	
Tasaitsat Angayukangnk	2.3	67.565977	-164.044756	
Tasaitsat Lagoons	1.73	67.583075	-164.070738	2 connected lagoons
Ipiavik	6.9	67.618856	-164.149012	
Imikruk	9.6	67.667769	-164.311815	
Kivalina	14.9	67.770818	-164.643601	
Asikpak	3.79	67.840518	-164.826582	
Kavrorak	1.92	67.86671	-164.902347	
Tugak	1.4	67.895806	-164.985171	
Pusaluk	2.1	67.911242	-165.027188	
Tasikpak	4.42	67.939176	-165.105690	
Seppings	1.19	67.957169	-165.169963	
NoName5	1.26	67.967568	-165.189258	
Singoalik	2.97	67.988782	-165.234006	
Pusigrak	2.19	68.012182	-165.296525	
Mapsorak	3.27	68.032874	-165.368762	
Atosik	0.95	68.049464	-165.439273	
Akoviknak	4	68.198634	-166.039193	
Kemegrak	3.65	68.226709	-166.094108	
Aiautak	22	68.295192	-166.335853	

Marryat Inlet	27.5	68.384677	-166.605426	Inlet
NoName6	0.39	68.872420	-166.061326	
NoName7	3.43	68.863471	-165.88084	
Ayugatak	7.29	68.853329	-165.665783	
Agiak	4.12	68.915184	-164.510214	
NoName8	1	68.936217	-164.203152	
Punuk	2.63	68.943676	-164.158533	
NoName9	0.45	68.959567	-164.10389	
NoName1	0.44	69.013299	-163.878301	
Omalik	2.73	69.153922	-163.512556	
Kasegaluk	192	70.072922	-162.510958	
NoName11	1.27	70.474762	-160.452178	
NoName12	2.46	70.493079	-160.402229	
NoName13	1.32	70.510563	-160.351475	
NoName14	0.44	70.517039	-160.331407	
NoName15	2.3	70.527595	-160.300487	
Wainwright Inlet	7.68	70.609905	-160.102942	Inlet
NoName16	6.44	70.796702	-159.638709	
Kugrua Bay	23.7	70.859339	-159.186895	
NoName17	0.2	70.830809	-158.032372	
NoName18	0.15	70.90792	-157.649591	
NoName19	0.37	71.012984	-157.329269	
NoName2	0.37	71.023969	-157.303946	
Walakpa Bay	1.18	71.149696	-157.073476	Bay
NoName21	0.83	71.242443	-156.89706	
Nunavak Bay	3.16	71.257147	-156.867126	Bay
Isatkoak Lagoon	1.18	71.298577	-156.774715	
South Salt Lagoon	0.98	71.312638	-156.72843	
Middle Salt Lagoon	1	71.321977	-156.699845	
North Salt Lagoon	1.21	71.338904	-156.629586	
Elson	71.3	71.206394	-155.714796	
NoName22	3.87	71.050867	-154.708879	
NoName23	1.98	71.019459	-154.623771	
NoName24	2.66	70.894597	-154.604693	
NoName25	0.81	70.876470	-153.944175	
NoName26	1.68	70.883862	-153.50672	
NoName27	0.71	70.894415	-153.381249	
NoName28	2.1	70.919568	-153.23415	
NoName29	2.9	70.876765	-152.706467	
NoName3	0.39	70.880279	-152.611343	Embayment
NoName31	0.55	70.881513	-152.590295	
NoName32	0.43	70.861887	-152.455718	
NoName33	0.75	70.856469	-152.396868	

NoName34	1.15	70.844408	-152.356676	
NoName35	1.16	70.834400	-152.287882	
NoName36	0.63	70.829505	-152.255953	
NoName37	0.0045	70.827394	-152.243445	
NoName38	2.75	70.80571	-152.193914	
Simpson	59	70.518307	-149.190945	Bounded by barrier islands
NoName39	2.54	70.205753	-147.571076	
NoName40	22.2	70.091894	-145.589101	
NoName41	14.2	70.039956	-144.332312	Barrier island lagoon
Arey	52.4	70.128326	-143.388220	
NoName42	39.9	69.867907	-142.169887	
NoName43	19.8	69.704395	-141.451472	Inlet
Total length adjacent to coastline	**986.0745**			
Total coastline length	**2690**			

Appendix 2: Metadata for Excel Archive

Tab 1: Water Quality

Field 1: Lagoon
Field 2: Depth
Field 3: Temperature
Field 4: Specific Conductivity
Field 5: Salinity
Field 6: Dissolved Oxygen %
Field 7: Dissolved Oxygen mg/L
Field 8: Chlorophyll
Field 9: Blue Green Algae
Field 10: Turbidity
Field 11: Grab Sample ID Number = Identification number for grab sample to be analyzed for nitrogen and phosphorus content
Field 12: Notes
Field 13: Date
Field 14: Water Quality Point Name
Field 15: Time of Day

Tab 2: Length and Weight Data

Field 1: Date
Field 2: Lagoon Name
Field 3: Site Description
Field 4: Latitude
Field 5: Longitude
Field 6: Gear Type
Field 7: Set Time
Field 8: Check Number = if gear type was a gillnet this field indicates what number replicate the specimen was recorded under
Field 9: Check Time
Field 10: Species
Field 11: Count
Field 12: Length
Field 13: Weight
Field 14: Sample Number = Reference number for laboratory analysis
Field 15: Sample type (where FC = Fin Clip, Ox# = Otolith and how may were successfully extracted, MP = Muscle Plug)
Field 16: Notes

Tab 3: Zooplankton

Field 1: Date
Field 2: Lagoon
Field 3: Site Name
Field 4: Latitude
Field 5: Longitude
Field 6: Time of Day
Field 7: Sample Name
Field 8: Flow meter reading at the beginning of the tow
Field 9: Flow meter reading at the end of the tow