

ABSTRACT

ARCTIC COASTAL LAGOONS OF CAPE KRUSENSTERN NATIONAL MONUMENT: SUBSISTENCE, ECOSYSTEM CHARACTERIZATION, AND MANAGEMENT

by

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The main objective of this research was to provide baseline water quality and species data for the five coastal lagoons in Cape Krusenstern National Monument (CAKR). Coastal lagoons are habitat for fish species that are utilized by many local residents in their subsistence lifestyle. The five chapters address the following: 1) background information, 2) summary of subsistence in Alaska, 3) physicochemical and species data collection in the CAKR lagoons between January 2003 – September 2004, 4) development of a long-term monitoring plan for the CAKR lagoons, and 5) overall conclusions.

The data demonstrate that salinity and dissolved oxygen were highly variable in all the lagoons, particularly during ice-covered seasons. In contrast, all CAKR lagoons showed little

ABSTRACT

variation in water temperature throughout the seven sampling periods. Multidimensional scaling plots of the physicochemical parameters indicated that Akulaaq, Krusenstern, and Sisualik each provide different environments that are influenced by estuarine connectivity, the conditions at freeze-up, and local weather conditions. Akulaaq Lagoon reached hypersaline levels in April 2003 ($62.1 \text{ psu} \pm 1.8$), but was back to estuarine levels by July 2003 ($8.1 \text{ psu} \pm 0.1$), representing a highly variable environment. Krusenstern Lagoon provided a more stable environment and is likely a potential overwintering habitat for fish species. Sisualik Lagoon was also highly variable and exhibited the greatest amount of station variability in salinity during any one sampling period (38.2%). It was the only lagoon to develop a halocline during July 2003 and September 2004. All the CAKR lagoons experienced an increase in chlorophyll *a* between January and April and in April 2003, a spring bloom was recorded in Krusenstern ($29.6 \text{ } \mu\text{g/L} \pm 8.2$). Copepods and Cladocerans were the most abundant zooplankton in all the lagoons. Several *Coregonus spp.* utilize Akulaaq, Krusenstern, and Sisualik with Sisualik having the greatest number of benthic macroinvertebrate and fish species ($N = 20$). The National Park Service long-term monitoring protocol for the CAKR coastal lagoons was a direct product of this research. Inventory and monitoring of the resources of the CAKR lagoons is critical during this period of increased resource exploration, global climate change, and continued subsistence in Northwest Alaska.

ARCTIC COASTAL LAGOONS OF CAPE KRUSENSTERN NATIONAL MONUMENT:
SUBSISTENCE, ECOSYSTEM CHARACTERIZATION,
AND MANAGEMENT

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By

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DEDICATION

To my mom and dad - You have always been there for me, encouraging me, believing in me when I couldn't believe in myself. This journey has been a long, often rough road, but in Dad's words, "all things are ephemeral". Dad, you left us mid-journey to be in a better place, but I know it is your undying love, support, and belief in me that has allowed me to complete this often, overwhelming task. I know you're looking down from above with tears in your eyes, happy tears, proud tears. I am indebted to you and mom for instilling in me the courage and strength to follow my heart to the Arctic. I know it wasn't easy to see me go so far away, but you never once tried to stop me. Thank you both for giving me the wings to soar and explore.

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TABLE OF CONTENTS

LIST OF TABLES	xiv
LIST OF FIGURES	xvi
CHAPTER 1: INTRODUCTION	1
1.1 Statement of the Problem	1
1.2 Study Area	4
1.2.1 Geographic Setting	4
1.2.2 Regional Climate	5
1.2.3 Regional Paleogeography	5
1.2.4 Cape Krusenstern National Monument Designation and Significance	8
1.2.5 Cape Krusenstern National Monument Coastal Lagoon Descriptions	9
1.3 Arctic Systems Literature Review	10
1.3.1 Physicochemical Parameters	10
1.3.2 Species Composition	16
1.3.2.1 Zooplankton	16
1.3.2.2 Benthic Invertebrates	17
1.3.2.3 Fish Species	18
1.4 Significance and Objectives	19
CHAPTER 2: THE ROLE OF SUBSISTENCE IN ALASKA	29
2.1 Subsistence Defined	29
2.2 Subsistence Resource Users	31
2.3 Subsistence in Northwest Alaska	32

TABLE OF CONTENTS

2.4	The History of Subsistence in Alaskan National Parks.....	35
2.5	Subsistence within Cape Krusenstern National Monument.....	39
2.5.1	Sisualik: A Seasonal Gathering Place for Subsistence Activities	40
2.5.2	Anigaaq: The Location of a Primary Subsistence Fishery within Cape Krusenstern National Monument	42
2.6	The Connection	44
CHAPTER 3: ARCTIC COASTAL LAGOONS OF CAPE KRUSENSTERN NATIONAL MONUMENT: BASELINE SPATIO-TEMPORAL PHYSICOCHEMICAL AND SPECIES DATA.....		56
3.1	Introduction	56
3.2	Setting and Methods.....	58
3.2.1	Site Description	58
3.2.2	Sampling Design	60
3.2.3	Sampling/Laboratory Methods.....	60
3.2.4	Data Analysis	63
3.3	Results	65
3.3.1	Spatial Comparisons.....	65
3.3.1.1	Physicochemical Parameters: Ice-Covered Seasons	66
3.3.1.1.1	January 2003	67
3.3.1.1.2	April 2003	67
3.3.1.1.3	January 2004	68
3.3.1.1.4	April 2004	69
3.3.1.2	Physicochemical Parameters: Open Water Seasons.....	69
3.3.1.2.1	July 2003	70

TABLE OF CONTENTS

3.3.1.2.2	September 2003	70
3.3.1.2.3	September 2004	71
3.3.1.3	Biological Parameters	71
3.3.1.3.1	Water Column Algal Biomass	71
3.3.1.3.2	Zooplankton	72
3.3.1.3.3	Benthic Macroinvertebrates and Ichthyofauna	73
3.3.2	Temporal Comparisons	74
3.3.2.1	Akulaaq	74
3.3.2.2	Krusenstern	75
3.3.2.3	Sisualik	76
3.3.3	Correlations	76
3.3.3.1	Ice-Covered Seasons	76
3.3.3.2	Open Water Seasons	77
3.4	Discussion	78
3.4.1	Physicochemical Parameter Comparisons	79
3.4.1.1	Ice-Covered Seasons	79
3.4.1.2	Open Water Seasons	82
3.4.1.3	Intra-Annual Comparisons	85
3.4.2	Biological Parameter Comparisons	86
3.4.2.1	Algal Biomass	86
3.4.2.2	Zooplankton	87
3.4.2.3	Benthic Macroinvertebrates and Ichthyofauna	88

TABLE OF CONTENTS

3.4.3	Parameter Relationships	92
3.4.3.1	Ice-Covered Seasons	92
3.4.3.2	Open Water Seasons.....	94
3.4.4	Summary and Recommendations	95
3.4.4.1	Future Management.....	98
CHAPTER 4: NATURAL RESOURCE MANAGEMENT IN THE NATIONAL PARK SERVICE AND THE DEVELOPMENT OF A COASTAL LAGOON MONITORING PROTOCOL FOR CAPE KRUSENSTERN NATIONAL MONUMENT		140
4.1	Sustainable Natural Resource Management.....	140
4.2	The National Park Service Approach	142
4.2.1	Developing Long-Term Monitoring Protocols in the National Park Service	147
4.2.2	The Proposed Long-Term Monitoring Protocol for CAKR Coastal Lagoons	148
4.2.2.1	Data Collection: What.....	149
4.2.2.2	Data Collection: When	150
4.2.2.3	Data Collection: How	152
4.2.3	Minimal Sampling Recommendations for CAKR Coastal Lagoons	154
4.2.3.1	Minimal Data Collection: What	154
4.2.3.2	Minimal Data Collection: When	155
4.2.3.3	Minimal Data Collection: How	155
4.3	Conclusion.....	157

TABLE OF CONTENTS

CHAPTER 5: CONCLUSION: A RETROSPECTIVE ON THE SAMPLING OF THE CAPE KRUSENSTERN NATIONAL MONUMENT COASTAL LAGOONS, BRIEF COMPARISONS, AND POTENTIAL SYSTEM STRESSORS.....	164
5.1 The Original Plan vs. Reality	164
5.2 Unexpected Developments / Outcomes	165
5.3 Lessons Learned	167
5.3.1 Logistics	167
5.3.2 Comparisons Between CAKR Lagoons	169
5.3.3 Comparisons Between CAKR Lagoons and Other Arctic Lagoons ..	171
5.4 Management Concerns - Potential Stressors on the CAKR Coastal Lagoons	175
REFERENCES	178
APPENDIX A: GPS COORDINATES	190
APPENDIX B: DEPTH PROFILES.....	191
APPENDIX C: STATION PHYSICOCHEMICAL MEANS / LAGOON.....	248
APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON.....	251
APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON	256
APPENDIX F: KRUSKAL-WALLIS RESULTS FOR SISUALIK LAGOON.....	262
APPENDIX G: STATION MEAN ALGAL BIOMASS / LAGOON	265
APPENDIX H: MEAN RELATIVE ABUNDANCE OF ZOOPLANKTON / LAGOON	266
APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON	268

LIST OF TABLES

1-1	Lagoon size and type of water exchange with the Kotzebue Sound	21
3-1	Lagoon size and type of water exchange with the Kotzebue Sound	100
3-2	Mean, standard deviation (± 1), and coefficient of variation (%) results for the physicochemical and pigment data collected from five coastal lagoons in CAKR between January 2003 and September 2004.....	101
3-3	Lagoon mean, standard deviation (± 1), and coefficient of variation (%) results for ice thickness, snow depth, and water depth collected from five coastal lagoons in CAKR during the four ice-covered sampling periods	103
3-4	Lagoon mean water depth, standard deviation (± 1), maximum water depth, and coefficient of variation for each lagoon in July 2003, September 2003, and September 2004	104
3-5	Zooplankton lagoon mean relative abundance and standard deviation (± 1) of the most abundant taxonomic groups in the five CAKR lagoons in July 2003, September 2003, and September 2004	105
3-6	List of benthos, epibenthos, and fish that were present in the lagoons between January 2003 and September 2004	106
3-7	Friedman Test results for the 2003 intra-annual comparison (January, April, July, and September) of physicochemical parameters at each station in each lagoon.....	107
3-8	Wilcoxon Signed Rank Test results for the interannual comparisons of physicochemical parameters measured in April 2003/2004 and September 2003/2004	108
3-9	Spearman rho correlation coefficients for six parameters in Akulaaq Lagoon during the 2003 ice-covered sampling periods (January 2003 and April 2003)....	110
3-10	Spearman rho correlation coefficients for six parameters in Krusenstern Lagoon during the 2003 ice-covered sampling periods (January 2003 and April 2003)	111
3-11	Spearman rho correlation coefficients for six parameters in Sisualik during the 2003 ice-covered sampling periods (January 2003 and April 2003)	112
3-12	Spearman rho correlation coefficients for five parameters in Akulaaq Lagoon during the open water sampling periods (July 2003, September 2003, and September 2004)	113

LIST OF TABLES

3-13	Spearman rho correlation coefficients for five parameters in Krusenstern Lagoon during the open water sampling periods (July 2003, September 2003, and September 2004)	114
3-14	Spearman rho correlation coefficients for four parameters in Sisualik during the open water sampling periods (July 2003, September 2003, and September 2004)	115
4-1	The 28 vital signs identified by the National Park Service Arctic Network Inventory and Monitoring Program	158
4-2	Recommended content for the protocol narrative portion of long-term monitoring protocols developed for the National Park Service.....	159
4-3	Revist sampling design for monitoring the coastal lagoons in CAKR	160

LIST OF FIGURES

1-1	Location of the four parklands that comprise the Western Arctic National Parklands (WEAR)	22
1-2	The location of the seven coastal lagoons in Cape Krusenstern National Monument.	23
1-3	Kotzebue Sound surrounds seasonal camps located at <i>Nuvuraq</i> , on the spit at Sisualik.....	24
1-4	A map of the beach ridges at Cape Krusenstern, indicating the shoreline changes of the past several thousand years.....	25
1-5	Sam Williams digging out his trench at Anigaaq in September 2003	26
1-6	Sam Williams waits for fish to enter the trench he dug at Anigaaq in September 2003	27
1-7	General reference map of Alaska.....	28
2-1	Cyrus Harris, Terry Reynolds, and Pedro Mendenhall pick sheefish out of a gillnet in February 2003.....	45
2-2	Lance Krammer harvesting a juvenile bearded seal in Kotzebue Sound in October 2004	46
2-3	A map of the beach ridges at Cape Krusenstern, indicating the shoreline changes of the past several thousand years.....	47
2-4	Whitefish harvested in the sloughs of Cape Krusenstern National Monument hang to dry at the seasonal camp of Sam Williams in July 2003	48
2-5	Denali Whiting, Village of Kotzebue Mayor Siikauraq Martha Whiting, and Augustine Johansen process whitefish harvested with gillnets in the sloughs of Cape Krusenstern National Monument in July 2003	49
2-6	Seasonal camps located at Sisualik in July 2002	50
2-7	An aerial view of Anigaaq in September 2003	51
2-8	Cyrus Harris digs a trench at Anigaaq in October 2004	52
2-9	Joanne Sheldon near the trench she and Cyrus Harris dug at Anigaaq in October 2004	53

LIST OF FIGURES

2-10	Joanne Sheldon and Cyrus Harris pick whitefish from the gillnets they set near Anigaaq in September 2004.....	54
2-11	Cyrus Harris enjoys fresh whitefish eggs from a fish he just harvested in a gillnet set at Anigaaq in September 2004	55
3-1	The location of the seven coastal lagoons in Cape Krusenstern National Monument.....	116
3-2	Akulaaq Lagoon Sampling Stations	117
3-3	Imik Lagoon Sampling Stations	118
3-4	Kotlik Lagoon Sampling Stations.....	119
3-5	Krusenstern Lagoon Sampling Stations.....	120
3-6	Sisualik Lagoon Sampling Stations	121
3-7	Mean salinity in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004)	122
3-8	Mean dissolved oxygen in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004).....	123
3-9	Mean water temperture in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004).....	124
3-10	Coefficient of variation for lagoon mean salinity, dissolved oxygen, and water temperature in Akulaaq, Krusenstern, and Sisualik between January 2003 and September 2004.	125
3-11	Multidimensional scaling plot of physicochemical parameters during seven sampling periods.....	126
3-12	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons between January 2003 and September 2004	127
3-13	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in January 2003	128
3-14	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in April 2003	129
3-15	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in January 2004	130

LIST OF FIGURES

3-16	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in April 2004	131
3-17	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in July 2003	132
3-18	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in September 2003	133
3-19	Multidimensional scaling plot of physicochemical parameters in CAKR lagoons in September 2004	134
3-20	Mean relative abundance of the most abundant zooplankton in five CAKR lagoons in July 2003, September 2003, and September 2004	135
3-21	Multidimensional scaling plot of zooplankton in CAKR lagoons in July 2003	136
3-22	Multidimensional scaling plot of zooplankton in CAKR lagoons in September 2003.	137
3-23	Multidimensional scaling plot of zooplankton in CAKR lagoons in September 2004.	138
3-24	Multidimensional scaling plot of benthic macroinvertebrates and ichthyofauna in CAKR lagoons between January 2003 and September 2004	139
4-1	The role of inventory and monitoring in resource management.....	161
4-2	The 32 Networks of the National Park Service Inventory and Monitoring Program.....	162
4-3	The four networks of the NPS Alaska Region Inventory & Monitoring Program.....	163

CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Continual monitoring of resources within an ecosystem allows for change to be detected over time. Identifying and interpreting these changes and trends, in turn, results in a more comprehensive understanding of the ecosystem. The first step in monitoring changes and trends is an inventory of the resources present, “the inventory establishes the point of departure for required monitoring activities” (NPS-75, 3). The National Park Service (NPS) has recognized the need to inventory and monitor resources within the parks, “The Service will identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge...that will help park managers accomplish park management objectives...” (NPS Management Policy, Chapter 4:2.1, 2006). Identifying the resources and understanding the trends those resources are experiencing can help park managers make management decisions based on data rather than on assumptions. The importance of incorporating scientific knowledge into natural resource planning and decision-making is stated in the Service-wide management policy document, “...the Service will use the findings of science and the analyses of scientifically trained resource specialists in decision-making” (NPS Management Policy 4:1, 2006). This statement demonstrates that the value of scientific data is recognized by the NPS and that the collection of data will assist resource managers in the decision-making process.

Cape Krusenstern National Monument (CAKR) is one of four park units of the Western Arctic National Parklands (WEAR) located in Northwest Alaska (Figure 1-1). CAKR is remote and access is possible only via plane, boat, snowmachine, or ATV. This remoteness has

contributed to the lack of data concerning the natural resources within CAKR. In particular, CAKR is currently lacking baseline data of its aquatic resources. This lack of information has been noted by the Alaska Natural Heritage Program (ANHP). Lenz *et al.* (2001) compiled vascular plant and vertebrate species lists from all the Alaskan National Parks and stated the following about Cape Krusenstern, "...little park specific information exists for fish observations...This park needs a better documented fish inventory". This need for a better inventory of park resources is also stated in the Cape Krusenstern National Monument Resources Management Plan (NPS 1999). The need to expand baseline inventory is the number one priority on the natural resources projects list in this plan. Other projects of priority include: assess coastal zone resources, develop management strategies for aquatic resources, and assess fisheries. This management plan states that there is a lack of basic data for all the aforementioned priorities and that baseline data would help resource managers understand park ecosystems and help them make better management decisions.

Cape Krusenstern National Monument contains seven coastal lagoons (Akulaaq, Imik, Ipiavik, Kotlik, Krusenstern, Port, and Sisualik; Figure 1-2) that are likely to be essential fish nurseries, over-wintering habitats, and major feeding locations along coastal bird migration routes, as well as important locations for subsistence fishing and hunting (ARRT 2001). During freeze-up, many people "catch their winter's supply of whitefish at the outlets of the lagoons near Cape Krusenstern" (Georgette and Loon 1993). An aquatic inventory of these lagoons is not only important to gain park-specific information, but also to know more about these locally utilized resources.

This dissertation provides baseline data for the aquatic resources in Cape Krusenstern National Monument. Both abiotic and biotic parameters were measured in the following five

lagoons in CAKR: Akulaaq, Imik, Kotlik, Krusenstern, and Sisualik, with an emphasis on Akulaaq, Krusenstern, and Sisualik. Minimal data were collected from Imik and Kotlik due to remoteness and logistical challenges. Spatial and temporal sampling were conducted to address the following objectives: 1) to determine the variability in physicochemical parameters in each lagoon, 2) to determine zooplankton relative abundance, and 3) to determine presence/absence of benthic and fish species in each lagoon. The layout for the remainder of this dissertation is as follows:

Chapter 1: background information and literature review;

Chapter 2: summary of subsistence in Alaska, written to inform the reader of the importance of subsistence resources/lifestyles in Alaska, particularly in CAKR;

Chapter 3: methods, results, and discussion of spatiotemporal physicochemical and species data in the CAKR lagoons during seven sampling periods (January 2003 – September 2004);

Chapter 4: how the baseline data collected herein are contributing to the development of a long-term monitoring plan for the coastal lagoons of CAKR, the highlights of the proposed long-term monitoring protocol for the CAKR lagoons, and a recommended “minimal sampling protocol” to be instituted when funding is limited;

Chapter 5: a retrospective on the CAKR coastal lagoon sampling discussed in Chapter 3, comparisons of the CAKR lagoons with other arctic lagoons, and potential impacts from two possible system stressors – resource exploration and global climate change.

1.2 Study Area

1.2.1 Geographic Setting

Cape Krusenstern National Monument (also referred to as the Monument or CAKR throughout this document) is located approximately 72 km above the Arctic Circle with the Monument centerpoint at latitude 67°26'N and longitude 163°32'W (Figure 1-2). The Monument lies in the Western Brooks Range foothills and valleys and encompasses 2670 km² of land and water. All areas are underlain by thick permafrost (Ferrians 1965; Brown *et al.* 1998). CAKR is largely a treeless coastal plain with the Mulgrave Hills in the northern portion of the Monument and the Igichuk Hills in the southern portion (Figure 1-2). There are numerous small creeks and rivers flowing throughout CAKR. The Monument is bordered on the west and south by the Chukchi Sea and Kotzebue Sound, respectively. The Native Village of Kivalina is located 17 km northwest of the park boundary, the Native Village of Noatak is situated 13 km east of the park boundary, and the Native Village of Kotzebue is located 15 km southeast of the Monument boundary. Red Dog Mine, the worlds largest zinc mine, is located just outside the northeast corner of the Monument boundary. The haul road for the mine traverses the northern section of CAKR (Figure 1-2).

Several coastal lagoons are located within Cape Krusenstern National Monument. These lagoons vary in size with the smallest being Port Lagoon (2 km²) and the largest being Krusenstern Lagoon (56 km²). Many of the lagoons extend longitudinally along the coast and are fronted by barrier beaches. Small creeks and rivers flow into several of these lagoons. Moore (1966) observed that the lagoons in northwest Alaska are located in areas where the beach gently slopes towards the sea and are absent in areas dominated by steep slopes.

Seasonal camps dot the CAKR coastline from the southern to the northern boundary, with most camps located between Sisualik and Cape Krusenstern (locally known as Sealing Point). Sheshalik Spit, locally known as Sisualik, is the site of many seasonal camps (Figure 1-3). CAKR has few year-round residents, with most camps occupied intermittently.

1.2.2 Regional Climate

Northwest Alaska experiences a semi-maritime climate. The coastal waters are frozen nine months of the year and the area does not receive the large amounts of precipitation that are typical in a maritime climate (Allen and Weedfall 1966). Kotzebue's 30-year average air temperature in January is -19 °C and the 30-year average air temperature in July is 13 °C. In terms of annual precipitation and snowfall, the 30-year average is 25 cm and 1 m, respectively (NOAA-NCDC). According to the Western Regional Climate Center, the annual average wind speed in Kotzebue from 1996-2006 was 18.5 km/h. November had the highest wind speed during this time with an average of 22.5 km/h over the course of the month. October and February experienced the next highest wind speeds with averages of 20.0 km/h and 19.8 km/h, respectively. Based on hourly data from 1992-2002, the prevailing wind direction in the summer (May – August) was from the west while during the remaining 8 months of the year, the prevailing winds were from the east (WRCC).

1.2.3 Regional Paleogeography

The Wisconsin Glaciation, the last Ice Age of the Cenozoic Era, occurred from approximately 110,000 – 10,000 Years Before Present (YBP). It included many glacial advances and retreats which, consequently, caused sea levels to drop and rise, respectively. The glacial coverage throughout northwest Alaska was not as continuous as the glacial coverage throughout

Canada (O'Neill 2004). According to West (1996), the following areas in northwest Alaska were glaciated during the late Wisconsin glaciation (25,000 – 10,000 YBP): a portion of the Brooks Range along the Kobuk River, the headwaters of the Colville River, and small areas on the Seward Peninsula. Although the intermittent presence of these glaciers had regional effects, one of the most significant global outcomes was the repeated emergence and submergence of the Bering Land Bridge.

The Bering Land Bridge helps provide a history of the region through its alternating periods of submergence and resurgence. Evidence of faunal interchange, pollen profiles, as well as sedimentation records help scientists determine when this landform was below or above sea level (Hopkins 1959). According to Hopkins (1959), the “Bering-Chukchi platform” first submerged approximately one million years ago, near the beginning of the Pleistocene Epoch and was submerged during each interglacial interval of the Pleistocene. During glacial periods, as sea levels dropped up to 49 m below present levels, the landform would rise above sea level and the continents would again be interconnected (O'Neill 2004). The Bering Land Bridge was last above sea level 25,000 – 14,000 YBP (O'Neill 2004), however the Bering Strait was not regularly flooded until around 10,000 YBP (Elias *et al.* 1992). Sea level along the northwest coast of Alaska reached its approximate current location about 5,000 years ago (Hopkins 1959, Moore 1966).

The post-Pleistocene rise in sea level was the beginning of sediment deposition at Cape Krusenstern (Moore 1966). Gravel beaches began to form southward and formed a sand spit. As the sand spit grew around a large bay, the spit eventually sealed the bay off from the Chukchi Sea, forming the present lagoon (Giddings and Anderson 1986).

Sisualik Lagoon is currently open to the Kotzebue Sound and according to Giddings and Anderson (1986), the spit and beach ridge plain are in earlier stages of development compared to Krusenstern Lagoon. Sisualik Spit is growing as a result of some gravel bypassing Cape Krusenstern and depositing at the Sisualik Spit instead (Moore 1966). Giddings and Anderson (1986) stated “approximately eighty percent of Sisualik Spit has been formed in the last millennium, with the shore-line building out in a southeasterly direction” (p. 20). Moore (1966) calculated that since A.D. 1000, 21 million m³ of sediment have been deposited at Sisualik Spit. This translates into an average alongshore transport of sediment of 22,000 m³/yr to the east.

Imik Lagoon and Kotlik Lagoon also contain beach ridges in the northern portions of the lagoons, which indicate that they were formed at least 3,500 years ago and possibly even 4,500 YBP (Hopkins 1977). These beach ridges are the result of lagoon waves as well as ice-push within the lagoon (Hopkins 1977). Hopkins (1977) believes these lagoons may be the remnants of thermokarst lakes that were breached during periods of erosion. The barrier bar was then slowly rebuilt to form the present lagoons.

Moore (1966) conducted beach sedimentation studies along the northwest coast of Alaska between Point Hope and Sisualik Spit and found permanent deposition of sediment on the south side of Cape Krusenstern and also at the Sisualik spit. This accretion of sediment has formed 5 km of beach-ridge plains at Cape Krusenstern (Moore 1966). The mechanism for deposition was determined to be alongshore transport of sediment rather than onshore and offshore transport (Moore 1966). Moore (1966) observed that the onshore and offshore transport of sediment onto the beach during strong storms had little effect on the position of the shoreline.

The shoreline changes observed in the beach-ridge complex at Cape Krusenstern over the last several thousand years were most likely a function of wind speed and direction (Moore 1966,

Hopkins 1977; Figure 1-4). The location of the ridges (oldest inland) shows the accretion of the area due to the alongshore deposition. The various heights of the beach ridges provide historical records of sea level positions over the past several thousand years (Moore 1966). According to Moore (1966), these ridges suggest that sea level has risen approximately 3 m over the last 5,000 years and that the highest sea level position, since the Wisconsin Glaciation, was reached during the 19th century. Sea-level location will be a function of local processes (e.g. accretion due to alongshore deposition), regional processes (e.g. isostatic rebound), and global processes (e.g. deglaciation).

1.2.4 Cape Krusenstern National Monument Designation and Significance

Cape Krusenstern National Monument was established in 1978 by presidential proclamation and was designated in 1980 as part of the Alaska National Interest Lands Conservation Act (ANILCA, 16 USC 3101). It was established primarily to protect the many archeological sites including the series of 114 beach ridges located along the shoreline of Krusenstern Lagoon (Figure 1-4). These beach ridges record thousands of years of changing shorelines and civilizations: “These beach ridges, formed of gravel deposited by major storms and regular wind and wave action, record in horizontal succession the major cultural periods of the Arctic over the last 4,500 years” (NPS 1986). The historical significance of Cape Krusenstern was prioritized in ANILCA, but the monument was also established to preserve and protect the current relationship between people, the land, and its resources, “the monument shall be managed for the following purposes...to protect habitat for and populations of birds and other wildlife, and fish resources; and to protect the viability of subsistence resources” (ANILCA 201 (3)).

The lagoons within CAKR continue to provide for subsistence activities: “the most significant fishery for whitefish in the Kotzebue area takes place at Anigaaq, the outlet to Krusenstern Lagoon...” (Georgette and Shiedt 2005). Every fall the mouth of the Tukrok River (locally referred to as Anigaaq), is the site of whitefish harvesting (Figure 1-2). Residents dig a channel, approximately 6 m in length, near the closed mouth of the Tukrok River (Figure 1-5). The fish are attracted to the current, travel down the channel, and are collected with either a shovel or by hand (Uhl and Uhl 1977) (Figure 1-6). Hundreds of whitefish are collected in this manner and then dried or frozen and put away for the winter (Harris, pers com.).

Many people in Alaska still practice a subsistence lifestyle, particularly the residents of northwest Alaska. Chapter 2 discusses the role/importance of subsistence activities in Alaska including those activities that take place at Sisualik and Anigaaq, two locations within Cape Krusenstern National Monument (Figure 1-2).

1.2.5 Cape Krusenstern National Monument Coastal Lagoon Descriptions

The lagoons in CAKR all differ in size - Imik is approximately 5 km², Akulaaq is approximately 9 km², Kotlik is around 24 km², Sisualik is around 34 km², and Krusenstern is approximately 56 km². They also vary in water exchange with the Kotzebue Sound (Akulaaq, Krusenstern, and Sisualik) or Chukchi Sea (Imik and Kotlik) (Table 1-1). Lenanton and Hodgkin (1985) classified southwestern Australian estuaries based on how often the sand bar of an estuary was breached. I am applying this classification scheme to the lagoons of CAKR, but note that seawater can also be pushed into any of the lagoons as a result of strong westerly storms. For this research water exchange with river, creek, or terrestrial sources was not explicitly included in classification schemes although sampling locations within the lagoons were placed near freshwater sources if present. Sisualik is open to the Kotzebue Sound year-

round and Akulaaq Lagoon, Imik Lagoon, and Kotlik Lagoon are intermittently open (water enters the lagoons at irregular intervals). Krusenstern Lagoon is seasonally-closed (river mouth opens up seasonally).

Akulaaq Lagoon can remain closed for a couple of years at a time (Georgette and Shiedt 2005) during which time it functions as a closed system. Young and Potter (2002) measured exceptionally high levels of salinity in a western Australian estuary that had been closed for approximately three years. Sisualik Lagoon experiences year-round water exchange with Kotzebue Sound. Roy *et al.* (2001) found that open estuaries in south-east Australia had defined salinity gradients whereas closed systems had only slight within-lagoon gradients. Krusenstern Lagoon is different from the other lagoons because it empties directly into the Tukrok River (Figure 1-2). The river empties into the Kotzebue Sound approximately 15 km downstream from the lagoon. The area between the Krusenstern Lagoon and the Kotzebue Sound is a wide expanse of wetlands with interconnecting sloughs. The mouth of the Tukrok River is often closed in the summer as a result of strong westerly storms, “By middle or late summer, wave action and coastal currents close the lagoon outlets by transporting beach gravel along the shoreline...” (Georgette and Shiedt 2005). The mouth of the river is typically opened again during spring thaw as a result of ice break-up (Lean, pers com).

1.3 Arctic Systems Literature Review

1.3.1 Physicochemical Parameters

Arctic oceanography has been the focus of much research including the following deep bodies of water: Arctic Ocean (e.g. Aagaard 1981; Bauch *et al.* 1995; Alkire *et al.* 2007), Barents Sea (e.g. Falk-Petersen *et al.* 2000; Furevik 2001; Loeng and Drinkwater 2007), Beaufort Sea (e.g. Carmack and MacDonald 2002; Ashjian *et al.* 2005), Bering Sea (e.g. Clement *et al.* 2005;

Wirts and Johnson 2005; Stabeno *et al.* 2007), Chukchi Sea (e.g. Feder *et al.* 2005; Weingartner *et al.* 2005; Woodgate *et al.* 2005), and Laptev Sea (e.g. Abramova and Tuschling 2005; Eicken *et al.* 2005). These studies have added to the understanding of physical conditions found in deep arctic waters as well as to how physicochemical parameters respond to the harsh environmental conditions of the arctic. Studies have also focused on shallow bodies of water throughout the arctic such as estuaries (Matthews and Stringer 1984; Macdonald *et al.* 1999; Feder *et al.* 2007) and ponds and lakes (Welch 1974; O'Brien 1975; Kling *et al.* 1992), but relatively few studies have been conducted in arctic coastal lagoons, especially the coastal lagoons located along the Chukchi Sea coast.

All coastal lagoons are dynamic systems due to their location along the coast. Arctic coastal lagoons experience additional environmental conditions including ice formation and ice melt, which affect physicochemical parameters. Studies have been conducted in Simpson Lagoon and other coastal lagoons located along the Beaufort Sea coast of Alaska (Griffiths *et al.* 1975; Barnes *et al.* 1984; Matthews and Stringer 1984; Craig *et al.* 1985; Jorgenson *et al.* 2002). A few studies have been conducted in the coastal lagoons located near Cape Thompson, along the Chukchi Sea coast of northwest Alaska (Johnson 1966; Tash 1964; Tash and Armitage 1967; Figure 1-7), but to my knowledge, the only study conducted in the coastal lagoons of Cape Krusenstern National Monument was that by Blaylock and Houghton (1983). Their research included two lagoons within the CAKR boundary, Port Lagoon and Ipiavik Lagoon (Figure 1-2). The other lagoons included in the Blaylock and Houghton (1983) study were north of Kivalina.

According to Griffiths *et al.* (1977), Kaktovik Lagoon became ice-covered in September when ice, 5-10 cm thick, formed overnight on the lagoon. The depth of the liquid water under the ice in Kaktovik Lagoon in late winter ranged from 0.2 m to 2.0 m (Griffiths *et al.* 1977).

Truett (1980) reported that ice began forming on Simpson Lagoon in late September or early October and that ice thickness increased approximately 1 cm/day until April. The ice thickness in November was reported to be 0.7 m and by February the ice thickness was 1.6 m (Craig and Haldorson 1981). The liquid water depth during that same period was 2.4 m and 1.2 m, respectively. Simpson Lagoon reached its maximum ice thickness of approximately 2 m in April (Craig and Haldorson 1981), when 90% of the water in Simpson Lagoon is frozen solid.

Tash and Armitage (1967) collected year-round samples in lakes and lagoons at Cape Thompson, Alaska and their data indicated that salinity increased during ice-covered sampling periods. Tash (1964) documented that salinity levels increased 10 – 100 times as the ice formed on these lagoons. The rejection of salt from ice as it increases in thickness (Matthews and Stringer 1984; Macdonald *et al.* 1999) and the formation of brine channels during ice formation are well documented (Cottier *et al.* 1999). The salinity in Simpson Lagoon was 24 ‰ in November and 36 ‰ in February (Craig and Haldorson 1981). By the end of winter (April), the water in the underlying water column of Simpson Lagoon became hypersaline (35 – 60 ‰; Craig and Haldorson 1981).

The dissolved oxygen concentration in the water under the ice typically decreases throughout the winter as the liquid water no longer interacts with the atmosphere. Low oxygen concentrations create a challenge for overwintering species. Tash (1964) documented that oxygen levels fell below the limits of oxygen detection during the ice-covered season in the coastal lagoons located near Cape Thompson. In contrast, Kaktovik Lagoon maintained year-round dissolved oxygen levels greater than 6 mg/L (Griffiths *et al.* 1977). Kogl and Schell (1974) reported dissolved oxygen levels between 2.3 mg/L – 7.8 mg/L in channels of the

Colville River Delta during April. Schmidt *et al.* (1989) reported high dissolved oxygen concentrations, greater than 5 mg/L, in the Sagavanirktok River Delta throughout the winter.

Water temperature under the ice is often below zero in various water bodies around Alaska. The water temperature in Simpson Lagoon in November was -1.5 °C to -2.0 °C and in February the water temperature was -2.0 °C (Craig and Haldorson 1981). In Pusigrak Lagoon, located near Cape Thompson, the water temperature in mid winter was also below 0 °C (Tash 1964). Schmidt *et al.* (1989) reported temperatures below zero between April and May in the Sagavanirktok River Delta located along the Beaufort Sea.

Ice cover and snow depth not only impact the physicochemical parameters already discussed, but also reduce the amount of light available to the underlying water column. Carmack *et al.* (2004) documented that primary production in the Arctic Ocean was delayed in the spring as a result of ice. This reduction in light ultimately limits the growth of primary producers (Rysgaard *et al.* 1999). Harrison *et al.* (1982) stated increases in primary production in aquatic arctic environments were limited by the amount of available light rather than nutrient concentrations in the system. Chlorophyll *a* concentration can be used to estimate the biomass of phytoplankton in the water column. A mean chlorophyll *a* concentration of 7.1 mg/m³ was reported for the nearshore area near Barrow, Alaska between January and March (Horner 1972; Alexander *et al.* 1975). Horner *et al.* (1974) measured a mean chlorophyll *a* concentration of 3.7 mg/m³ in Prudhoe Bay in February.

The spring break-up process in arctic coastal lagoons typically includes the following steps: 1) large amounts of spring floodwaters from the rivers enter lagoons and coastal waters; 2) the over-ice floodwaters seep into cracks and holes in the lagoon, which creates a freshwater wedge; and 3) over time, the surface ice melts and the freshwater mixes with the

saline/hypersaline water that was present all winter, creating a brackish environment (Truett 1980).

According to Griffiths *et al.* (1977), spring break-up in Kaktovik Lagoon began in early June and the lagoon was ice-free by early July. Prior to final break-up, the salinity of Kaktovik Lagoon dropped from 23 ‰ in May to 3.5 ‰ by the end of June (Griffiths *et al.* 1977). The authors attributed this rapid drop in salinity to the freshwater released as ice melts during spring break-up. Simpson Lagoon was nearly fresh with salinities ranging from 1-10 ‰ over the spring break-up period (Craig and Haldorson 1981). Salinity changes can also occur on short time scales. Matthews and Stringer (1984) reported a salinity drop of 20 ‰ within 20 minutes in the Egg Island Channel, a major channel within the Simpson Lagoon complex, during spring flushing.

Tash (1964) measured high dissolved oxygen concentrations during spring flushing in coastal lagoons. Dissolved oxygen levels during break-up measured approximately 10 mg/L in two of the coastal lagoons located south of Cape Thompson along the Chukchi Sea coast (Tash 1964).

Water temperature also increases during break-up. The water temperature of Simpson Lagoon during spring break-up increased from 0 °C to 5 °C (Craig and Haldorson 1981). Tash (1964) recorded water temperatures between 3 - 10 °C during spring break-up in coastal lagoons near Cape Thompson. Matthews and Stringer (1984) documented the rise in water temperatures from -2 °C to 0 °C during spring flushing (May – June) in Simpson Lagoon.

Chlorophyll *a* data collected from arctic coastal lagoons during spring flushing are sparse, at best. In the nearshore area near Barrow, Alaska, Horner (1972) measured a mean chlorophyll *a* concentration of 15.8 mg/m³ between June and July. Apollonio (1965) reported a

mean chlorophyll *a* concentration of 82.3 mg/m³ in Jones Sound in mid-June. A mean chlorophyll *a* concentration of 67.8 mg/m³ was measured along the north coast of Alaska in early June (Horner 1972).

Studies of arctic coastal lagoons during the open water season typically report shallow water depths. Tash (1964) documented that the lagoons were generally less than 3 m deep in the Cape Thompson region of Alaska. Kaktovik Lagoon, located along the coastline of the Beaufort Sea, had a maximum depth of 4 m (Griffiths *et al.* 1977). The average depth of Simpson Lagoon was 2 m with a maximum depth of 3 m (Craig and Haldorson 1981).

Arctic coastal lagoons typically exhibit estuarine salinity levels during the open water season. The salinity in Kaktovik Lagoon steadily increased during the open water season and reached a maximum of 20.8 ‰ in September (Griffiths *et al.* 1977). During the open water period, the salinity in Simpson Lagoon was between 18-25 ‰ (Craig and Haldorson 1981).

Several studies measured high dissolved oxygen concentrations in arctic coastal lagoons during the open water period. Dissolved oxygen levels remained high for the duration of the open water season in both Kaktovik Lagoon (Griffiths *et al.* 1977) and Nuneluk Lagoon (Griffiths *et al.* 1975), two lagoons located along the Beaufort Sea coast of Alaska and Canada, respectively. The dissolved oxygen levels in Simpson Lagoon also remained high for the duration of the open water season (Craig and Haldorson 1981). In the lagoons located along the Chukchi Sea coast, dissolved oxygen concentrations were high and often supersaturated during open water periods (Tash 1964).

Water temperature can be quite variable in various arctic coastal lagoons during the open water season. Kaktovik Lagoon water temperatures ranged between 2 – 12 °C during the open water period (Griffiths *et al.* 1977). The water temperature of Simpson Lagoon during the

summer (mid-July to mid-August) was between 7 – 10 °C and in the falltime, just before freeze-up, the water temperature was between 0 – 6 °C (Craig and Haldorson 1981). Blaylock and Houghton (1983) reported mid-June and mid-July water temperatures between 2.1 °C - 12.8 °C in the coastal lagoons located just north and south of Kivalina.

Wide ranges in chlorophyll *a* concentrations during the open water period have been reported. Alexander *et al.* (1975) measured a mean chlorophyll *a* concentration of 1.86 µg/l with a maximum concentration of 14.59 µg/L in Simpson Lagoon during the open water season. Horner (1984) documented a chlorophyll *a* range of 0.21 – 18.84 mg/m³ in the western Beaufort Sea during the open water seasons of 1973, 1976-1978.

1.3.2 Species Composition

1.3.2.1 Zooplankton

Abramova and Tuschling (2005) documented that the species richness of zooplankton in the bays of the Laptev Sea was influenced by the seasonal variability (i.e. large amounts of freshwater discharge and large fluctuations in salinity) of the area. The authors reported that the zooplankton species richness and abundance during the summer were more diverse when compared to the overwintering populations. Abramova and Tuschling (2005) found that the mesozooplankton in the Laptev Sea, near the estuaries, were dominated by freshwater and brackish-water species in the summer, but brackish-water species dominated the system in the winter. Salinity thus can be the dominant driver of zooplankton species composition in arctic lagoons (Pörtner and Playle 1998).

Many arctic studies have involved the collection of zooplankton in order to examine the change in species composition and community structure in response to zooplankton community predation (Byron *et al.* 1984), fish predation (Kling *et al.* 1992; O'Brien 1979; O'Brien *et al.*

2004) and physicochemical parameters (Tash and Armitage 1966; Moore 1978). Several studies (Moore 1978; Hebert and Hann 1986; Kling *et al.* 1992) found few cladocerans in the samples collected from coastal lakes in arctic Alaska and Haney and Buchanan (1987) state that this limited distribution may be due to photoperiod and light transmission. Predation amongst the zooplankton community may also be playing a role in the types of zooplankton that are present. Byron *et al.* (1984) found that the cladoceran *Bosmina longirostris* was limited due to predation by the copepod *Epischura nevadensis* in an oligotrophic lake. However, O'Brien *et al.* (2004) collected zooplankton samples from 104 arctic lakes in Alaska and reported seven species, all copepods and cladocerans, in the lakes. Tash and Armitage (1966) reported 14 species of Cladocera and 38 species of Copepoda in lakes, pools, and lagoons near the Cape Thompson area. Moore (1978) identified 37 different species of zooplankton in 18 Canadian arctic and subarctic lakes. All these species belonged to the following taxonomic groups: Calanoida, Cyclopoida, Cladocera, Rotifera, and Protozoa. Mysids were the most common crustacean in the coastal lagoons near Kivalina with *Neomysis intermdia*, a common freshwater crustacean, the most abundant (Blaylock and Houghton 1983). This species was present in Ipiavik Lagoon, a lagoon located at the far, north end of CAKR (Figure 1-2). The only known zooplankton sample from Krusenstern Lagoon in Cape Krusenstern National Monument was collected by Schizas and Shirley (1994) where they identified a new harpacticoid copepod species, *Onychocamptus krusensterni*. The sample came from the slough area, not inside the lagoon-proper.

1.3.2.2 Benthic Invertebrates

Ingólfsson (2002) identified macrobenthic animals from 54 Icelandic lagoons and found few specialist or characteristic lagoon species in these macrotidal regions. He did state that one possible lagoon specialist was identified, the priapulid *Halicryptus spinulosus*. Blaylock and

Houghton (1983) reported that chironomids, in several different life history stages, were the most common dipteran and occurred in approximately 94% of the samples collected from the coastal lagoons south and north of Kivalina. They also reported that oligochaetes, nematodes, and halcaridae were common, but not abundant. Blaylock and Houghton (1983) also collected the bivalve, *Macoma balthica*, Isopoda, Amphipoda and other Arthropoda species.

1.3.2.3 Fish Species

As noted above, species inhabiting coastal lagoon environments must be able to withstand frequent and rapid physicochemical change. Griffiths and West (1999) conducted fisheries investigations in intermittently open estuaries in south eastern Australia and found that the fish species inhabiting these estuaries were able to handle high amounts of osmotic stress and that abundances were quite high. Bennett (1985) conducted fisheries investigations in an intermittently open estuary in South Africa and documented a mass fish mortality when salinity levels dropped to 3 ‰. He hypothesized that the resultant osmoregulatory stress on the various species became too great.

According to Craig *et al.* (1984), seasonality played a role in what fish species were present. Anadromous species entered Simpson Lagoon during spring break-up and subsequently returned to rivers or estuaries in the fall to spawn or overwinter (Craig *et al.* 1984). During the ice-covered season, marine species dominated Simpson Lagoon (Craig *et al.* 1984). Craig and Haldorson (1981) conducted fisheries investigations in Simpson Lagoon and concluded that fish species inhabiting arctic lagoons were mobile and/or had the ability to withstand a wide range of conditions. Simpson Lagoon has open water exchange with the Beaufort Sea and more than 30 species of fish have been found (Craig 1984). Griffiths *et al.* (1977) conducted fisheries investigations in Kaktovik Lagoon and found that a mix of marine, anadromous, and freshwater

species inhabited the lagoon. A total of 12 species were collected with gillnets and seines and 9 of the 12 species were marine. This is in contrast to the fisheries investigations conducted by Griffiths *et al.* (1975) in Nuneluk Lagoon. In that study, the authors collected a total of eight species and only 2 were marine. The authors attributed the differences in species composition between the two lagoons to the influence of two rivers in Nuneluk Lagoon (Griffiths *et al.* 1977).

In the CAKR region fisheries work has been done by Blaylock and Houghton (1983). They reported that open lagoons (Ipiavik and Singoalik) had greater fish species diversity than closed lagoons (Imikruk, Port, and Pusigrak). The greatest number of fish species were collected in Ipiavik Lagoon where a total of nine species were taken including: three freshwater species (*Cottus cognatus*, *Pungitius pungitius*, and *Thymallus arcticus*) three anadromous species (*Salvelinus alpinus*, *Oncorhynchus gorbuscha*, and *Osmerus mordax dentens*), and three marine or estuarine species (*Eleginus gracilis*, *Platichthys stellatus*, and *Myoxocephalus quadricornis*; Blaylock and Houghton 1983). *Pungitius pungitius* was present at 53% of the stations throughout the five lagoons in this study and it was the most abundant species in all lagoons except Singoalik Lagoon. *Dallia pectoralis* was only collected in Imikruk Lagoon (located just north of the northern boundary of CAKR). Port Lagoon did not contain any live fish during the 1983 study – only dead *Pungitius pungitius* were collected (Blaylock and Houghton 1983).

1.4 Significance and Objectives

This research provides insight into the coastal lagoons of Cape Krusenstern National Monument. It provides baseline information on many of the fundamental components necessary for subsequent monitoring of an ecosystem. These baseline data will increase understanding of these locally utilized, dynamic systems and will, hopefully, act as the impetus for future monitoring studies.

The overall objective of this study was to collect spatial and temporal baseline information about the coastal lagoon ecosystems within Cape Krusenstern National Monument (CAKR). This effort was made as a means to characterize these coastal aquatic resources, both intra-annually and interannually, with respect to physicochemical parameters and zooplankton and fish species composition. More specifically, the objectives were as follows: 1) to determine spatial and temporal variability of physicochemical parameters in five lagoons in CAKR, 2) to determine the relative abundance of zooplankton in the five CAKR lagoons, 3) to determine the presence/absence of benthic invertebrates in the five CAKR lagoons, and 4) to determine the presence/absence of fish species in the five CAKR lagoons.

Table 1-1. Lagoon size and type of water exchange with the Kotzebue Sound (Akulaaq, Krusenstern, and Sisualik) or Chukchi Sea (Imik, Ipiavik, Kotlik, and Port). *Blaylock and Houghton (1983).

Lagoon	Size (km²)	Connection
Akulaaq	9	Intermittently Open
Imik	5	Intermittently Open
Ipiavik	14	Open*
Kotlik	24	Intermittently Open
Krusenstern	56	Seasonally-Closed
Port	2	Closed*
Sisualik	34	Open

Inventory and Monitoring Program Networks Alaska Region

National Park Service
Department of the Interior

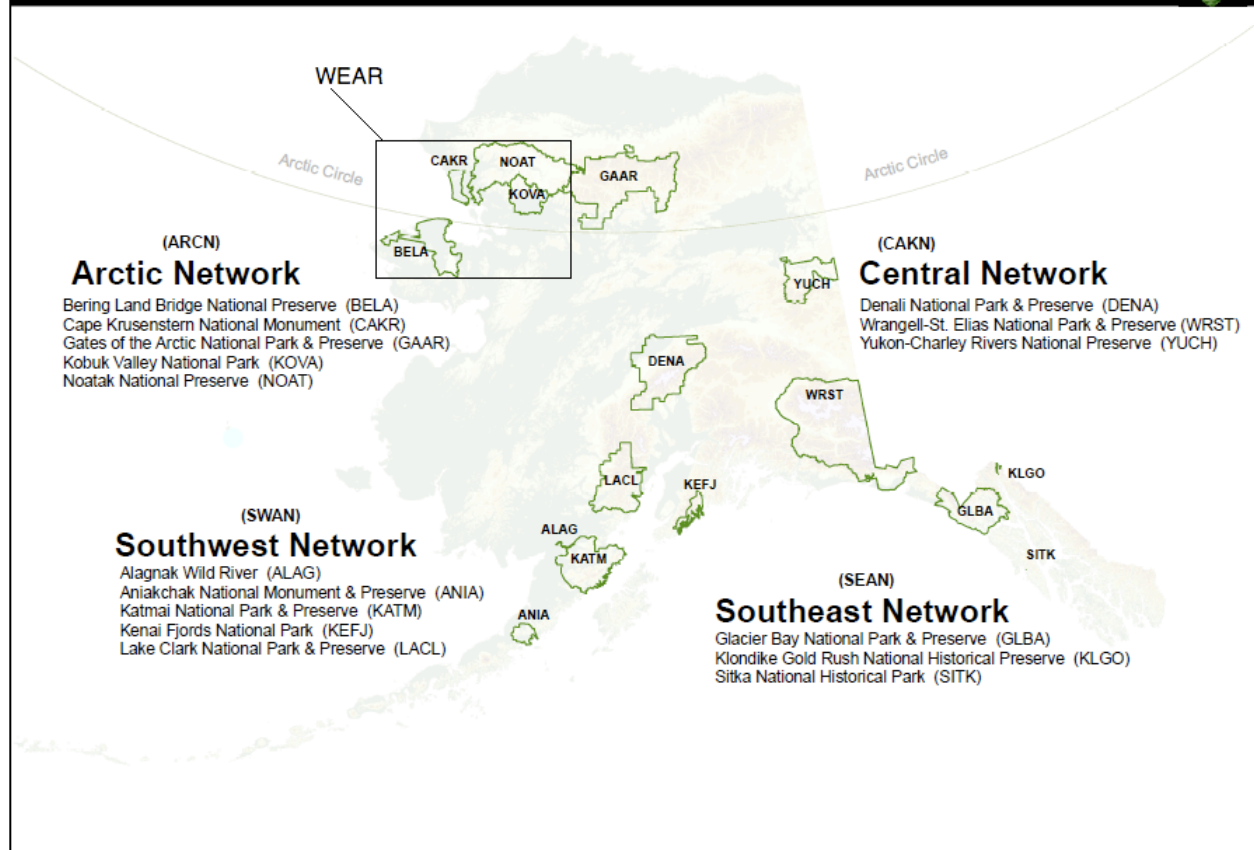


Figure 1-1. Location of the four parklands that comprise the Western Arctic National Parklands (WEAR) - Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Kobuk Valley National Park, and Noatak National Preserve. Modified map courtesy of NPS.

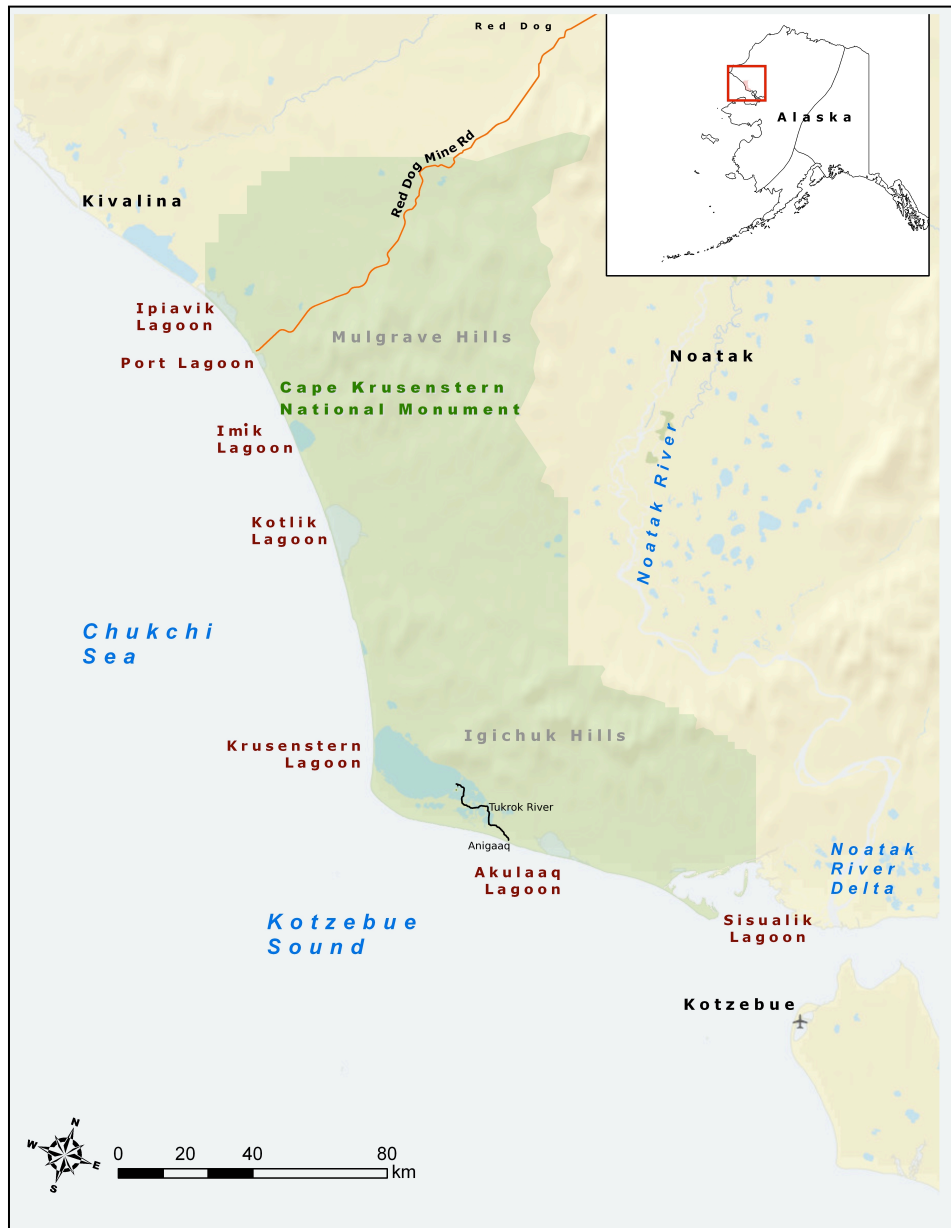


Figure 1-2. The location of the seven coastal lagoons in Cape Krusenstern National Monument. Ipiavik Lagoon and Port Lagoon, located at the northern end of the Monument, were not part of this research. Map courtesy of Terry Reynolds.



Figure 1-3. Kotzebue Sound surrounds seasonal camps located at *Nuvuraq*, on the spit at Sisualik. The entrance to the lagoon is in the lower right corner of the picture. This picture was taken in July 2009 and has a west-northwest orientation. Photo by Melinda Reynolds.

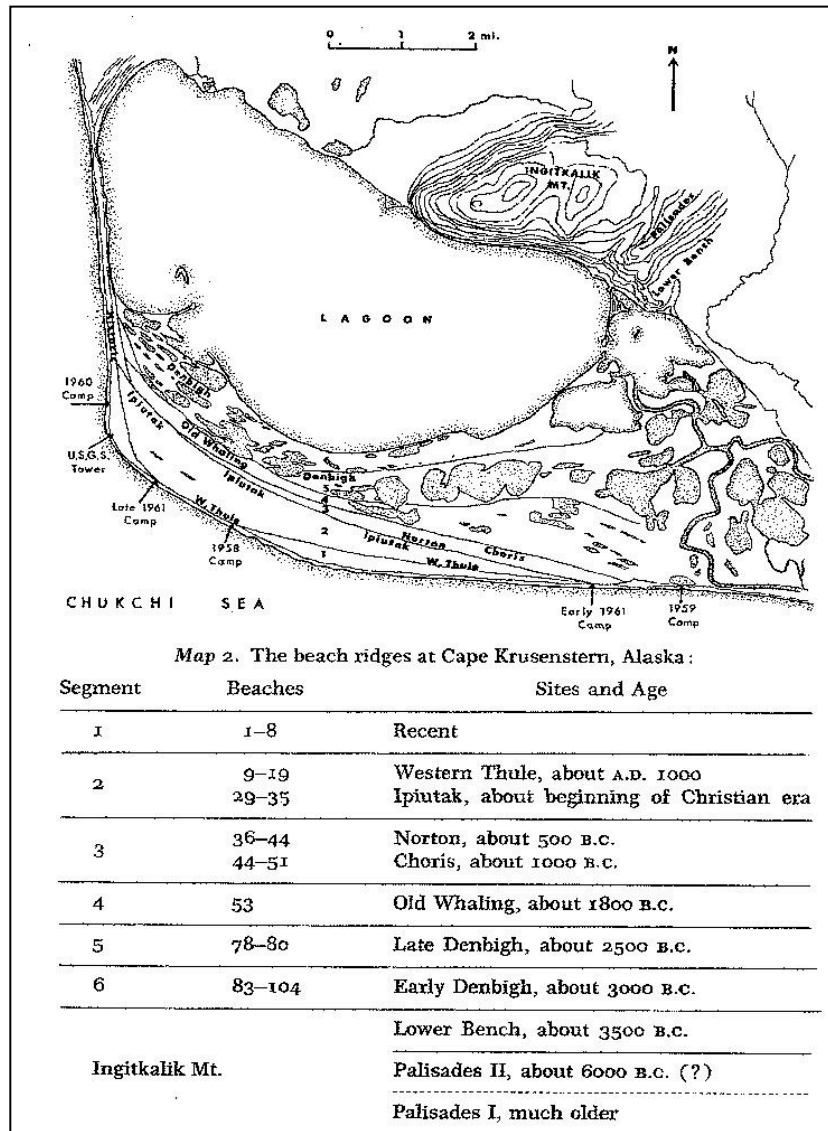


Figure 1-4. A map of the beach ridges at Cape Krusenstern, indicating the shoreline changes of the past several thousand years. Segment numbers are shown on the map (reproduced from Giddings 1967).



Figure 1-5. Sam Williams digging out his trench at Anigaaq in September 2003. Whitefish (*Coregonus spp.*) can be seen in the upper portion of the trench. The Tukrok River is in the background. Photo by Melinda Reynolds.



Figure 1-6. Sam Williams waits for fish to enter the trench he dug at Anigaaq in September 2003. Tukrok River in the background. Photo by Melinda Reynolds.

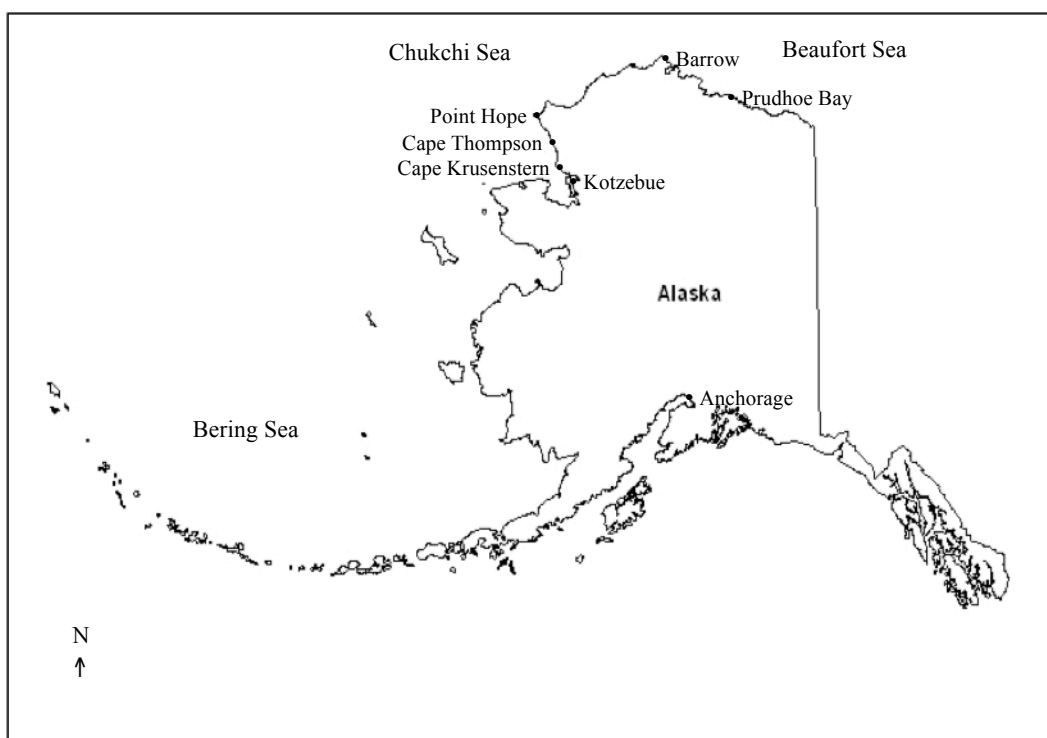


Figure 1-7. General reference map of Alaska and many of the northern locations referred to throughout this dissertation, including Cape Krusenstern located within CAKR.

CHAPTER 2

THE ROLE OF SUBSISTENCE IN ALASKA

2.1 Subsistence Defined

The topic of subsistence in Alaska is both complex and controversial. What follows is an introduction into subsistence and how the subject has evolved over time within both Alaska and the National Park Service. The final sections of this chapter cover Cape Krusenstern National Monument with discussion of two specific locations within the Monument, Sisualik and Anigaaq. Subsistence activities at these locations continue to play a vital role in the lives of those who partake in such a lifestyle.

In addition to Native Alaskans, the lure of “The Last Frontier” has brought different types of resource users (i.e. recreational and commercial) to the state. Conflict has often arisen among subsistence, recreational, and commercial users as they share and/or compete for the natural resources within the state. These conflicts have given rise to laws, which in recent years protect the subsistence resources that many Natives throughout Alaska depend upon for everyday life.

As previously stated, indigenous people have been subsisting off the land and water for thousands of years. The first modern law that dealt with subsistence in Alaska was the Alaska Native Claims Settlement Act (ANCSA), which was enacted in 1971. ANCSA actually abolished Native rights to hunting and fishing on federal lands in exchange for 44 million acres of land and approximately \$1 billion. In 1978, the State of Alaska passed its first subsistence law, HB 960. It stated, “it is in the public interest to clearly establish subsistence use as a priority use of Alaska’s fish and game resources and to recognize the needs, customs, and traditions of Alaskan residents” (as cited in Norris 2002; 67). The law gave priority to

subsistence users and stated that race would not determine who had access to subsistence resources. Then in 1980, The Alaska National Interest Lands Conservation Act (ANILCA) was signed into law by President Jimmy Carter. The Law established, revised, and set aside more than 100 million acres of federal land, which doubled the amount of land protected by the U.S. National Park Service and tripled the amount of land in the U.S. wilderness system (Nash 2001). According to Nash (2001), the signing of ANILCA was "...the greatest single act of wilderness preservation in world history" (p. 272). The purpose of ANILCA was not only to set-aside these federal lands for future conservationism, it was also to allow subsistence activities to continue, "It is further the intent and purpose of this Act...to provide the opportunity for rural residents engaged in a subsistence way of life to continue to do so" (ANILCA, Section 101(c)). ANILCA reinstated Native rights to hunting and fishing that ANCSA had taken away nine years prior.

Title VIII of ANILCA specifically addresses subsistence and is entitled "Subsistence Management and Use Findings". It defines subsistence as follows:

The customary and traditional uses by rural Alaska residents of wild, renewable resources for direct personal or family consumption as food, shelter, fuel, clothing, tools, or transportation; for the making and selling of handicraft articles out of nonedible by-products of fish and wildlife resources taken for personal or family consumption; for barter, or sharing for personal or family consumption; and for customary trade.

(ANILCA, Section 803)

This definition clarifies 'who and what' qualifies as subsistence and provides federal protection for the lifestyle that indigenous peoples throughout Alaska had been carrying out for generations.

One final definition for subsistence remains – that provided by the State of Alaska. According to the State, "subsistence fishing" is defined as the taking of fish, shellfish, or other

fisheries resources by Alaska residents for subsistence uses (AS 16.05.940[30]). Subsistence uses of wild resources are defined as ‘noncommercial, customary, and traditional uses’ for a variety of purposes. These include:

direct personal or family consumption as food, shelter, fuel, clothing, tools, or transportation, for the making and selling of handicraft articles out of nonedible by-products of fish and wildlife resources taken for personal or family consumption and for the customary trade, barter, or sharing for personal or family consumption.

(AS 16.05.940[32])

The differences between the federal law and the state law should be duly noted. According to federal law, an individual must be a *rural* Alaska resident to participate in subsistence activities, but according to state law an individual must only be a resident of Alaska in order to participate in such activities. As a result of these differing laws, there is currently a dual management system set up between the Federal government and the State of Alaska.

2.2 Subsistence Resource Users

The human population within Alaska is divided into two groups – rural and urban. Rural residents, which include the inhabitants of 270 communities, represent approximately 20% of Alaska’s population or roughly 123,000 individuals (Wolfe 2000). Within this rural population, 51% are Alaska Natives and 49% are non-Natives. An understanding of this designation of rural vs. urban is fundamental in understanding the management of subsistence resources.

According to Wolfe (2000), wild food harvests vary significantly between rural and urban residents. There was an average of 375 lbs per person per year harvested by rural residents during the 1990’s, while the urban harvest was 22 lbs per person per year (Wolfe 2000). In terms of nutritional value, wild food harvests can provide 242% of the necessary protein and

35% of the caloric requirements for rural residents whereas wild food harvests can provide 15% of the necessary protein and 2% of the caloric requirements for urban residents (Wolfe 2000).

The percentage of households that participated in various subsistence activities within rural areas varied based upon the type of subsistence activity: 60% harvested game, 86% used game, 83% harvested fish, and 95% used fish (Wolfe 2000). Most rural residents shared subsistence foods with family and friends and it was this sharing that accounted for the differences between “harvested” and “used” resources (Figure 2-1).

Subsistence activities remain vital in the lives of Natives despite the fact that many changes (i.e. influences from Western societies) have occurred throughout the Native cultures of Alaska (Huntington 1992). The traditional cycle of hunting and gathering resources from the water and the land continues to be paramount in the lives of many Natives (Rennick 2001). Traditional knowledge of seasonal subsistence activities has been, and continues to be, passed on from generation to generation. And while these activities supply food for everyday living, they provide much more. According to Uhl and Uhl (1977), the value of these subsistence activities goes beyond that of providing sustenance for those that participate by also contributing to and becoming an integral part of their Being, “Status, appreciation, acceptance, and probably most important of all, self-worth, is often established through subsistence harvesting activities, for both males and females” (p. 199).

2.3 Subsistence in Northwest Alaska

The Northwest Arctic Borough is located within the NANA Region of Northwest Alaska, along the coast of the Chukchi Sea. The following 12 communities are part of the Borough: Ambler, Buckland, Candle, Deering, Kiana, Kivalina, Kobuk, Kotzebue, Noatak, Noorvik, Selawik, and Shungnak. According to the 2000 U.S. Census, the population for the Borough is

estimated at 7,200, which is approximately 1% of the entire state population. Seventy five percent of the total population of the Borough is Iñupiat Eskimo. What follows is a brief overview of the contribution of subsistence resources for four of the 12 Native villages of the Borough.

Deering is a small, Iñupiaq village located at the mouth of the Inmachuk River, approximately 60 miles southwest of Kotzebue. According to the 2000 U.S. Census, the total population is 136, 93% of whom are Alaska Natives. In 1994, Magdanz *et al.* (2002) conducted household surveys in Deering and reported an average of 2,449 total edible pounds of wild foods were harvested per household. Fish provided the greatest proportion of the total amount of wild foods harvested at 34.0%. Marine mammals and land mammals each contributed 32.9% and 28.2% of the total, respectively (Magdanz *et al.* 2002). For the residents of Deering, subsistence activities are a vital component of everyday life and it is clear that a subsistence lifestyle is the norm, “nine out of ten adults in...Deering harvested, processed, or distributed some kind of wild food for one or more households...” (Magdanz *et al.* 2002; 47).

Kivalina is a small, Iñupiaq village on the tip of a barrier island located along the coast of the Chukchi Sea (Figure 1-2). It is approximately 80 miles northwest of Kotzebue. According to the 2000 U.S. Census, the population of Kivalina is 377, 97% of whom are Alaska Natives. Burch (1985) conducted two, two-year studies (1964-1966 and 1982-1984) of subsistence activities in Kivalina. In 1964-1965 the residents of Kivalina harvested a total of 369,832 total pounds of major food resources. Sea mammals provided 57.1% of the total harvest by weight of major food resources and fish and land mammals each provided 26.5% and 16.4% of the total harvest by weight, respectively. In 1983-1984 the residents of Kivalina harvested a total of 496,393 pounds of major food resources. Sea mammals contributed the greatest amount of wild

foods harvested at 57.2% of the total harvest by weight, land mammals contributed 27.2% of the total by weight, and fish contributed 15.6% of the total by weight (Burch 1985). Burch (1985) was able to demonstrate through his surveys of subsistence activities in Kivalina that, although 20 years had passed between the two studies and many changes had occurred throughout the village, one thing remained constant – the dependence on subsistence resources for the supply of Native foods.

Kotzebue is the regional center for the Northwest Arctic Borough. None of the 11 surrounding villages are accessible via road so all northwest Alaska residents must pass through Kotzebue, where the regional airport is located. Kotzebue is located on a 3-mile long spit on the northwest corner of the Baldwin Peninsula (Figure 1-2). It is the largest village in the Borough with a population of approximately 3,000, 71% of whom are Alaska Natives (2000 U.S. Census). Most natives residing in Kotzebue continue to participate in subsistence activities at least on a seasonal basis (Figure 2-2). A household survey conducted by Georgette and Loon (1993) in Kotzebue in 1986 found that 78% of the households surveyed harvested wild resources (i.e. big game, marine mammals, small game and furbearers, birds and eggs, fish, and berries and plants) and 100% of the households used these wild resources. The amount of sharing between family and friends accounts for the differences between “harvested” and “used”. Fish provided the greatest contribution to the overall harvest, providing 40.6% of the total pounds edible weight and big game and marine mammals were the next largest, each contributing 28.1% and 27.5% of the total, respectively (Georgette and Loon 1993). According to Georgette and Loon (1993), Kotzebue households harvested approximately 1,067,278 total pounds of edible wild resources in 1986. This equates to an average household harvest of 1,395.2 pounds and an average per capita harvest of 398.1 pounds (Georgette and Loon 1993).

Shungnak is a small, Iñupiaq village located on the Kobuk River, approximately 150 miles east of Kotzebue. According to the 2000 U.S. Census, the population is 256, 95% of whom are Alaska Natives. Magdanz *et al.* (2004) conducted household surveys in Shungnak and documented that approximately 151, 911 pounds of edible wild foods were harvested by the residents in 2002. The harvest per household was an average of 2,813 pounds and the harvest per person was 610 pounds (Magdanz *et al.* 2004). As in Deering and Kotzebue, fish provided the greatest contribution to the total amount of wild foods harvested at 54% and of the fish, whitefish accounted for 31% of the total fish harvested. Land mammals were next in contributing the greatest amount of total wild foods harvested at 41% (Magdanz *et al.* 2004). For the indigenous people of Shungnak, subsistence activities are pivotal.

The above summaries supply basic, subsistence resource use data for a few of the Native villages within the Borough. Although the specifics of the data are different for each community, one overarching theme persists throughout – all the communities within the Northwest Arctic Borough rely heavily upon subsistence resources for everyday sustenance and thus, subsistence living continues to play a central role in the lives of the residents of Northwest Alaska.

2.4 The History of Subsistence in Alaskan National Parks

National Park Service lands within Alaska cover approximately 55 million acres or 13% of the state. In addition to covering the largest percent of any state in the U.S., Alaskan National Parks also include subsistence use provisions, which do not exist in most non-Alaskan parklands. This relationship between subsistence lifestyles and the National Park Service began when the first park unit (Sitka National Monument) was established in Alaska in 1910. This relationship, often invoking intense emotions, continues today in most National Park units throughout Alaska.

Knowledge of the timing of the establishment of the various park units within Alaska is critical to understanding the history of subsistence within these parks as well as understanding the role of subsistence in the parks, especially CAKR.

The establishment of Sitka National Monument in 1910 represents the first holdings of the National Park Service within Alaska. By 1925, three other park units were established: Mount McKinley National Park in 1917, Katmai National Monument in 1918, and Glacier Bay National Monument in 1925 (Williss 1985). These were the only park units that existed within Alaska (Old Kasaan National Monument was established in 1916, but was abolished in 1955) until 1971. During this span of six decades, subsistence activities were not high on the priority list of the NPS although attempts were made to accommodate local users of the land.

Mount McKinley National Park was the first National Park or Monument to allow subsistence activities within the designated boundaries. Upon its establishment in 1917, it became the only park unit in the nation to allow subsistence hunting, under specified conditions, and it retained this status for more than a decade (Norris 2002). In 1928, Congress repealed the allowance of subsistence hunting within the Park as there was abuse of the stated allowance. The new provision prohibited all hunting within Mount McKinley National Park (Norris 2002).

When Glacier Bay National Monument was established in 1925 President Calvin Coolidge's proclamation did not recognize the history of the area in terms of Native resource use. This was despite the fact that indigenous peoples had been subsisting in the area for generations. The National Park Service was unaware that Tlingit Natives were using the area for subsistence activities and had no intention of permitting those activities to take place within the Monument, "...from the monument's inception, the agency intended to keep such uses away from the monument" (Norris 2002; 38). To its credit, once the NPS gained knowledge of local

resource use, temporary agreements were set up to allow Natives to gather and hunt within the Monument. However, these agreements were often challenged by the NPS and in fact, Natives were arrested by the Fish & Wildlife Service for hunting and trapping within the Monument (Catton 1997; Norris 2002). These intense interactions between the NPS and the Hoonah Tlingit Natives continued for years over the subsistence use of resources within Glacier Bay National Monument. Even after the passage of ANILCA in 1980, which specifically defined and protected subsistence users in other Alaskan parks, the Hoonah Tlingits were not allowed to carry out traditional fishing and seal hunting within the re-designated, but pre-ANILCA Glacier Bay National Park (Catton 1997; Norris 2002). Glacier Bay National Park was one of the few parks where subsistence activities were specifically prohibited by provisions in ANILCA. Today, subsistence hunting and fishing are not allowed within the boundaries of Glacier Bay National Park and Preserve.

The Glacier Bay example demonstrates that subsistence lifestyles were not easily accepted, and oftentimes even opposed, by the National Park Service. This despite the fact that park resources were utilized for generations before any park boundary was drawn on a map. The tide began to change in 1971 upon the enactment of the Alaska Native Claims Settlement Act (ANCSA).

The Alaska Native Claims Settlement Act set up 12 regional Native corporations, but did not have any special provisions with respect to subsistence activities. It was a separate conference report that was attached to the bill that protected Natives and their subsistence activities (Catton 1997; Norris 2002). The report gave the Secretary of the Interior the ability to classify lands based on the following:

...protect native subsistence needs and requirements by closing appropriate lands to entry by non-residents when the subsistence resources of these land are in short supply or otherwise threatened. The conference committee expects both the secretary and the state to take any action necessary to protect the subsistence needs of the Natives. (ANCSA Conference Report 1971, as cited in Norris 2002; 50)

Along with this indirect protection of subsistence lifestyles, ANCSA allowed for the possible addition of millions of acres into four National Systems. This Act contained a National Interest Lands provision in Section 17 (d)(2) and with this provision, the Secretary of the Interior had the authority to withdraw up to 80 million acres of land. These “d-2” lands were to be deemed suitable by the Secretary, “...suitable for addition to or creation as units of the National Park, Forest, Wildlife Refuge, and Wild and Scenic Rivers Systems” (ANCSA 17 (d)(2)(A)). Cape Krusenstern National Monument was not part of the initial, March 1972 list of proposed NPS lands, but gained a spot on the list by December 1973 (Williss 1985; Norris 2002).

Subsistence was becoming more recognized by the NPS during this time of land selection and all of the proposed park units had subsistence provisions included in their draft environmental impact statements (Norris 2002). By the time final environmental statements were completed most of the proposals for the proposed park units included sections regarding Native subsistence activities. Cape Krusenstern had one of the strongest statements by the NPS with regards to subsistence, “to encourage and assist in every way possible the preservation and interpretation of present-day Native cultures” (as cited in Norris 2002; 61).

The passage of ANILCA in 1980 was the impetus for a new vision by the National Park Service within Alaska. The 10 new National Park units were not only seen as environments conducive to ecological preservation and change, but also cultural preservation and change.

According to Catton (1997), the NPS was attempting to meet the following objectives: “(1) to protect native cultures; (2) to satisfy wilderness preservationists; (3) to treat resident peoples justly; and (4) to maintain pristine environments for ecological study – all at the same time” (p. 5). Cape Krusenstern National Monument was one of these “new” Alaska parks, where subsistence activities and park resources were, and continue to be, so intimately connected.

2.5 Subsistence within Cape Krusenstern National Monument

The cultural resources located within Cape Krusenstern National Monument were the driving force behind the designation of the Monument. These cultural resources are largely located within a beach ridge complex that encompasses 114 beach ridges (Figure 2-3). The length of these ridges varies with the longest extending approximately 8 miles in a west to east direction and extending approximately 3 miles inland (Giddings 1967). Giddings (1967) explored the idea of “beach ridge archeology” and in 1958, during a summer trip along the coast of northwest Alaska, discovered these “fossil shorelines”. The idea behind “beach ridge archeology”, according to Giddings (1967), “...is that any people in this part of the world who live near a shoreline will prefer to camp on a sand or gravel beach from which they can most conveniently scan both land and sea” (p. 17). Giddings (1967) goes on to state the importance of the camp location with respect to subsistence activities, “Food – fish, seals, and whales – is available just off the shore, increasing in abundance at certain seasons” (p. 17). Artifacts representing seven different cultures have been discovered within the beach ridge complex at Cape Krusenstern. These discoveries help document the presence of hundreds of generations of Arctic people (Figure 2-3). The presence of these artifacts (i.e. arrowheads, whaling harpoon heads, assortment of whale bones, etc.), indicative of ancient cultures along historical coastlines, documents that subsistence lifestyles have been in existence in Alaska, and more specifically

Cape Krusenstern National Monument, for thousands of years (Giddings 1967). Today, throughout Alaska, villages continue to be located along the coast and even inland communities are located along a river as subsistence activities continue to be practiced and resources continue to be relied upon for sustenance.

Cape Krusenstern National Monument is currently not an area where most people reside permanently, but rather a seasonal gathering place for subsistence activities. Only a few Krusenstern residents remain in the Monument year-round, making the trip into town (Kotzebue) when supplies are needed, but mainly living off the land. According to Uhl and Uhl (1977), each subsistence resource has a season and generalized location. Subsistence resources include: plants, fish, marine mammals, land mammals, and birds (Uhl and Uhl 1977) (Figure 2-4). Uhl and Uhl (1977) stated, “the continued use of “Eskimo Foods” by virtually all residents of the area...makes harvesting time on the Monument a very real and important part of present-day life in this portion of Northwest Alaska” (p. v). Georgette and Shiedt (2005) conducted research regarding the traditional ecological knowledge of whitefish in the Kotzebue region and were able to document an unusual harvest technique for whitefish in Cape Krusenstern National Monument and stated that it “...takes place in a vital subsistence use area in the heart of one of the Western Arctic National Parklands” (p. 132). This land that is rich in cultural and natural resources continues to be a vital part of the subsistence lifestyle that so many Iñupiat continue to participate in today (Figure 2-5).

2.5.1 Sisualik: A Seasonal Gathering Place for Subsistence Activities

Sisualik (or Sheshalik) is the name of the peninsula at the southern-most tip of Cape Krusenstern National Monument (Figure 1-2). In Iñupiaq it means “place of white whales” with white whales being a reference to beluga whales (Uhl and Uhl 1977; 38). Historically, residents

from the village of Noatak traveled to the Sisualik spit after ice break-up to set up camp in anticipation of the arrival of beluga whales (Uhl and Uhl 1977; Burch 1998). But Noatak families were not the only people to partake in this seasonal movement to Sisualik, many other Iñupiat of the early nineteenth century also participated (Giddings and Anderson 1986, Burch 1998). According to Burch (1998), several Eskimo Nations (e.g. *Napaaqtuġmiut* (lower Noatak people), *Nuataaġmiut* (upper Noatak people), *Qikiqtagruṇmiut* (Kotzebue people), *Kuuṇmiut* (Kobuk Delta people), *Kuuvaum Kaṇiaġmiut* (upper Kobuk people) and *Kivalliñiġmiut* (Kivalina people)) were present at Sisualik immediately after ice break-up (i.e. early June). The *Nuataaġmiut* (upper Noatak people) Nation arrived at Sisualik prior to the other Nations and while they waited for the others, the impending beluga hunt kept them preoccupied (Burch 1998). The hunt for these whales began once “...the belukha really started running eastward along the southern shore of Sheshalik Spit” (Burch 1998; 93). This gathering at Sisualik, that involved hundreds of people from Northwest Alaska and beyond, was a trade fair and type of celebration that “...involved feasting, dancing, and games, as well as trading” (Burch 1998; 72). Many different items were traded and desired by those who attended the fair. The *Kivalliñiġmiut*, for example, brought seal oil, caribou skins, and furs for the people of Kobuk, Wales, Buckland, Diomedes, and Asia while their desires included: pottery from Buckland and Wales people and jade from the people of Kobuk (Burch 1998). This fair continued until early August, with staggered departures timed with the arrival of subsistence resources in the territory of each Nation (Burch 1998). According to Giddings and Anderson (1986), “As a trading center, Sisualik perhaps was at its greatest prominence during the second half of the nineteenth century” (p. 36).

The historical use of Sisualik is also evident in the beach ridges that were discovered by Giddings in 1958 while he was on his trip up the coast to explore Cape Krusenstern (Giddings 1967). Sisualik had 15 beach ridges on the tip of the peninsula, all containing house pits and/or cache pits (Giddings 1967). Giddings (1967) concluded that the cache pits were mainly for storing meat and whale and seal skins during the spring and summer hunting seasons. Cultural artifacts have been found in the area dating to approximately 1100 A.D. (Giddings 1967).

The seasonal movement to Sisualik by Noatak people continues to be part of the annual cycle of subsistence activities. Today, the place name in Iñupiaq for this Noatak camp is *Nuvuraq* and is a direct reference to Sisualik Point (Uhl and Uhl 1977) (Figure 1-3). The camps at *Nuvuraq* are full of activity in early June, just after ice break-up, by Noatak families harvesting and drying whitefish (Georgette and Shiedt 2005) (Figure 2-6). It is believed that these whitefish are headed up the coast to where they will enter the coastal lagoons (Uhl and Uhl 1977; Georgette and Shiedt 2005). Families from Kotzebue as well as from Krusenstern also have camps at Sisualik. These camps are utilized on a seasonal basis and their occupancy coincides with the arrival of various subsistence resources within the Monument. In 1977, Uhl and Uhl (1977) stated that beluga whales were still being harvested from the Monument, but not in large numbers. At that time, large mesh nets (14 inch) were set in an area between Sisualik and Kotzebue right after ice break-up in the spring (Uhl and Uhl 1977).

2.5.2 Anigaaq: The Location of a Primary Subsistence Fishery within Cape Krusenstern National Monument

Anigaaq is the Iñupiaq name for the location where the gravel bar along the coast of Cape Krusenstern National Monument opens up seasonally to the Kotzebue Sound (Figure 1-2 and Figure 2-7). In Iñupiaq it is defined as “place of going out” (Uhl and Uhl 1977; 219). The mere

fact that this place name holds such a definition is indicative of the history of the location.

According to Georgette and Shiedt (2005), “in past years Anigaaq was a major fall camp with 8 to 10 extended families usually camped there for two or more months” (p. 112). The primary purpose of these camps was to collect enough whitefish to provide for both, humans and dogs, throughout the winter (Georgette and Shiedt 2005). Uhl and Uhl (1977) stated that “...this is the major source of frozen winter whitefish for the residents of Kotzebue and Sisualik” (p. 12).

The Krusenstern area is best described as a waterway system as it is composed of: a large, brackish lagoon, several miles of winding sloughs, freshwater creeks, and various lakes and ponds. All these waterways intertwine, connect, and empty into the Tukrok River. This river exchanges water with the Kotzebue Sound at Anigaaq when the gravel bar is open. This opening occurs on a seasonal basis, coinciding with ice break-up during the spring as ice gets pushed down the river.

The Anigaaq whitefish fishery occurs in the fall, just before freeze-up. A ditch or trench is dug from the river towards the Kotzebue Sound, “a simple three foot wide “irrigation” ditch is dug in the porous gravel 20 feet long with a 10 foot diameter, circular “stomach” and the end away from the edge of the water” (Uhl and Uhl 1977; 11). The trench is dug on a decline to create a good current thus making it attractive to the fish (Figure 2-8). The porous gravel empties the “stomach” of water making it difficult, if not impossible, for the fish to swim back up the ditch to escape entrapment (Figure 2-9). Hundreds of whitefish are collected in this manner and placed into burlap bags (Harris, pers comm.). This method of harvest continues today, but other methods, such as gillnets, are also being utilized (Figure 2-10).

Whatever the harvest method employed, be it trench or gillnet, the goals of this subsistence activity are the same, to collect large numbers of whitefish to stock up for the winter

and to share with family and friends. This subsistence fishery that takes place at Anigaaq continues to hold its place in the annual cycle of subsistence activities that occur within Cape Krusenstern National Monument. The pleasure gained by the participants in this subsistence fishery is based on individual judgment, but my field experience as well as my immersion into the community for two years allowed me to witness the great enjoyment that many natives obtain from harvesting resources from the land and sea (Figure 2-11).

2.6 The Connection

This chapter is intended to give a synopsis of subsistence and how subsistence activities have been carried out for generations amongst Natives, particularly the Iñupiat who used and continue to use Cape Krusenstern National Monument. Participating in a subsistence lifestyle and/or subsistence activities continues to be paramount to the people who call Northwest Alaska home. The interaction between the Iñupiat and the resources of Northwest Alaska needs to be understood for the successful management of parklands. The science behind management can only succeed if an understanding of subsistence is recognized as important and incorporated into the management process. Catton (1997) sums it up best, “preserving ecosystems without their human constituents or creating wildernesses at the expense of native cultures would be hollow achievements and ultimately self-defeating” (p.5).



Figure 2-1. Cyrus Harris, Terry Reynolds, and Pedro Mendenhall pick sheefish (*Stenodus leucichthys*) out of a gillnet in February 2003. The net was set under the ice in Kobuk Lake (Hotham Inlet). Cyrus participates in this subsistence activity throughout the winter so he can provide family, friends, and elders with fresh fish. Photo by Melinda Reynolds.



Figure 2-2. Lance Krammer harvesting a juvenile bearded seal (*Erignathus barbatus*) in Kotzebue Sound in October 2004. Photo by Terry Reynolds.

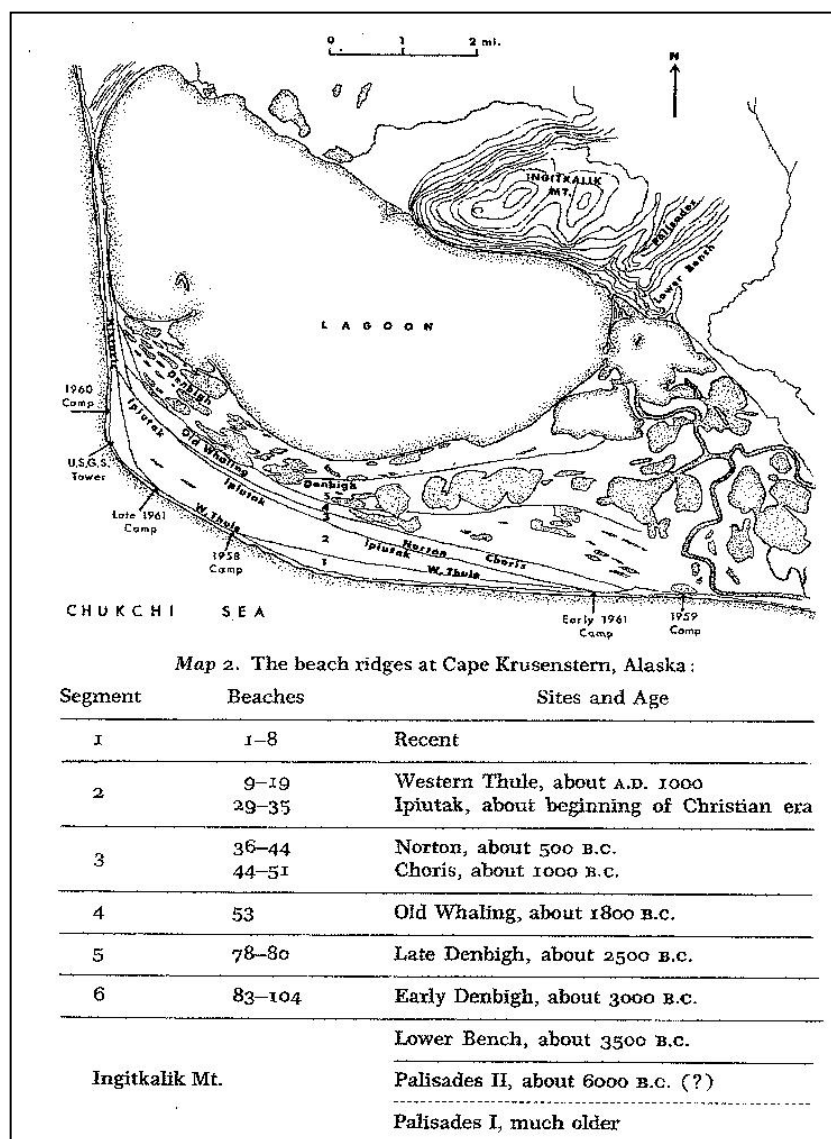


Figure 2-3. A map of the beach ridges at Cape Krusenstern, indicating the shoreline changes of the past several thousand years. Segment numbers are shown on the map (reproduced from Giddings 1967).



Figure 2-4. Whitefish (*Coregonus spp.*) harvested in the sloughs of Cape Krusenstern National Monument hang to dry at the seasonal camp of Sam Williams in July 2003. Photo by Melinda Reynolds.



Figure 2-5. Denali Whiting, Village of Kotzebue Mayor Siikauraq Martha Whiting, and Augustine Johansen process whitefish (*Coregonus spp.*) harvested with gillnets in the sloughs of Cape Krusenstern National Monument in July 2003. Mayor Whiting utilizes her family seasonal camp at Cape Krusenstern to participate in seasonal subsistence activities. Photo by Melinda Reynolds.



Figure 2-6. Seasonal camps located at Sisualik in July 2002. The place name for this particular area is *Nuvuraq* and is a direct reference to Sisualik Point. These camps are occupied by Noatak families in early June, just after ice break-up, in order to harvest the subsistence resources that Cape Krusenstern National Monument has to offer. Photo by Melinda Reynolds.



Figure 2-7. An aerial view of Anigaaq in September 2003. This picture is taken in a west – northwest direction with Kotzebue Sound off to the left and the Tukrok River to the right. Evidence of two trenches used to harvest whitefish can be seen in the lower reaches of the river. The seasonal opening to the river, which eventually leads to the lagoon, can be seen on the gravel bar, just above the trenches. Photo by James Magdanz, ADF&G (Georgette and Shiedt 2005).



Figure 2-8. Cyrus Harris digs a trench at Anigaaq in October 2004. The created current entices the fish to enter the trench. The Tukrok River is in the background. Photo by Joanne Sheldon.



Figure 2-9. Joanne Sheldon near the trench she and Cyrus Harris dug at Anigaaq in October 2004. The fish feel the current and travel down the declining trench to where they eventually reach an empty “bowl” as the water seeps down into the gravel. The “bowl” is filled with whitefish (*Coregonus spp.*). Photo by Cyrus Harris.



Figure 2-10. Joanne Sheldon and Cyrus Harris pick whitefish (*Coregonus spp.*) from the gillnets they set near Anigaaq in September 2004. The Tukrok River is to the left. Photo by Terry Reynolds.

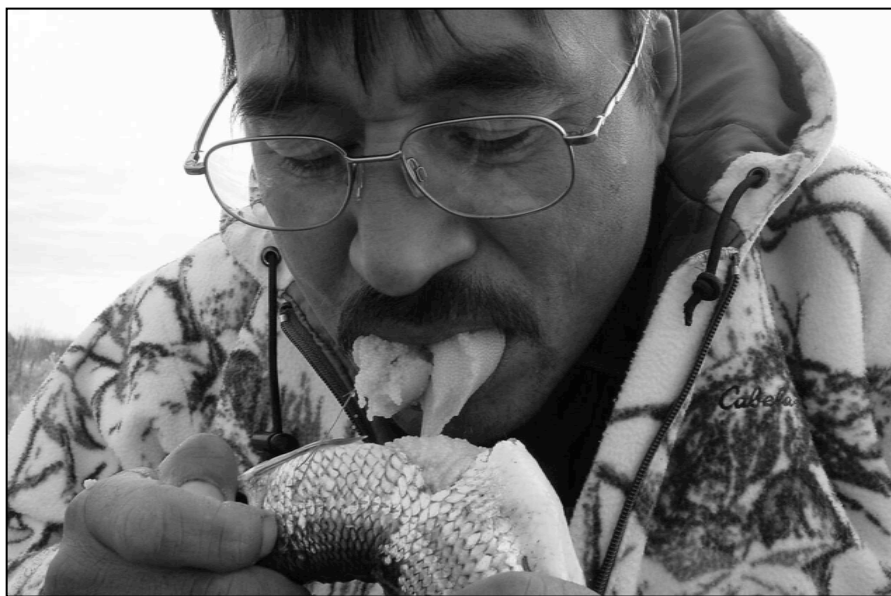


Figure 2-11. Cyrus Harris enjoys fresh whitefish eggs (*Coregonus spp.*) from a fish he just harvested in a gillnet set at Anigaaq in September 2004. According to Cyrus, fresh eggs are a delicacy that he likes to eat as a quick energy snack when out in the country. Photo by Terry Reynolds (Reynolds *et al.* 2005).

CHAPTER 3

ARCTIC COASTAL LAGOONS OF CAPE KRUSENSTERN NATIONAL MONUMENT: BASELINE SPATIO-TEMPORAL PHYSICOCHEMICAL AND SPECIES DATA

3.1 Introduction

Coastal lagoons are located from the tropics to the arctic and comprise approximately 13% of the world's coastline (Barnes 1980; Kjerfve 1986). From the human perspective lagoons provide the following important resources: areas for recreation, nursery habitats for various fishes (Griffiths and West 1999), food for anadromous and marine fishes (Craig *et al.* 1985), habitats for various subsistence fish resources (Uhl and Uhl 1977; Craig *et al.* 1985, Georgette and Shiedt 2005), and resting and breeding grounds, as well as food, for migratory birds and waterfowl (Lawler *et al.* 2009). Lagoon ecosystems are dynamic due to irregular and/or regular influxes of seawater that influence physicochemical properties. Arctic coastal lagoons experience additional fluctuations such as ice formation and ice melt, which affect the physicochemical parameters of these often shallow, relatively small bodies of water. The rejection of salt from ice as it increases in thickness (Matthews and Stringer 1984; Macdonald *et al.* 1999) primarily through the formation of brine channels during ice formation, is well documented (Cottier *et al.* 1999).

Most arctic coastal lagoons in Alaska have received little scientific attention. The Simpson Lagoon complex, located along the Beaufort Sea coast, has been studied (e.g. Griffiths *et al.* 1977; Matthews and Stringer 1984; Craig *et al.* 1985; Jorgenson *et al.* 2002) and a few lagoons located near Cape Thompson, along the Chukchi Sea coast of northwest Alaska, have been studied (e.g. Johnson 1966; Tash 1964; Tash and Armitage 1967. Thus far Blaylock and Houghton (1983) have conducted the only water quality studies of the coastal lagoons of Cape

Krusenstern National Monument (CAKR). Their research included Port Lagoon and Ipiavik Lagoon, two of the seven lagoons found within the CAKR boundary (Figure 3-1). This lack of basic, baseline data for the coastal lagoons in CAKR limits the understanding of the spatial and temporal variability of physicochemical parameters despite the critical role lagoons play in subsistence resources and hence, subsistence lifestyles (Uhl and Uhl 1977). This limited knowledge also makes management decisions (i.e. permitting resource extraction) difficult at best.

Cape Krusenstern National Monument (CAKR) is one of the four park units of Western Arctic National Parklands (WEAR) that is currently lacking baseline data of its aquatic resources. The Alaska Natural Heritage Program (ANHP) compiled vascular plant and vertebrate species lists from all the Alaskan National Parks. The ANHP report states the following about CAKR, "...little park specific information exists for fish observations...This park needs a better documented fish inventory" (Lenz *et al.* 2001). This need for better inventory of park resources is also stated in the Cape Krusenstern National Monument Resources Management Plan (NPS 1999). The need to expand baseline inventory is the number one priority on the natural resources projects list in this plan. Other projects of priority include: assess coastal zone resources, develop management strategies for aquatic resources, and assess fisheries. This management plan cites the lack of basic data for all the aforementioned priorities and that baseline data would help resource managers understand park ecosystems and help them make better management decisions. This echoes the broader, service-wide, inventory and monitoring guidelines, "knowing the condition of natural resources within the National Park system is fundamental to the Service's ability to protect and manage the parks" (NPS 1992; ii).

The overall objective of this research was to characterize water quality and species presence/absence for five of the coastal lagoons. More specifically, the objectives were: 1) to determine spatial (within lagoons and between lagoons) and temporal (seasonal and year-to-year) physicochemical variability, 2) to determine zooplankton abundance and variability, and 3) to determine benthic and ichthyofaunal presence/absence.

3.2 Setting and Methods

3.2.1 Site Description

Cape Krusenstern National Monument (CAKR) is located along the Chukchi Sea coast in northwest Alaska (Figure 3-1). It is approximately 72 km above the Arctic Circle and the centerpoint is situated at latitude N67°26' and longitude W163°32'. The area experiences harsh environmental conditions with snow and ice present typically 9 months (mid September – mid June) of the year. Using data available from NOAA, the 30-year average temperature in January for Kotzebue is -19 °C and the 30-year average temperature in July is 13 °C. The average annual wind speed in Kotzebue from 1992-2006 was 18.5 km/h with November having the highest average wind speed of 20.0 km/h (WRCC). Hourly data collected by the Western Regional Climate Center from 1992-2002 illustrated that prevailing winds in the summer (May – August) were from the west and for the remaining 8 months of the year, prevailing winds were from the east.

The Monument lies in the foothills and valleys of the Western Brooks Range and encompasses 2670 km² of land and water. It is largely a treeless coastal plain with the Mulgrave Hills in the northern portion of the monument and the Igichuk Hills in the southern portion. Red Dog Mine, the world's largest zinc mine, is located just outside the northeast corner of the CAKR boundary and the haul road traverses the northern portion of the monument (Figure 3-1).

Cape Krusenstern National Monument is remote and access is via floatplane, boat, or snowmachine. Three Native villages are located just outside the CAKR boundary: Kivalina is approximately 17 km northwest of the monument boundary, Noatak is approximately 13 km east of the boundary, and Kotzebue, the regional hub, is roughly 15 km southeast of the CAKR boundary. The monument is utilized by the inhabitants of these villages for subsistence resources that are found within the boundary. Seasonal subsistence harvesting takes place at various locations throughout CAKR (Uhl and Uhl 1977).

Seven coastal lagoons are located along the coastline of Cape Krusenstern National Monument (Figure 3-1). These lagoons vary in size with the smallest being Port Lagoon (2 km²) and the largest being Krusenstern Lagoon (56 km²; Table 3-1). Many of the lagoons extend longitudinally along the coast and are fronted by barrier beaches. Five of the lagoons (Akulaaq, Imik, Kotlik, Krusenstern, and Sisualik) were the focus of this research with the most complete data coming from Akulaaq, Krusenstern, and Sisualik due to logistical constraints.

The five lagoons vary in their water exchange with the Kotzebue Sound (Akulaaq, Krusenstern, and Sisualik) or Chukchi Sea (Imik and Kotlik). Akulaaq Lagoon, Imik Lagoon, and Kotlik Lagoon are all intermittently open, meaning that seawater enters the lagoons at irregular times (Table 3-1). Krusenstern Lagoon is seasonally-closed. The Tukrok River, which flows out of Krusenstern, travels approximately 15 km before it meets the Kotzebue Sound. This connection is only open seasonally – during ice break-up, as the ice flows down the river, it pushes the gravel bar open and the waters between the Tukrok River and Kotzebue Sound meet. This seasonal opening typically occurs in mid to late June. By mid-July, strong westerly storms push the gravel back into the opening and close off the connection between the river and the sound. The process will begin again the following spring. Sisualik is open to the Kotzebue

Sound year-round and Kotzebue Sound has a mean tidal range of 0.64 m (NOAA-NDBC). It should be noted that strong westerly storms can push seawater into all of the lagoons at any point during the open water season.

3.2.2 Sampling Design

The number of sampling points in each lagoon varied depending on the size of the lagoon, but points were typically located in the following areas: (a) near creek/river inlets and outlets, (b) in the middle of the lagoon, (c) along the shoreline-side of the lagoon, and (d) near any known anomalies (e. g. springs). This sampling scheme was similar to the one followed in the Blaylock and Houghton (1983) lagoon study. Extra sampling sites were added as the size of the lagoon increased. This design resulted in the following maximum number of sampling points in each lagoon: Akulaaq (5), Imik (3), Kotlik (3), Krusenstern (7), and Sisualik (6). Figures 3-2 through 3-6 show the location of the sampling stations within each lagoon, along with the location of beach seine hauls and gillnet sets. Each sampling location was recorded on a hand-held GPS unit so subsequent samples could be collected from the same approximate location (Appendix A).

3.2.3 Sampling/Laboratory Methods

The sampling methods utilized in this research were based on a combination of the protocols used in the USGS National Water-Quality Assessment Program (Moulton II *et al.* 2002) and the EPA National Coastal Assessment Field Operations Manual (U.S. EPA 2001). Modifications to the protocols were made to accommodate site-specific challenges and the incorporation of local knowledge. There were a total of seven sampling periods between January 2003 and August 2004. Four of the sampling periods were during ice-covered conditions

(January 2003, April 2003, January 2004, and April 2004) and three of the sampling periods were during open water conditions (July 2003, September 2003, and September 2004).

Ice-covered sampling took place during the winter (January 2003 and 2004) and spring (April 2003 and 2004). Access to all lagoons in the ice-covered periods was via snowmachine. An approximate 1m x 1m hole was drilled at each sampling site. Actual sampling did not occur until 24 hours later so that the water column had a chance to re-equilibrate after drilling. During the four sampling periods, physicochemical data and benthic grabs were obtained from each sampling station. An initial attempt was made to collect zooplankton samples, but the net froze-up and was non-functional, so further sampling was eliminated.

Ice thickness and snow depth were measured at each station. A minisonde was then lowered through the hole in the ice and a depth profile of water depth, salinity, dissolved oxygen, and water column temperature was collected from the unfrozen water. Water was collected mid-water column with a Niskin bottle and brought back to camp in the dark in a cooler in order to filter for chlorophyll *a*. Three subsamples were obtained from each sampling location. Water was filtered through glass-fiber filters (GF/F) under low light conditions. Once back in Kotzebue, the filters were placed in a freezer and then shipped to East Carolina University for chlorophyll *a* analysis. Fluorometric analysis was used to determine the chlorophyll *a* and phaeophytin concentrations.

Benthic grabs were also collected at each station to collect benthic invertebrate presence/absence data. A petite ponar grab was used to collect three replicates at each site. Each sample was kept cool and dark in a cooler until back in Kotzebue. Once back in town, the samples were sieved through a 500 μ m sieve with collected site water. Samples were then

preserved with 10% formalin and Rose Bengal stain. Identification was to the lowest possible taxon level (typically class or family level).

Open water sampling took place in the summer (July 2003) and in the fall (September 2003 and 2004). Akulaaq was sampled with a small zodiac boat and Krusenstern and Sisualik were sampled with a 15 ft aluminum boat. Imik and Kotlik were accessed via floatplane and sampled with a small zodiac boat. Sampling at Imik and Kotlik was limited due to logistical constraints. During the three sampling periods, physicochemical data, benthic grabs, zooplankton tows, and fish presence/absence data were collected. A depth profile of the following abiotic parameters was obtained with a Hydrolab Minisonde: water depth, salinity, dissolved oxygen, and water column temperature. As during the ice-covered sampling, water was collected with a Niskin bottle, transferred to a 4-L jug, and kept in a dark cooler. Once back at camp (within 12 hours of collection), three subsamples from the collected site water were filtered through glass-fiber filters (GF/F). Filters were wrapped in aluminum foil, and then placed in a cooler with ice packs until back in Kotzebue, where wrapped filters were placed in the freezer. Frozen filters were shipped to East Carolina University for chlorophyll *a* analysis. Fluorometric analysis was used to determine the chlorophyll *a* and phaeophytin concentrations.

Benthic grabs were collected as during the ice-covered seasons, except that sieving took place immediately. The less than 500 μm fraction was preserved with 10% formalin and Rose Bengal stain. Identification was to the lowest possible taxon level (typically class or family level). Zooplankton samples were collected at each station. An 8-in diameter, 153 μm zooplankton net was used to collect three vertical tows (from bottom to surface) at each site, with each tow being one replicate. The 125 ml sample was then preserved with 10% formalin. Identification was to the lowest possible taxon level (typically class or family level).

A beach seine and gillnets were used to assess fish presence/absence data. A 37 m bag beach seine, the same as that used in the Blaylock and Houghton (1983) lagoon study, was hauled in each lagoon, with seining locations ultimately determined by the depth of the water column and the ability to walk out far enough to haul the net (Figures 3-2 through 3-6). One team member held the beach seine on land using a pole while two team members dragged the net perpendicular to shore, and back to the beach in a U pattern. Fish were identified and returned to the water as soon as possible in order to limit the amount of fish mortality. As a means to capture larger, pelagic species, 5-panel experimental gillnets were anchored onshore so locations were largely determined by the presence of a suitable anchor site. Each panel was 7.6 m in length, for a total net length of 38.1 m. Stretch measurement of the individual panels were as follows: 2.5 cm, 3.8 cm, 5.1 cm, 7.6 cm, and 10.2 cm. The smallest mesh was anchored closest to shore, just off the beach and immersed in water and the largest mesh was anchored perpendicular to the shore. Gillnets were checked after a few hours. If the net was empty, we put it back down and checked it the next day. If the net was full, we picked it and set it back down for another few hours. Harvested specimens were identified to the genus and/or species level and released back into the water as soon as possible so as to limit the amount of fish mortality. A few minnow traps were set near the locations of the gillnets and were checked along with the nets.

3.2.4 Data Analysis

Both down and up profiles were obtained from the Hydrolab Minisode at sampling locations during all seven sampling periods. Only the down data were used for data analysis. In order to determine if stratification occurred in the water column, delta salinity and temperature were calculated for each site during each sampling period. If these calculations revealed a

number ≥ 5 units (e.g. °C, mg/L, etc) then it was determined that the water column was stratified for that particular parameter. During open water seasons, all available down measurements to a depth of 0.5 m were used to calculate the site-specific surface mean. During ice-covered seasons, only measurements in non-frozen water obtained under the ice were used to calculate the average. These calculations allowed for comparisons between stations within a lagoon as well as between lagoons. A lagoon-wide mean for surface waters was determined by combining each of the station means. Coefficient of variation (CV) calculations were made for physicochemical parameters as a means to compare the variation within and among the variables at the stations within a lagoon.

Two-dimensional metric multidimensional scaling (MDS) was used to explore spatial and temporal similarities/dissimilarities amongst the data for all sampling seasons and all physicochemical parameters. Specifically, MDS was used to explore spatial and temporal comparisons on a station-by-station basis within a lagoon throughout the seven sampling periods. Changes in zooplankton composition within the lagoons over time were also examined via MDS analysis. Macroinvertebrate and ichthyofauna presence/absence data were also analyzed via MDS. Euclidean distances were used along with stress values of Kruskal's stress formula 1 (Kruskal 1964). The statistical program SPSS 19 was utilized to carry out all statistical analyses.

Non-parametric statistics were used to carry out various analyses as the data sets were quite small and the data did not meet the normal distribution assumption. The Kruskal-Wallis Test was used to make comparisons between the different stations in each lagoon. The Friedman Test was used to make repeated-measures comparisons and determine significant differences on an intra-annual time scale. The Wilcoxon Signed Rank Test was used to make repeated-

measures comparisons on an inter-annual scale. Relationships between parameters were explored using Spearman's rho correlation analysis.

3.3 Results

The data results are organized into three main types: (1) spatial comparisons, (2) temporal comparisons, and (3) correlations. Spatial comparisons for both physicochemical and biological data are made within each lagoon for each season. Temporal comparisons for physicochemical data are presented, including both intra-annual and interannual comparisons within one lagoon. Correlations between physicochemical and biological parameters during ice-covered and open water seasons are explored. Statistics were not carried out for Imik and Kotlik due to the limited amount of data collected.

3.3.1 Spatial Comparisons

The results that follow are organized by season including: ice-covered seasons, and open water seasons. Complete depth profiles for salinity, dissolved oxygen, and water temperature at each station during each sampling period are presented in Appendix B. Station means and lagoon means during ice-covered periods are calculated using readings collected in non-frozen water under the ice and not those readings collected within the ice column. The station means and lagoon means during open water periods are calculated using all available down readings to a depth of 0.5 m. Individual station means for salinity, dissolved oxygen, and water temperature for each lagoon, in each season can be found in Appendix C.

The lowest lagoon mean salinity was measured in Krusenstern in September 2004 and the highest was measured in Akulaaq in April 2003 (Table 3-2; Figure 3-7). During seven sampling periods dissolved oxygen was lowest in Akulaaq in April 2004 and highest in Krusenstern in

September 2003 (Table 3-2; Figure 3-8). The lowest mean water temperature for the research period was recorded in Akulaaq in April 2003 and the highest mean water temperature was measured in Sisualik in July 2003 (Table 3-2; Figure 3-9). Coefficient of variation calculations indicated that water temperature was the least variable parameter in all the lagoons for all samplings (Figure 3-10). The largest CV for water temperature was calculated for Sisualik in September 2004 (0.40%) whereas the largest CV for salinity was in Sisualik in April 2003 (38.2%) and the largest CV for dissolved oxygen was in Akulaaq in January 2004 (53.2%; Table 3-2).

Metric multidimensional scaling (MDS) was utilized as a means to visualize and explore any type of similarity/dissimilarity amongst the seasons and the lagoons. A two-dimensional MDS analysis of environmental data collected during the seven sampling periods revealed that clustering appeared to be based on the presence or absence of ice (Stress = 0.02; Figure 3-11). The year in which the data were collected also influenced clustering of seasons, such that ice-covered seasons from the same year were most similar and open-water seasons from the same year were most similar. MDS analysis of stations within each lagoon for all environmental parameters throughout all seven sampling periods revealed strong clustering by lagoon (Stress = 0.10; Figure 3-12). All the Akulaaq and Krusenstern stations were tightly clustered, and the Sisualik stations were separated from both Akulaaq and Krusenstern, but not as tightly clustered. Based on these MDS findings, the results are organized in terms of ice-covered or open water season and then each sampling period and each lagoon within that season.

3.3.1.1 Physicochemical Parameters: Ice-Covered Seasons

Table 3-3 contains the lagoon mean, standard deviation (± 1), and coefficient of variation for ice thickness, snow depth, and water depth in each of the lagoons during the four ice-covered

sampling periods. All lagoons experienced a large amount of variability in these three parameters throughout the ice-covered seasons. Krusenstern had the thickest ice over these four sampling periods with an overall mean of 1.2 m. Sisualik had the deepest snow with a four-season mean of 18.3 cm and the deepest water was in Krusenstern, which had a four-season average of 1.1 m of water.

3.3.1.1.1 January 2003

A multidimensional scaling plot of environmental data for each of the sampling stations in each lagoon during January 2003 revealed clustering based on lagoon (Stress = 0.00; Figure 3-13). Significant within lagoon differences were detected despite the clustering. For Akulaaq Lagoon, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature between the five sampling stations during January 2003 (Appendix D). Kruskal-Wallis test also revealed statistically significant differences ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the seven Krusenstern Lagoon sampling stations in January 2003 (Appendix E). In Sisualik Lagoon, samples were only collected from stations SI1, SI2, and SI3 as stations SI4, SI5, and SI6 were frozen to the bottom in January 2003. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the three sampling stations (Appendix F).

3.3.1.1.2 April 2003

A multidimensional scaling plot of environmental data for each of the sampling locations in each lagoon during April 2003 revealed loose clustering based on lagoon (Stress = 0.00; Figure 3-14). No lagoon demonstrated tight clustering across all of its stations. Kruskal-Wallis test revealed statistically significant differences ($p < 0.05$) in salinity, dissolved oxygen, and

water temperature across the five sampling stations in Akulaaq Lagoon in April 2003 (Appendix D). The MDS plot of environmental data for April 2003 formed two groups for Akulaaq stations: AU2 and AU3 grouped together and AU1, AU4, and AU5 grouped together (Figure 3-14). Stations AU1 and AU5 showed the greatest amount of similarity. Samples were not collected from stations KR4 and KR7 because the sampling holes were submerged in a large amount of melt water. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across five sampling stations in April 2003 (Appendix E). The MDS plot of physicochemical data for April 2003 grouped stations KR1, KR3, and KR5 (Figure 3-14). Station KR6 was located a distance away from the group, with station KR2 located even further from the group (Figure 3-14). A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the three non-frozen sampling stations in Sisualik Lagoon in April 2003 (Appendix F). The MDS plot of environmental parameters grouped stations SI1 and SI2, while station SI3 appeared to be more similar to Krusenstern stations (Figure 3-14).

3.3.1.1.3 January 2004

Data used to produce a MDS plot of environmental data for all stations in all lagoons for January 2004 were quite limited due to minimal data collection. No samples were collected from Sisualik as it was frozen to the bottom. The MDS revealed that Akulaaq stations, as a whole, were dissimilar to the Krusenstern stations, which were loosely clustered (Stress = 0.00; Figure 3-15). Only two (AU2 and AU4) out of the five stations in Akulaaq were sampled due to extremely cold temperatures (i.e. air temperatures $< -20^{\circ}\text{C}$), equipment failure, and limited personnel. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the two sampling stations in January

2004 (Appendix D). Similarly, only three stations (KR1, KR4, and KR6) were sampled in Krusenstern Lagoon. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the three sampling stations in January 2004 (Appendix E).

3.3.1.1.4 April 2004

A multidimensional scaling plot of environmental data for each of the sampling stations in each lagoon during April 2004 revealed clustering based on lagoon (Stress = 0.00; Figure 3-16). All Akulaaq stations clustered together and all Krusenstern stations clustered. As in January, no stations were sampled in Sisualik as all six sampling stations froze to the bottom. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the five sampling stations in Akulaaq Lagoon in April 2004 (Appendix D). In Krusenstern Lagoon, the Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the seven sampling stations in April 2004 (Appendix E).

3.3.1.2 Physicochemical Parameters: Open Water Seasons

Table 3-4 contains the mean lagoon water depth, maximum water depth, and coefficient of variation for the five coastal lagoons during the open water sampling periods of July 2003, September 2003, and September 2004. In July, Imik and Sisualik were the shallowest with both lagoons having a lagoon mean depth of $0.9 \text{ m} \pm 0.1$ (Table 3-4). Krusenstern was the deepest in July 2003 with a lagoon mean of $2.0 \text{ m} \pm 0.2$. Station depth variability was low for most lagoons throughout the three open water sampling periods except for Kotlik in July 2003, which had a CV of 35.7% and Sisualik in September 2004, which had a CV of 22.3% (Table 3-4).

3.3.1.2.1 July 2003

A multidimensional scaling plot of environmental data at all stations in each lagoon during July 2003 revealed clustering based on lagoon (Stress = 0.02; Figure 3-17). All five Akulaaq stations were tightly clustered and all seven Krusenstern stations were tightly clustered. All six Sisualik stations were similar, but not as tightly clustered as the other two lagoons (Figure 3-17). A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the five Akulaaq Lagoon sampling stations in July 2003 (Appendix D). In Krusenstern Lagoon, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the seven sampling stations in July 2003 (Appendix E). Finally, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the six Sisualik Lagoon sampling stations in July 2003 (Appendix F).

3.3.1.2.2 September 2003

A multidimensional scaling plot of environmental data for each of the sampling stations in each lagoon during September 2003 revealed loose clustering based on lagoon (Stress = 0.02; Figure 3-18). Akulaaq and Sisualik stations loosely clustered and overlapped, while Krusenstern stations demonstrated more similarity amongst stations within the lagoon. In Akulaaq Lagoon, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the five sampling stations in September 2003 (Appendix D). A Kruskal-Wallis test also revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the seven Krusenstern Lagoon sampling stations in September 2003 (Appendix E). Only three stations were sampled in Sisualik in September

2003. A Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the three sampling stations (Appendix F).

3.3.1.2.3 September 2004

A multidimensional scaling plot of environmental data for each of the sampling stations in each lagoon during September 2004 revealed clustering based on lagoon (Stress = 0.01; Figure 3-19). All Akulaaq stations were tightly clustered and all Krusenstern stations were tightly clustered. Sisualik stations were clustered, but not as tightly as the other two lagoons, and seemed to form two different groups. In Akulaaq Lagoon, Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the five sampling stations (Appendix D). In Krusenstern Lagoon, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity and water temperature across the seven sampling stations (Appendix E), however dissolved oxygen was not shown to be statistically significant across these stations. In Sisualik Lagoon, a Kruskal-Wallis test revealed a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the six sampling stations (Appendix F). A MDS plot of environmental data for September 2004 showed stations SI1 and SI2 were most similar, and distinct from stations SI3, SI4, SI5 and SI6 (Figure 3-19).

3.3.1.3 Biological Parameters

3.3.1.3.1 Water Column Algal Biomass

Water column chlorophyll *a* and phaeophytin were measured in January 2003, April 2003, and September 2004. Individual station means are located in Appendix G. A look at

lagoon mean concentrations revealed that, out of these three sampling periods, the lagoons reached their highest concentrations in April 2003 (Table 3-2).

Coefficient of variation calculations revealed that, in January 2003, Akulaaq stations experienced that greatest amount of variation for chlorophyll *a* (133.3%) and phaeophytin (100.0%) and Krusenstern stations the least amount of variation for chlorophyll *a* (40.0%) and phaeophytin (45.5%; Table 3-2). Coefficient of variation results for April 2003 indicated that, once again, variation was greatest in Akulaaq for chlorophyll *a* and phaeophytin and lowest in Krusenstern for chlorophyll *a* and for phaeophytin (Table 3-2).

3.3.1.3.2 Zooplankton

All zooplankton samples were collected during open water seasons (July 2003, September 2003, and September 2004) as the net froze during ice-covered sampling periods. Copepods were present at all stations in all lagoons and cladocerans were present in Akulaaq and Imik in July 2003, in Akulaaq and Krusenstern in September 2003, and in Akulaaq in September 2004 (Appendix H). Akulaaq was the only lagoon during all three sampling periods to have both copepods and cladocerans present. Sampling did not occur in Imik or Kotlik in September 2003 or September 2004.

Mean relative copepod abundance was lowest in Krusenstern in September 2003 and highest in Akulaaq in July 2003 (Table 3-5; Figure 3-20). For cladocerans the lowest mean relative abundance was in Krusenstern in September 2003 and the highest mean relative abundance was in Imik in July 2003 (Table 3-5; Figure 3-20). Individual station mean relative abundance and standard deviation are located in Appendix H.

Comparison of zooplankton abundance among stations within a lagoon was completed with a Kruskal-Wallis test. The test revealed that, for both copepods and cladocerans, there was

no statistically significant difference ($p < 0.05$) between any of the sampling stations in Akulaaq, Krusenstern, or Sisualik during the three open water sampling periods (Appendix I).

Multidimensional scaling of the zooplankton data was used to explore similarities/dissimilarities amongst the lagoons. The MDS plot of mean relative abundance zooplankton at each station in July 2003 revealed that Krusenstern and Sisualik stations were similar whereas Akulaaq stations were dissimilar to both Krusenstern and Sisualik stations and not tightly clustered (Stress = 0.00; Figure 3-21). The MDS plot for September 2003 was similar to that for July 2003 in that both Krusenstern and Sisualik clustered while Akulaaq stations were separate from those two lagoons (Stress = 0.00; Figure 3-22). Station AU2 was separated from the other Akulaaq stations in both months. The MDS plot for September 2004 revealed tight clustering amongst Akulaaq and Krusenstern stations, with the exception of one station in Akulaaq (AU2), which was dissimilar from all stations and lagoons (Stress = 0.00; Figure 3-23). Sisualik stations were more similar to both Akulaaq and Krusenstern stations than in previous months.

3.3.1.3.3 *Benthic Macroinvertebrates and Ichthyofauna*

The data presented here are presence/absence data, as much of the data could not be scaled to per unit area (or catch per unit effort). Table 3-6 is a list of all benthic, epibenthic, and ichthyofauna collected between January 2003 and September 2004. Chironomids and clams (*Macoma* sp) were present in all lagoons. Imik had the fewest kinds of organisms present, as no fish were captured in Imik Lagoon; Sisualik had the most (Table 3-6). The Alaska Blackfish (*Dallia pectoralis*) was the only fish collected in Akulaaq in 2003. All other types of fish collected in Akulaaq were harvested in 2004. Various species of whitefish were present in all the lagoons except Imik. While numbers and the size of fish were not recorded, there were

numerous whitefish collected of harvestable size. Sheefish (*Stenodus leucichthys*) were harvested in both Krusenstern and Sisualik. Two arctic grayling (*Thymallus arcticus*) were harvested on the river-side of the outlet of Krusenstern Lagoon.

A multidimensional scaling plot of the presence/absence benthic macroinvertebrate and ichthyofauna data for each lagoon during the entire research period showed no clustering amongst lagoons (Stress = 0.00; Figure 3-24). The MDS plot revealed that Krusenstern was more similar to Sisualik than to Akulaaq and that Kotlik was most similar to Imik.

3.3.2 Temporal Comparisons

The results that follow are temporal comparisons of physicochemical parameters, both intra-annual (includes all four sampling periods in 2003) and interannual (April 2003/2004 and September 2003/2004). Multidimensional plots indicated that Akulaaq, Krusenstern, and Sisualik were not similar in terms of environmental data (Figure 3-12) therefore statistical comparisons between lagoons were not conducted.

3.3.2.1 Akulaaq

The Friedman Test was used to make intra-annual comparisons between the four sampling periods in 2003 (January, April, July, and September). There was a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the four sampling periods of 2003 (Table 3-7). Mean ranks revealed the following for the 2003 sampling periods: salinity was lowest in September and highest in April, dissolved oxygen was lowest in January and highest in September, and water temperature was lowest in April and highest in July (Table 3-7).

Comparisons between April 2003/2004 and between September 2003/2004 were carried out using the Wilcoxon Signed Rank Test. This test revealed that salinity, dissolved oxygen, and water temperature were all significantly different ($p < 0.05$) between the two years (Table 3-8). April 2003 salinity and dissolved oxygen were significantly greater than April 2004 salinity and dissolved oxygen. April 2003 water temperature was significantly lower than April 2004 water temperature. Salinity and water temperature in September 2003 were significantly less than in September 2004 and September 2003 dissolved oxygen was significantly greater than September 2004 dissolved oxygen (Table 3-8).

3.3.2.2 Krusenstern

Intra-annual comparisons (January, April, July, and September 2003) were made based on the seven sampling stations in Krusenstern Lagoon. Friedman Test results for these repeated measures indicated that there was a statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the four sampling periods of 2003 (Table 3-7). Mean ranks revealed the following: salinity was lowest in September and highest in April, dissolved oxygen was lowest in January and highest in September, and water temperature was lowest in January and highest in July (Table 3-7).

The interannual comparisons between physicochemical parameters measured in April 2003/2004 and September 2003/2004 using the Wilcoxon Signed Rank Test revealed that April 2003 salinity and dissolved oxygen were significantly greater than April 2004 salinity and dissolved oxygen (Table 3-8). This test also showed that April 2003 water temperature was not significantly different from April 2004 water temperature (Table 3-8). September comparisons revealed that September 2003 salinity and dissolved oxygen were significantly greater than

September 2004 salinity and dissolved oxygen, while September 2003 water temperature was significantly lower than September 2004 water temperature (Table 3-8).

3.3.2.3 Sisualik

The results of the Friedman Test indicated that there was no statistically significant difference ($p < 0.05$) in salinity, dissolved oxygen, and water temperature across the four sampling periods of 2003 (Table 3-7). The interannual comparison was made between September 2003/2004 because all six stations in Sisualik were frozen to the bottom in April 2004. Wilcoxon Signed Rank Test showed that there was no significant difference between September 2003/2004 salinity, dissolved oxygen, and water temperature (Table 3-8).

3.3.3 Correlations

Relationships between physicochemical parameters and biological parameters during the 2003 ice-covered seasons (January 2003 and April 2003) and all three open water seasons (July 2003, September 2003, and September 2004) were explored using Spearman rho correlation. Only 2003 ice-covered data were used due to the limited amount of chlorophyll *a* data collected. Results are presented in tables for each lagoon during each season.

3.3.3.1 Ice-Covered Seasons

Spearman rho identified several significant correlations between physicochemical parameters in Akulaaq, Krusenstern, and Sisualik. In Akulaaq there was a negative relationship between salinity and water temperature, and a positive correlation between salinity and snow depth and between salinity and the amount of daylight (Table 3-9). Water temperature and ice thickness, water temperature and snow depth, and water temperature and the amount of daylight were all negatively correlated in Akulaaq (Table 3-9). Positive relationships between ice

thickness and snow depth, ice thickness and the amount of daylight, and snow depth and the amount of daylight were seen in Akulaaq (Table 3-9). In Krusenstern, salinity was positively correlated with ice thickness and the amount of daylight. Ice thickness and the amount of daylight were also positively correlated in Krusenstern (Table 3-10). In Sisualik, there was a negative relationship between salinity and water temperature. Ice thickness and snow depth, and ice thickness and daylight were positively correlated in Sisualik. Snow depth was also positively correlated with the amount of daylight in Sisualik (Table 3-11).

Relationships between chlorophyll *a* concentration and five physicochemical parameters (salinity, water temperature, ice thickness, snow depth, and daylight hours) were also explored in Akulaaq, Krusenstern, and Sisualik. In Akulaaq, there was a positive correlation between chlorophyll *a* and both snow depth and daylight hours (Table 3-9). In Krusenstern, there was a positive correlation between chlorophyll *a* and salinity, ice thickness, and daylight hours (Table 3-10). In Sisualik, there was a positive relationship between chlorophyll *a* and snow depth and daylight hours (Table 3-11).

3.3.3.2 Open Water Seasons

Spearman rho identified few significant correlations between the physicochemical parameters in Akulaaq, Krusenstern, and Sisualik in the open-water period. A negative relationship between salinity and dissolved oxygen and a positive correlation between salinity and water temperature in Akulaaq were observed (Table 3-12). A negative relationship between dissolved oxygen and water temperature was observed in Akulaaq (Table 3-12). This negative relationship was also observed in Krusenstern (Table 3-13). In Sisualik, a negative relationship between salinity and dissolved oxygen was observed (Table 3-14).

Relationships between copepods and cladocerans and three physicochemical parameters (salinity, dissolved oxygen, and water temperature) were also explored in Akulaaq, Krusenstern, and Sisualik using Spearman rho correlation coefficient. In Akulaaq, there was a negative relationship between the mean relative abundance of copepods and mean salinity (Table 3-12). In Krusenstern Lagoon, there was a positive relationship between the mean relative abundance of copepods and mean salinity (Table 3-13), and a positive relationship between mean relative abundance of cladocerans and mean dissolved oxygen. Negative relationships were also identified in Krusenstern. There was a negative relationship between the mean relative abundance of cladocerans and mean water temperature and between the mean relative abundance of cladocerans and the mean relative abundance of copepods (Table 3-13). In Sisualik, Spearman rho correlation coefficient analysis did not reveal any relationships between mean relative abundance of copepods and mean salinity, mean dissolved oxygen, or mean water temperature (Table 3-14).

3.4 Discussion

Through the collection of these data, much has been learned about the CAKR coastal lagoons. Sampling in such a remote area proved to be quite challenging. Accessing the lagoons during ice-covered sampling periods was, in many ways, easier than during open water seasons. This was especially true for Akulaaq, Krusenstern, and Sisualik where there was a snowmachine trail to follow and a National Park Service camp (Anigaaq) to use as a base camp. Imik and Kotlik proved to be more difficult due to increased distances. Low air temperatures, especially in January, hindered sampling. Equipment failure (i.e. minisonde freezing, zooplankton net freezing) was often the reason behind the limited data collection in ice-covered periods.

Lagoon access during open water sampling presented other challenges as boat access was not simple. The only lagoon with direct boat access was Sisualik. Krusenstern access required piloting a boat to the typically closed seasonal opening spot of the Tukrok River, driving the boat onto land, and rolling it via PVC pipes roughly 45 meters to the Tukrok River. This process took approximately one hour with two fourwheelers attached to the boat for extra pulling power. Once in the river, it was roughly 15 km to the lagoon opening. Akulaaq access was via boat, then fourwheeler and raft. Both Imik and Kotlik were accessed via floatplane and once onsite, a raft was inflated and utilized to sample each lagoon. Sampling at these two lagoons was quite limited, even during open water seasons, due mainly to budget constraints.

3.4.1 Physicochemical Parameter Comparisons

The results from the physicochemical data collection demonstrate that the coastal lagoons of Cape Krusenstern National Monument are naturally dynamic aquatic systems that not only undergo intra-annual temporal changes, but also interannual seasonal changes. These systems are also all quite different in their water depths, sizes, and/or connections to and from other water sources. The physicochemical conditions are very different during the ice-covered and open water seasons. Each will be discussed in turn.

3.4.1.1 Ice-Covered Seasons

Not all of the lagoons froze to the bottom during the winter and spring, despite having water depths between 0.7 m and 2.5 m during open water seasons (Table 3-4). None of the stations in Krusenstern froze to the bottom, and water depths under the ice were between 0.8 m and 1.3 m during the four ice-covered seasons. By comparison, Imik stations were frozen in April 2004, Sisualik stations SI4, SI5, and SI6 were frozen to the bottom in both January and

April 2003 and all Sisualik stations were frozen to the bottom in January and April 2004.

Minimal water depths under the ice likely also indicate minimum free-flowing water. These data reveal that, in terms of water availability, Krusenstern is the most likely lagoon to contain overwintering locations for fish.

Ice is present on the lagoons approximately nine months (mid-September to mid-June) out of the year and the data presented here suggest that this ice influences the physicochemical parameters of the underlying water column. Coefficient of variation (CV) results indicate that all the lagoons experience the greatest amount of spatial physicochemical variability during ice-covered sampling periods (Figure 3-10), and salinity and dissolved oxygen varied more than temperature. Station-to-station variability for salinity was different for each of the three lagoons. The CV decreased from January to April in both 2003 and 2004 in Akulaaq, while Krusenstern stations exhibited no consistent pattern (Table 3-2). The larger size and the likely greater amount of flowing water under the ice in Krusenstern are likely impacting this minimal variability in salinity during ice-covered seasons. Sisualik stations experienced the greatest variability in salinity in 2003, with a CV of 23.5% in January and a CV of 38.2% in April (Table 3-2). The shallow depth, the variable nature of this tidally-influenced, open lagoon, and the conditions at freeze-up are likely observed in these salinity CV calculations.

The greatest within lagoon station-to-station variability during the ice-covered seasons was in the dissolved oxygen concentrations (except stations in Sisualik in January 2003). The wind that regularly keeps these coastal lagoons well-mixed during open water seasons has negligible impact during ice-covered seasons due to the presence of ice. The dissolved oxygen levels are reduced under ice-cover as: 1) respiration takes place and uses up oxygen, 2) the presence of the ice prevents atmosphere-surface winter interaction, and 3) the limited amount of

light reduces photosynthesis until sufficient light is again available. While low, all the lagoons had mean D.O. concentrations higher than 5.0 mg/L in January, and in April 2003, except for Akulaaq, which had a mean of 3.1 mg/L in January 2003 (Table 3-2; Figure 3-8). In April 2004 the highest lagoon mean D.O. concentration was 2.7 mg/L in Krusenstern. These low dissolved oxygen levels were also observed by Tash and Armitage (1966) who measured dissolved oxygen concentrations in various lagoons, lakes, and pools of the Cape Thompson area. They recorded values around 0.0 mg/L in these various water bodies during ice-covered seasons. The low and irregular D.O. concentrations in Akulaaq and Krusenstern will limit which fish species can successfully overwinter in the lagoons as dissolved oxygen levels below 4 mg/L are regarded as limiting for many species.

Interannual comparisons of physicochemical parameters during ice-covered seasons were limited to April 2003 and April 2004. Sisualik froze to the bottom in 2004 so only stations within Akulaaq and within Krusenstern were compared. The Wilcoxon Signed Rank test results indicated a significant difference between April 2003 and April 2004 salinity, dissolved oxygen, and water temperature in Akulaaq (Table 3-8). In April 2003, a mean salinity of $62.1 \text{ psu} \pm 1.8$ was measured in Akulaaq. This hypersaline level was only observed in Akulaaq and only in 2003. In April 2004 the mean salinity in Akulaaq was $19.4 \text{ psu} \pm 1.4$, a clear contrast from the year before (Table 3-2). The conditions in April are most likely a function of the physicochemical conditions that were present at the time of freeze-up. A big influx of seawater at the time of freeze-up will increase the salinity of the lagoon and ultimately increase the salinity of the underlying water column because of brine loss from the ice over the winter. In Krusenstern, Wilcoxon Signed Rank test results also indicated a significant difference between April 2003 and April 2004 salinity and dissolved oxygen, but no significant difference for water

temperature. Dissolved oxygen was the parameter with the biggest annual change for Krusenstern. In April 2003, the mean dissolved oxygen was $9.6 \text{ mg/L} \pm 1.7$ and the following year in April 2004, the mean dissolved oxygen was only $2.7 \text{ mg/L} \pm 1.3$ (Table 3-2). Perhaps this significant decrease in available oxygen is a function of the greater amount of snow measured in April 2004 as opposed to April 2003 (Table 3-3). The snow layer limits the amount of light penetrating the ice layer thereby reducing the amount of light available for chlorophyll *a* production (Smith *et al.* 1993). Mean chlorophyll *a* for Krusenstern in April 2003 was quite high at $29.6 \text{ } \mu\text{g/L} \pm 8.2$ when D.O. was also high, but unfortunately chlorophyll *a* data for April 2004 were not available for comparison (Table 3-2). The results observed here suggest a high degree of interannual variability in Akulaaq and Krusenstern during ice-covered seasons and reinforce the dynamic nature of these coastal lagoons.

3.4.1.2 Open Water Seasons

The open water season up in this arctic region is only three months (mid-June to mid-September) long. Coefficient of variation results indicate that all lagoons, except for Sisualik, experience low ($< 6\%$) station-to-station variability in both salinity and dissolved oxygen during open water seasons. This is in contrast to the maximum CV for salinity (22.8%) in Krusenstern and the maximum CV for dissolved oxygen (53.2%) in Akulaaq during ice-covered seasons (Table 3-2). Sisualik is the exception in terms of station variability, where the CV for salinity was 21.9% in July 2003, 26.4% in September 2003, and 15.4% in September 2004 (Table 3-2). However, the variability for dissolved oxygen in Sisualik during the open water seasons was similar to that measured in the other lagoons. A look at the CV for water temperature indicates low station-to-station variability for all three lagoons during open water periods. The highest CV for water temperature was in Sisualik in September 2004 (0.40%; Table 3-2). The shallow

depths along with the frequent winds of the area certainly play a role in keeping the lagoon waters well mixed during open water seasons.

Sisualik salinity was unique in that it appeared to develop a halocline during the July 2003 and September 2004 open water periods (Appendix B). The type of water connection to the Kotzebue Sound likely contributes to this salinity stratification. Sisualik is the only CAKR lagoon that is completely open to the Kotzebue Sound and the tides, despite their microtidal designation, are clearly influencing the salinity at various locations around the lagoon. Additionally, the freshwater inflow from the Noatak River located to the east of Sisualik (Figure 3-1) is likely one of the major sources of freshwater entering the lagoon. Future studies investigating currents would help in understanding water flow and sources in and out of the lagoon.

The distance from the back of the lagoon to the inlet (approximately 7 km) is another explanation for the significant station variability. In July, stations furthest from the inlet (SI1, SI2, and SI3) tended to be more saline than SI5, which was located at the inlet (Appendix C and Figure 3-6). The multidimensional scaling plot of environmental data for July supported these differences and indicated that stations SI1, SI2, and SI3 were most similar and that stations SI1 and SI5 had the greatest amount of dissimilarity when compared to the other stations in Sisualik (Figure 3-17). The station trend reversed in September where stations inland were less saline than those closest to the Sound. Station SI5 had the highest salinity in both September 2003 and 2004. The MDS plots of September 2003 (Figure 3-18) and September 2004 (Figure 3-19) were similar to July 2003 in that inland stations were dissimilar to inlet stations. Perhaps the shift in station salinity can be explained by the seasonal changes that occur as winter approaches. August is typically the rainy season so land runoff could be impacting the salinity at the inland

locations. By September ice begins to form on freshwater bodies of water so perhaps the freshwater flow from the nearby Noatak River is reduced thereby reducing the amount of freshwater flowing into the lagoon.

Interannual comparisons were made between the physicochemical parameter data collected in September 2003 and September 2004. Wilcoxon Signed Rank Test results indicated a significant difference between September 2003 and September 2004 salinity, dissolved oxygen, and water temperature in Akulaaq stations and Krusenstern stations (Table 3-8). Mean dissolved oxygen concentrations were higher in September 2003 as opposed to September 2004 in both lagoons (Figure 3-8) and the inverse was true for mean water temperatures in Akulaaq and Krusenstern (Table 3-2; Figure 3-9). This dissolved oxygen and water temperature pattern is readily explained by the well-known relationship between water temperature and dissolved oxygen whereby colder water holds more oxygen. The warmer water temperatures of September 2004 could be explained by the timing of sampling as the September 2004 sampling occurred approximately three weeks earlier than the September 2003 sampling.

The Wilcoxon Signed Rank test did not identify any significant differences in the September 2003 and September 2004 salinity, dissolved oxygen, or water temperature in Sisualik stations (Table 3-8). This lack of significant difference is a function of the small sample size. Only three stations were sampled in September 2003 due to limited water depths which made boat maneuvering difficult and minimal personnel assistance. Sisualik developed a halocline in September 2004, but not in September 2003 and also developed a halocline in July 2003 (Appendix B). The interannual data presented here highlight the importance of larger numbers of samples, and consistent sampling times if information on temporal changes in the coastal lagoons is desired.

3.4.1.3 Intra-Annual Comparisons

Intra-annual comparisons of physicochemical parameters during the four sampling seasons of 2003 (January, April, July, and September) were carried out using the Friedman Test. It comes as no surprise in this environment of ice-covered and open water seasons that salinity, dissolved oxygen, and water temperature, were all found to be significantly different in Akulaaq and Krusenstern during the four seasons (Table 3-7). A look at salinity in Akulaaq supports the dynamic nature of these coastal lagoons on a seasonal basis. In January 2003, Akulaaq had a mean salinity of $36.0 \text{ psu} \pm 4.0$ and three months later in April 2003, the mean salinity was up to $62.1 \text{ psu} \pm 1.8$ (Table 3-2). Akulaaq was the only lagoon to reach this hypersaline level throughout the research period. Friedman Test results indicated that none of the three parameters were found to be significantly different in Sisualik during the four sampling seasons of 2003, however this lack of significance is a function of the small number of samples obtained. In both January and April 2003 only three stations in Sisualik were sampled as the other three stations froze to the bottom. This severely limited the amount of data available for comparison and should thus be considered when interpreting the results.

The intra-annual dynamic nature of these lagoons was evident as the physical conditions changed from ice-cover to open water. The hypersaline level in Akulaaq in April 2003 was reduced to an estuarine level of $8.1 \text{ psu} \pm 0.1$ just three months later in July 2003 (Table 3-2; Figure 3-7). Krusenstern and Sisualik also experienced a drop in salinity between April and July 2003. This decrease in salinity can partly be attributed to spring break-up and flushing as was also observed in Simpson Lagoon, along the Beaufort Sea (Matthews and Stringer 1984). Mean dissolved oxygen levels increased in all the lagoons as the ice layer melted between the April 2003 sampling and July 2003 sampling and the highest D.O. concentrations, in all the lagoons,

were measured during the open water periods (Figure 3-8). Again, the high winds, shallow depths, and absent ice layer are all contributing factors. Not surprisingly, water temperature was greatest during the open water periods in all the lagoons (Figure 3-9).

3.4.2 Biological Parameter Comparisons

3.4.2.1 Algal Biomass

The lowest mean chlorophyll *a* and phaeophytin concentrations in Akulaaq, Krusenstern, and Sisualik were measured in January 2003 and the highest mean chlorophyll *a* and phaeophytin concentrations in all three lagoons were measured in April 2003 (Table 3-2). Coefficient of variation results indicate a high degree of station variability in algal biomass in all three lagoons during all three sampling periods, with the least amount of variability in chlorophyll *a* and phaeophytin concentrations measured between the Krusenstern stations in April 2003 (Table 3-2). The large size of Krusenstern along with the greatest amount of unfrozen water under the ice are most likely impacting the lower amount of station variability in Krusenstern. This decreased variability implies a more stable food base for primary consumers during the ice-covered seasons thus providing a food base for overwintering fish species (if they survived the low oxygen concentrations).

It is evident from the chlorophyll *a* data presented here that these lagoons experience a spring bloom just as observed in deeper, ocean waters (Horner and Schrader 1982). Of note, this lagoon bloom takes place prior to ice-loss. Mean chlorophyll *a* and phaeophytin concentrations increased in all the lagoons between January 2003 and April 2003 (Table 3-2). As winter moves to spring the amount of available light is certainly playing a role in these increasing concentrations. In January the region averages four hours of daylight whereas in April, the average amount of daylight is 16 hours (USNO). Ice thickness and snow depth may also be

impacting the amount of chlorophyll *a* in the lagoons. Relationships between ice thickness, snow depth, average daylight, and algal biomass are further explored and discussed in a subsequent section entitled, Parameter Relationships.

3.4.2.2 Zooplankton

Multiple studies have been conducted about zooplankton in arctic lakes and lagoons (Tash and Armitage 1966; Moore 1978; O'Brien 1979; Kling *et al.* 1992), but few have been conducted in the CAKR coastal lagoons. Shizas and Shirley (1994) identified a new harpacticoid copepod (*Onychocamptus krusensterni*) in the sloughs of Krusenstern Lagoon, but to my knowledge no further zooplankton studies have been conducted in the coastal lagoons of CAKR. The coarse-level of zooplankton identification that was made in this study was designed to give a broad understanding of zooplankton within the CAKR lagoons. Zooplankton samples were only collected during the open water periods of July 2003, September 2003, and September 2004. A few opportunistic samples were collected under ice-cover and those data are included in Appendix H.

The dominant taxa in all the lagoons were copepods and cladocerans. Kling *et al.* (1992) looked at zooplankton in arctic lakes and rivers and found few cladocerans living in coastal lakes. Other studies have shown that the low water temperatures and short growing seasons of the arctic limit the diversity and distribution of cladocerans (Moore 1978; Hebert and Hann 1986).

Kruskal-Wallis results did not indicate any significant difference in the relative abundance of zooplankton between the different stations in each lagoon throughout the three open water sampling periods (Appendix I). A look at the lagoon means indicates that the highest lagoon mean relative abundance of copepods was in Akulaaq in July 2003 (Table 3-5). It should

be noted here that only one fish, the Alaska Blackfish (*Dallia pectoralis*) was collected from Akulaaq in July 2003 (Table 3-6). This absence of ichthyofauna likely allowed the zooplankton to flourish as predation was limited within the lagoon. Similarly, the highest mean relative abundance of cladocerans was in Imik in July 2003 (Table 3-5). No fish were harvested from the lagoon despite two, 24-hour gillnet sets in July 2003 (Table 3-6). Again, the lack of predation is likely influencing the high numbers of zooplankton in the lagoon. The importance of predation is further supported by the interannual comparison between the September 2003 and September 2004 zooplankton data in Akulaaq Lagoon. Copepod numbers declined in September 2004 (Table 3-5) when multiple fish were collected (Table 3-6).

Multidimensional scaling plots for July 2003 and September 2003 lagoon zooplankton were similar (Figures 3-21 and 3-22, respectively). Krusenstern and Sisualik stations clustered together while Akulaaq stations were separated from the other two lagoons. The large mean relative abundance of cladocerans in Akulaaq is most likely influencing this dissimilarity from the other two lagoons. The MDS plot for September 2004 placed all lagoons together (except for station AU2; Figure 3-23). The presence of various fish species in Akulaaq in 2004, but not in 2003 is a major difference in the 2003 and 2004 open water periods. Several of my results indicate the amount of ichthyofauna predation appears to have a direct impact on the type and abundance of zooplankton present in these coastal lagoons.

3.4.2.3 *Benthic Macroinvertebrates and Ichthyofauna*

The study described herein was designed to give a general overview of the types of organisms present in the lagoons rather than a quantitative measure of individual species abundances. Chironomids (Chironomidae) were present in all the lagoons (Table 3-6). These aquatic insects are very diverse, can live in many habitats, and tolerate a wide range of water

quality. They are often used as water pollution indicators as some species are very tolerant to pollution while others are very sensitive to pollution. These aquatic insects are known to be a food of choice for many species of fish.

Fish were collected from all the lagoons except Imik, where an experimental gillnet set for 48 hours failed to collect any fish (Table 3-6). The only chum salmon (*Oncorhynchus keta*) harvested throughout this research, a spawning male, was harvested in a gillnet at the entrance to Sisualik in September 2004. Various species of whitefish (*Coregonus* sp.) were collected in all the lagoons except Imik. Least Cisco (*Coregonus sardinella*) are often found in lakes and estuaries and Bering Cisco (*Coregonus laurettae*) are tolerant of high salinity waters. Both species feed on invertebrates and both species were collected in Akulaaq, Krusenstern, and Sisualik. Humpback whitefish (*Coregonus pidschian*) were plentiful in Krusenstern (personal observation). The data presented here demonstrate that most of the fish species that utilize these coastal lagoons are anadromous and can live in marine, brackish, and even freshwater environments (Table 3-6).

Only two species collected in the lagoons are typically classified as freshwater species – the Alaska Blackfish (*Dallia pectoralis*), and Arctic Grayling (*Thymallus arcticus*). The Alaska Blackfish was only harvested in Akulaaq Lagoon. One juvenile was captured in a minnow trap in July 2003 near the creek inlet at the northwest end of the lagoon. One other blackfish, a large (21 cm) adult male, was harvested in a gillnet set in September 2003 at the same creek inlet. The Alaska blackfish is a unique species found only in Alaska and eastern Siberia - it is endemic to Beringia (Mecklenburg *et al.* 2002). It is a hardy species that has a modified esophagus that allows it to absorb atmospheric oxygen. They feed on various benthic invertebrates (Armstrong 1994). Two Arctic Grayling (*Thymallus arcticus*) were collected just outside the outlet of

Krusenstern Lagoon. Grayling are a freshwater species and are also tolerant of low dissolved oxygen waters.

Resident fish species in Akulaaq (i.e. *Dallia pectoralis*) must be able to tolerate the high amount of intra-annual and interannual variability. The two Alaska Blackfish harvested in Akulaaq were the only fish species harvested in Akulaaq in 2003; all the other species collected in this lagoon were taken in 2004 (Table 3-6). One possible explanation may be a breaching of the lagoon in 2004, which would have allowed fish to enter and exit the lagoon. There is no knowledge of this breaching event, but the area is quite isolated so such events can easily go unnoticed. Future research should incorporate more local knowledge and utilize the local users of CAKR in any monitoring activities.

By comparison, the data suggest that Krusenstern Lagoon provides a more stable environment. For example, in 2003 the minimum lagoon mean salinity was in September ($3.4 \text{ psu} \pm 0.1$) and the maximum lagoon mean salinity was in April ($6.5 \text{ psu} \pm 0.3$; Table 3-2; Figure 3-7). This stability is partially supported by the location of the lagoon outlet and its connection to Kotzebue Sound. The Tukrok River flows out of the lagoon and winds around for approximately 15 km before it meets the Kotzebue Sound. This distance makes it highly unlikely that there is a direct influx of Sound water into the lagoon. Ocean spray and underwater seeps are the more likely sources of salt water into Krusenstern. However, the seasonal opening of the river mouth does provide a means for various pelagic species to enter and exit the wetland/estuarine area. Krusenstern also had the greatest amount of available unfrozen water under the ice in both 2003 and 2004 (Table 3-3) and mean dissolved oxygen levels in 2003 were species-supporting (Table 3-2; Figure 3-8). Craig *et al.* (1985) found that in the winter, the species in Simpson Lagoon near the Beaufort Sea were marine species, mainly Arctic cod and

fourhorn sculpin, as the anadromous species returned to rivers and lakes to overwinter. A major limiting factor to fish species in the winter is the availability of habitat (Schmidt *et al.* 1989). Krusenstern supports many different fish species during open water seasons and the fact that it doesn't freeze to the bottom in winter suggests that it could provide the physical habitat required for fish to overwinter. Setting nets under the ice in Krusenstern would help identify overwintering areas and promote our understanding of overwintering biology.

Sisualik is open to Kotzebue Sound and is subject to the minimal tides of the area. When water levels are low, a sandbar is exposed on the outer portion of the lagoon, the area closest to the delta created by the Noatak River. Large amounts of *Potamogeton spp.* were observed in the lagoon during the July 2003 sampling period. The openness of the lagoon to Kotzebue Sound gives fish the opportunity to enter and exit this microtidal lagoon on a regular basis during open water seasons. During this research period, the greater number of species harvested in Sisualik when compared to the other four lagoons is most likely a function of its open connection to Kotzebue Sound.

A multidimensional scaling plot of all the benthic macroinvertebrate and ichthyofauna presence/absence data collected between January 2003 and September 2004 supports the conclusion that all five coastal lagoons are quite different (Figure 3-24). The type of water connection a lagoon has to the Kotzebue Sound and the amount of breaching is most likely impacting this dissimilarity. The collection of quantitative abundance data would increase the understanding of any connection-type similarities/differences and benefit area managers as these lagoons continue to be utilized for subsistence resources.

3.4.3 Parameter Relationships

Relationships amongst the physicochemical parameters in each lagoon were explored through the use of Spearman rho correlation coefficient. Each lagoon was treated as its own entity rather than combining the parameter data; this was due to the differences already identified and discussed in the sections above. Ice-covered parameters included: mean salinity, mean water temperature, ice thickness, snow depth, average daylight hours, and mean chlorophyll *a*. Open water parameter relationships explored were: mean salinity, mean dissolved oxygen, mean water temperature, mean relative abundance of copepods, and mean relative abundance of cladocerans.

3.4.3.1 Ice-Covered Seasons

A significant negative correlation ($p < 0.01$) was found between the mean salinity and mean water temperature in both Akulaaq and Sisualik (Tables 3-9 and 3-11). The increasing salinities in both Akulaaq and Sisualik from January to April can readily be explained by the well known fact that salt-exclusion occurs during the freezing process (Wiseman 1979; Matthews and Stringer 1984; Cottier *et al.* 1999). As salt water freezes, brine channels form and the extruded salt is added to the non-frozen water under the ice. This additional salt lowers the freezing point of the water (NSIDC). Both Akulaaq and Sisualik experienced mean water temperatures well below 0 °C (Table 3-2). Spearman rho correlation did not identify any significant correlation between mean salinity and mean water temperature in Krusenstern (Table 3-10). Krusenstern had more available water (Table 3-3) therefore the resultant brine from the forming ice was diluted, additionally initial salinity in Krusenstern was also lower, so less brine was released during ice formation.

As discussed, the conditions at freeze-up influence the physicochemical parameters during the ice-covered seasons. This was perhaps best observed in the interannual comparison of

the Akulaaq and Krusenstern salinity data of January 2003 and January 2004. Both lagoons experienced higher salinities in 2003 as opposed to 2004 and these higher salinities are most likely explained by a strong westerly storm that hit the area in October 2002 (personal observation). It is likely the coastal lagoons received an influx of ocean water just as they were about to freeze. This high saline water was then locked into the lagoons until spring flushing nine months later. All six Sisualik stations were frozen to the bottom in 2004 which was perhaps also a function of the less saline water at the time of freeze-up.

The only significant correlation between ice thickness and chlorophyll *a* was in Krusenstern where a strong positive relationship was identified (Table 3-10). A look at ice thickness (Table 3-3) reveals that Krusenstern had the thickest ice during April and also the highest chlorophyll *a* concentration (Table 3-2). The snow depth reveals that Krusenstern was snowless during the 2003 ice-covered sampling periods (Table 3-3). This lack of snow on the CAKR coastal lagoons is not unusual as the region experiences high winds throughout the year. The location of Krusenstern Lagoon right on the Cape makes it highly susceptible to these high winds thus preventing the buildup of snow (Figure 3-1). The thick ice, lack of snow, and high chlorophyll *a* concentration data of Krusenstern all support the idea that snow depth rather than ice thickness is the biggest driver of light availability for marine systems and that snow depth is most likely the limiting factor in terms of spring algal blooms in the arctic (Smith *et al.* 1993). The Krusenstern data also support the understanding that the light-attenuating property of ice is lower than that for snow (Thomas 1963).

Counter to this, Spearman rho correlation revealed a positive relationship between snow depth and chlorophyll *a* concentration in both Akulaaq and Sisualik (Tables 3-9 and 3-11). Snow depth at both Akulaaq and Sisualik increased between January 2003 and April 2003 (Table 3-3)

as did the chlorophyll *a* concentration (Table 3-2). These results are in contrast to many studies that report an inverse relationship between snow depth and chlorophyll *a* (Alexander 1974; Horner and Schrader 1982; Mundy *et al.* 2005) and the Thomas (1963) study indicating the lower light-attenuating property of ice. Perhaps it is the timing of the snowfall at both Akulaaq and Sisualik, with snow depth increasing later in the season. Another contributing factor is the increasing amount of daylight that occurs as the months progress from January to April. A highly positive relationship between the number of daylight hours and the chlorophyll *a* concentration of the underlying water column in Akulaaq, Krusenstern, and Sisualik was identified using Spearman rho correlation (Tables 3-9, 3-10, and 3-11).

3.4.3.2 Open Water Seasons

A negative correlation was identified in Akulaaq between mean salinity and the mean relative abundance of copepods (Table 3-12). This inverse relationship was observed by Finney (1979) where some harpacticoid copepods went dormant under high salinity conditions (i.e. 60 ppt), but were revived once salinity levels dropped (i.e. 30 ppt). Perhaps the hypersaline conditions in Akulaaq in April 2003 caused many copepods to go dormant and then in July 2003, once the salinity had dropped down to an estuarine level, the copepods came out of dormancy (Table 3-5). A look at the mean salinity data reveals that the September 2004 mean was higher than the September 2003 mean (Table 3-2; Figure 3-7). It is likely that both salinity and predation play a role in the copepod population in Akulaaq during open water seasons. This relationship was reversed in Krusenstern where mean salinity was positively correlated with the mean relative abundance of copepods (Table 3-13). The salinity range in Akulaaq was much greater than that for Krusenstern so perhaps the greater range in salinity has a negative impact on the copepod population.

A positive relationship between the mean relative abundance of copepods and the mean relative abundance of cladocerans was identified in Akulaaq (Table 3-12). This relationship is most likely the result of ichthyofauna predation impacting both in a similar manner, as discussed previously. An inverse relationship between the mean relative abundance of copepods and the mean relative abundance of cladocerans was observed in Krusenstern (Table 3-13). A closer look at the zooplankton data revealed that cladocerans were only present in Krusenstern in September 2003 (Table 3-5). Byron *et al.* (1984) found that the cladoceran *Bosmina longirostris* was limited by the predation of the omnivorous calanoid copepod *Epischura nevadensis* in an oligotrophic lake. More quantitative ichthyofauna and zooplankton data would assist in understanding the population dynamics within Krusenstern Lagoon.

Spearman rho correlations did not identify any significant relationships between environmental parameters and the mean relative abundance of copepods in Sisualik (Table 3-14). The open connection to Kotzebue Sound and the micro tides imply that the physicochemical parameters are constantly changing and that fish are able to enter and leave on a regular basis. Cladocerans were never present in the Sisualik samples (Table 3-5; Figure 3-20). Quantitative zooplankton and fish data would most certainly assist in identifying predator-prey relationships not only in Sisualik, but in all the coastal lagoons of CAKR.

3.4.4 Summary and Recommendations

The data presented here demonstrate spatiotemporal variability in physicochemical and biological parameters within and amongst the coastal lagoons of Cape Krusenstern National Monument. The conditions at freeze-up (related to storms) and the type of water connection a lagoon has to the open ocean both impact these parameters on an intra-annual and interannual basis. These shallow coastal lagoons are dynamic and are clearly different during the two major

seasons of ice-cover and open water. Understanding basic system response to these major seasonal changes is critical to the long-term management of these coastal lagoon habitats.

Not all these shallow, coastal lagoons freeze to the bottom in the dead of winter. Krusenstern had the greatest amount of non-frozen water under the ice and none of the sampling stations were close to freezing solid thus the lagoon could provide habitat for overwintering species. Akulaaq and Sisualik had minimal water available under the ice and/or froze to the bottom thus leaving no overwintering habitat. Minimal data on biological parameters were collected under ice-cover during this study, but of note is the increase in chlorophyll *a* between January and April in all the lagoons. Krusenstern experienced the greatest increase in chlorophyll *a* concentration during this time despite having the thickest ice. This spring bloom is consistent with other bodies of water in the arctic and perhaps provides a potential food source for overwintering fish in Krusenstern or zooplankton in all the lagoons. Certainly more chlorophyll *a* data are warranted as well as zooplankton and fish data under ice-cover. An effort should be made to put nets under the ice in Krusenstern Lagoon in order to identify species, if any, are inhabiting the lagoon during ice-cover.

The type of connection a lagoon has to the Kotzebue Sound or Chukchi Sea impacts the physicochemical and biological parameters during the open water seasons. In Akulaaq, irregular breaching events change the salinity levels as well as allow fish to enter and exit the lagoon. These irregular inputs to and outputs from the lagoon create an unstable environment for species. The closed-nature of Krusenstern is such that an indirect connection is made when an opening to the Sound occurs 15 km south, at the mouth of the Tukrok River. This opening allows anadromous and other species to enter and exit the lagoon-slough system of Krusenstern, but doesn't have much impact on the physicochemical parameters of the lagoon. This indirect

connection as well as the large size of Krusenstern results in a more stable environment for various species. Sisualik is the only lagoon with an open connection to Kotzebue Sound and is the only lagoon to develop a halocline during open water periods. The microtides of the area along with the nearby Noatak River delta are most likely impacting the physicochemical parameters of this shallow lagoon. The lagoon provides a more stable environment such that the tides of the area provide a consistent input and output to the system, with the lagoon acting in a manner similar to a salt marsh. Monitoring of the physicochemical parameters in Sisualik should involve data collection at multiple locations around the lagoon as a result of the high site-to-site variability measured in this study.

As with ice-covered periods, water temperature was the least variable parameter in all the lagoons during open water periods so any type of long-term monitoring must include water temperature as a means of detecting long-term change rather than just natural, cyclic change. This study also highlighted the importance of conducting sampling at the same time each year as a means of limiting the detection of natural temporal changes so that long-term changes could be identified.

Zooplankton collected during open water periods indicated that copepods and cladocerans were the dominant taxa in all the lagoons. The presence/absence of ichthyofauna certainly plays a role in the zooplankton abundance in these coastal lagoons. Most of the fish in these lagoons are likely transient species. Several whitefish species (*Coregonus spp.*) utilize Akulaaq, Krusenstern, and Sisualik. These fish enter and exit the lagoons during breaching events (Akulaaq), river mouth openings (Krusenstern), and during open water connections (Sisualik). Resident Alaska Blackfish (*Dallia pectoralis*) inhabit Akulaaq and can move into the connecting creek to escape harsh environmental conditions. According to local knowledge,

Akulaaq can go years without breaching so this would certainly impact the abundance of zooplankton and ichthyofauna and in the lagoon.

3.4.4.1 Future Management

Seasonal changes occur rapidly in the Arctic and these natural changes along with the dynamic nature of these lagoon systems must be accounted for in any type of monitoring plan that has the ultimate goal of detecting change over time. The results presented here demonstrate that monitoring these lagoons for physicochemical changes would best be accomplished by monitoring seasonal water temperature as salinity and dissolved oxygen are much more variable throughout each lagoon. By monitoring the least variable parameter, true change rather than natural system fluctuation can be identified in a system (Mulder *et al.* 1999).

The study described herein was a broad-level ecosystem characterization of five coastal lagoons in Cape Krusenstern National Monument. The data collected can now act as a baseline for future, more detailed studies. Recommendations for future sampling include: more complete sampling in Imik and Kotlik, sediment grain size and accumulation rate measurements, quantitative zooplankton and fish species collection, population dynamics of species utilizing the lagoons, more complete bathymetry data/mapping, current measurements, heavy metal analysis in both sediments and fish, baseline nutrient sampling, and algal and seagrass inventory.

With continued climate change the duration of ice cover will decrease allowing for higher waves and storm surges along coastal areas, sea level will rise, coastal erosion will increase, air temperatures will increase, and permafrost will collapse (ACIA 2004). These climate change impacts will change the coastal lagoon systems of Cape Krusenstern National Monument. These remote, arctic systems serve as a bellwether of global climate change as arctic ecosystems are expected to experience climate change impacts before more temperate regions (ACIA 2004).

Climate change as well as resource exploration and development are already challenging northwest Alaska, so monitoring these locally-important coastal waters is vital. Further understanding of how these arctic systems function biologically and the role they play in the lives of local users is critical to developing a long-term monitoring plan.

Table 3-1. Lagoon size and type of water exchange with the Kotzebue Sound (Akulaaq, Krusenstern, and Sisualik) or Chukchi Sea (Imik, Ipiavik, Kotlik, and Port). *Blaylock and Houghton (1983)

Lagoon	Size (km²)	Connection
Akulaaq	9	Intermittently Open
Imik	5	Intermittently Open
Ipiavik	14	Open*
Kotlik	24	Intermittently Open
Krusenstern	56	Seasonally-Closed
Port	2	Closed*
Sisualik	34	Open

Table 3-2. Mean, standard deviation (± 1), and coefficient of variation (%) results for the physicochemical and pigment data collected from five coastal lagoons in CAKR between January 2003 and September 2004. During open water periods, numbers were calculated based on all available readings to a depth of 0.5m. * = Only 1 sample collected; ** = No samples collected due to logistical/funding constraints; *** = Mean converted to Kelvin.

Date	Lagoon	Salinity (psu)			Dissolved Oxygen (mg/L)			Water Temperature (°C)			Chlorophyll-a (µg/L)			Phaeophytin (µg/L)		
		Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)***	Mean	SD	CV (%)	Mean	SD	CV (%)
January 2003	Akulaaq	36.0	4.0	11.0	3.1	1.0	33.7	-2.4	0.1	0.04	0.6	0.8	133.3	1.0	1.0	100.0
	Imik*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kotlik	15.8	3.1	19.5	9.3	0.8	8.5	-1.2	0.0	0.01	0.1	0.0	0.0	0.2	0.0	0.0
	Krusenstern	5.0	0.1	1.4	7.8	1.5	18.9	-0.3	0.2	0.06	1.0	0.4	40.0	1.1	0.5	45.5
	Sisualik	28.3	6.7	23.5	8.8	0.7	7.9	-1.8	0.1	0.03	0.4	0.3	75.0	0.6	0.5	83.3
April 2003	Akulaaq	62.1	1.8	2.9	5.3	1.5	29.5	-3.7	0.1	0.04	4.3	7.1	165.1	3.9	5.6	143.6
	Imik															
	Kotlik	12.0	11.0	91.6	10.5	3.7	35.0	-0.2	0.8	0.29	1.3	0.8	61.5	0.7	0.4	57.1
	Krusenstern	6.5	0.3	5.0	9.6	1.7	18.2	-0.1	0.3	0.09	29.6	8.2	27.7	23.2	8.9	38.4
	Sisualik	36.2	13.8	38.2	5.5	2.5	44.9	-2.2	0.8	0.30	6.0	1.9	31.7	6.9	3.6	52.2
July 2003	Akulaaq	8.1	0.1	1.1	10.4	0.2	2.4	8.9	0.1	0.05	-	-	-	-	-	-
	Imik	2.5	0.0	0.6	9.8	0.1	0.6	12.1	0.1	0.02	-	-	-	-	-	-
	Kotlik	13.4	0.2	1.5	9.0	0.4	4.8	12.9	0.5	0.17	-	-	-	-	-	-
	Krusenstern	3.6	0.1	1.5	11.0	0.2	2.2	8.9	0.1	0.02	-	-	-	-	-	-
	Sisualik	7.3	1.6	21.9	10.0	0.2	2.2	17.2	0.6	0.20	-	-	-	-	-	-
September 2003	Akulaaq	6.1	0.2	3.3	11.5	0.2	1.9	5.0	0.4	0.13	-	-	-	-	-	-
	Imik**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kotlik**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Krusenstern	3.4	0.1	2.3	11.8	0.1	1.2	5.0	0.2	0.07	-	-	-	-	-	-
	Sisualik	7.0	1.9	26.4	11.6	0.1	1.0	4.6	0.1	0.04	-	-	-	-	-	-
January 2004	Akulaaq	8.6	1.6	18.4	8.8	4.7	53.2	-0.5	0.2	0.07	-	-	-	-	-	-
	Imik	3.5	1.1	31.4	8.0	3.8	47.7	-0.6	0.0	0.00	-	-	-	-	-	-

NO DATA - LAGOON TOO THAWED

Table 3-2. Mean, standard deviation (± 1), and coefficient of variation (%) results for the physicochemical and pigment data collected from five coastal lagoons in CAKR between January 2003 and September 2004. During open water periods, numbers were calculated based on all available readings to a depth of 0.5m. * = Only 1 sample collected; ** = No samples collected due to logistical/funding constraints; *** = Mean converted to Kelvin.

Date	Lagoon	Salinity (psu)			Dissolved Oxygen (mg/L)			Water Temperature (°C)			Chlorophyll-a ($\mu\text{g/L}$)			Phaeophytin ($\mu\text{g/L}$)		
		Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)***	Mean	SD	CV (%)	Mean	SD	CV (%)
January 2004 (Cont.)	Kotlik*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Krusenstern	3.8	0.9	22.8	5.4	1.7	31.5	-0.3	0.1	0.02	-	-	-	-	-	-
	Sisualik	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ALL STATIONS FROZEN TO THE BOTTOM																
April 2004	Akulaaq	19.4	1.4	7.3	0.8	0.2	28.1	-1.2	0.1	0.03	-	-	-	-	-	-
	Imik	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kotlik*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September 2004	Krusenstern	5.1	0.0	0.0	2.7	1.3	46.9	-0.2	0.2	0.06	-	-	-	-	-	-
	Sisualik	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Akulaaq	10.7	0.1	0.6	8.6	0.3	4.0	13.3	0.2	0.09	1.8	0.8	44.4	1.0	0.4	40.0
September 2004	Imik**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Kotlik**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Krusenstern	3.1	0.2	5.8	10.8	0.2	2.2	13.7	0.7	0.24	6.5	2.8	43.1	1.3	0.8	61.5
September 2004	Sisualik	11.9	1.8	15.4	9.3	0.2	1.8	8.2	1.1	0.40	-	-	-	-	-	-

Table 3-3. Lagoon mean, standard deviation (± 1), and coefficient of variation (%) results for ice thickness, snow depth, and water depth collected from five coastal lagoons in CAKR during the four ice-covered sampling periods. Water depths were measured under the ice and did not include the water within the hole. * = Only 1 sample collected; ** = No samples collected

Date	Lagoon	Ice Thickness (m)			Snow Depth (cm)			Water Depth (m)		
		Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
January 2003	Akulaaq	0.6	0.1	14.4	5.1	0.0	0.0	0.2	0.1	37.3
	Imik*	0.8	-	-	5.1	-	-	0.2	-	-
	Kotlik	1.0	0.1	7.4	2.6	3.6	141.4	0.7	0.5	70.1
	Krusenstern	1.0	0.0	0.0	0.0	0.0	0.0	1.1	0.2	17.2
	Sisualik	0.5	0.1	12.4	10.2	0.0	0.0	0.2	0.0	0.0
April 2003	Akulaaq	0.7	0.1	10.1	30.5	0.0	0.0	0.1	0.0	0.0
	Imik	1.3	0.1	7.7	0.0	0.0	0.0	**	**	**
	Kotlik	1.2	0.2	14.4	15.2	6.7	44.2	0.5	0.5	105.8
	Krusenstern	1.5	0.0	0.0	0.0	0.0	0.0	0.8	0.1	16.7
	Sisualik	0.8	0.0	0.0	24.5	8.9	36.4	0.1	0.1	43.3
January 2004	Akulaaq	0.7	0.3	40.4	3.8	1.8	48.4	0.1	0.0	0.0
	Imik	0.8	0.1	9.4	0.0	0.0	0.0	0.2	0.1	47.1
	Kotlik	1.1	0.0	0.0	0.8	1.4	173.2	0.2*	-	-
	Krusenstern	0.9	0.0	0.0	10.2	8.8	86.3	1.3	0.3	24.1
	Sisualik	**	**	**	**	**	**	**	**	**
April 2004	Akulaaq	1.0	0.1	7.1	5.3	4.5	84.3	0.2	0.1	34.2
	Imik**	**	**	**	**	**	**	**	**	**
	Kotlik**	**	**	**	**	**	**	**	**	**
	Krusenstern	1.3	0.1	4.9	7.9	9.9	125.0	1.2	0.2	19.3
	Sisualik	0.9	0.1	10.4	20.3	10.3	50.7	**	**	**

Table 3-4. Lagoon mean water depth, standard deviation (± 1), maximum water depth, and coefficient of variation for each lagoon in July 2003, September 2003, and September 2004. -- No samples collected; *Data were only collected at certain depth intervals so complete depth profiles were not obtained.

<i>Lagoon</i>	<i>July 2003</i>			<i>September 2003</i>			<i>September 2004</i>		
	Mean Depth (m)	Maximum Depth (m)	CV (%)	Mean Depth (m)	Maximum Depth (m)	CV (%)	Mean Depth (m)	Maximum Depth (m)	CV (%)
Akulaaq	1.3 ± 0.1	1.4	10.2	1.4 ± 0.0	1.5	3.1	0.8 ± 0.1	0.9	10.7
Imik	0.9 ± 0.1	0.9	8.3	--	--	--	--	--	--
Kotlik	1.2 ± 0.4	1.5	35.7	--	--	--	--	--	--
Krusenstern	2.0 ± 0.2	2.2	10.5	2.4 ± 0.2	2.6	7.4	*	*	*
Sisualik	0.9 ± 0.1	1.0	9.4	0.8 ± 0.1	0.9	13.9	0.7 ± 0.2	0.9	22.3

Table 3-5. Zooplankton lagoon mean relative abundance and standard deviation (± 1) of the most abundant taxonomic groups in the five CAKR lagoons in July 2003, September 2003, and September 2004. -- No samples collected.

<i>Lagoon</i>	<i>July 2003</i>		<i>September 2003</i>		<i>September 2004</i>	
	Copepod (ind/m ³)	Cladoceran (ind/m ³)	Copepod (ind/m ³)	Cladoceran (ind/m ³)	Copepod (ind/m ³)	Cladoceran (ind/m ³)
Akulaaq	28414 $\pm$ 3914	2333 $\pm$ 1029	12254 $\pm$ 2370	2071 $\pm$ 778	1502 $\pm$ 3069	728 $\pm$ 1602
Imik	1227 $\pm$ 216	5579 $\pm$ 4489	--	--	--	--
Kotlik	9628 $\pm$ 2591	0	--	--	--	--
Krusenstern	1373 $\pm$ 604	0	91 $\pm$ 28	12 $\pm$ 18	109 $\pm$ 45	0
Sisualik	1209 $\pm$ 1572	0	630 $\pm$ 102	0	1910 $\pm$ 1198	0

Table 3-6. List of benthos, epibenthos, and fish that were present in the lagoons between January 2003 and September 2004. Collection methods included: a beach seine, 5-panel experimental gillnet, minnow cages, and/or a petite ponar. X indicates presence. General life history is indicated by the following: ¹marine/estuarine species, ²anadromous species, and ³resident species. Some species can vary in their life history; these are generalizations (Armstrong 1994; Mecklenburg *et al.* 2002).

Scientific Name	Common Name	Akulaaq	Imik	Kotlik	Krusenstern	Sisualik
<i>Clupea pallasii</i>	Pacific Herring ¹			X		X
<i>Coregonus laurettae</i>	Bering Cisco ²	X			X	X
<i>Coregonus nasus</i>	Broad Whitefish ²	X			X	
<i>Coregonus pidschian</i>	Humpback Whitefish ²	X		X	X	X
<i>Coregonus sardinella</i>	Least Cisco ²	X			X	X
<i>Coregonus</i> sp.	Cisco ²			X		
<i>Crangon</i> sp.	Shrimp ¹	X				X
<i>Dallia pectoralis</i>	Alaska Blackfish ³	X				
<i>Eleginus gracilis</i>	Saffron Cod ¹					X
<i>Gasterosteus aculeatus</i>	Threespine Stickleback ¹				X	X
Juvenile <i>Salvelinus</i> sp.	Trout ²			X		
<i>Lepidopsetta</i> sp.	Sole ¹	X				
<i>Limanda aspera</i>	Yellowfin Sole ¹					X
<i>Macoma</i> sp.	Clam ¹	X	X	X	X	X
<i>Megalocottus platycephalus</i>	Belligerent Sculpin ¹			X		
<i>Myoxocephalus quadricornis</i>	Fourhorn Sculpin ¹	X		X		X
<i>Mytilus</i> sp.	Mussel ¹			X		
<i>Oncorhynchus keta</i>	Chum Salmon ²					X
<i>Osmerus mordax</i>	Rainbow Smelt ²				X	
<i>Platichthys stellatus</i>	Starry Flounder ¹				X	X
<i>Pleuronectes glacialis</i>	Arctic Flounder ¹					X
<i>Pungitius pungitius</i>	Ninespine Stickleback ¹			X	X	X
<i>Salvelinus malma</i>	Dolly Varden ²			X		
<i>Stenodus leucichthys</i>	Sheefish ²				X	X
<i>Thymallus arcticus</i>	Arctic Grayling ³				X	
	Chironomid	X	X	X	X	X
	Isopod	X	X			
	Polychaete	X			X	X
	Amphipods				X	X
	Mysid shrimp				X	X
	Smelt ²					X
Total species		12	3	11	15	20

Table 3-7. Friedman Test results for the 2003 intra-annual comparison (January, April, July, and September) of physicochemical parameters at each station in each lagoon. The mean at each station was used to calculate the statistics. *statistically significant ($p < 0.05$)

<i>Lagoon</i>	<i>Parameter</i>	<i>Month</i>	<i>Mean Rank</i>	<i>N</i>	<i>X²</i>	<i>df</i>	<i>p-value</i>
Akulaaq	Salinity (psu)	January	3.00	5	15.000	3	0.002*
		April	4.00				
		July	2.00				
		September	1.00				
	Dissolved Oxygen (mg/L)	January	1.20	5	14.040	3	0.003*
		April	1.80				
		July	3.00				
		September	4.00				
	Water Temperature (°C)	January	2.00	5	15.000	3	0.002*
		April	1.00				
		July	4.00				
		September	3.00				
Krusenstern	Salinity (psu)	January	3.00	5	15.000	3	0.002*
		April	4.00				
		July	2.00				
		September	1.00				
	Dissolved Oxygen (mg/L)	January	1.20	5	14.040	3	0.003*
		April	1.80				
		July	3.00				
		September	4.00				
	Water Temperature (°C)	January	1.20	5	14.040	3	0.003*
		April	1.80				
		July	4.00				
		September	3.00				
Sisualik	Salinity (psu)	January	3.50	2	5.400	3	0.145
		April	3.50				
		July	2.00				
		September	1.00				
	Dissolved Oxygen (mg/L)	January	2.00	2	6.000	3	0.112
		April	1.00				
		July	3.00				
		September	4.00				
	Water Temperature (°C)	January	1.50	2	5.400	3	0.145
		April	1.50				
		July	4.00				
		September	3.00				

Table 3-8. Wilcoxon Signed Rank Test results for the interannual comparisons of physicochemical parameters measured in April 2003/2004 and September 2003/2004. - Statistics were not computed for Sisualik in April 2003/2004 because all six stations were frozen to the bottom in April 2004. *statistically significant ($p < 0.05$; 2-tailed)

Lagoon		Parameter	April 2003 vs. April 2004						September 2003 vs. September 2004					
			Type of Rank	N	Mean Rank	Sum of Ranks	z	p-value		N	Mean Rank	Sum of Ranks	z	p-value
Akulaaq		Salinity (psu)	Negative Ranks	5	3.00	15.00				0	0.00	0.00		
			Positive Ranks	0	0.00	0.00	-2.023	0.043*	5	3.00	15.00	-2.032	0.042*	
			Ties	0					0					
			Total	5					5					
		Dissolved Oxygen (mg/L)	Negative Ranks	5	3.00	15.00				5	3.00	15.00		
			Positive Ranks	0	0.00	0.00	-2.032	0.042*	0	0.00	0.00	-2.023	0.043*	
			Ties	0					0					
			Total	5					5					
		Water Temperature (°C)	Negative Ranks	0	0.00	0.00				0	0.00	0.00		
			Positive Ranks	5	3.00	15.00	-2.041	0.041*	5	3.00	15.00	-2.023	0.043*	
			Ties	0					0					
			Total	5					5					
Krusenstern		Salinity (psu)	Negative Ranks	5	3.00	15.00				7	4.00	28.00		
			Positive Ranks	0	0.00	0.00	-2.032	0.042*	0	0.00	0.00	-2.388	0.017*	
			Ties	0					0					
			Total	5					7					
		Dissolved Oxygen (mg/L)	Negative Ranks	5	3.00	15.00				7	4.00	28.00		
			Positive Ranks	0	0.00	0.00	-2.023	0.043*	0	0.00	0.00	-2.388	0.017*	
			Ties	0					0					
			Total	5					7					
		Water Temperature (°C)	Negative Ranks	3	3.00	9.00				0	0.00	0.00		
			Positive Ranks	1	1.00	1.00	-1.461	0.144	7	4.00	28.00	-2.371	0.018*	
			Ties	1					0					
			Total	5					7					

Table 3-8. Wilcoxon Signed Rank Test results for the interannual comparisons of physicochemical parameters measured in April 2003/2004 and September 2003/2004. - Statistics were not computed for Sisualik in April 2003/2004 because all six stations were frozen to the bottom in April 2004. *statistically significant ($p < 0.05$; 2-tailed)

Lagoon	Parameter	April 2003 vs. April 2004						September 2003 vs. September 2004					
		Type of Rank	N	Mean Rank	Sum of Ranks	z	p-value	Type of Rank	N	Mean Rank	Sum of Ranks	z	p-value
Sisualik	Salinity (psu)	Negative Ranks	-	-	-	-	-	Negative Ranks	0	0.00	0.00		
		Positive Ranks	-	-	-	-	-	Positive Ranks	3	2.00	6.00		
		Ties	-	-	-	-	-	Ties	0			-1.604	0.109
		Total	-	-	-	-	-	Total	3				
	Dissolved Oxygen (mg/L)	Negative Ranks	-	-	-	-	-	Negative Ranks	3	2.00	6.00		
		Positive Ranks	-	-	-	-	-	Positive Ranks	0				
		Ties	-	-	-	-	-	Ties	0			-1.633	0.102
		Total	-	-	-	-	-	Total	3				
	Water Temperature (°C)	Negative Ranks	-	-	-	-	-	Negative Ranks	0				
		Positive Ranks	-	-	-	-	-	Positive Ranks	3	2.00	6.00		
		Ties	-	-	-	-	-	Ties	0			-1.604	0.109
		Total	-	-	-	-	-	Total	3				

Table 3-9. Spearman rho correlation coefficients for six parameters in Akulaaq Lagoon during the 2003 ice-covered sampling periods (January 2003 and April 2003). *Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean Water Temperature (°C)	Ice Thickness (m)	Snow Depth (m)	Average Daylight (hrs)	Mean Chlorophyll <i>a</i> (ug/L)
Mean Salinity (psu)	rho	-					
	p	-					
	n	-					
Mean Water Temperature (°C)	rho	-0.770**					
	p	0.009					
	n	10					
Ice Thickness (m)	rho	0.553	-0.814**				
	p	0.097	0.004				
	n	10	10				
Snow Depth (m)	rho	0.870**	-0.870**	0.657*			
	p	0.001	0.001	0.039			
	n	10	10	10			
Average Daylight (hrs)	rho	0.870**	-0.870**	0.657*	1.000**		
	p	0.001	0.001	0.039	.		
	n	10	10	10	10		
Mean Chlorophyll <i>a</i> (ug/L)	rho	0.552	-0.406	0.458	0.661*	0.661*	-
	p	0.098	0.244	0.184	0.037	0.037	-
	n	10	10	10	10	10	-

Table 3-10. Spearman rho correlation coefficients for six parameters in Krusenstern Lagoon during the 2003 ice-covered sampling periods (January 2003 and April 2003). *Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean Water Temperature (°C)	Ice Thickness (m)	Snow Depth (m)	Average Daylight (hrs)	Mean Chlorophyll <i>a</i> (ug/L)
Mean Salinity (psu)	rho	-					
	p	-					
	n	-					
Mean Water Temperature (°C)	rho	0.007					
	p	0.983					
	n	12					
Ice Thickness (m)	rho	0.857**	0.319				
	p	0.001	0.312				
	n	12	12				
Snow Depth (m)	rho	.	.	.			
	p	.	.	.			
	n	12	12	14			
Average Daylight (hrs)	rho	0.857**	0.319	1.000**	.		
	p	0.001	0.312	0.001	.		
	n	12	12	14	14		
Mean Chlorophyll <i>a</i> (ug/L)	rho	0.618*	-0.087	0.866**	.	0.866**	-
	p	0.043	0.800	0.001	.	0.001	-
	n	11	11	13	13	13	-

Table 3-11. Spearman rho correlation coefficients for six parameters in Sisualik during the 2003 ice-covered sampling periods (January 2003 and April 2003). *Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean Water Temperature (°C)	Ice Thickness (m)	Snow Depth (m)	Average Daylight (hrs)	Mean Chlorophyll <i>a</i> (ug/L)
Mean Salinity (psu)	rho	-					
	p	-					
	n	-					
Mean Water Temperature (°C)	rho	-1.000**					
	p	0.001					
	n	6					
Ice Thickness (m)	rho	0.278	-0.278				
	p	0.594	0.594				
	n	6	6				
Snow Depth (m)	rho	0.555	-0.555	0.900*			
	p	0.252	0.252	0.014			
	n	6	6	6			
Average Daylight (hrs)	rho	0.293	-0.293	0.949**	0.949**		
	p	0.573	0.573	0.004	0.004		
	n	6	6	6	6		
Mean Chlorophyll <i>a</i> (ug/L)	rho	0.429	-0.429	0.741	0.926**	0.878*	-
	p	0.397	0.397	0.092	0.008	0.021	-
	n	6	6	6	6	6	-

Table 3-12. Spearman rho correlation coefficients for five parameters in Akulaaq Lagoon during the open water sampling periods (July 2003, September 2003, and September 2004).

*Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean DO (mg/L)	Mean Water Temperature (°C)	Mean Relative Abundance Copepods (ind/m ³)	Mean Relative Abundance Cladocerans (ind/m ³)
Mean Salinity (psu)	rho	-				
	p	-				
	n	-				
Mean DO (mg/L)	rho	-0.884**				
	p	0.001				
	n	15				
Mean Water Temperature (°C)	rho	0.903**	-0.910**			
	p	0.001	0.001			
	n	15	15			
Mean Relative Abundance Copepods (ind/m ³)	rho	-0.560*	0.502	-0.475		
	p	0.037	0.067	0.086		
	n	14	14	14		
Mean Relative Abundance Cladocerans (ind/m ³)	rho	-0.333	0.385	-0.356	0.528	-
	p	0.244	0.174	0.212	0.053	-
	n	14	14	14	14	-

Table 3-13. Spearman rho correlation coefficients for five parameters in Krusenstern Lagoon during the open water sampling periods (July 2003, September 2003, and September 2004).

*Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean DO (mg/L)	Mean Water Temperature (°C)	Mean Relative Abundance Copepods (ind/m ³)	Mean Relative Abundance Cladocerans (ind/m ³)
Mean Salinity (psu)	rho	-				
	p	-				
	n	-				
Mean DO (mg/L)	rho	0.236				
	p	0.303				
	n	21				
Mean Water Temperature (°C)	rho	-0.331	-0.848**			
	p	0.142	0.001			
	n	21	21			
Mean Relative Abundance Copepods (ind/m ³)	rho	0.651**	-0.281	0.191		
	p	0.001	0.217	0.407		
	n	21	21	21		
Mean Relative Abundance Cladocerans (ind/m ³)	rho	-0.160	0.534*	-0.600**	-0.467*	-
	p	0.489	0.013	0.004	0.033	-
	n	21	21	21	21	-

Table 3-14. Spearman rho correlation coefficients for four parameters in Sisualik during the open water sampling periods (July 2003, September 2003, and September 2004). *Correlation is significant ($p < 0.05$ level; 2-tailed), **Correlation is significant ($p < 0.01$ level; 2-tailed).

Parameter	Statistic	Mean Salinity (psu)	Mean DO (mg/L)	Mean Water Temperature (°C)	Mean Relative Abundance Copepods (ind/m ³)
Mean Salinity (psu)	rho	-			
	p	-			
	n	-			
Mean DO (mg/L)	rho	-0.864**			
	p	0.001			
	n	15			
Mean Water Temperature (°C)	rho	0.029	-0.143		
	p	0.919	0.612		
	n	15	15		
Mean Relative Abundance Copepods (ind/m ³)	rho	0.489	-0.243	-0.379	-
	p	0.064	0.383	0.164	-
	n	15	15	15	-

Cape Krusenstern National Monument

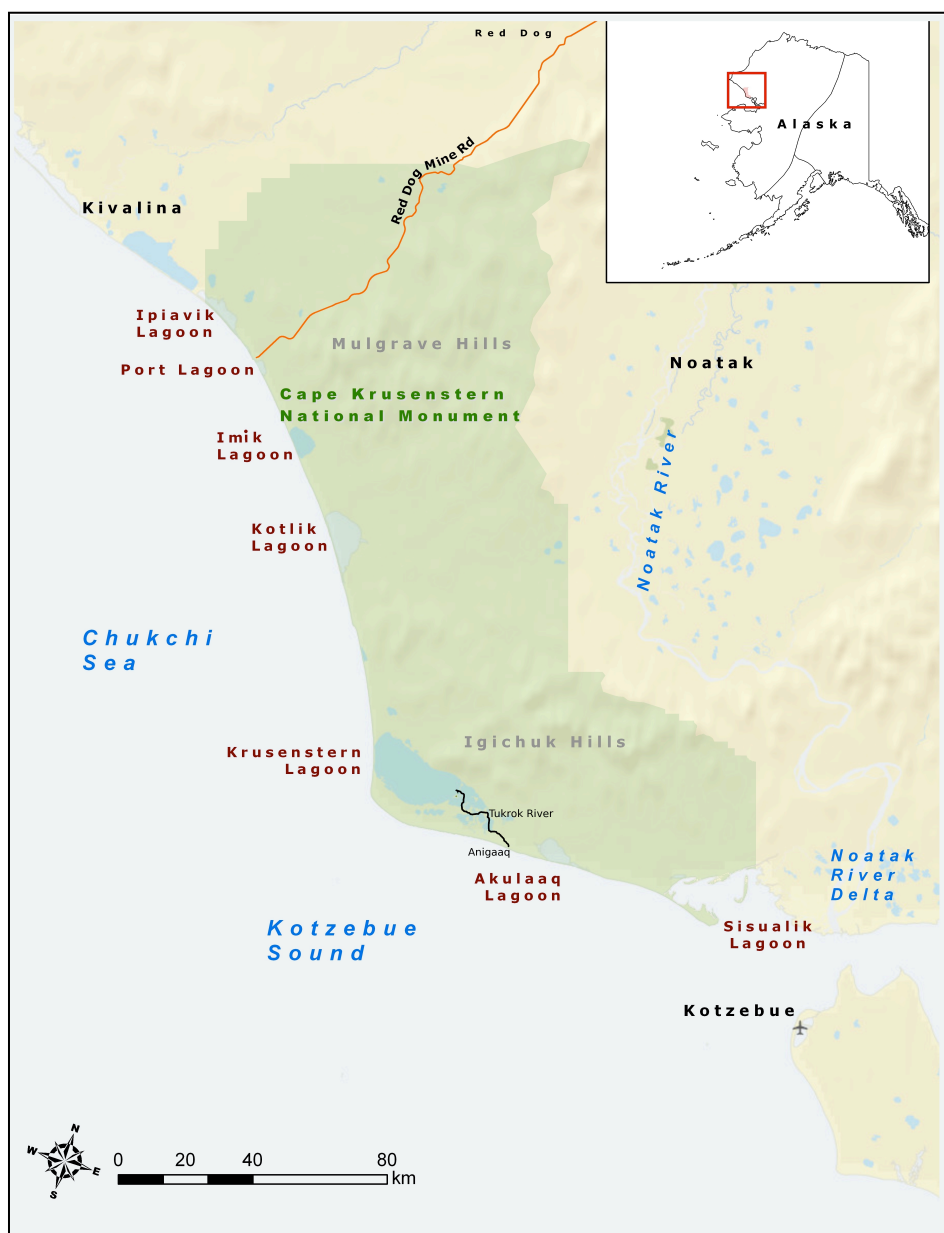


Figure 3-1. The location of the seven coastal lagoons in Cape Krusenstern National Monument. Ipiavik Lagoon and Port Lagoon, located at the northern end of the monument, were not part of this research. Map courtesy of Terry Reynolds.

Akulaaq Lagoon Sampling Stations

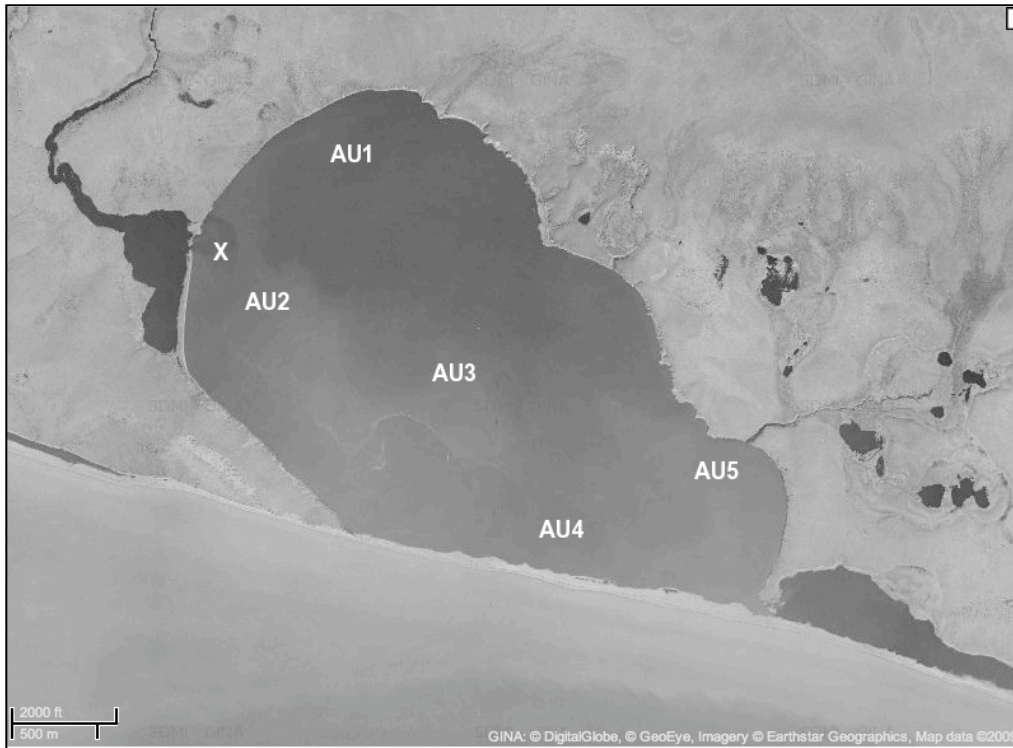


Figure 3-2. The location of the five physicochemical, zooplankton, and benthic sampling stations in Akulaaq Lagoon. **X** indicates the location of the gillnet. Modified Geographic Information Network of Alaska (GINA) map.

Imik Lagoon Sampling Stations

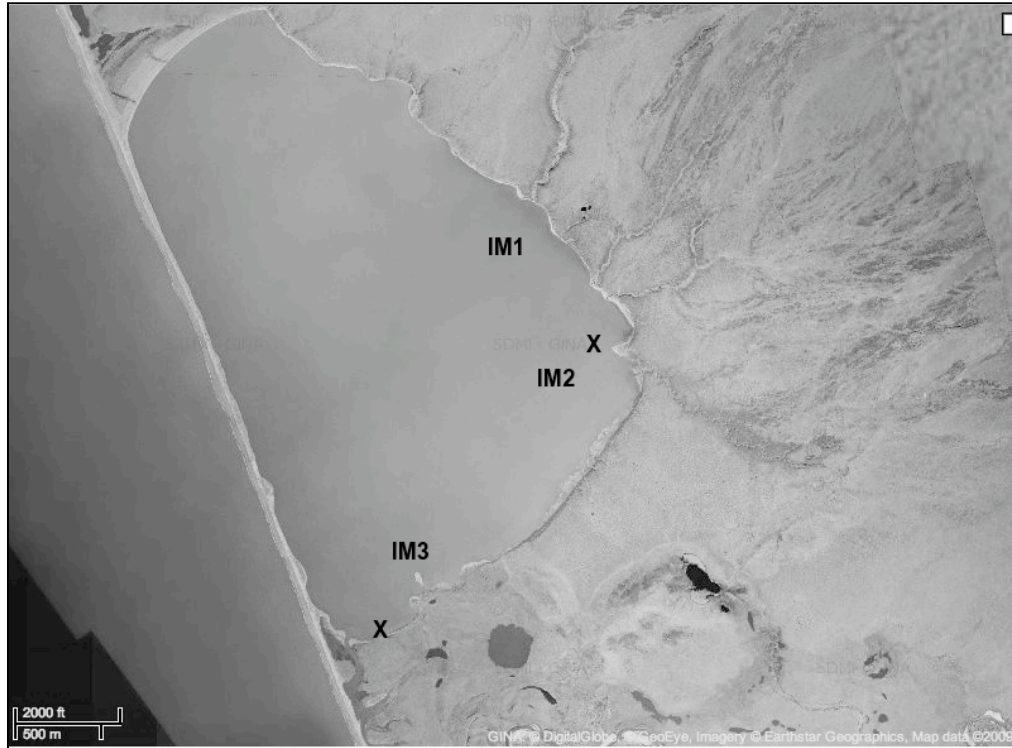


Figure 3-3. The location of the three physicochemical, zooplankton, and benthic sampling stations in Imik Lagoon. **X** indicates the location of the gillnets. Modified GINA map.

Kotlik Lagoon Sampling Stations

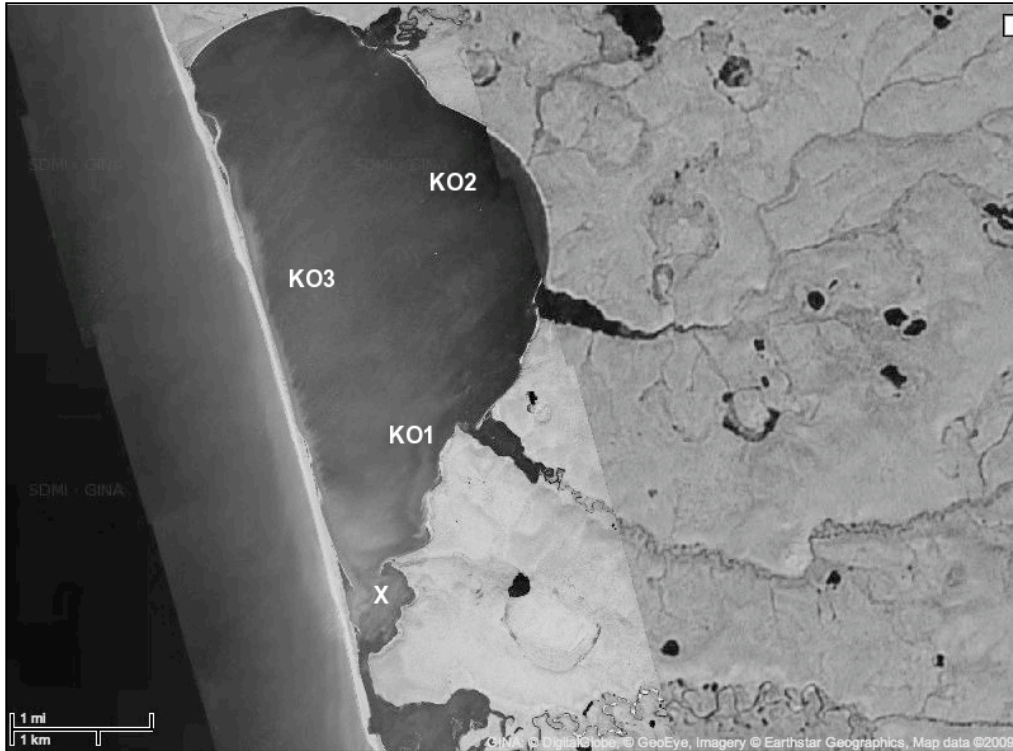


Figure 3-4. The location of the three physicochemical, zooplankton, and benthic sampling stations in Kotlik Lagoon. X indicates the location of the gillnet. Modified GINA map.

Krusenstern Lagoon Sampling Stations

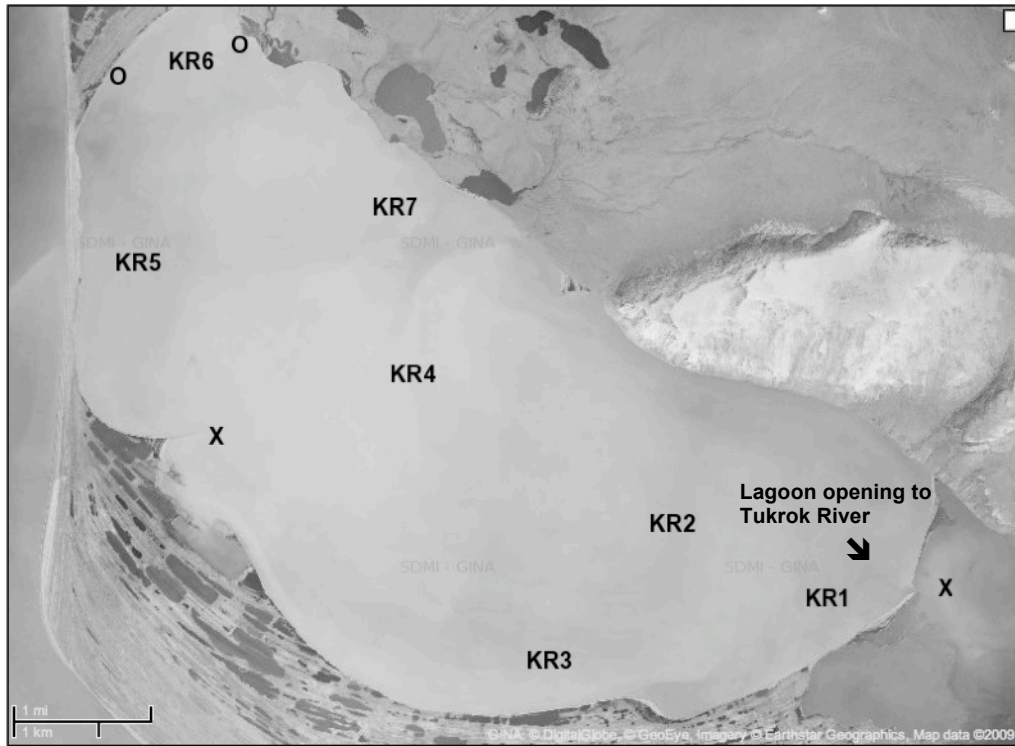


Figure 3-5. The location of the seven physicochemical, zooplankton, and benthic sampling stations in Krusenstern Lagoon. **X** indicates the location of gillnet sets and **O** indicates location of the beach seine hauls. The lagoon outlet to the Tukrok River is also indicated. Modified GINA map.

Sisualik Lagoon Sampling Stations

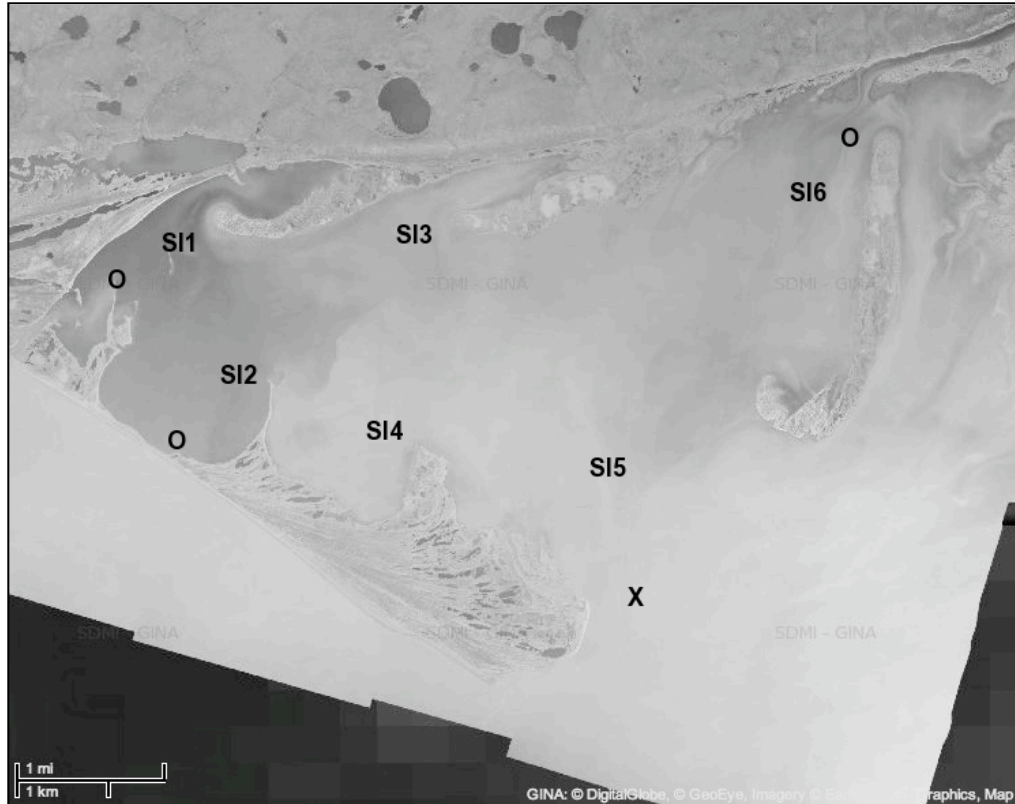


Figure 3-6. The location of the six physicochemical, zooplankton, and benthic sampling stations in Sisualik. **X** indicates the location of the gillnet sets and **O** indicates the location of the beach seine hauls. Modified GINA map.

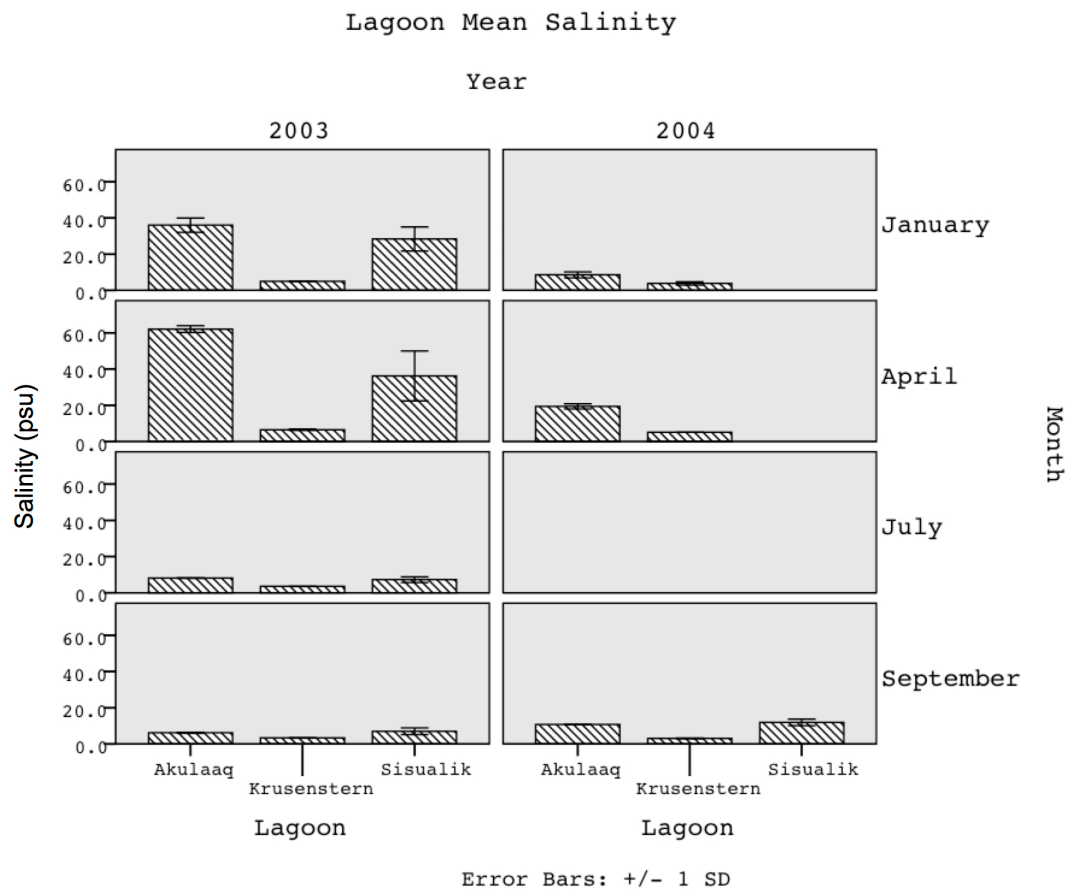


Figure 3-7. Mean salinity in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004).

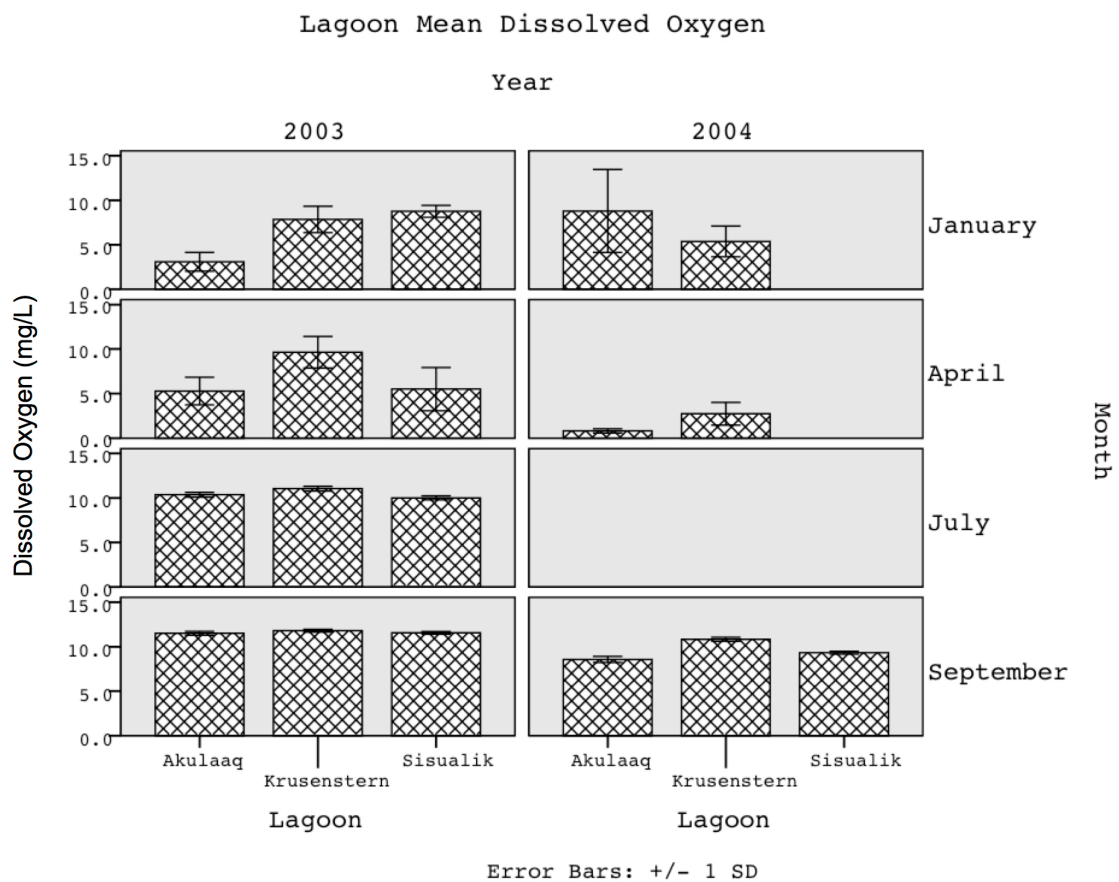


Figure 3-8. Mean dissolved oxygen in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004).

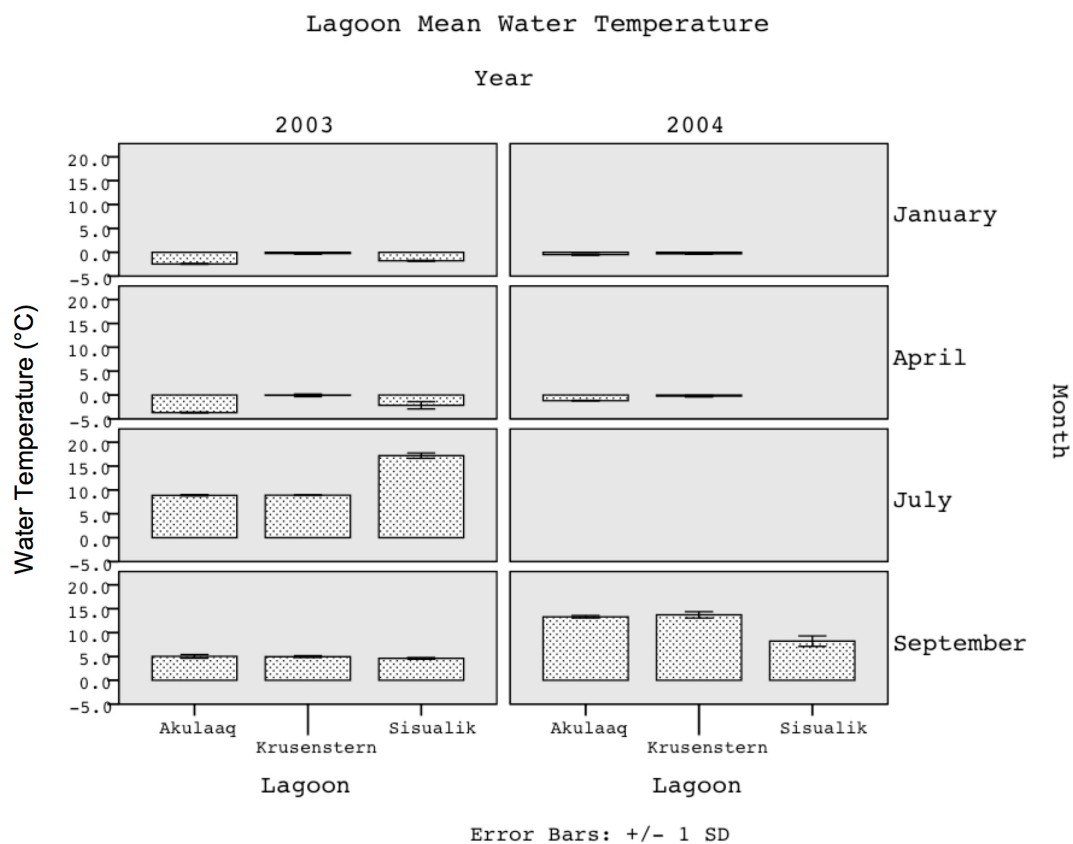


Figure 3-9. Mean water temperture in Akulaaq, Krusenstern, and Sisualik during the seven sampling periods (January 2003 – September 2004).

Coefficient of Variation for Physicochemical Parameters in Three CAKR Coastal Lagoons During Seven Sampling Periods

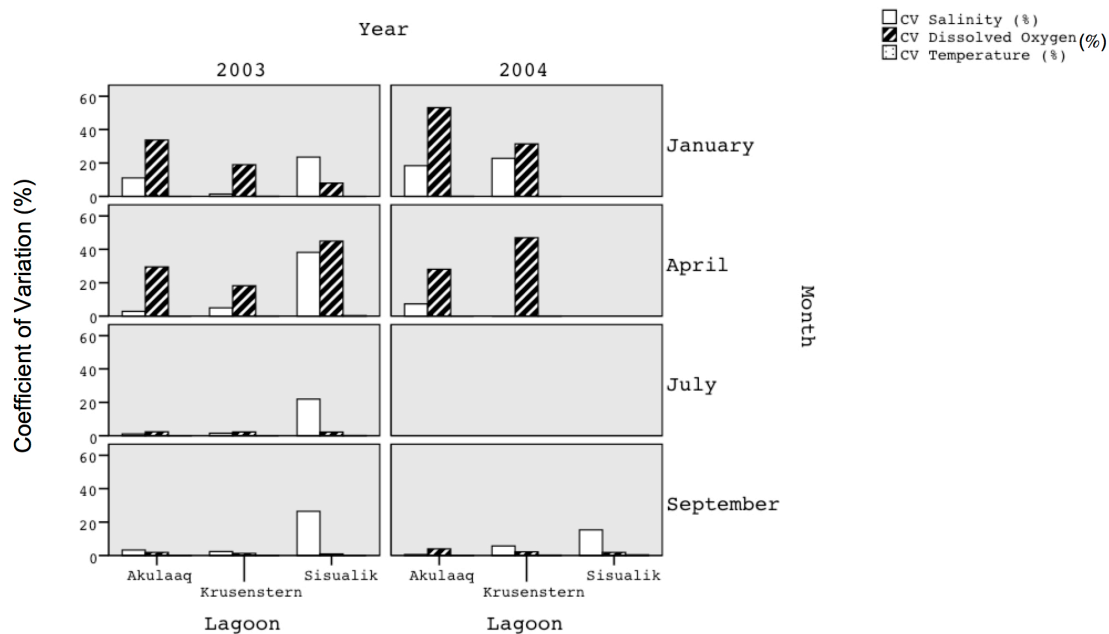


Figure 3-10. Coefficient of variation for lagoon mean salinity, dissolved oxygen, and water temperature in Akulaaq, Krusenstern, and Sisualik between January 2003 and September 2004. Lagoon mean water temperatures converted to Kelvin before calculating CV. No samples collected in July 2004.

Multidimensional Scaling Plot of Physicochemical Parameters
During Seven Sampling Periods

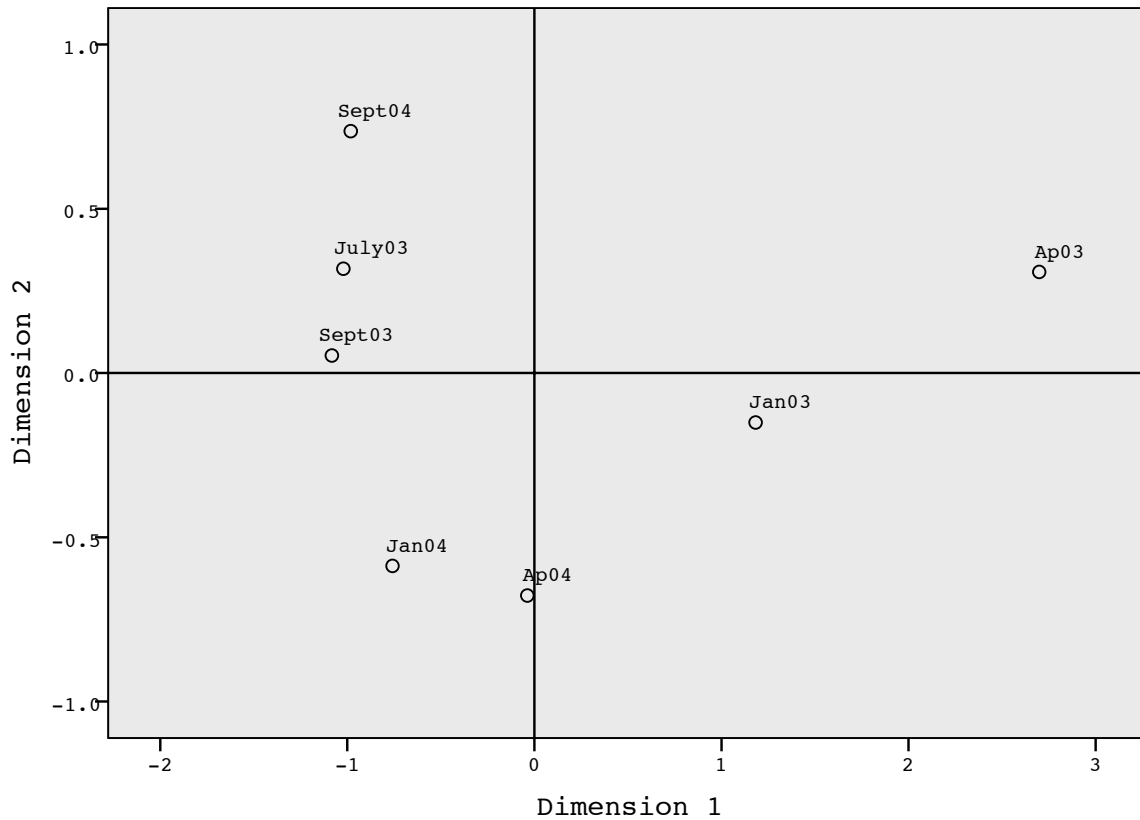


Figure 3-11. Multidimensional scaling plot of the seven sampling periods between January 2003 and September 2004 and the salinity, dissolved oxygen, and water temperature data collected in Akulaaq, Krusenstern, and Sisualik. Stress = 0.02

Multidimensional Scaling Plot of Physicochemical Parameters in
CAKR Lagoons Between January 2003 and September 2004

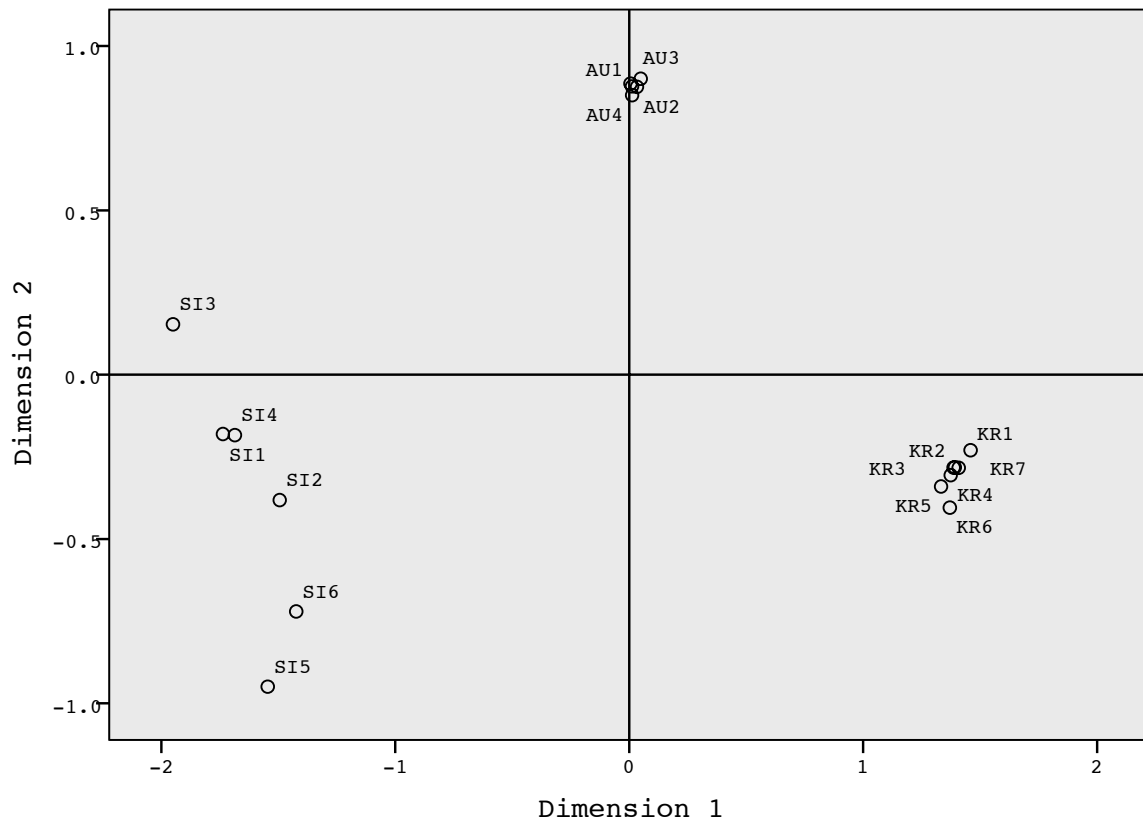


Figure 3-12. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik between January 2003 and September 2004. Stress = 0.10

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in January 2003

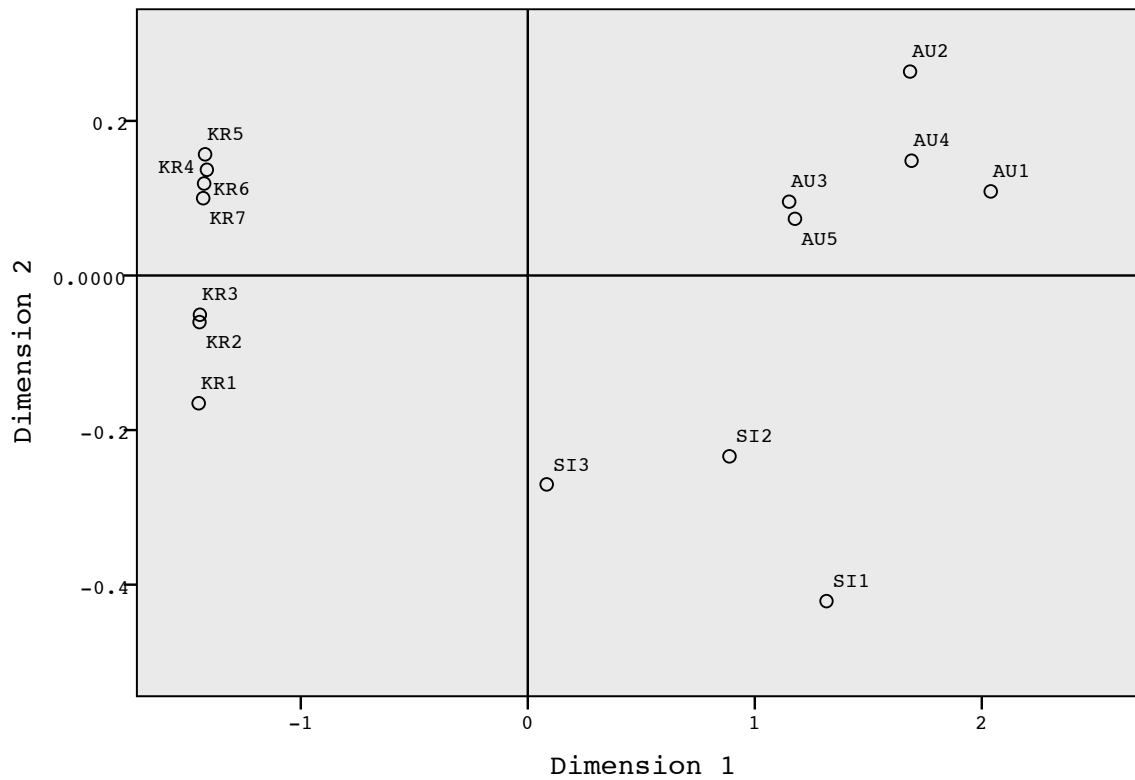


Figure 3-13. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in January 2003. Stress = 0.00

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in April 2003

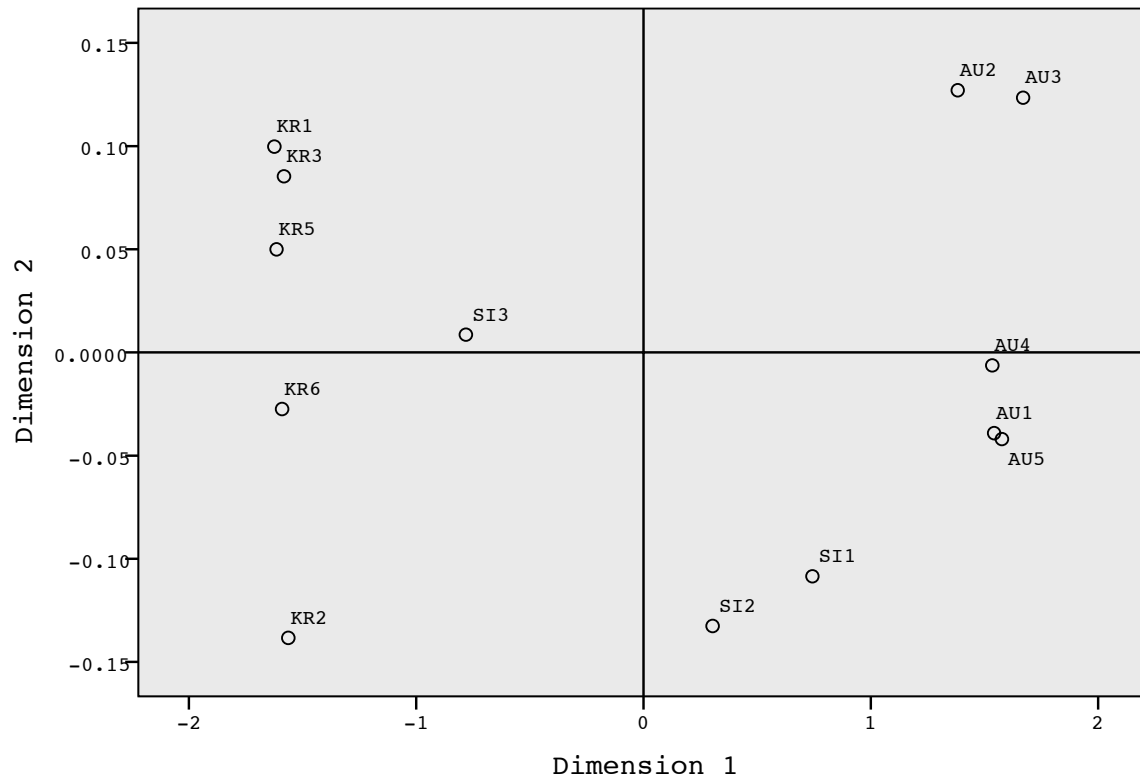


Figure 3-14. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in April 2003. Stress = 0.00

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in January 2004

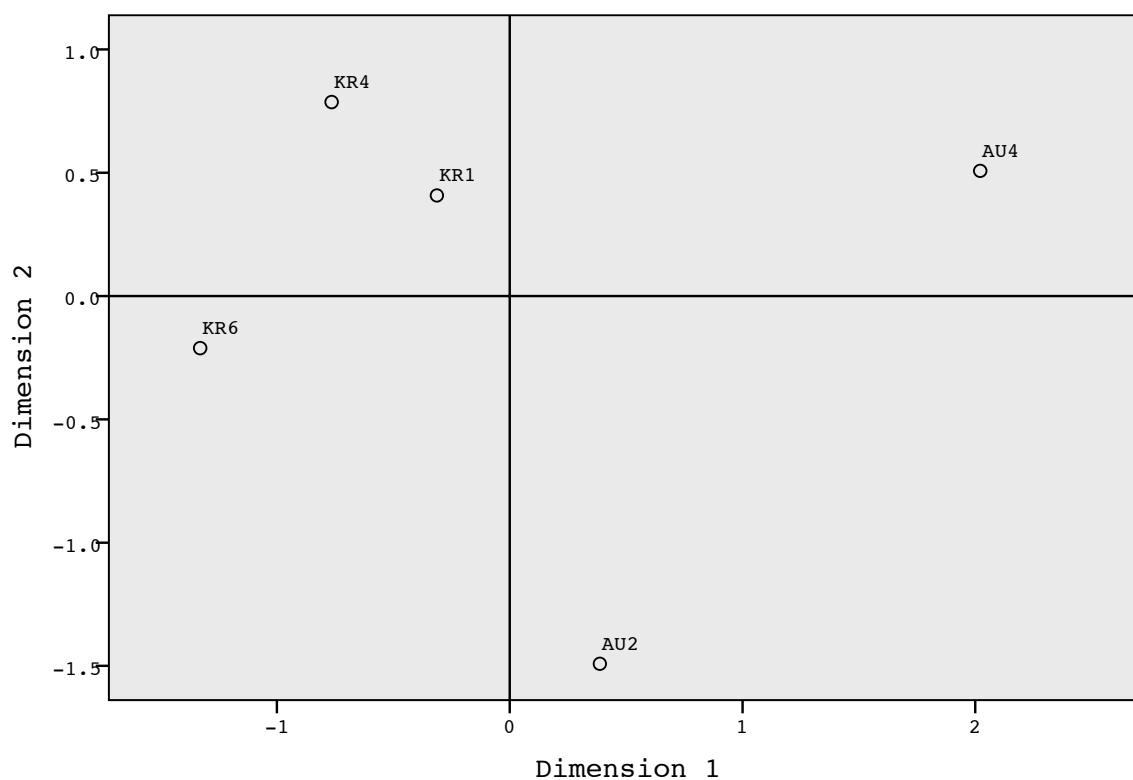


Figure 3-15. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in January 2004. Stress = 0.00

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in April 2004

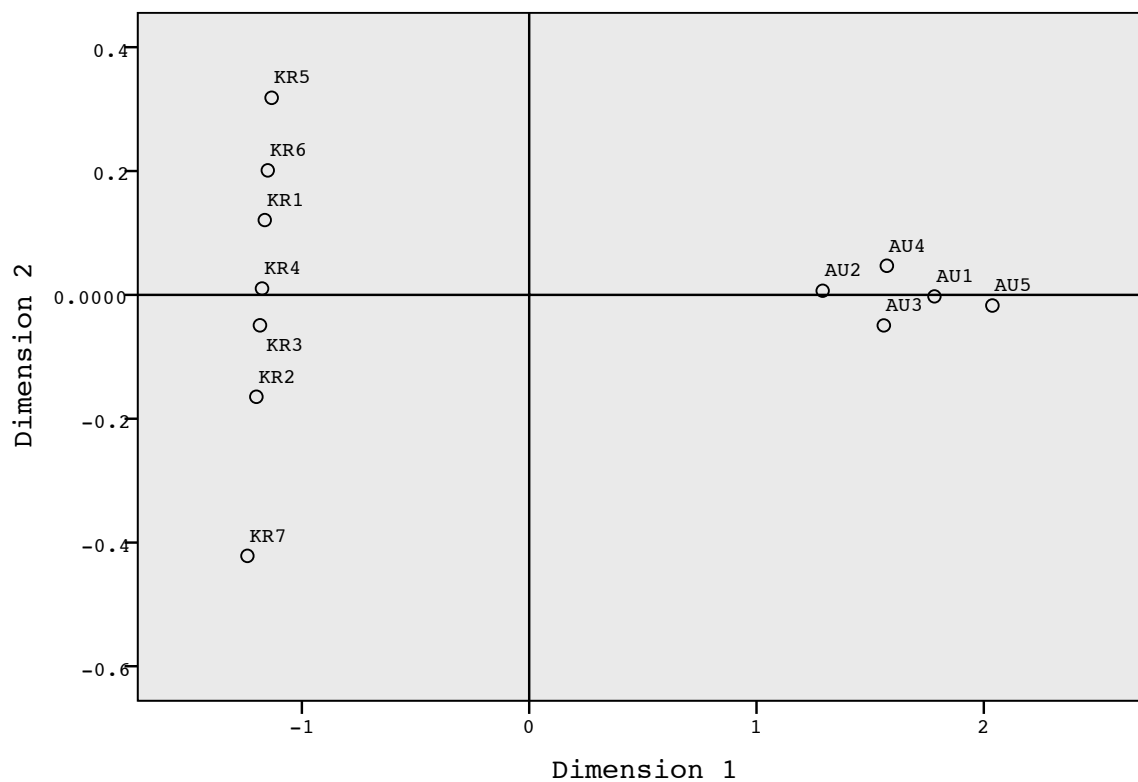


Figure 3-16. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in April 2004. Stress = 0.00

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in July 2003

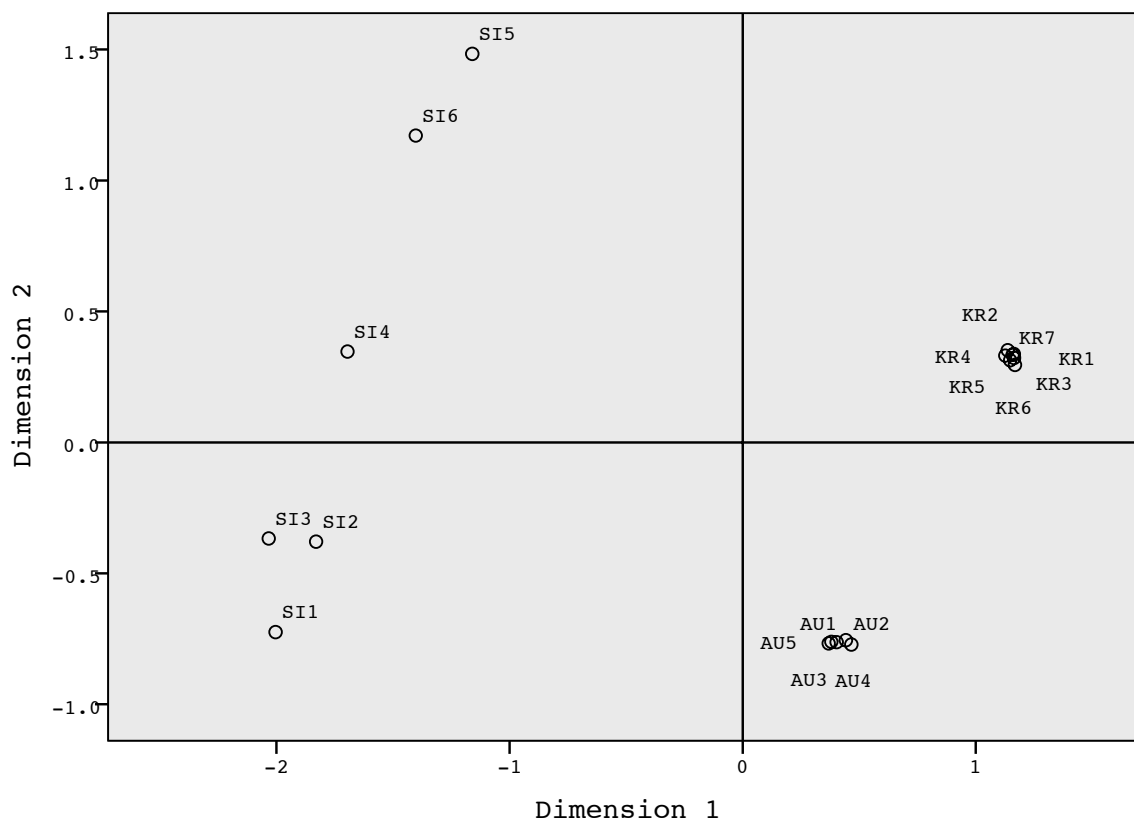


Figure 3-17. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in July 2003. Stress = 0.02

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in September 2003

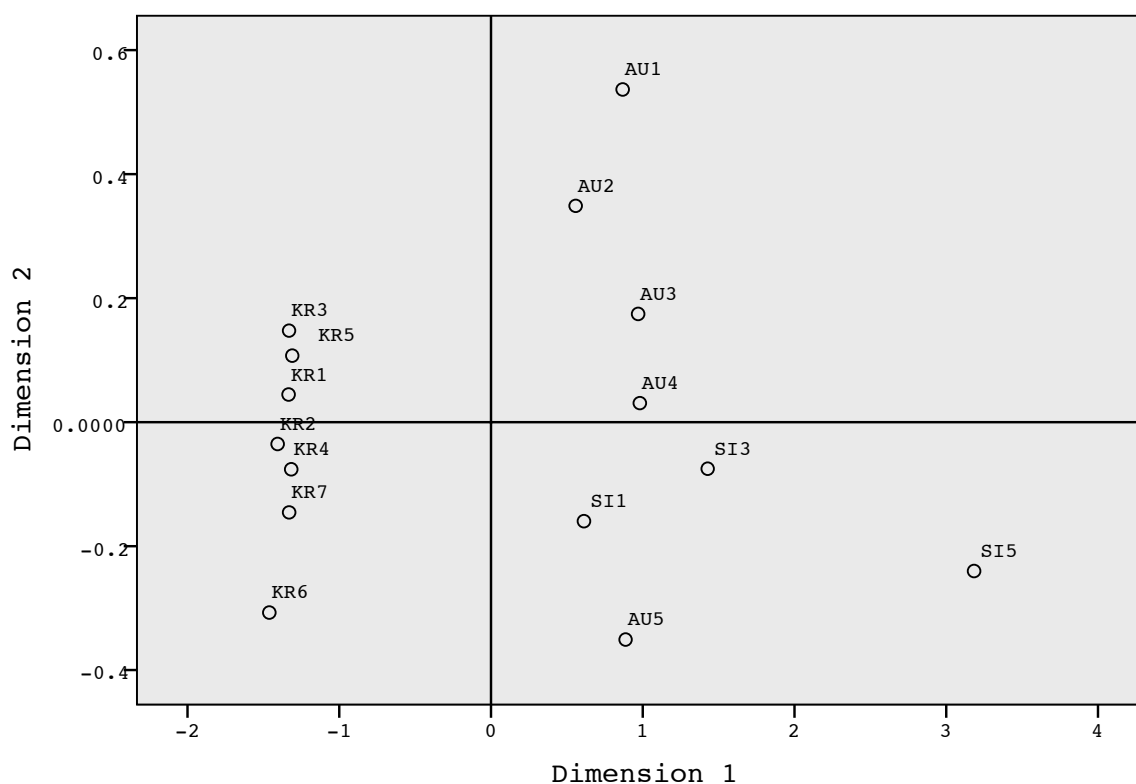


Figure 3-18. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in September 2003. Stress = 0.02

Multidimensional Scaling Plot of Physicochemical Parameters
in CAKR Lagoons in September 2004

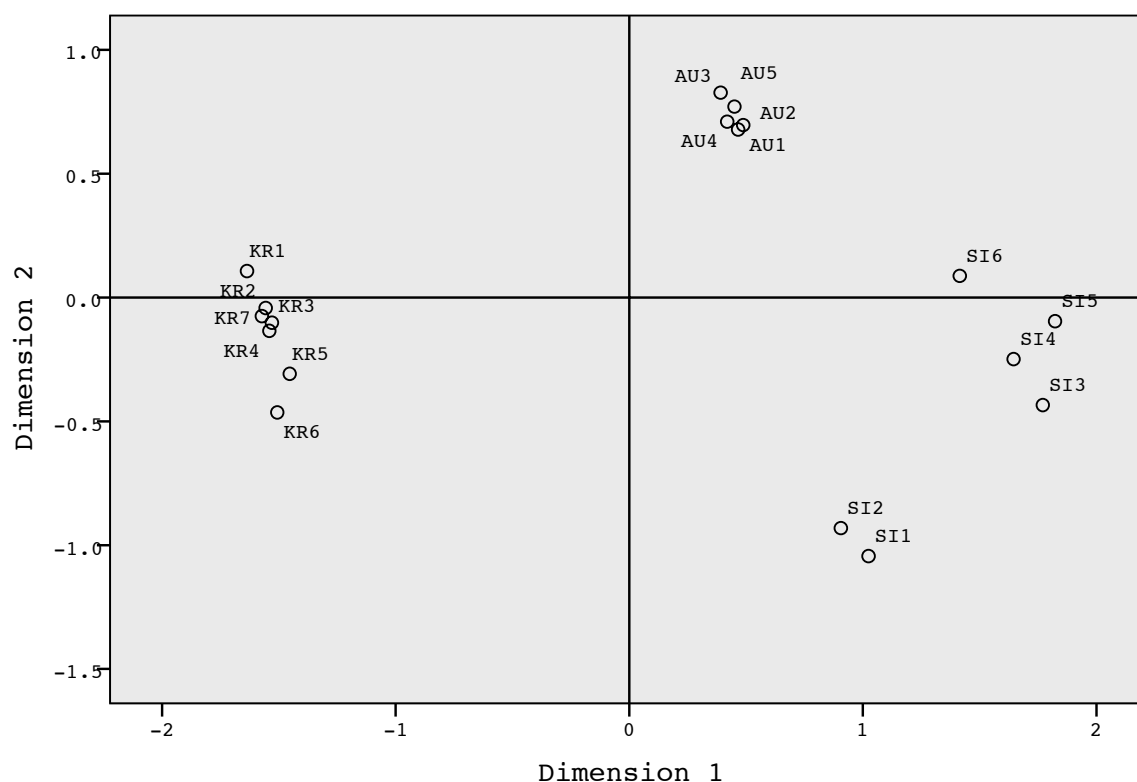


Figure 3-19. Multidimensional scaling plot for salinity, dissolved oxygen, and water temperature at all sampling stations in Akulaaq, Krusenstern, and Sisualik in September 2004. Stress = 0.01

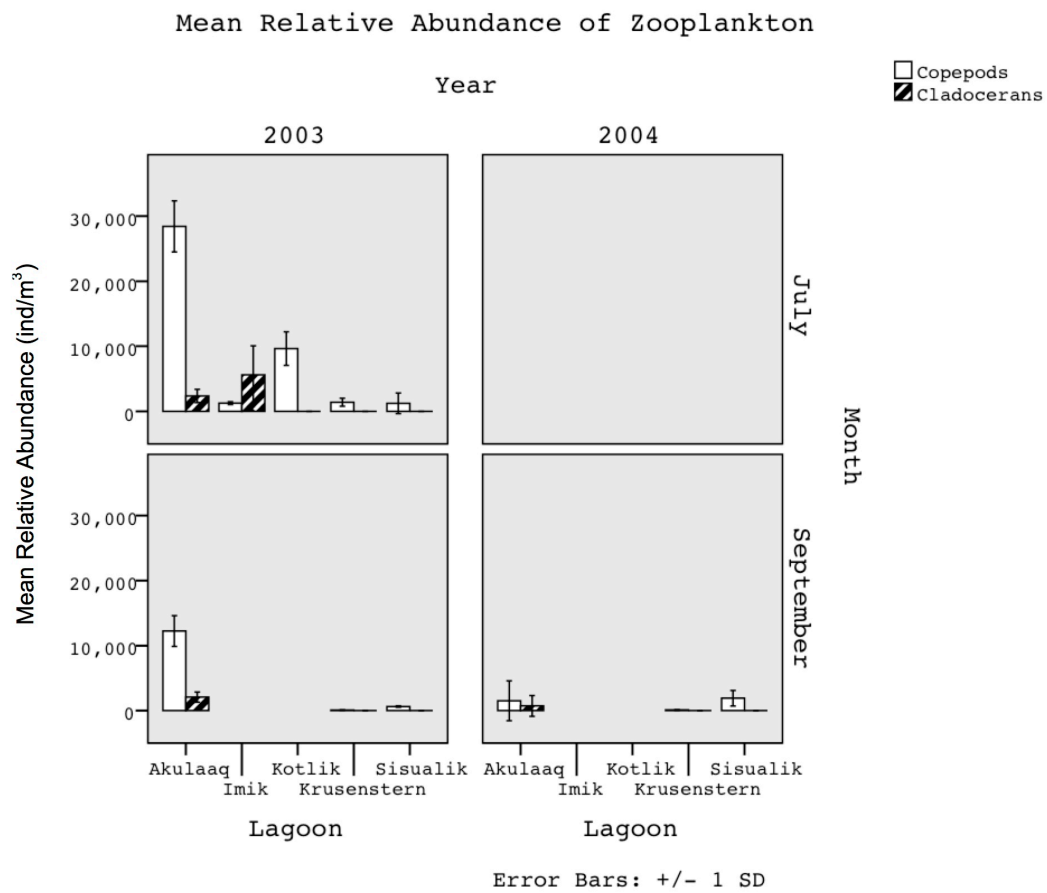


Figure 3-20. Mean relative abundance of the most abundant zooplankton in five CAKR lagoons in July 2003, September 2003, and September 2004.

Multidimensional Scaling Plot of Zooplankton
in CAKR Lagoons in July 2003

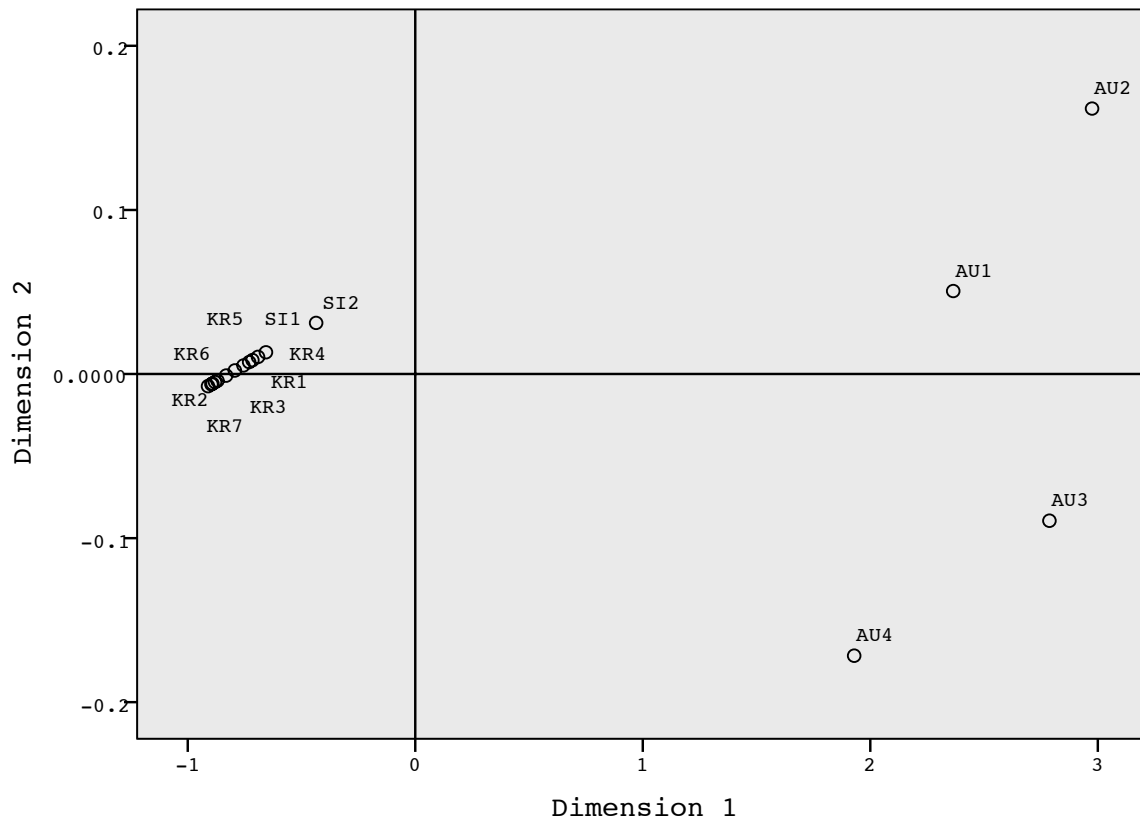


Figure 3-21. Multidimensional scaling plot of copepods and cladocerans at all sampling stations in Akulaaq, Krusenstern, and Sisualik in July 2003. Stress = 0.00

Multidimensional Scaling Plot of Zooplankton
in CAKR Lagoons in September 2003

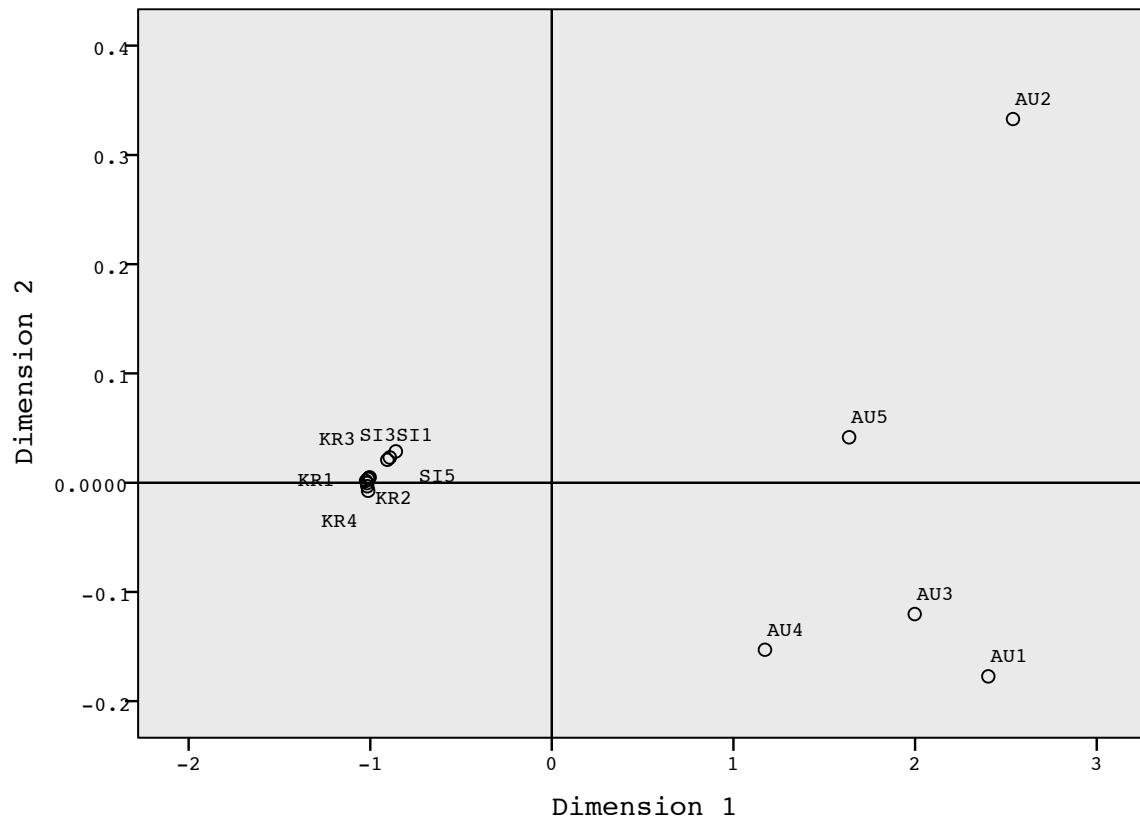


Figure 3-22. Multidimensional scaling plot of copepods and cladocerans at all sampling stations in Akulaaq, Krusenstern, and Sisualik in September 2003. Stress = 0.00

Multidimensional Scaling Plot of Zooplankton
in CAKR Lagoons in September 2004

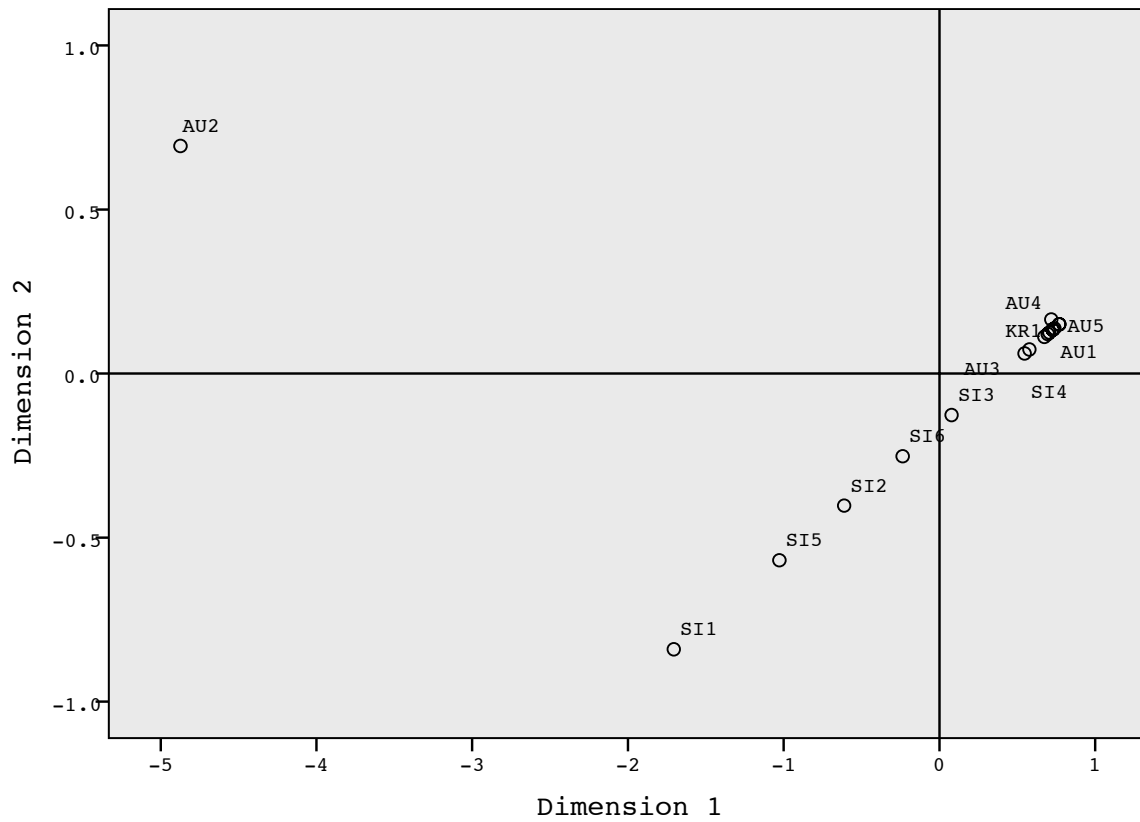


Figure 3-23. Multidimensional scaling plot of copepods and cladocerans at all sampling stations in Akulaaq, Krusenstern, and Sisualik in September 2004. Stress = 0.00

Multidimensional Scaling Plot of Benthic Macroinvertebrates and Ichthyofauna
in CAKR Lagoons Between January 2003 and September 2004

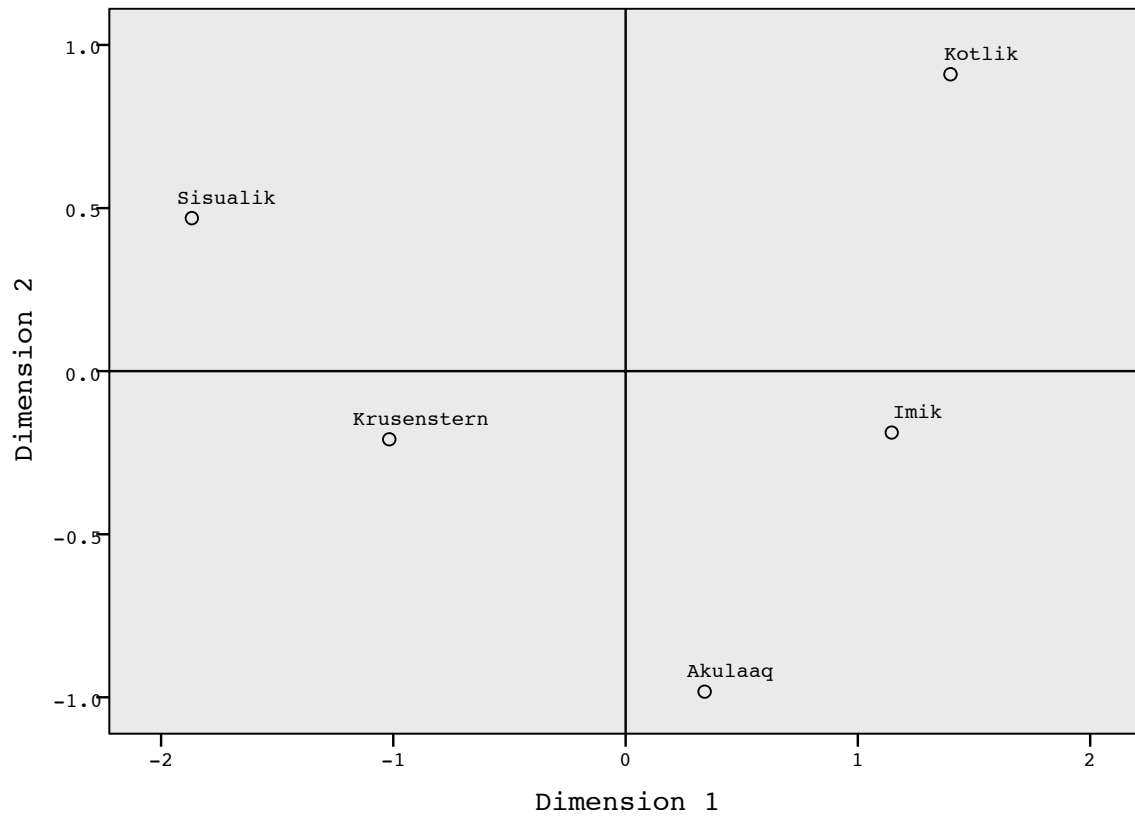


Figure 3-24. Multidimensional scaling plot of benthic macroinvertebrates and ichthyofauna in Akulaaq, Imik, Kotlik, Krusenstern, and Sisualik between January 2003 and September 2004. Based on presence/absence data. Stress = 0.00

CHAPTER 4

NATURAL RESOURCE MANAGEMENT IN THE NATIONAL PARK SERVICE AND THE DEVELOPMENT OF A COASTAL LAGOON MONITORING PROTOCOL FOR CAPE KRUSENSTERN NATIONAL MONUMENT

4.1 Sustainable Natural Resource Management

As the coastal zone around the world becomes more populated and coastal resources are more heavily utilized and relied upon, management of these resources will become even more necessary. If current and future generations are to enjoy and thrive in the coastal zone, management decisions about the coastal resources must be made based on current scientific and local knowledge of the system rather than opinions and/or suspected status and trends. Integrating current scientific and local knowledge is paramount to attaining this ultimate goal of sustainable natural resource management.

Identifying the ultimate goal or desired outcome for the natural resource is fairly straightforward and often uncomplicated. It's the path that leads to the desired outcome that can be riddled with disagreement, lack of action, and ultimately, the mismanagement of resources. The issues or problems underlying disagreements may develop as a result of the following:

- 1) critical needs are not identified and monetary resources are then utilized for non-critical information gathering, 2) not all parties involved in the management of the resources are invested in the process, and 3) information gathered is not shared with everyone involved or if it is, it is not presented in a useable format (Lubchenco 1998; Cash *et al.* 2003, UNEP/GPA 2006; Leslie and McLeod 2007). The potential lack of communication, cooperation, and information sharing must be recognized and addressed in order to achieve successful resource management.

Another critical component of resource management is the monetary support needed to sustain management development, including the research needed to assist in critical management decisions (Schmoldt and Peterson 2001). Baseline ecosystem data are lacking for many remote areas in Alaska due in part to the remote locations, harsh weather conditions, and limited funding. Sampling remote areas is costly, due to high logistic costs, which makes the collection of basic ecosystem data difficult (Lawler *et al.* 2009). Managers are often forced by budget constraints to select the types of data to be collected thus leaving gaps in the information gathered and thereby only gaining partial understanding of the system and how it functions. However management decisions must be made, and are made despite the insufficient data to support such decisions (Schmoldt and Peterson 2001). Ideally, data on all the different ecosystem components would allow for the best management decisions, but in reality managers must prioritize and decide which data are critical to the local area/users of the land. Determining the minimal amount of data necessary for effective management is one critical management tool allowing information to be gathered on a limited basis, yet still providing useful knowledge about a system.

All-inclusive ecosystem-based management (EBM) approaches to natural resource management are well-recognized and accepted guiding management principles (Grumbine 1994; POC 2003; USCOP 2004; UNEP/GPA 2006; Leslie and McLeod 2007). A holistic approach is based on an understanding that the various parts of an ecosystem, including humans, interact to affect the health of the entire system. By employing the EBM concept in the stewardship of natural resources, integrating science with management becomes of utmost importance. Successful management needs to “...integrate ecosystem science into the management arena, and

share knowledge and priorities between scientists, managers, and citizen-stakeholders. To date, such integration has been lacking” (deReynier *et al.* 2010, 534).

The sharing of information across agencies/departments also helps to reduce the amount of redundancy in studies ideally allowing more data to be collected and hence promote informed management decisions. Opportunistic sampling is also taking place as agencies/departments assist each other in data collection. A great example of this is the use of ferryboats as collectors of water quality data where ferryboats are seen as “ships of opportunity” (Buzzelli *et al.* 2003; Petersen *et al.* 2005; and Ensign and Paerl 2006). These projects assist in monitoring water quality in North Carolina estuaries (Buzzelli *et al.* 2003; Ensign and Paerl 2006) as well as the North Sea (Petersen *et al.* 2005). These types of collaboration support and contribute to an ecosystem-based management principle. ROV’s have been used on the moon and deep under the ocean, and unmanned sampling is quickly becoming the data collection method of choice in less extreme, but still remote environments, particularly in times of limited funding and personnel.

What follows is a discussion of how an integrated approach to ecosystem management has been instituted into National Park Service natural resource management policies. The discussion then moves to how this process is being carried out through the development of a long-term monitoring protocol for the coastal lagoons of Cape Krusenstern National Monument. The chapter ends with the description of the submitted monitoring protocol for the lagoons and recommendations for sampling under budgetary constraints.

4.2 The National Park Service Approach

The National Park Service is one example of a federal agency that has taken action to improve the management of natural resources (NPS 2009). The need to integrate science and management has been identified and steps have been taken to fill this recognized gap in the

agency. Complete programs have been developed to accomplish this task of integration where one of the primary goals is to incorporate scientific knowledge into management planning and decision-making (NPS-75). These new programs bring updated information to the table, yet still remain true to the original mission of the National Park Service.

In 1916, the Organic Act established the National Park Service and stated the purpose and mission of the NPS, "...To conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (16 U.S.C. §1). While carrying out this original purpose and mission, the Service identified a need to integrate science and management. In 1992, the NPS established the Inventory and Monitoring Program (I&M) "...to provide funding, technical assistance, and coordination for more than 270 parks to complete 12 basic natural resource inventories and to begin monitoring the status and trend of park natural resources" (NPS 2009, vii). The official mandate for the NPS I&M Program came in the National Parks Omnibus Management Act that Congress enacted in 1998. This Act directed the NPS to "undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources" (16 U.S.C. §5934).

In FY 2000, Congress greatly increased the budget for the NPS Inventory and Monitoring Program and the Appropriations Committee report stated the following about the resources in the parks:

A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment...to insist that the superintendents carry out a systematic, consistent,

professional inventory and monitoring program...that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data. (NPS 2009)

This budget increase was also intended to be used to design and implement a monitoring program, within the NPS I&M, to monitor park vital signs or measures of resource condition (NPS 2009).

The National Park Service requires continual modification and further development of park-specific and even Service-wide management plans and/or policies. The most current Service-wide management policy is the NPS Management Policies of 2006: The Guide to Managing the National Park System. The guide is quite broad and covers everything from the foundation of the Park System to wilderness protection and management. These policies are the backbone of natural resource management throughout all parks, “The National Park Service will preserve and protect the natural resources, processes, systems, and values of units of the national park system in an unimpaired condition to perpetuate their inherent integrity and to provide present and future generations with the opportunity to enjoy them” (NPS 2006, 35). It is here that the National Park Service discusses the importance of managing the natural resources in a holistic manner, “park units must be managed in the context of their larger ecosystems” (NPS 2006, 36). In following through with this idea and statement, park-specific managers are mandated to incorporate all parties with a vested interest in the management of the specific park unit, “The Service will act to protect natural resources...by working cooperatively with federal, state, and local agencies; tribal authorities; user groups; adjacent landowners; and others to identify and achieve broad natural resource goals” (NPS 2006, 36).

The 2006 Management Policies Guide also reiterates the importance of scientific knowledge in the management process and state how the Service will carry out the directives of

the National Parks Omnibus Management Act, “ the Service will use the findings of science and the analyses of scientifically trained resource specialists in decision-making” (NPS 2006, 36). The role of monitoring is also highlighted in these policies, “The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions” (NPS 2006, 37). Figure 4-1 demonstrates the various pathways through which the National Park Service incorporates the science of inventory and monitoring into resource management.

The following definitions have been adopted by the National Park Service Inventory and Monitoring Program (NPS I&M online glossary):

Inventory: An extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource.

Monitoring: Collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga *et al.* 1998).

Protocol: Detailed study plan that explains how data are to be collected, managed, analyzed, and reported and are a key component of quality assurance for natural resource monitoring programs (Oakley *et al.* 2003).

Vital Signs: A subset of physical, chemical, and biological elements and processes of park ecosystems that 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.

In order to more effectively carry out the NPS Inventory & Monitoring Program and to follow through with the FY 2000 Congressional mandate to monitor vital signs, $\approx$ 270 park units were organized into 32 biome-based networks (Fancy 2000). The formation of these networks

was “to more efficiently conduct inventory and monitoring and to facilitate collaboration, information sharing, and economies of scale...” (NPS 2009). These networks were organized based on geography and shared natural resource characteristics (Lawler *et al.* 2009) (Figure 4-2). The Arctic Network Inventory and Monitoring Program (ARCN) is one of four networks in the Alaska Region (Figure 4-3). The five NPS units within the ARCN are: Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve.

Each network identified and prioritized vital signs within the particular network. This identification and prioritization process was extensive (i.e. workshops, working group meetings, technical committee meetings, etc.) and took years to complete in the case of the Arctic Network (Lawler *et al.* 2009). The final outcome was a list of 28 vital signs that met the following criteria:

- sensitive ecological indicators of change,
- relevant at various spatial and temporal scales,
- important for sound management,
- unique to arctic parks,
- strongly linked with other vital signs, and
- provide leverage for additional resources, either within the NPS or with collaborators (Lawler *et al.* 2009).

Table 4-1 is a list of the 28 vital signs identified by the ARCN. Once these resource components and/or processes were selected and prioritized, the development of long-term monitoring for many of the specified vital signs commenced.

4.2.1 *Developing Long-Term Monitoring Protocols in the National Park Service*

Natural resource monitoring in the National Park Service is based on the foundation that “...monitoring in parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems” (Fancy *et al.* 2009; 161). This overall purpose is the driving force behind the development of long-term monitoring protocols within the NPS. Using this purpose as a guideline, these monitoring protocols will: detect changes over a long period of time, add consistency in data collection thus allowing for data comparability amongst agencies, and provide quality assurance through the peer review process (Oakley *et al.* 2003).

The Oakley *et al.* (2003) guidelines for protocol development act as an outline for scientists working to develop long-term monitoring protocols for natural resources in national parks. According to these guidelines, the protocol should contain the following three components: 1) protocol narrative, 2) standard operating procedures (SOPs), and 3) supplementary material. The protocol narrative is the detailed sampling plan that discusses project justification, objectives, sampling design, field methods, data analysis, and personnel and operational requirements (Table 4-2). The SOPs are even more detailed methods descriptions, with step-wise instructions, for each component stated in the protocol narrative. All changes made to the SOPs must be documented in a revision history log. Supplementary material includes items such as: paper maps, photographs, reviewer comments, supporting reports, etc. The complete protocol (all three components) is peer-reviewed by external as well as internal reviewers so as to develop the most complete and scientifically sound monitoring protocol. Existing protocols, including those from other agencies, are utilized as much as possible as a

means to decrease the time for protocol development, increase the comparability of data, and decrease the funds expended in the process. This extensive and thorough process will add credibility to the data and information gathered thus providing natural resource managers with the tools needed to make well-informed management decisions (Oakley *et al.* 2003; Fancy *et al.* 2009).

In 2007 a collaborative effort began between East Carolina University and the National Park Service Arctic Network Inventory and Monitoring Program to develop the long-term monitoring protocol for the coastal lagoons in Cape Krusenstern National Monument (CAKR). A Protocol Development Summary (PDS) was developed to identify and justify the vital signs that would be monitored in the final protocol. A PDS acts as an executive summary of the future monitoring plan and states monitoring questions to be answered along with measureable objectives (NPS 2005). The questions and methods may change, but the PDS is a good starting point for project development.

The next step in protocol development for the coastal lagoons in CAKR was the planning and execution of pilot sampling. This pilot sampling took place in July 2009 (Reynolds and Clough 2010). The objectives for this sampling were as follows: 1) to develop and refine sampling protocols, 2) to gain a better understanding of the logistics since sampling would be in such a remote area, and 3) to gain a visual understanding of the area.

4.2.2 The Proposed Long-Term Monitoring Protocol for CAKR Coastal Lagoons

The long-term monitoring protocol for the coastal lagoons of Cape Krusenstern National Monument was submitted to the National Park Service Arctic Network Inventory and Monitoring Program on December 31, 2010. It is currently in the review and modification

process. What follows are the key elements of the protocol answering the questions of what, when, and how data are collected so that long-term decadal change can be detected.

4.2.2.1. *Data Collection: What*

The overall objective of the CAKR coastal lagoons monitoring protocol is to document the long-term status and trends of physical, chemical, and biological components within the coastal lagoons of Cape Krusenstern National Monument. More specifically, the protocol narrative and standard operating procedures address the following objectives:

- 1) to determine the variability in water quality parameters in selected lagoons during open water sampling periods.
- 2) to measure and identify decadal trends in water quality parameters.
- 3) to measure the decadal trends in surface area of selected lagoons.
- 4) to measure and identify decadal trends of nutrients in the water column of selected lagoons.
- 5) to measure and identify decadal trends in species richness and relative abundance of biota (i.e. fish, benthic macroinvertebrates, and zooplankton) in selected lagoons.

The key variables of interest include: physicochemical parameters, biotic communities, and geomorphology. The following core water quality parameters are to be monitored as required by the Water Resources Division, National Park Service (Roman *et al.* 2003): water temperature (°C), dissolved oxygen (mg/L), pH (pH units), conductivity (mS/cm), and salinity (psu). In addition to this suite of parameters, the following will also be monitored: water depth, water clarity (Secchi disk), chlorophyll *a*, total nitrogen, dissolved nitrogen, and total phosphorus. In terms of biotic communities, the species richness and relative abundance of the following are monitored: fish, benthic macroinvertebrates, and zooplankton. Geomorphological

data collection includes: surface area, shoreline length, and bathymetry. Aerial photos are taken to assist in measuring geomorphological changes over time.

4.2.2.2 Data Collection: When

Determining when samples are collected is critical to any type of monitoring program as consistency is key to producing quality data. A revisit sampling design and the splitting of the lagoons into two panels helps organize this frequency of sampling. The timing of sampling depends on the component being sampled (i.e. water quality, biological, geomorphological). Table 4-3 displays the frequency of sampling for each component. Lagoons that are larger than 20 km² and used for subsistence activities are referred to as Panel 1 (i.e. Kotlik, Krusenstern, and Sisualik). These lagoons are sampled more frequently within this revisit sampling design. Panel 2 lagoons (i.e. Akulaaq, Imik, and Ipiavik) are smaller and sampled every five years according to this design.

Physicochemical parameters are sampled most frequently, with sampling for this component occurring every year in Panel 1 lagoons (Kotlik, Krusenstern, and Sisualik) and every five years in the Panel 2 lagoons (Akulaaq, Imik, and Ipiavik). Fish and benthic invertebrates are only sampled in the Panel 1 lagoons and are sampled every five years. Zooplankton are also sampled every five years, but are collected in both Panel 1 and Panel 2 lagoons. Geomorphology data are collected from all the lagoons every ten years. The hope is that these geomorphology data are collected in conjunction with the coastal erosion vital sign protocol.

During the annual physicochemical sampling, each station is considered a replicate in the corresponding lagoon. Therefore, every year, there are a minimum of three replicates for physicochemical parameters in each of the Panel 1 lagoons. Data are collected from a floatplane during the years of decreased sampling intensity (i.e. years 2-5), which decreases station

selection within a lagoon as floatplane challenges (i.e. anchoring, depth variations, etc) are limiting. At each sampling station continuous depth profiles of the physicochemical parameters should be collected thus allowing for comparisons within and amongst lagoons. Data presented in Chapter 3 showed halocline development in Sisualik in July 2003 (Appendix B) therefore obtaining complete vertical depth profiles allows for stratification identification.

Every year continuous data loggers are placed into Kotlik and Krusenstern. They are deployed at the same time the physicochemical data are collected. These loggers remain in the lagoons until late September or early October, just before freeze-up. Data loggers may also be placed into other lagoons (i.e. Ipiavik), but that will be determined once the depth of the lagoons is measured. The collection of continuous data adds to the understanding of the cyclic change that these lagoons experience as was discussed in Chapter 3. A multiparameter data sonde is used to collect physicochemical data when the data loggers are retrieved in the falltime. These data are collected at the logger-deployment station before the logger is removed from the water. This serves as a quality control check for the data logger.

Every five years all the locations in all the lagoons (Panel 1 and 2) are sampled for various components (Table 4-3). Fish are collected in the Panel 1 lagoons (Kotlik, Krusenstern, and Sisualik) on this 5-year cycle. The beach seine is hauled at a minimum of three locations in each of these lagoons. The experimental gillnet is set for 1-hour at a minimum of three locations within each Panel 1 lagoon. The shallow depths of Sisualik can hinder the gillnet set, so the protocol states the net be set 3 different times at the same location (i.e. entrance to the lagoon). Benthic invertebrates are also collected every five years in the Panel 1 lagoons. At each station the petite ponar is dropped three different times. These replicates are then averaged in order to calculate a location mean.

Zooplankton are collected in all the lagoons (Panel 1 and 2) every five years. At each station, three vertical tow samples are collected. These three replicates are then averaged to calculate a station mean. This allows for the comparison of each station within each lagoon. Every ten years aerial photos are taken of all the lagoons. These are used to help determine surface area, shoreline length, and areas of erosion (lagoon-side).

It is recommended that sampling occur during the second and third week of July. The coefficient of variation data (Table 3-2 and Figure 3-10) and the multidimensional scaling plot for July 2003 (Figure 3-17) demonstrate that station-to-station variability is low for this time period, particularly for Akulaaq and Krusenstern. My dissertation data show that the open water period is the most stable and therefore the best season to sample in order to detect decadal change rather than cyclical change. It is critical to sample at the same time each year, to the extent possible. The data presented in Chapter 3 also demonstrate that sampling a few weeks earlier or later can potentially influence the data. Weather changes quickly in this area of northwest Alaska and within the span of a few weeks, the air temperature can change dramatically thereby causing changes in the water temperature of these shallow coastal lagoons.

4.2.2.3 Data Collection: How

The sampling design for this long-term monitoring of the CAKR coastal lagoons is designed based on a combination of the following: NPS-WRD requirements, knowledge of already-existing monitoring protocols for similar biotic and abiotic components, an ecological understanding of the identified biotic and abiotic components, previous sampling experience in the area, the results of the data collection from those sampling periods, knowledge of the logistics involved in sampling such a remote area, knowledge of the weather in the area, and an

understanding of the limited amount of monetary funds and limited number of personnel available for such sampling.

Many of the sampling stations in the Reynolds *et al.* (2005) study (along with those discussed in Chapter 3 and presented in Appendix A) were incorporated into this lagoon monitoring. This decision to use the same locations and methods allows the data already collected to act as baseline. It also allows for comparisons to be made and will help with the identification of trends. As discussed in Chapter 3, the sampling locations in the lagoons were chosen based on a study conducted by Blaylock and Houghton (1983), which included Ipiavik Lagoon and Port Lagoon as well as lagoons north of the Monument boundary. Blaylock and Houghton (1983) had four criteria for their sampling locations: 1) on the shoreline-side of the lagoon, 2) in the middle of the lagoon, 3) near creek and river inlets/outlets, and 4) near any known anomalies.

Each lagoon has at least three sampling stations. The three stations act as three replicates so that lagoon averages and statistical analyses can be carried out for the various components. This allows for comparison between lagoons as well as helps to identify trends in the various components of each lagoon. Kotlik, Krusenstern, and Sisualik all have a greater number of sampling stations due to their size, subsistence resource utilization, and accessibility. Data presented in Chapter 3 showed the development of a halocline in Sisualik in July 2003 (Appendix B) and high station-to-station variability (Figure 3-17). For these reasons samples in Sisualik should be collected above the halocline and below it in order to account for the stratification.

4.2.3 Minimal Sampling Recommendations for CAKR Coastal Lagoons

These recommendations are a simplified version of the above-discussed protocol. The above protocol can be thought of as a “best-case scenario monitoring plan” while this section can be thought of as a “minimal sampling protocol” for the coastal lagoons of CAKR. As mentioned, agencies/departments are often forced to operate under limited funding. The research and data discussed in Chapter 3 can now be used to help prioritize sampling in the remote coastal lagoons of Cape Krusenstern National Monument.

The importance of these lagoons on a local level was discussed in both Chapters 2 and 3 of this dissertation, but in summary, they provide habitat for fish species that are utilized for subsistence resources by local users. Long-term monitoring of these coastal lagoons with basic, minimal sampling will provide the information needed to detect any non-cyclical change that these dynamic systems experience. The sampling recommendations presented here are for sampling under conditions of severe monetary restrictions.

4.2.3.1 Minimal Data Collection: What

It is recommended that sampling focus on physicochemical parameters during times of limited budgets. The data are easier to collect, fewer personnel are needed, the gear requirements are much less, and the logistics involved are far fewer for the collection of basic water quality data than for ichthyofauna data. The minimal data collected will provide the information needed to detect decadal change in the coastal lagoons of CAKR.

The Coefficient of Variation (CV) data presented in Chapter 3 revealed that water temperature was the least variable parameter in Akulaaq, Krusenstern, and Sisualik throughout ice-covered and open water seasons (Table 3-2; Figure 3-10). In terms of monitoring this means

that water temperature is the best physicochemical indicator of change as it is the least variable water quality parameter (Mulder *et al.* 1999).

Opportunistic zooplankton, nutrient, and chlorophyll *a* samples can also be collected during each sampling event. These samples do require more in terms of supplies/gear and money for the actual processing of samples, but if monetarily possible, it is recommended that these types of samples be included in the basic monitoring of these lagoons. The information gained will provide managers with additional knowledge to make better-informed decisions about the lagoonal systems.

4.2.3.2 Minimal Data Collection: When

Collection should still take place in July, and should happen every year in all the coastal lagoons as only the physicochemical data will be collected during budget-restricting times. This will allow more physicochemical sampling to occur in all the lagoons as less time and resources are expended collecting data on a multitude of components.

4.2.3.3 Minimal Data Collection: How

As stated above, the most stable physicochemical parameter should be part of the annual monitoring of the coastal lagoons and in this case, water temperature is that parameter. It can be sampled via temperature Tidbit data loggers that are placed in the lagoons soon after break-up (mid-June) and picked up in mid-September just before freeze-up. Since these lagoons are so remote it is advised to stick with simple data collectors that don't require much cleaning and maintenance. Basic temperature tidbits are low maintenance and will collect the data needed to detect long-term water temperature change.

The best-case scenario would include at least three data loggers in various locations in each lagoon as this would allow statistical analyses to be completed. The Kruskal-Wallis results from Chapter 3 did show statistical differences in the different stations in all the lagoons (Appendix D, E, and F), but a look at the data in Table 3-2 reveals that these differences are very small and perhaps insignificant to the various plankton and ichthyofauna in the lagoons. The multidimensional scaling plot for July 2003 (Figure 3-17) showed that all the stations in Akulaaq and Krusenstern were very similar therefore minimal sampling stations in these two lagoons would be needed. Sisualik is different in that all six stations in the MDS plot appeared to be dissimilar (Figure 3-17). Sampling in this lagoon should entail more samples and samples collected at a minimum of two depths, above the halocline and below the halocline. The open-water nature of this lagoon is such that perhaps the best way to monitor water temperature would be to sample Kotzebue Sound, at the lagoon entrance. This would require fewer tidbits, easier data logger deployment and retrieval, and the least amount of personnel – all critical during times of budget restrictions.

Data loggers can be deployed by floatplane in Imik, Kotlik, and Krusenstern. Deployment by floatplane in Akulaaq will depend on water depths at the time. Akulaaq is approximately 1 m in depth so if too shallow then deployment will require a floatplane landing in the Tukrok River (near the Anigaaq cabin) followed by a fourwheeler trip down the beach assuming the opening to the river is closed. A flyover or a simple request from local pilots about the coast a few days before sampling should be conducted. Once at Akulaaq a zodiac will need to be used to deploy the data loggers. Sisualik (i.e. Kotzebue Sound) data logger deployment can be accomplished by a boat trip across the Sound.

A week should be set aside for actual logger deployment as the weather, particularly the wind, can certainly impact flying and boating opportunities. The same time scale is recommended for data logger retrieval in the fall. Adding opportunistic sampling to the data logger deployment and retrieval process will add a few days to a week to each sampling event.

4.3 Conclusion

The long-term monitoring protocol for the coastal lagoons of Cape Krusenstern National Monument is one that, if implemented properly, could be an excellent example of the integration of science and management. The CAKR protocol is focused on the identification of decadal trends that will help area managers gain a better understanding of the lagoonal systems as well as identify long-term changes to the aquatic habitats that sustain subsistence resources. The original protocol is a “best case scenario” protocol that should be instituted, but the “minimal sampling protocol” is a simplified version to be carried out when managers are faced with tight budget constraints. The minimal sampling will produce quality data and provide the data necessary to identify long-term trends, albeit with data from limited system components. Perhaps over time, parameters can be added back so as to restore the full protocol thus providing a more holistic picture of the CAKR coastal lagoon system dynamics. The hope is that these lagoon protocols become a part of, and contribute information to, other monitoring plans for the Cape Krusenstern area. Under ideal conditions the local users of the land and resources would help collect these data thus building a partnership between scientists, managers, and local users. This partnership could prove to be a great example of the integration of science and management policy that has been adopted by the National Park Service.

Table 4-1. The 28 vital signs identified by the National Park Service Arctic Network Inventory and Monitoring Program (Lawler *et al.* 2009).

1. Air Contaminants
2. Brown Bears
3. Caribou
4. Climate
5. Coastal Erosion
6. Dall's Sheep
7. Fire Extent and Severity
8. Fish Assemblages
9. Invasive/Exotic Species - Plants
10. Invasive/Exotic Species – Animal Diseases
11. Lagoon Communities and Ecosystems
12. Lake Communities and Ecosystems
13. Landbirds
14. Moose
15. Muskox
16. Permafrost
17. Point Source Human Effects
18. Sea Ice
19. Small Mammal Assemblages
20. Snowpack
21. Stream Communities and Ecosystems
22. Subsistence/Harvest
23. Surface Water Dynamics and Distribution
24. Terrestrial Landscape Patterns and Dynamics
25. Terrestrial Vegetation and Soils
26. Visitor Use
27. Wet and Dry Deposition
28. Yellow-billed Loons

Table 4-2. Recommended content for the protocol narrative portion of long-term monitoring protocols developed for the National Park Service (Oakley *et al.* 2003).

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1. Background and Objectives
 - a. Background and history; describe resource issue being addressed
 - b. Rationale for selecting this resource to monitor
 - c. Measurable objectives
 2. Sampling Design
 - a. Rationale for selecting this sampling design over others
 - b. Site selection
 - i. Criteria for site selection; define the boundaries or “population” being sampled
 - ii. Procedures for selecting sampling locations; stratification, spatial design
 - c. Sampling frequency and replication
 - d. Recommended number and location of sampling sites
 - e. Recommended frequency and timing of sampling
 - f. Level of change that can be detected for the amount/type of sampling being instituted
 3. Field Methods
 - a. Field season preparations and equipment setup (including permitting and compliance procedures)
 - b. Sequence of events during field season
 - c. Details of taking measurements, with example field forms
 - d. Post-collection processing of samples (e.g. lab analysis, preparing voucher specimens)
 - e. End-of-season procedures
 4. Data Handling, Analysis, and Reporting
 - a. Metadata procedures
 - b. Overview of database design
 - c. Data entry, verification, and editing
 - d. Recommendations for routine data summaries and statistical analyses to detect change
 - e. Recommended reporting schedule
 - f. Recommended report format with examples of summary tables and figures
 - g. Recommended methods for long-term trend analysis (e.g. every 5 or 10 years)
 - h. Data archival procedures
 5. Personnel Requirements and Training
 - a. Roles and responsibilities
 - b. Qualifications
 - c. Training procedures
 6. Operational Requirements
 - a. Annual workload and field schedule
 - b. Facility and equipment needs
 - c. Startup costs and budget considerations
 7. References
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Table 4-3. Revisit sampling design for monitoring the coastal lagoons in CAKR. An 'X' indicates samples will be collected. *Panel #1: Kotlik, Krusenstern, and Sisualik (lagoons > 20 km² and used for subsistence), Panel #2: Akulaaq, Imik, and Ipiavik

<i>Component</i>	<i>Revisit Notation</i>	<i>Panel #*</i>	<i>Month</i>	<i>Year</i>										
			July	1	2	3	4	5	6	7	8	9	10	11
Physicochemical	[1-0]	1	X	X	X	X	X	X	X	X	X	X	X	X
	[1-4]	2	X	X					X					X
Fish	[1-4]	1	X	X					X					X
Benthic Invertebrates	[1-4]	1	X	X					X					X
Zooplankton	[1-4]	1	X	X					X					X
		2	X	X					X					X
Geomorphology	[1-9]	1	X	X										X
		2	X	X										X

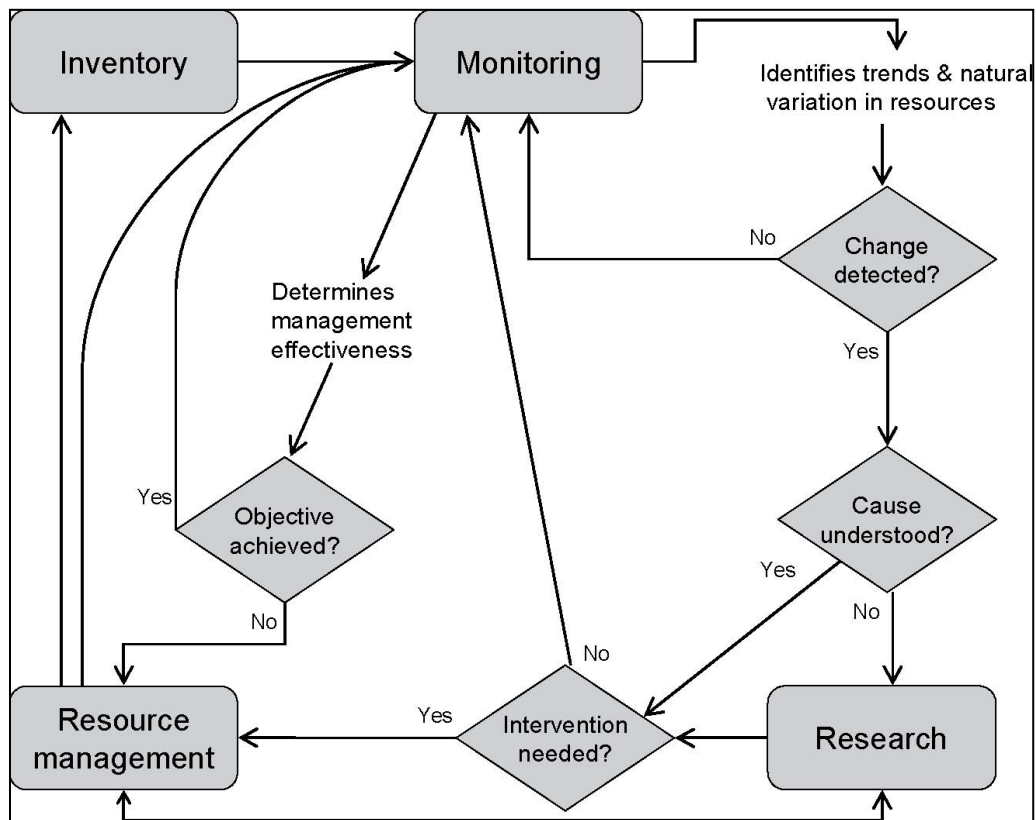


Figure 4-1. The role of inventory and monitoring in resource management. A basic schematic for the integration of science and management and the relationships between activities in national parks (Lawler *et al.* 2009).

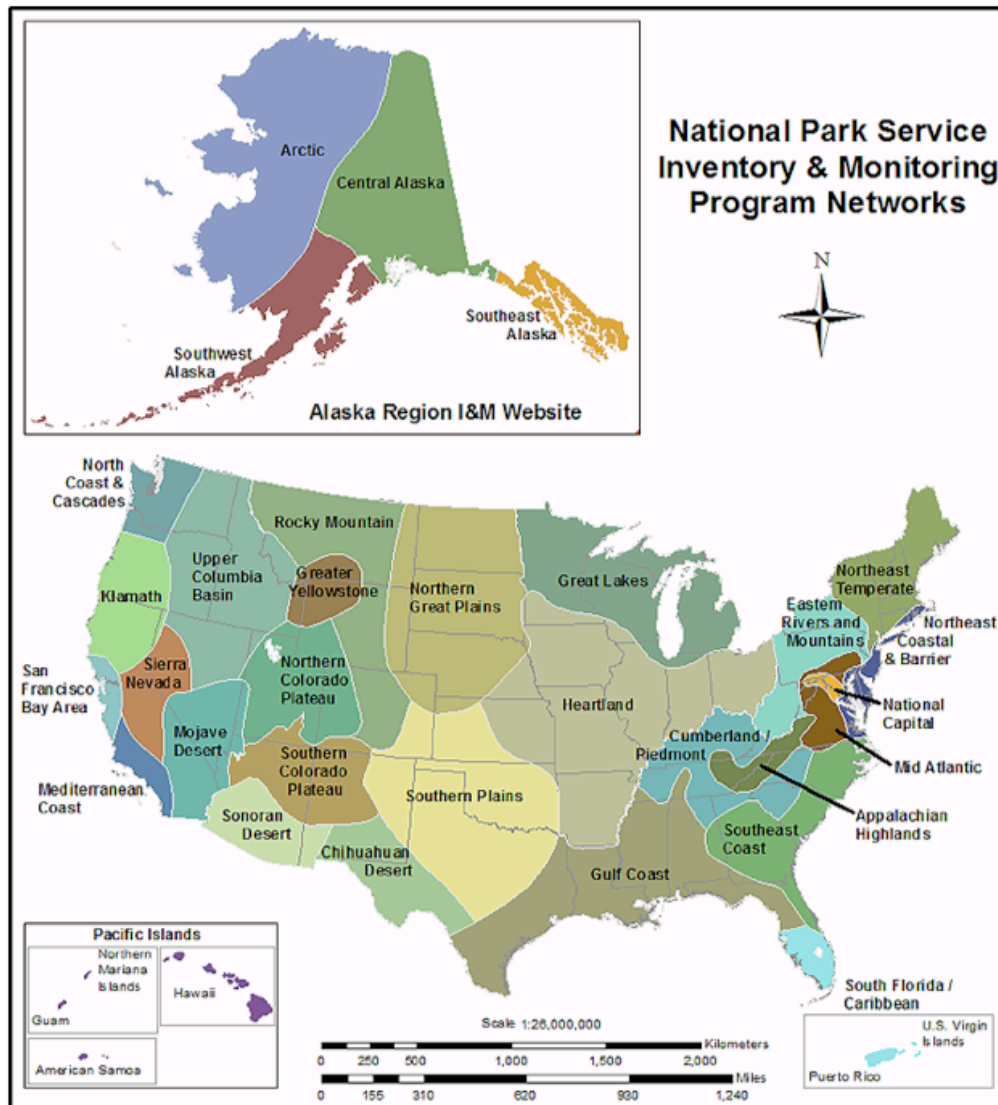


Figure 4-2. The 32 Networks of the National Park Service Inventory and Monitoring Program. Each network is identified with a different color. Map courtesy of the NPS.

Inventory and Monitoring Program Networks Alaska Region

National Park Service
Department of the Interior

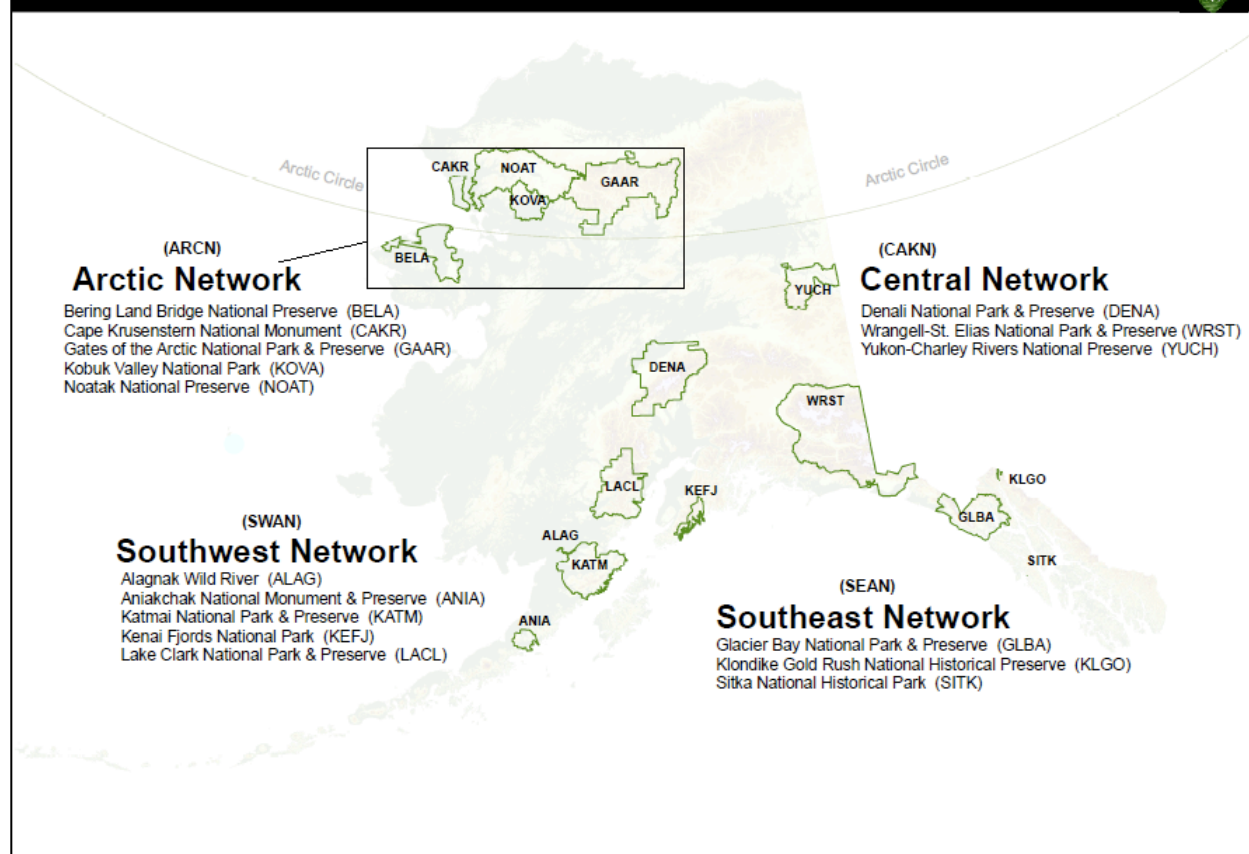


Figure 4-3. The four networks of the NPS Alaska Region Inventory & Monitoring Program. The five parks that comprise the Arctic Network are located within the box on the map. Modified map courtesy of the NPS.

CHAPTER 5

CONCLUSION: A RETROSPECTIVE ON THE SAMPLING OF THE CAPE KRUSENSTERN NATIONAL MONUMENT COASTAL LAGOONS, BRIEF COMPARISONS, AND POTENTIAL SYSTEM STRESSORS

5.1 The Original Plan vs. Reality

Chapter 1 reflects my original intentions regarding the collection of baseline physicochemical and species data in five coastal lagoons in Cape Krusenstern National Monument (CAKR). I set out to collect spatial and temporal data in all five coastal lagoons (Akulaaq, Imik, Kotlik, Krusenstern, and Sisualik) over the course of two years with sampling taking place four times each year – two sampling periods during ice-covered seasons (January and April) and two sampling periods during open water seasons (July and September) – for a total of eight sampling periods. All five lagoons were to have a minimum of five sampling stations and nets were to be set in three different locations around each lagoon.

Sampling during ice-covered seasons proved to be quite challenging – particularly in January. Low temperatures were the main reason for the low number of samples collected in each lagoon. Equipment broke and people were freezing so decisions were made to cut back on sampling. Sampling at Imik and Kotlik was minimal during ice-covered periods because of the distance from our base camp at Krusenstern. Light availability in January was at a minimum and the snowmachine trail was unmarked so this left little time for actual sampling. April sampling was much warmer ($\approx 3.9^{\circ}\text{C}$), but the Imik and Kotlik lagoons were often too flooded with melt water to sample.

Sampling during the open water season occurred for three out of the four dates originally planned. The July 2004 sampling did not occur due to personal circumstances and the

September 2004 sampling occurred approximately three weeks earlier than the September 2003 sampling. Sampling of Imik and Kotlik was limited to July 2003 because of cost. We also quickly realized that planning for the correct amount of gas in such remote areas is critical. The low number of sample locations (3) in both Imik and Kotlik were due to this miscalculation.

In order to carry out this research, I resided in Kotzebue for two years. This allowed me to gain a better understanding of life in northwest Alaska, including: weather patterns and anomalies, the dependence on subsistence lifestyles, the value of subsistence lifestyles, and the role/value of CAKR in the lives of those who utilize the land and its resources. I would argue that one cannot gain these understandings by simply “passing through” to collect the desired data. Understanding the human population that utilizes the resources is critical in resource management therefore residing in the community was a vital component of my research. By living in the community I was able to form partnerships/friendships that contributed invaluable local knowledge to the project. My one big regret is that I did not officially document these talks and the information gained. In retrospect, it would have been a great chance to collect the local knowledge along with the collection of the scientific data. Future sampling should incorporate this type of data collection so as to bring the local knowledge together with the scientific knowledge about these coastal lagoons in a systematic and synergistic way.

5.2 Unexpected Developments/Outcomes

At the outset, my goal was to contribute baseline physicochemical and species data for the coastal lagoons of Cape Krusenstern National Monument. These data gaps were recognized by local park staff and this project materialized due, in large part, to their input and willingness to support my research, both monetarily and logistically. The need to expand the baseline

inventory of coastal aquatic resources in CAKR was the number one priority in the 1999 Resource Management Plan for CAKR.

Simultaneously, the National Park Service was moving forward with their congressional mandate to develop an inventory and monitoring program (16 U.S.C. §5934). This resulted in the creation of 32 I&M networks, including the Arctic Network (ARCN), covering five different parklands, including Cape Krusenstern National Monument (Figure 4-2). The ARCN became interested in the CAKR lagoons and my data as a means to add to the inventory database and potentially develop a long-term monitoring plan for these aquatic resources. The NPS decided that exploratory sampling needed to be conducted before the long-term monitoring plan could be developed.

The pilot sampling took place in July 2009 and the complete report can be found on the NPS Arctic Network Inventory and Monitoring Program website (Reynolds and Clough 2010). Monetary support for this pilot sampling was limited and we were presented with additional logistical challenges. The take-away is that data collection in remote, northwest Alaska presents many challenges, including, but certainly not limited to the following: sample storage - especially for time-sensitive samples, laboratory needs, sample shipping, equipment and gear storage, floatplane access, boat needs and maintenance, and basic lagoon access. The pilot sampling contributed to the already existing data of Chapter 3, and allowed the development of the long-term monitoring plan for the coastal lagoons of CAKR to move forward.

I submitted the complete monitoring protocol for the CAKR lagoons to the NPS ARCN for review on December 31, 2010. It is currently under review, both internally and externally, and will hopefully proceed once all has been approved. The hope is that over time, more ecosystem components will be added to the protocol and that data collected for the lagoon

protocol will contribute to other monitoring plans. This will result in an ecosystem-based management approach.

5.3 Lessons Learned

5.3.1 Logistics

The logistics involved in sampling remote areas are vitally important; one must strive to collect the desired samples within the designated timeframe all the while keeping safety at the forefront. It cannot be overstated how critical it is to plan for sampling events well before the actual sampling occurs. Each sampling season (ice-covered and open water) presented its own challenges in sampling the CAKR coastal lagoons.

Safety cannot be overstated. During ice-covered sampling seasons it is critical to have someone on the sampling team that knows the land and snowmachine trails that are often unmarked. Winter survival training should be part of the preparation for ice-covered season sampling. All involved should also know basic snowmachine operation and mechanics. I also think each sampling team should have a mechanic along because breakdowns will occur when the visibility is down to zero, air temperatures are well below zero, and the team is miles from any cabin. Extra gas must always be brought along and it can be staged at the Anigaaq cabins before the sampling team heads out. This helps lighten the load and leaves more room for sampling and personal gear on the sleds. Day-trip sampling must also include extra gas. The “trail” up to Kotlik and Imik is tough and if basing out of the NPS Anigaaq cabins then the amount of gas needed must be carefully calculated and extra gas brought along for the trip. Clearly, snowmachines and gas are a critical component of ice-covered sampling so planning accordingly will help ensure the safety of all involved and the successful collection of data.

In planning for ice-covered season sampling it must also be remembered that drinking water is not easily accessible. Ice must be collected from a freshwater source which takes time, but is a necessary camp chore. It must be remembered that all things simply take longer when the air temperatures are so low. Simple sample processes (i.e. writing on bags, tying bags, filling water jugs, etc.) all take longer and often lead to numb fingers which then need to warm, perhaps over a snowmachine engine. The limited light conditions in the winter must also be considered. In summary, sampling will not happen quickly during ice-covered seasons so plan accordingly.

With respect to the actual collection of samples during ice-covered seasons, we quickly realized that drilling a hole in the ice completely stirred up the water column. The solution was to drill all sampling holes on the first day of sampling and then wait 24 hrs before actual sampling commenced. We covered the holes with cardboard after drilling in order to minimize the amount of refreezing. Sampling for benthic invertebrates during ice-covered seasons also presented unique challenges. Samples could not be sieved on-site. Our solution was to place all samples into ziplock bags and sieve once back in Kotzebue. The water collected at each site for chlorophyll *a* was then used for the actual sieving so that site water was used. Bringing jugs of water and bags of sediment back to Kotzebue in the sleds must also be accounted for as it will add weight and take up room on the sleds.

One final thought about sampling during ice-covered seasons. While packing all equipment and gear it must be remembered that the “trails” are extremely rough therefore everything will be subjected to a large amount of bouncing. This could easily “make or break” the sampling event and the quality of data collected and is a critical consideration, particularly for any electronics used in sampling. Extra care must be considered when packing and special containers need to be constructed. Any probes stored in water (i.e. deionized or distilled water)

will freeze during transport. Solutions, perhaps from the manufacturer, must be sought before sampling commences.

Sampling during open water seasons presented different, but still important logistic challenges. Lagoon access is one of the main logistical hurdles. Sisualik can be accessed via boat from Kotzebue. Akulaaq, Imik, and Kotlik can all be accessed via floatplane when the water is deep enough. Akulaaq can also be sampled by fourwheeler and zodiac. This can only be accomplished when the opening of the Tukrok River is closed. It is highly recommended that a fly-over be completed just days before the sampling team heads. Krusenstern can be accessed with a boat from Kotzebue, but one can only enter the lagoon if the Tukrok River is open. When the opening of the river is closed then the boat must be pushed and pulled over the beach and into the river, a process that takes many people and fourwheelers, and also depends on the size of the boat. It is not recommended that an inflatable zodiac be used for sampling Krusenstern as the lagoon is quite large and strong winds can produce large waves.

In terms of actual sampling procedures/processes during open water seasons, keeping samples cold and working with time-sensitive samples (i.e. nutrients) can be particularly challenging when in remote areas for an extended period of time. Arranging for sample pick-up via floatplane reduces the amount of sample degradation. It must also be remembered that there are no official lab facilities in Kotzebue so arrangements with local agencies should be made well in advance of sampling to ensure availability.

5.3.2 Comparisons Between CAKR Lagoons

A brief comparison of abiotic and biotic parameters in Akulaaq, Krusenstern, and Sisualik identifies some basic similarities however, three very different systems emerge upon closer examination of the data. All lagoons experienced an increase in salinity between January

and April. Salinity and dissolved oxygen were highly variable in all the lagoons, particularly during ice-covered seasons. In contrast, all CAKR lagoons experienced low coefficient of variation in water temperature throughout all seven sampling periods. All the CAKR lagoons experienced an increase in chlorophyll *a* between January and April indicating a spring bloom despite the thickest ice of the season. The data also indicate that the open water season provides a more stable environment for the pelagic species inhabiting the lagoon waters. The most abundant zooplankton in all the lagoons are copepods and cladocerans. The presence/absence of ichthyofauna affects the zooplankton dynamics in all the CAKR lagoons, but further examination of species richness should be conducted to gain a better understanding of predator-prey relationships.

Akulaaq Lagoon is an intermittently-open lagoon with a highly variable and unstable environment. This lagoon can go from estuarine to hypersaline and back to estuarine in the span of six months and the most abundant zooplankton seem to go dormant as a means of dealing with the stressful environment. The biota present in Akulaaq fluctuate with the frequency and duration of breaching events. This lagoon did not completely freeze to the bottom, but minimal water remained under the ice, likely limiting the amount of overwintering habitat.

Krusentern Lagoon is a seasonally-closed lagoon with indirect openings to the Kotzebue Sound. The physicochemical parameters were the most stable in this, the largest and deepest lagoon. This lagoon is also the only CAKR lagoon that has the potential to provide overwintering habitat for fish. Krusenstern experienced the largest chlorophyll *a* concentrations in April. The lagoon also hosts a large population of *Coregonus spp.*

Sisualik Lagoon is completely open to the Kotzebue Sound and provides a stable environment in a manner similar to a salt marsh as the micro tides provide predictable

physicochemical changes. Sisualik was the only lagoon to develop a halocline during open water periods. This lagoon also exhibited the greatest amount of station-to-station variability during any one sampling period. Sisualik also had the greatest number of benthic macroinvertebrates and ichthyofauna out of all the CAKR lagoons. The lagoon can freeze to the bottom during ice-covered seasons, so is unlikely to provide significant overwintering habitat.

5.3.3 Comparisons Between CAKR Lagoons and Other Arctic Lagoons

What follows is a brief, general overview of how the CAKR lagoons compare with other arctic lagoons with respect to physicochemical parameters during both ice-covered and open water seasons, and with regard to zooplankton and ichthyofauna.

All the CAKR coastal lagoons appear similar to Simpson Lagoon up on the Beaufort Sea coast in terms of ice thickness in April. According to Craig and Haldorson (1981) April is when the ice was the thickest and this was also reported for the CAKR lagoons (Table 3-3). The amount of available water under the ice in Krusenstern Lagoon was similar to that report for Simpson Lagoon (Craig and Haldorson 1981).

In terms of salinity, Tash and Armitage (1967) collected year-round samples in lakes and lagoons at Cape Thompson, Alaska and their data indicated that salinity increased during ice-covered sampling periods. As presented in Chapter 3, this was certainly the case for the CAKR lagoons. Craig and Haldorson (1981) reported that the salinity in Simpson Lagoon was 24 ‰ in November and 36 ‰ in February. By the end of April salinity levels in Simpson Lagoon had become hypersaline (Craig and Haldorson 1981). This increase in salinity as winter progressed was also observed in all the sampled CAKR coastal lagoons. Hypersaline conditions were also observed in Akulaaq Lagoon in April 2003 (Table 3-2).

Dissolved oxygen levels in arctic lagoons seem to vary, but the CAKR coastal lagoons appear to be most similar to those measured in channels of the Colville and Sagavanirktok River Delta. Kogl and Schell (1974) reported dissolved oxygen levels in the Colville between 2.3 mg/L – 7.8 mg/L. Relatively high D.O. concentrations were also reported for the Sagavanirktok River Delta (> 5 mg/L; Schmidt *et al.* 1989). Lagoons near Cape Thompson reportedly had D.O. levels around 0 mg/L during ice-covered seasons (Tash 1964). The CAKR D.O. concentrations were never that low.

The water temperature under the ice in Simpson Lagoon in February was below 0 °C (Craig and Haldorson 1981). Tash (1964) reported water temperatures below zero in Pusigrak Lagoon, located near Cape Thompson and Schmidt *et al.* (1989) reported water temperatures below zero between April and May in the Sagavanirktok River Delta located along the Beaufort Sea. Water temperatures below 0 °C during ice-covered seasons were observed in all the CAKR lagoons (Table 3-2).

Data collected during break-up were not collected for the CAKR lagoons, but samples were collected in April and then again in July, about one month after break-up. A look at salinity levels in Akulaaq between April 2003 and July 2003 showed a large decrease in salinity levels as ice melted and hypersaline concentrations were gone by the open water season (Table 3-2). This freshening of the water was also observed by Griffiths *et al.* (1977) in Kaktovik Lagoon and also by Matthews and Stringer (1984) who reported a salinity drop of 20 ‰ within 20 minutes in the Egg Island Channel, a major channel within the Simpson Lagoon complex, during spring flushing.

Water depths between Krusenstern Lagoon and other arctic coastal lagoons during the open water season appear to be quite similar. Tash (1964) reported that lagoons in the Cape

Thompson area had depths < 3 m deep and Craig and Haldorson (1981) reported depths in Simpson Lagoon between 2 m and 3 m during the open water season.

Salinity levels during the open water seasons were higher in Simpson Lagoon than those measured in the CAKR lagoons. Craig and Haldorson (1981) reported salinities between 18-25 ‰ whereas the range for all the CAKR lagoons during the open water seasons was between 2.5 psu – 13.4 psu (Table 3-2). In the Blaylock and Houghton lagoon (1983) study, Ipiavik and Singoalik, two reportedly open lagoons had salinity concentrations in July 1982 that were twice as those measured in Sisualik in July 2003 (Table 3-2). A comparison of closed lagoons revealed that Imikruk and Pusigrak had very low salinities in July 1982 as opposed to Akulaaq, Imik, Kotik, and Krusenstern that were all more estuarine.

Water temperatures during the open water seasons were quite similar amongst the various arctic lagoons. Griffiths *et al.* (1977) reported water temperatures in Kaktovik Lagoon between 2 – 12 °C and Craig and Haldorson (1981) reported water temperatures in Simpson Lagoon between 7 – 10 °C. All the CAKR lagoons had open water temperatures between 4.6 °C – 17.2 °C (Table 3-2) so the CAKR lagoons were slightly higher. In comparing the Blaylock and Houghton (1983) lagoons, water temperatures were higher in Sisualik as opposed to those measured in both Ipiavik and Singoalik, the two open lagoons. The water temperatures of Akulaaq, Imik, Kotlik, and Krusenstern were very similar to those measured in the closed lagoons of the Blaylock and Houghton (1983) study.

The CAKR lagoons appear to be similar to many arctic lagoons in terms of zooplankton species. O'Brien *et al.* (2004) collected zooplankton samples from 104 arctic lakes in Alaska and reported seven species, all copepods and cladocerans, in the lakes. Tash and Armitage (1967) reported 14 species of Cladocera and 38 species of Copepoda in lakes, pools, and lagoons

near the Cape Thompson area. The most abundant zooplankton in all the sampled CAKR lagoons were copepods and cladocerans (Table 3-5).

The fish species inhabiting the CAKR coastal lagoons appear to be similar to those found in other arctic lagoons. Craig *et al.* (1984) reported that anadromous species entered Simpson Lagoon during spring break-up and returned to rivers or estuaries to spawn (although some would overwinter if the lagoon was not frozen to the bottom). This seasonal movement of species seems likely in Krusenstern Lagoon since the lagoon had sufficient water under the ice to support overwintering areas (Table 3-3). Several anadromous species were collected in Krusenstern Lagoon (Table 3-6), just as in Simpson Lagoon (Craig *et al.* 1984). Both lagoons have openings, even if only seasonally (Krusenstern) that allow the anadromous species to enter and exit. Simpson Lagoon is continually open to the Beaufort Sea as Sisualik is continually open to the Kotzebue Sound. Both lagoons have a large number of species utilizing the habitats (Craig 1984 and Table 3-6, respectively). Blaylock and Houghton (1983) also reported the marine species *Myoxocephalus quadricornis* in Singoalik Lagoon, an open lagoon. This marine/estuarine species was also present in Akulaaq and Kotlik, both intermittently open and Sisualik, an open lagoon.

Closed lagoons seem to have few fish species present. Blaylock and Houghton (1983) reported *Dallia pectoralis* in Imikruk Lagoon, a closed lagoon north of the CAKR boundary. The research presented in Chapter 3 showed *Dallia pectoralis* only present in Akulaaq (Table 3-6). *Pungitius pungitius* was present at 53% of the stations in the study by Blaylock and Houghton (1983) and was present in Kotlik, Krusenstern, and Sisualik (Table 3-6). Relative abundance data needs to be collected in the CAKR coastal lagoons in order to better understand the species inhabiting these coastal lagoons.

5.4 Management Concerns - Potential Stressors on the CAKR Coastal Lagoons

More data, particularly fish data, are warranted in order to gain a better understanding of the natural resources of the CAKR coastal lagoons. As previously stated, these lagoons are used by locals for subsistence harvesting and that use should continue. The number of people harvesting these resources is minimal and the area is not easily accessible therefore the possibility of overharvesting the fisheries is at present small. In the meantime, management should collect relative abundance data and continue to monitor not only the biotic parameters, but also the abiotic parameters as a means to identify the long-term trends of these coastal systems, especially in light of possible system stressors – resource development and global climate change.

Offshore resource exploration is exploding in northwest Alaska as the first exploratory wells are expected in the Chukchi Sea and Beaufort Sea in Summer 2012 (Shell 2011). Shell Gulf of Mexico, Inc. has proposed six exploration wells along the Chukchi Sea coast and four exploration wells have been proposed for the Beaufort Sea coast (Shell 2011). According to the map presented by Shell (2011) the potential well locations in the Chukchi Sea would be located north of the CAKR boundary, between Point Hope and Barrow. The various currents in the Chukchi Sea, including the Bering Shelf Water and the Alaska Coastal Water, have been measured to have an annual mean flow to the north (Woodgate *et al.* 2005; Weingartner and Danielson 2010). This implies that the coastal waters along the CAKR boundary would most likely not be directly impacted by potential oil spills from this exploratory drilling as the Monument boundary is located to the south of all proposed drilling sites. However, Moore (1966) conducted arctic beach sedimentation studies along the northwest coast of Alaska between Point Hope and Sisualik Spit and reported that sediment deposition was the result of

alongshore transport rather than onshore and offshore transport. Moore (1966) and Giddings and Anderson (1986) reported that the beach-ridge complex at Cape Krusenstern was formed by the southward movement of gravel. Contaminated sediment could impact the anadromous fish species (*Coregonus spp.*) that utilize the coastal waters before traveling into the coastal lagoons. The coastline processes of accretion and erosion must also be considered with regard to the potential impacts of offshore resource extraction. It is recommended that the sediment deposition data for Cape Krusenstern National Monument be updated so as to help predict other potential impacts from area development.

Other potential stressors on the CAKR coastal lagoons are the already observed and expected-to-continue climatic and physical changes collectively known as global climate change. Weather patterns, ocean currents, and the ice edge extent are all predicted to change in response to climate change (NOAA 2011). Climatic pattern changes (i.e. wind speed and direction) will most likely affect the CAKR lagoons as Moore (1966) and Hopkins (1977) reported that the movement of gravel along the CAKR coast was most likely a function of wind speed and direction. Storm surges are predicted to increase as the open water season extends with the decreasing ice extent (NOAA 2011). These surges could cause large amounts of erosion in some places resulting in an accretion of sediment in other areas. Changing currents and wind speed and direction will most certainly play a role in where the erosion and accretion occur.

Global sea level rose approximately 1.8 mm/yr between 1961 and 1993 and then accelerated to 3.1 mm/yr between 1993 and 2003 (IPCC 2007). This rise is expected to continue so what does that mean for the CAKR coastal lagoons? If sea level rises faster than sediment deposition then the smaller lagoons (i.e. Akulaaq, Imik, and Kotlik) will open up as the current sediment barrier is minimal between the Chukchi Sea and these lagoons. Krusenstern has a large

beach-ridge complex, but perhaps the predicted strong storm surges and changing currents will erode various parts of the coastline ultimately causing a breach. Sisualik will remain open if sea level rises faster than sediment deposition.

However, sediment accretion could occur faster than sea level rise. The sediment barrier for Akulaaq, Imik, and Kotlik could increase thereby reducing the number of breaching events for these intermittently-open lagoons. This scenario would result in additional ridges within the Krusenstern beach-ridge complex and the Sisualik beach barrier would continue to grow resulting in a closure of the current open lagoon.

It is highly recommended that missing baseline data for the coastal lagoons of CAKR be collected. Monitoring plans should continue to be developed for the various components of the CAKR coastal lagoons to help identify long-term trends. Collecting as much data as possible before local area disturbance (i.e. resource exploration) and any further climatic changes (i.e. global climate change) will help identify potential impacts on these aquatic ecosystems that play an integral role in the subsistence lifestyle of the region.

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APPENDIX A: GPS COORDINATES

Table A. Latitude and longitude coordinates for sampling stations in the CAKR lagoons that were sampled in this research. Coordinates are in decimal degrees.

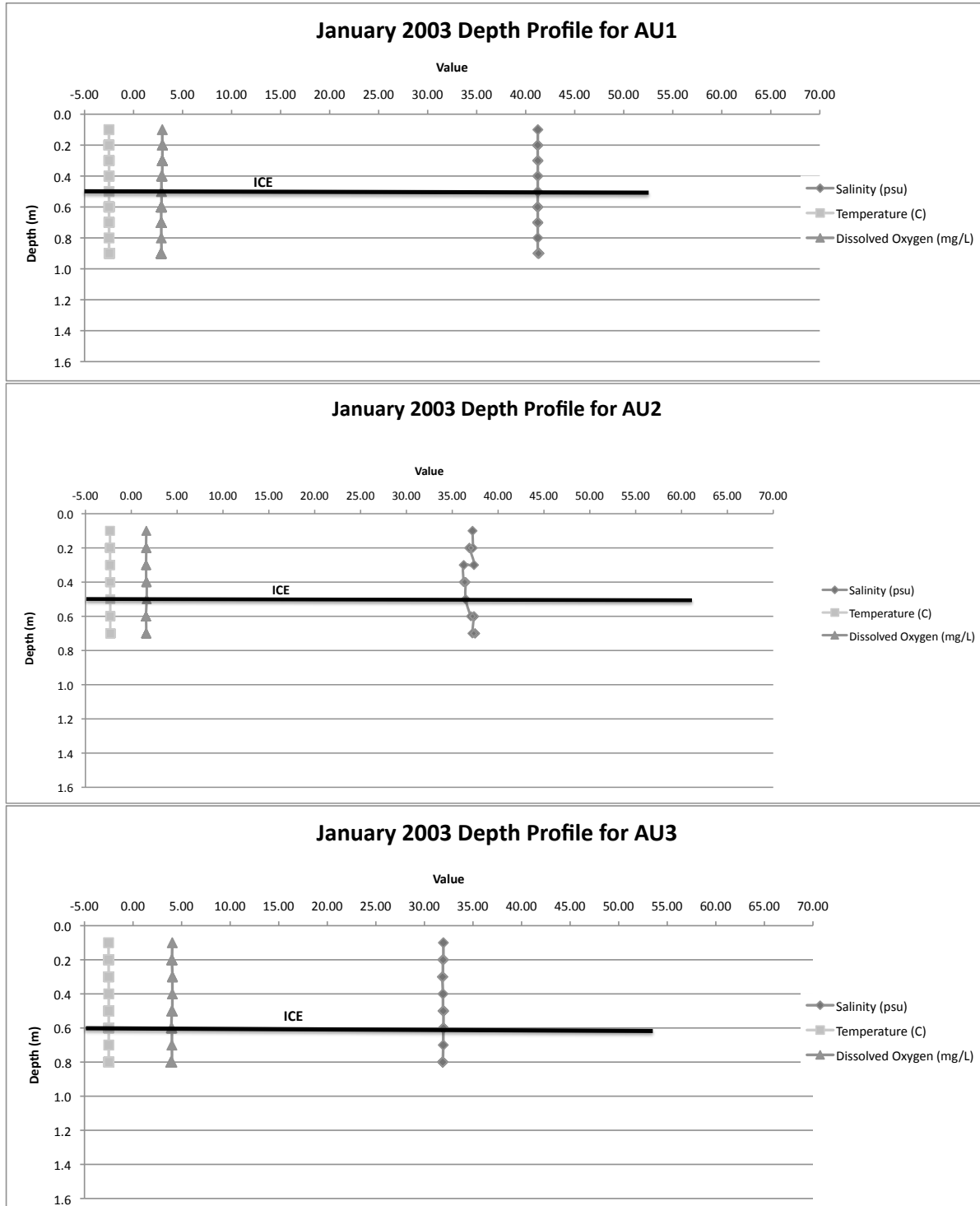
Lagoon	Station	Datum	Latitude (DD.dddd°)	Longitude (DD.dddd°)
Akulaaq	AU1	WGS84	N67.08062	W163.27019
	AU2	WGS84	N67.07390	W163.28689
	AU3	WGS84	N67.06912	W163.26295
	AU4	WGS84	N67.06067	W163.25070
	AU5	WGS84	N67.06284	W163.22788
Imik	IM1	WGS84	N67.49595	W163.93037
	IM2	WGS84	N67.50565	W163.94923
	IM3	WGS84	N67.49394	W163.94923
Kotlik	KO1	WGS84	N67.36555	W163.82050
	KO2	WGS84	N67.39955	W163.82630
	KO3	WGS84	N67.39159	W163.83857
Krusenstern	KR1	WGS84	N67.13077	W163.55505
	KR2	WGS84	N67.14073	W163.61715
	KR3	WGS84	N67.12515	W163.63335
	KR4	WGS84	N67.15778	W163.66188
	KR5	WGS84	N67.16890	W163.72043
	KR6	WGS84	N67.18730	W163.69825
	KR7	WGS84	N67.16928	W163.63843
Sisualik	SI1	WGS84	N67.03225	W162.92774
	SI2	WGS84	N67.02162	W162.91885
	SI3	WGS84	N67.02921	W162.88273
	SI4	WGS84	N67.02032	W162.86495
	SI5	WGS84	N67.01403	W162.81605
	SI6	WGS84	N67.03333	W162.77882

APPENDIX B: DEPTH PROFILES

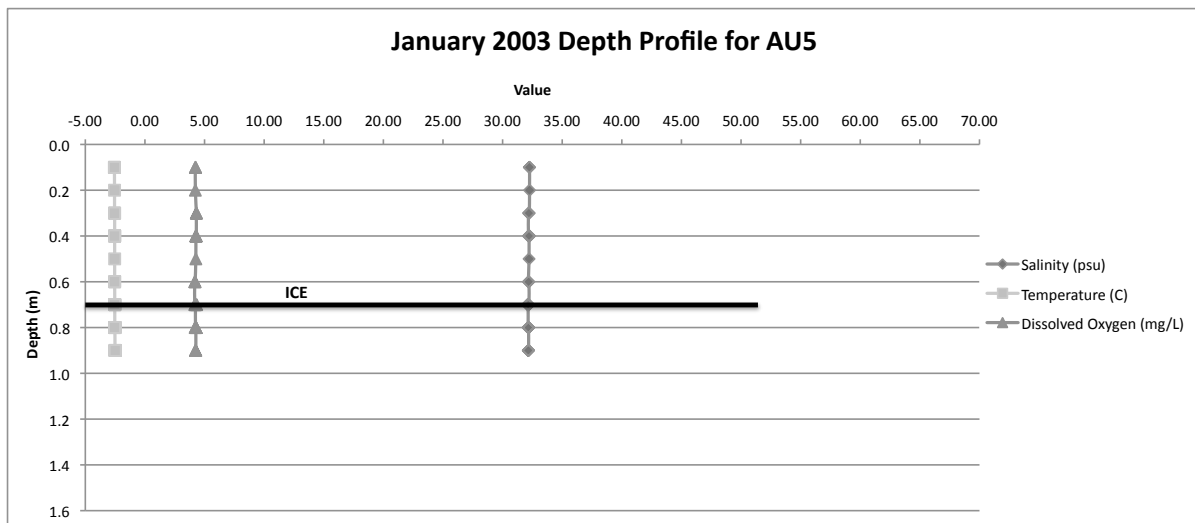
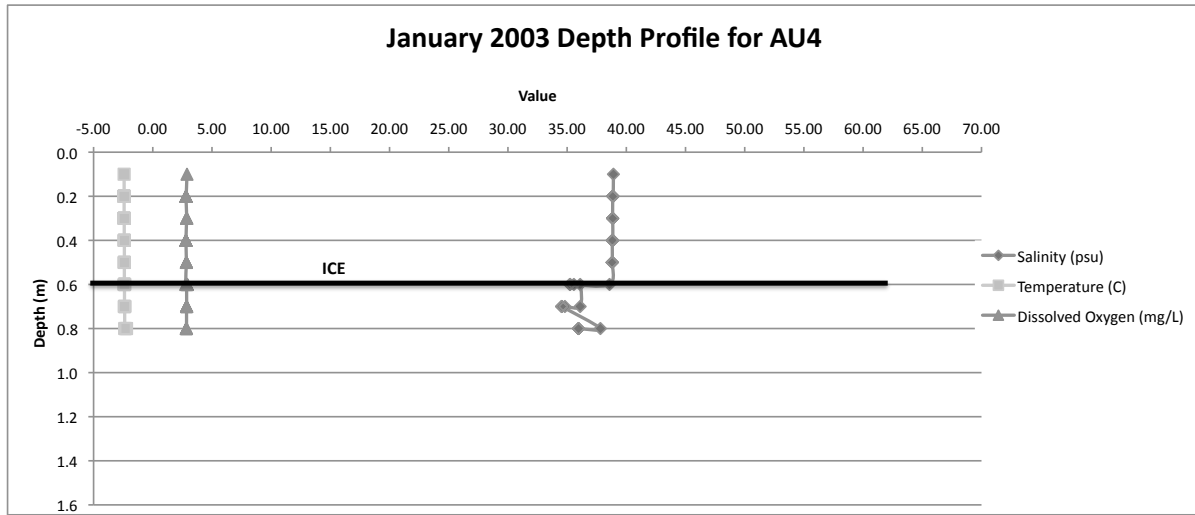
Note – Scales are different for each lagoon during each sampling period

APPENDIX B: DEPTH PROFILES

AKULAAQ – JANUARY 2003

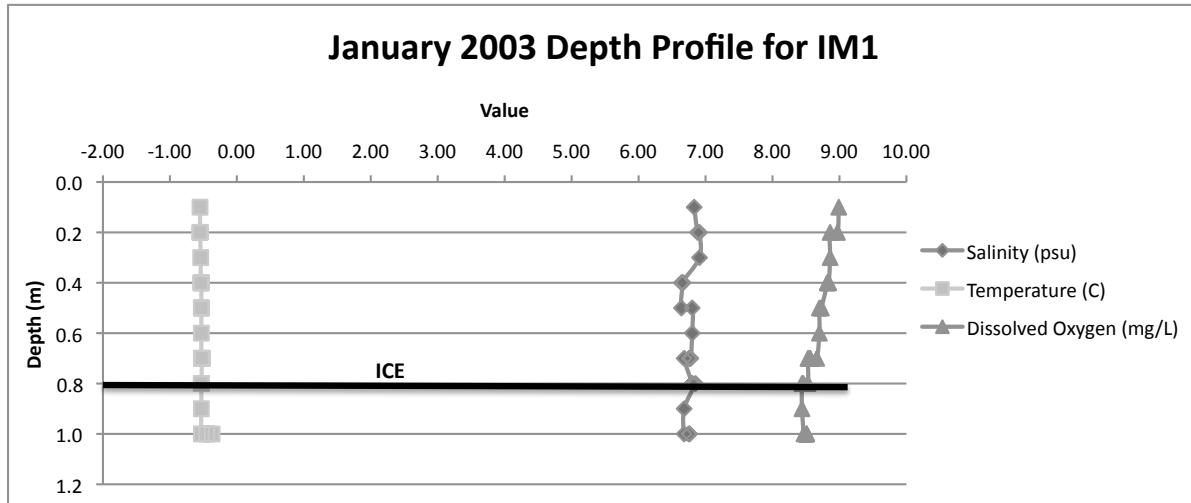


APPENDIX B: DEPTH PROFILES



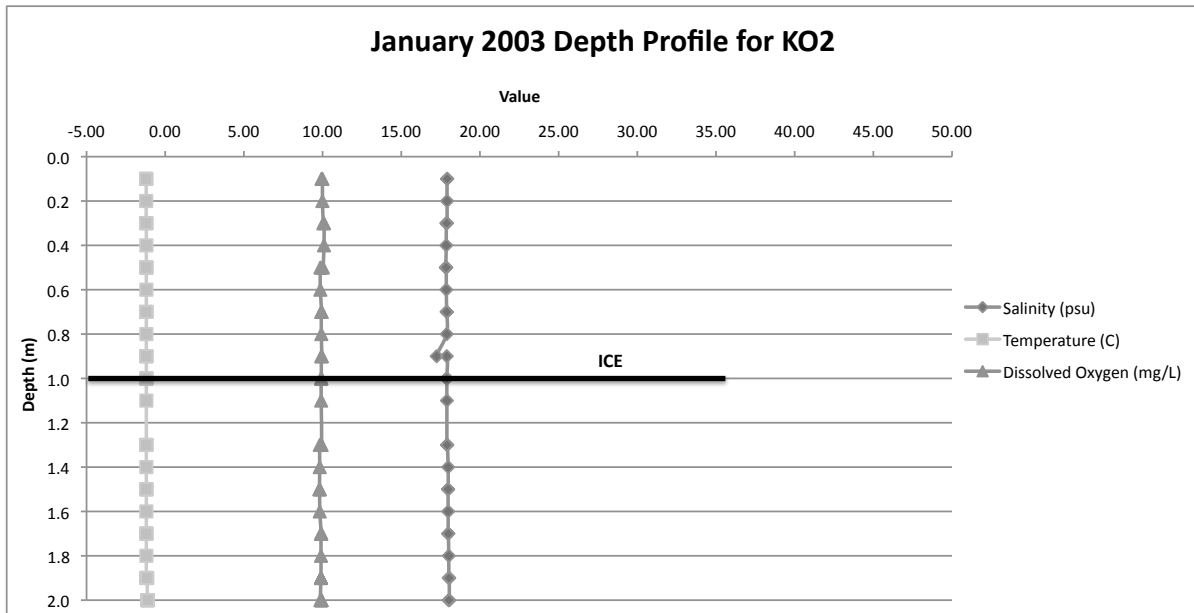
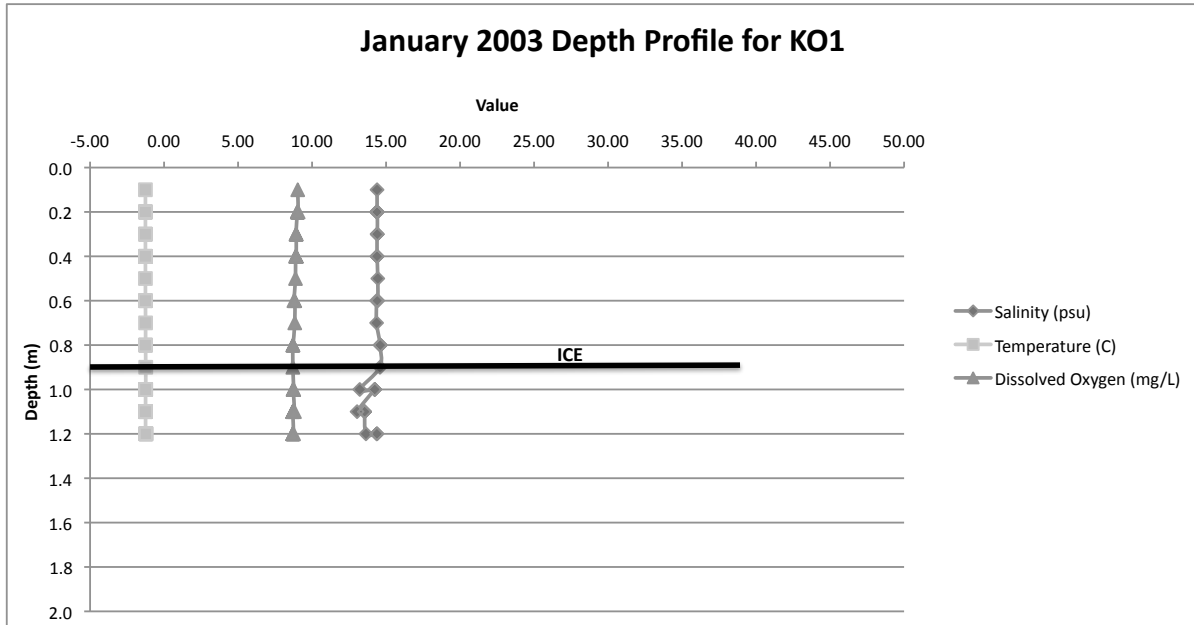
APPENDIX B: DEPTH PROFILES

IMIK – JANUARY 2003



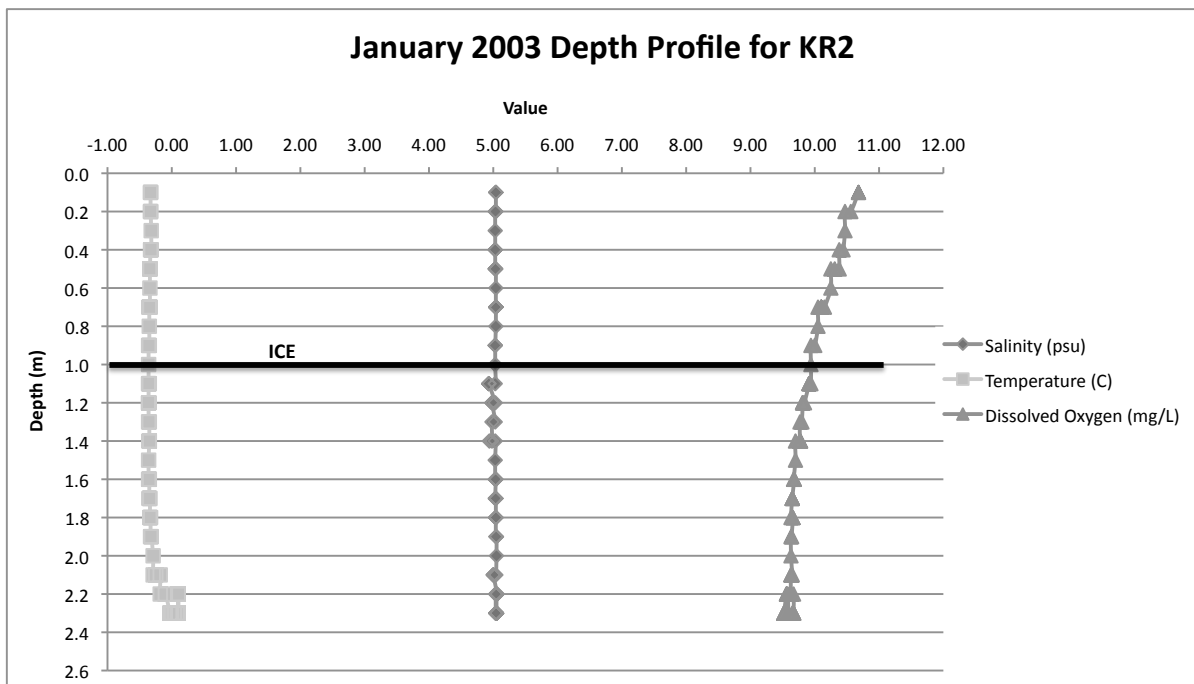
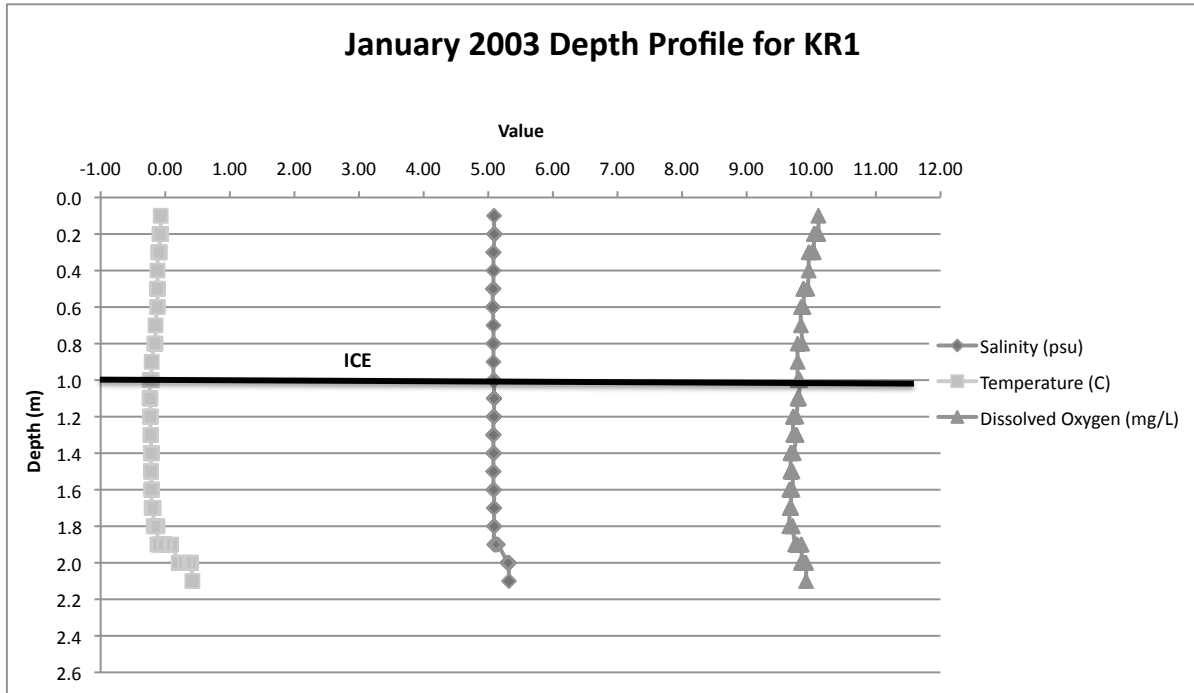
APPENDIX B: DEPTH PROFILES

KOTLIK – JANUARY 2003

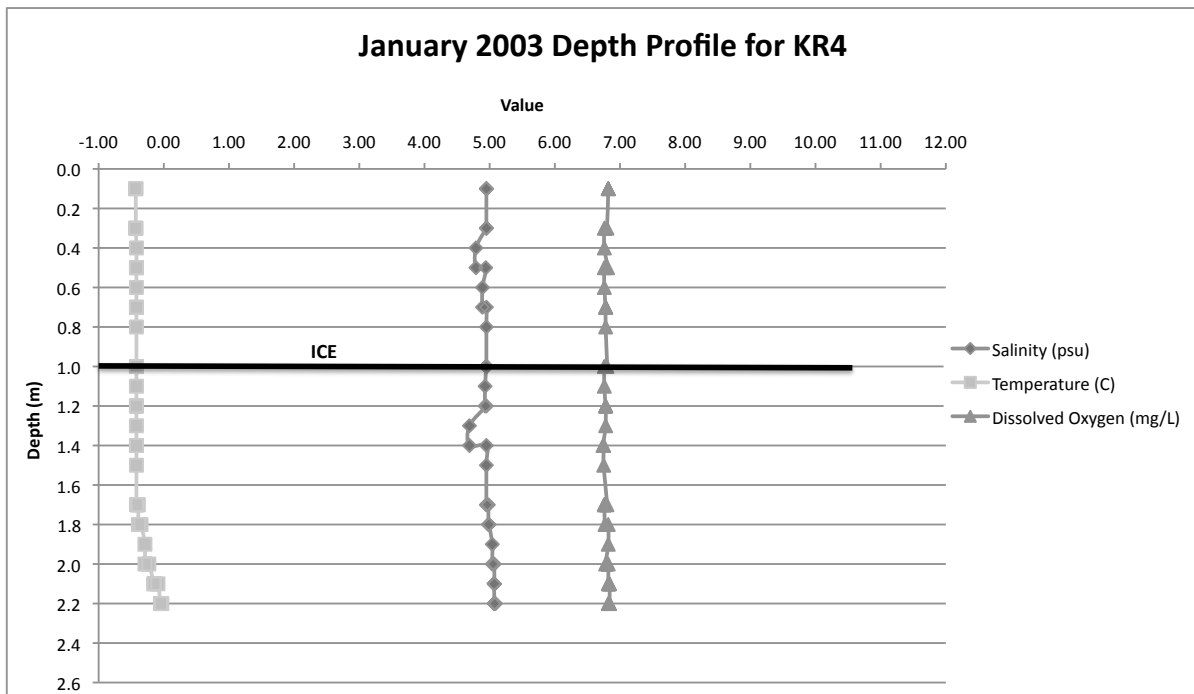
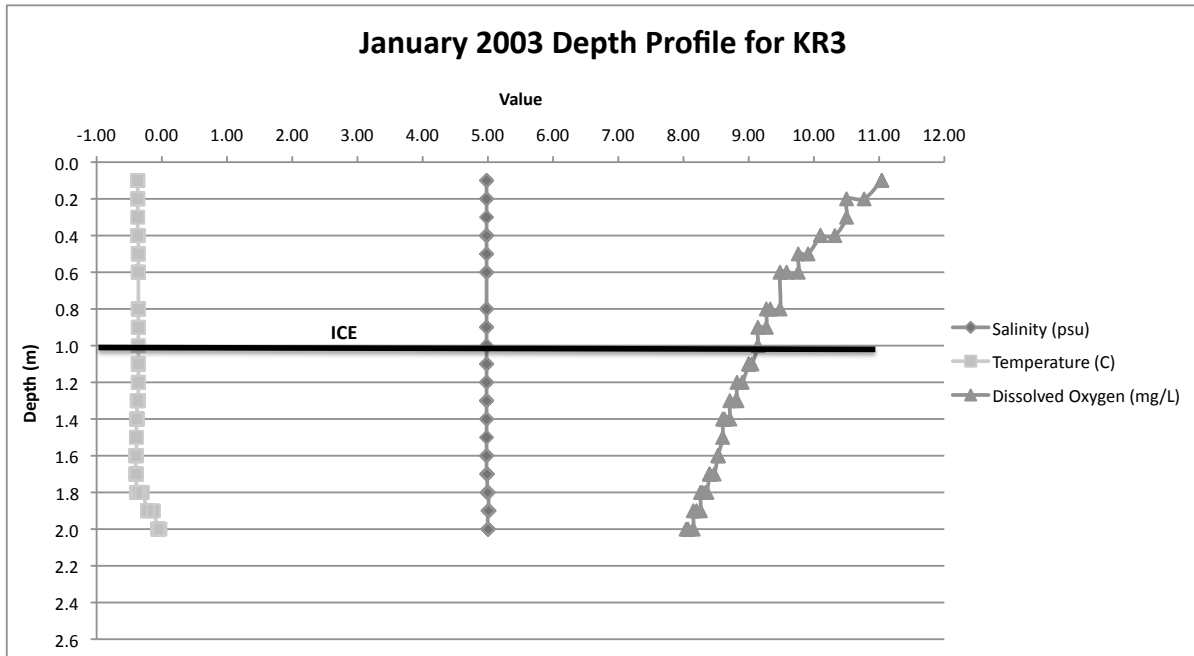


APPENDIX B: DEPTH PROFILES

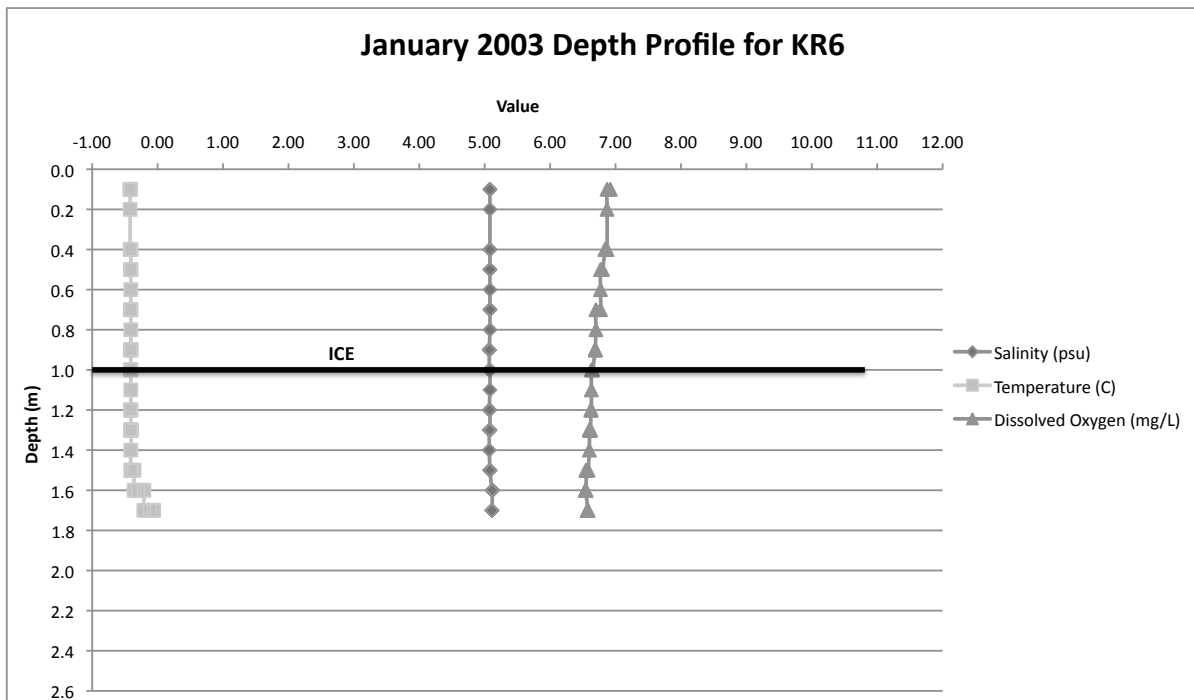
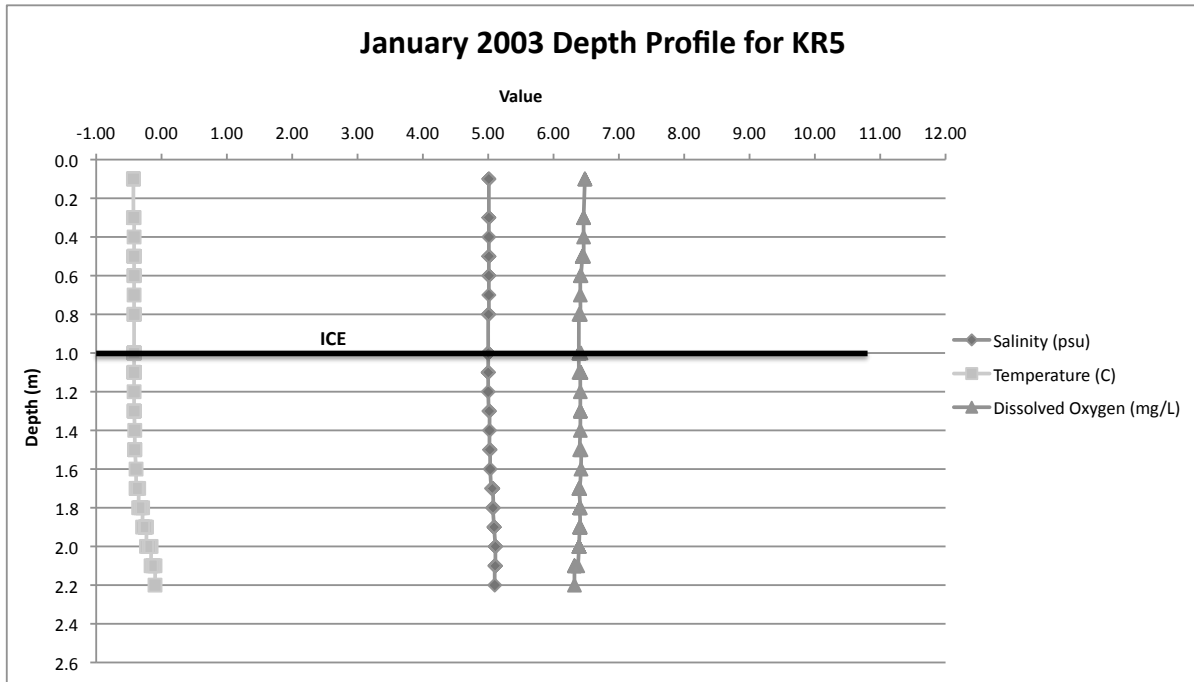
KRUSENSTERN – JANUARY 2003



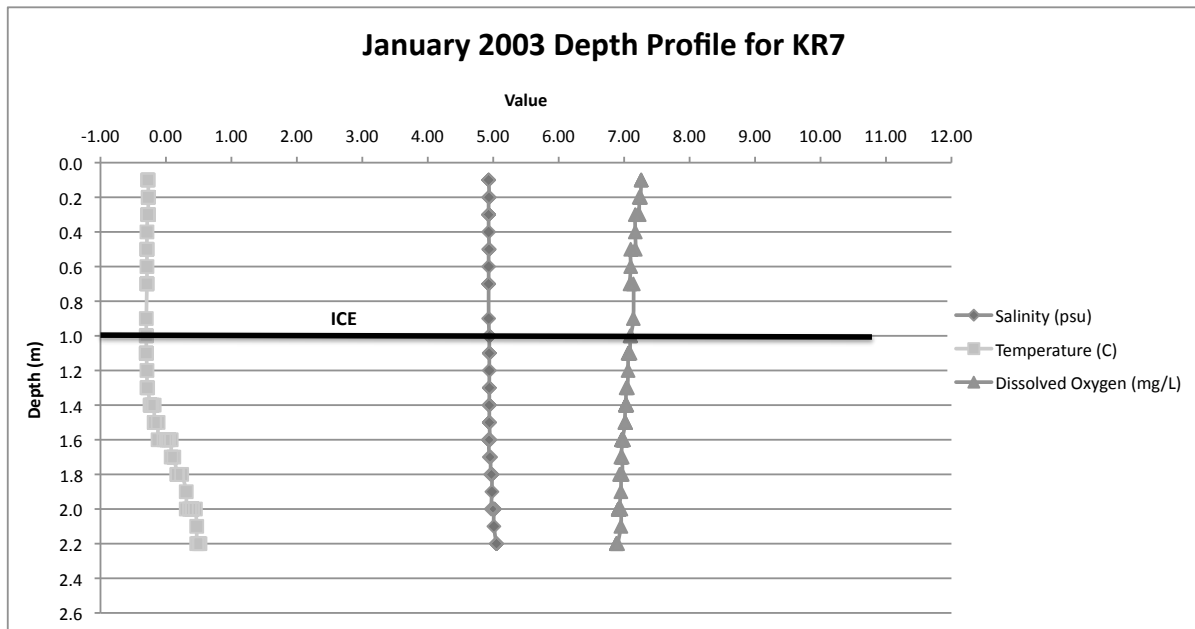
APPENDIX B: DEPTH PROFILES



APPENDIX B: DEPTH PROFILES

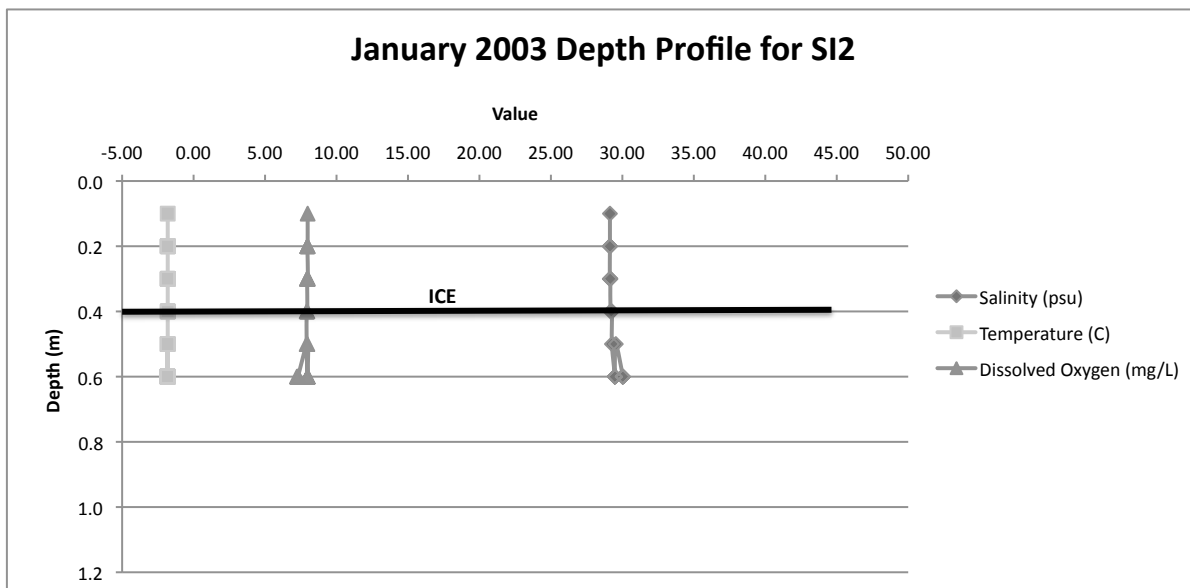
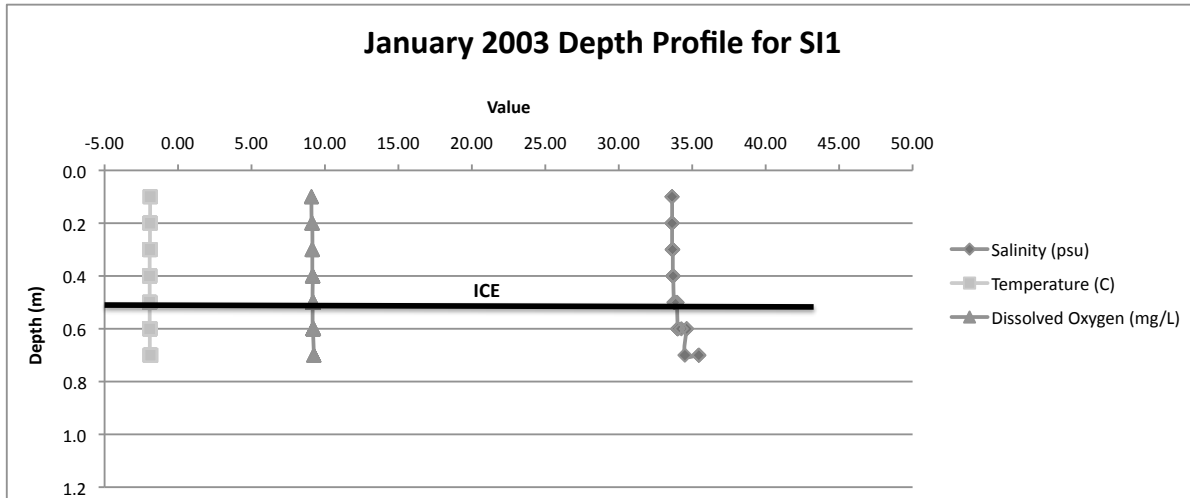


APPENDIX B: DEPTH PROFILES

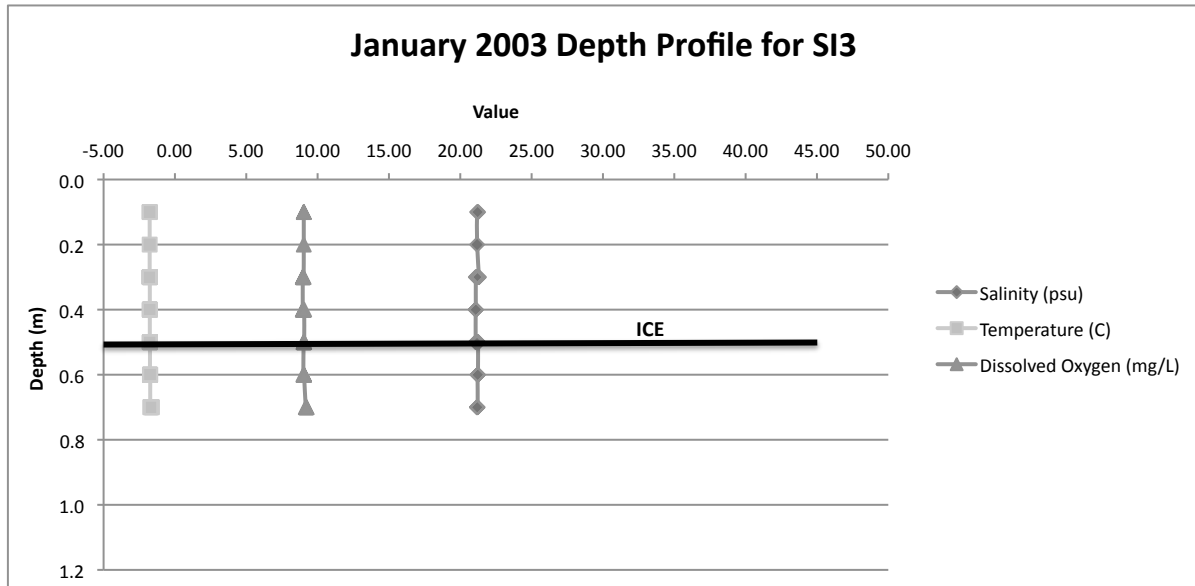


APPENDIX B: DEPTH PROFILES

SISUALIK – JANUARY 2003

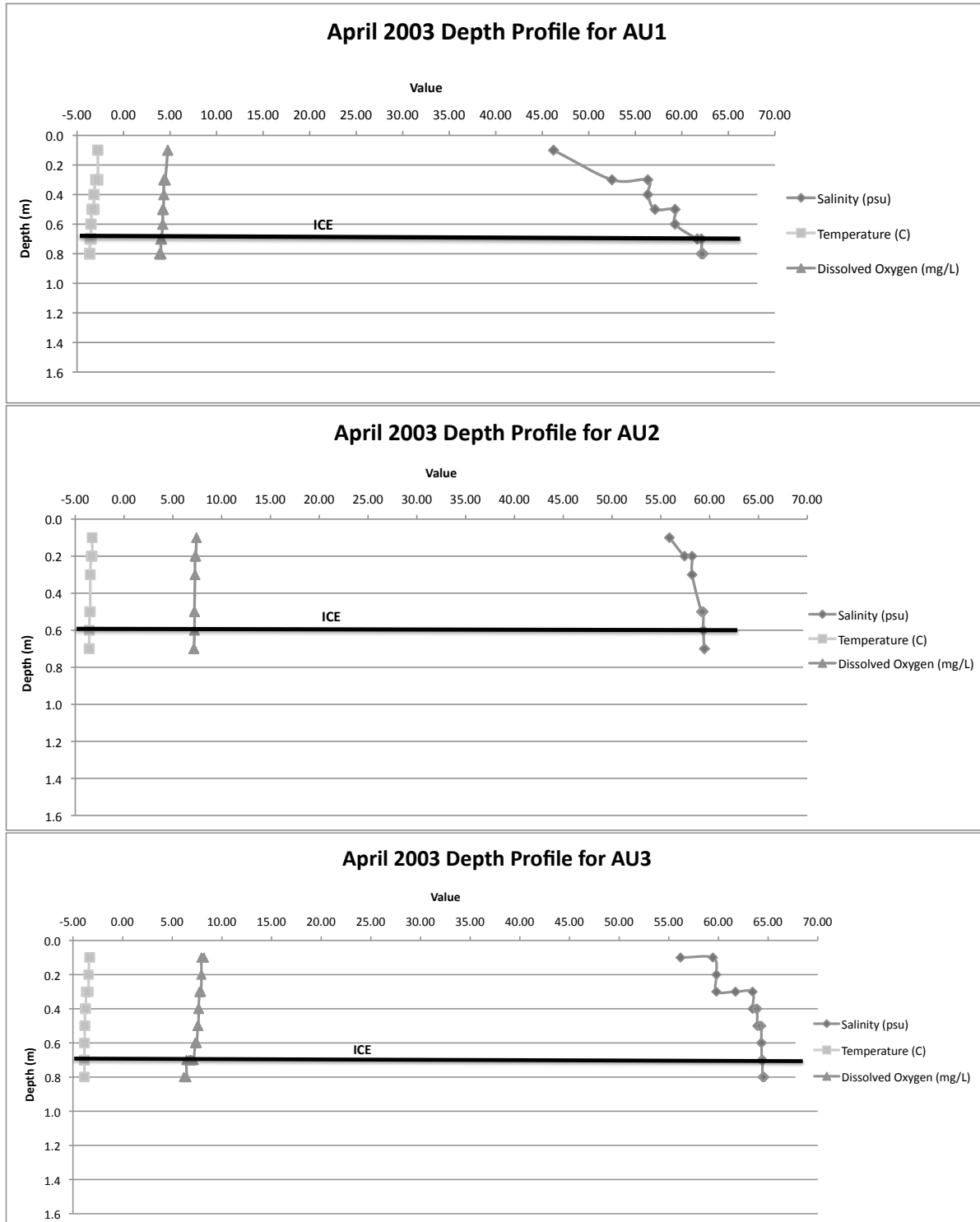


APPENDIX B: DEPTH PROFILES

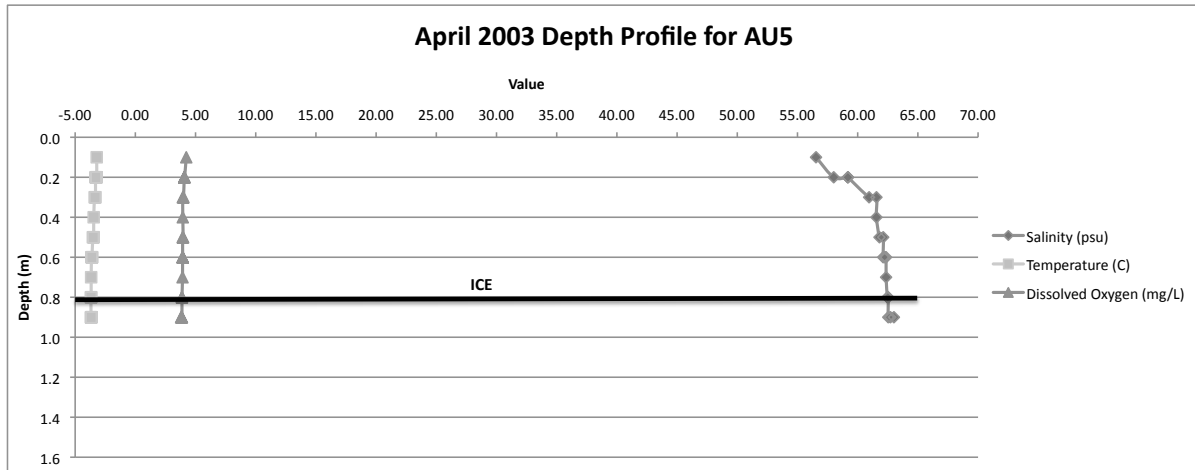
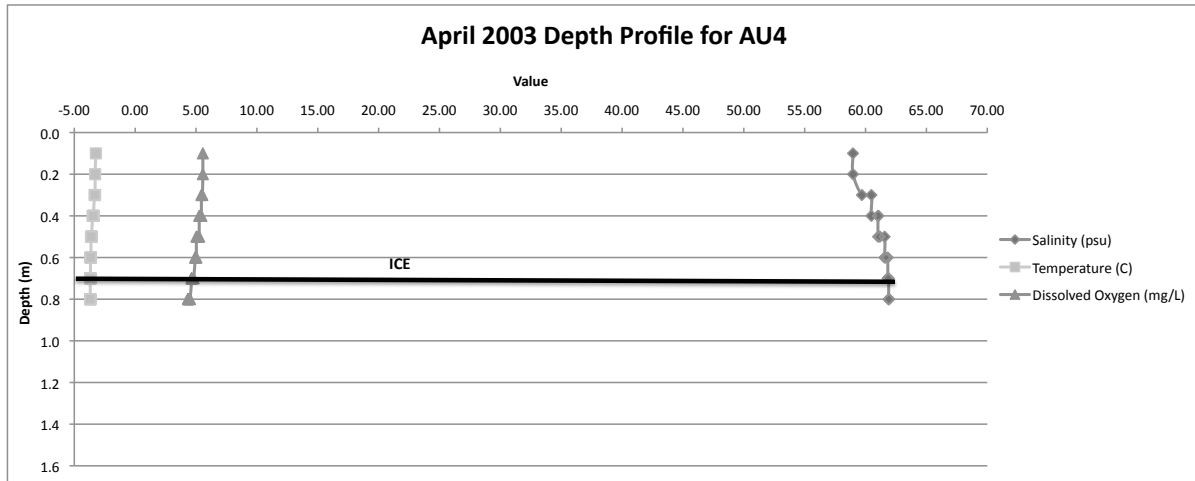


APPENDIX B: DEPTH PROFILES

Akulaaq – April 2003

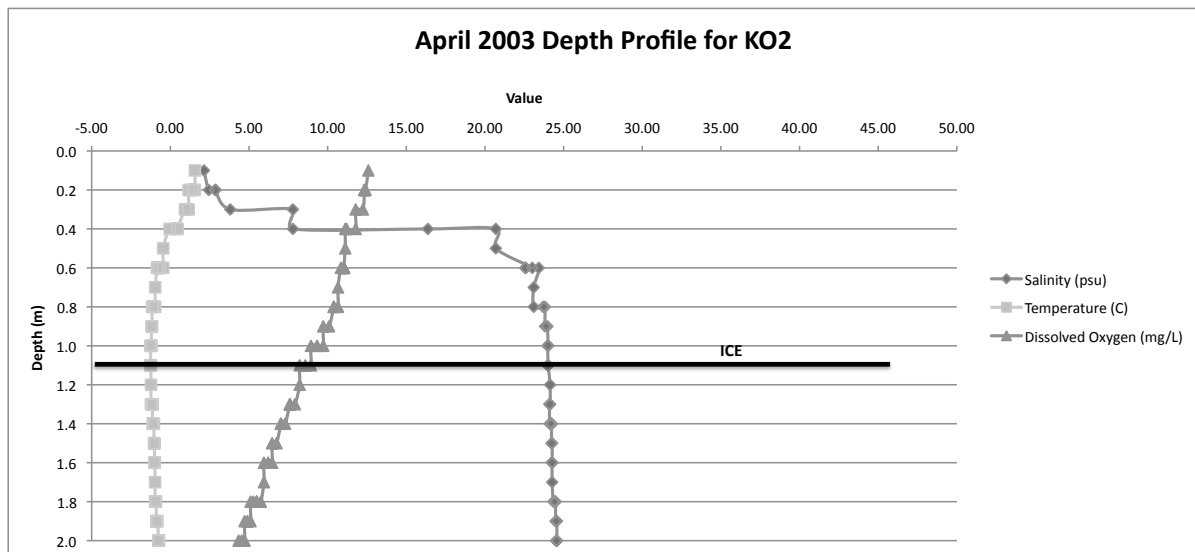
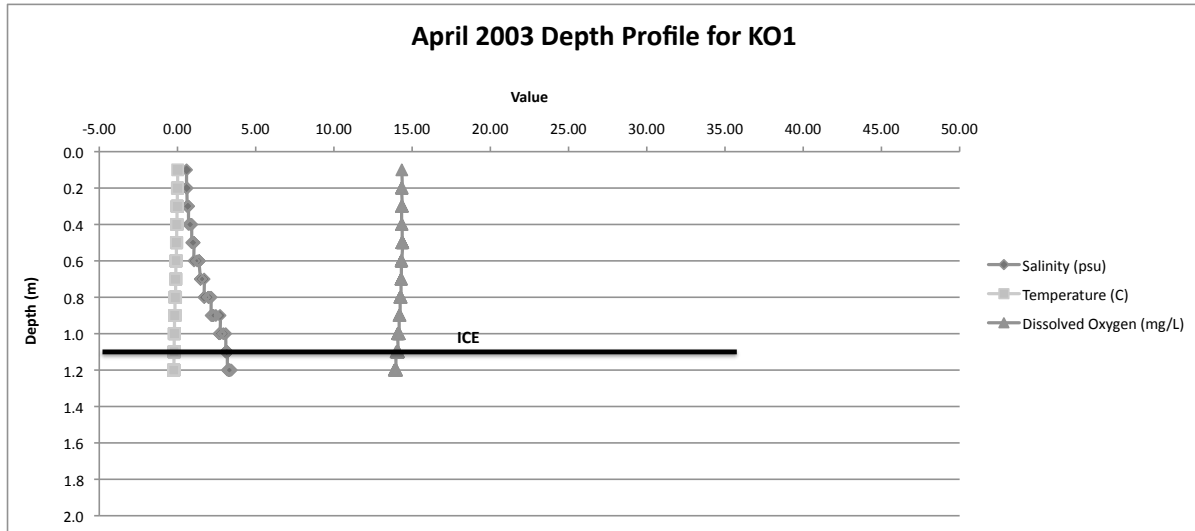


APPENDIX B: DEPTH PROFILES

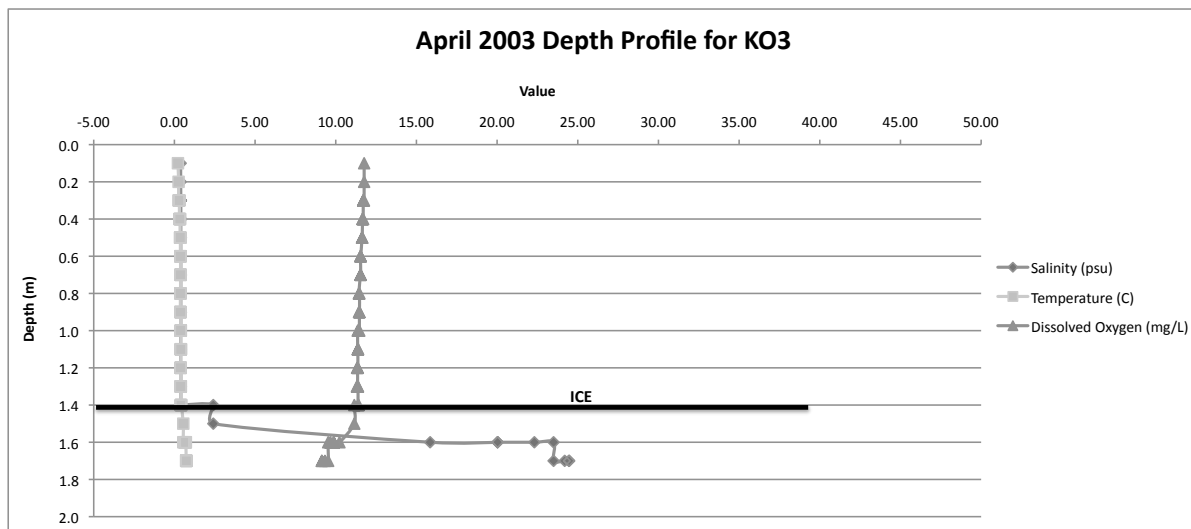


APPENDIX B: DEPTH PROFILES

Kotlik – April 2003

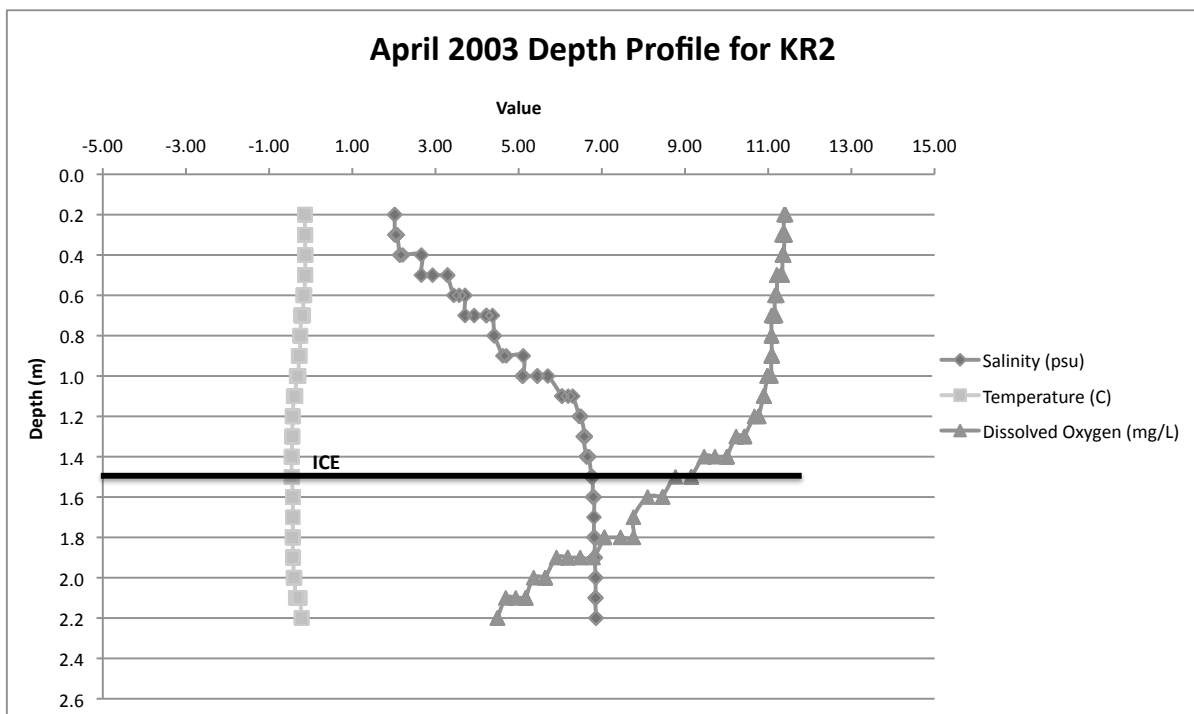
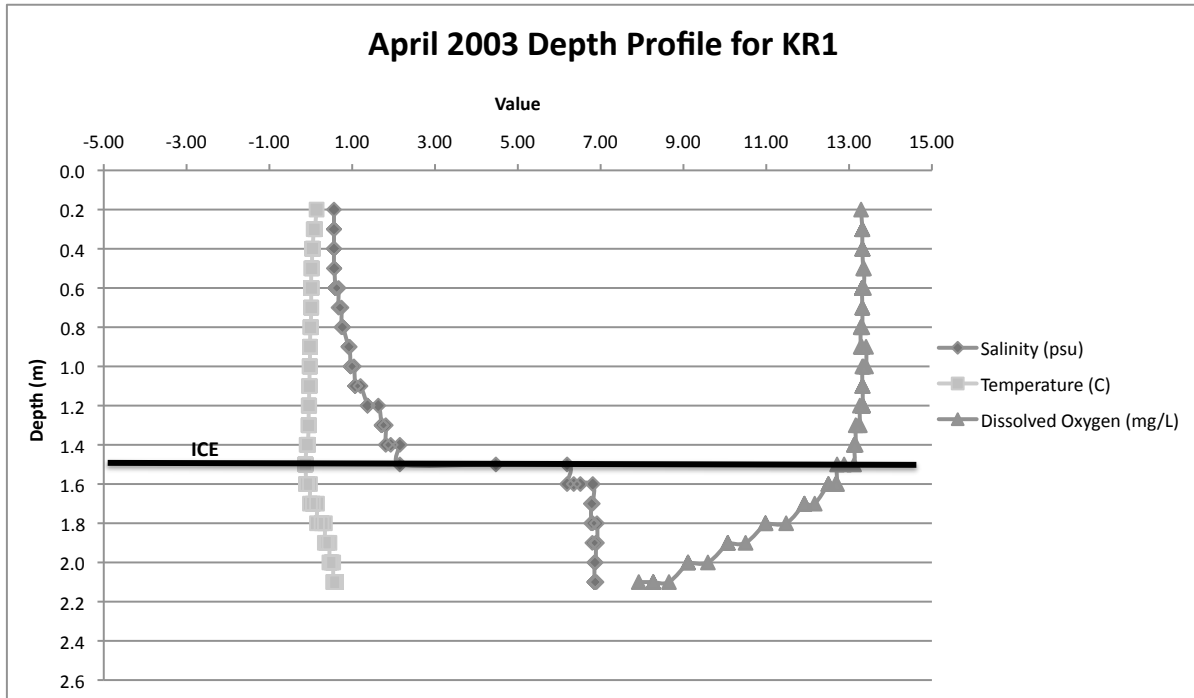


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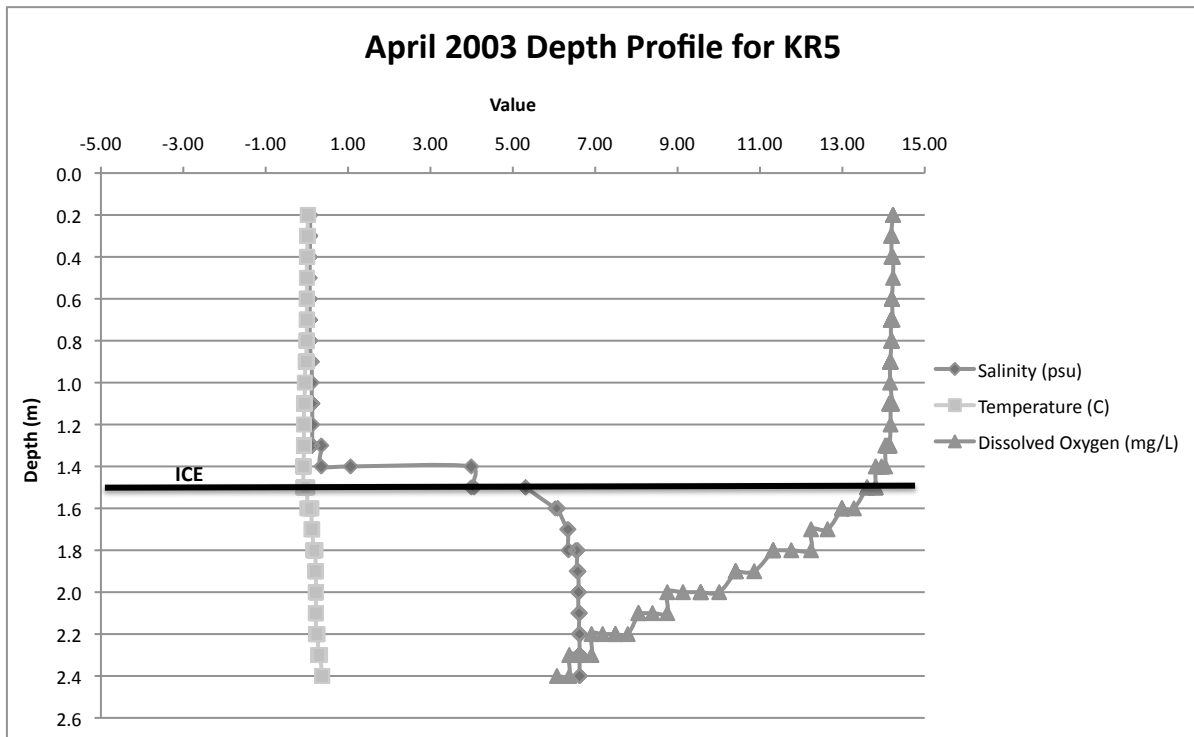
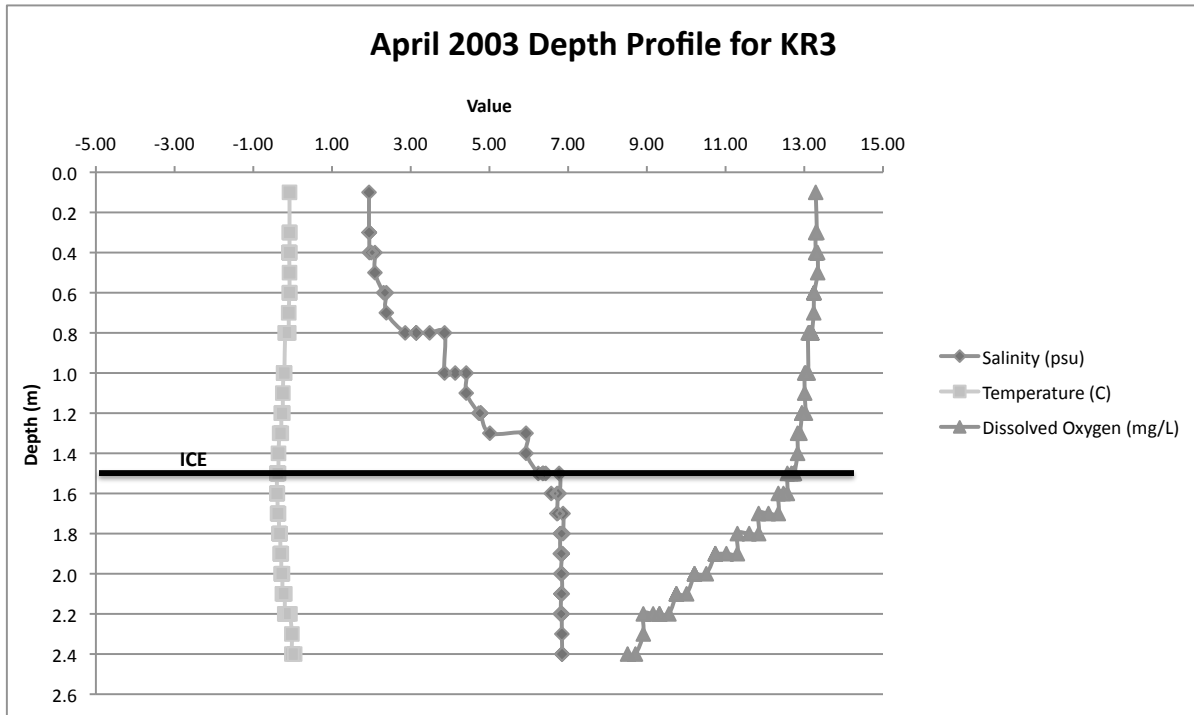


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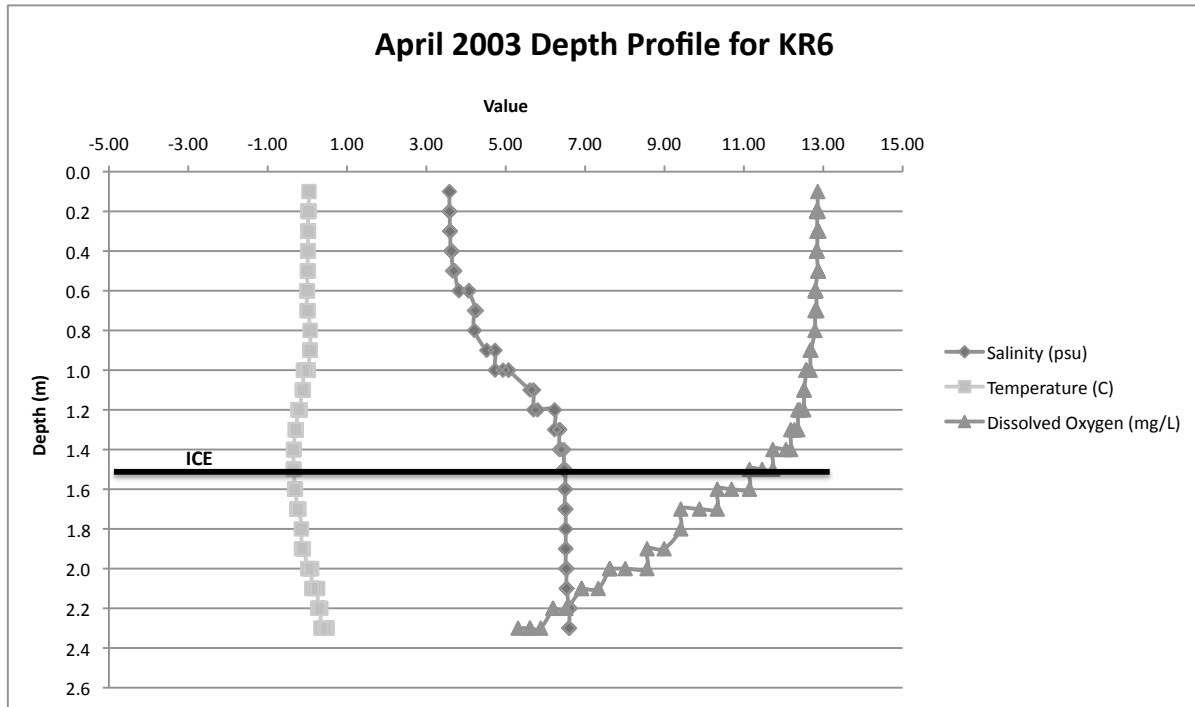
Krusenstern – April 2003



APPENDIX B: DEPTH PROFILES

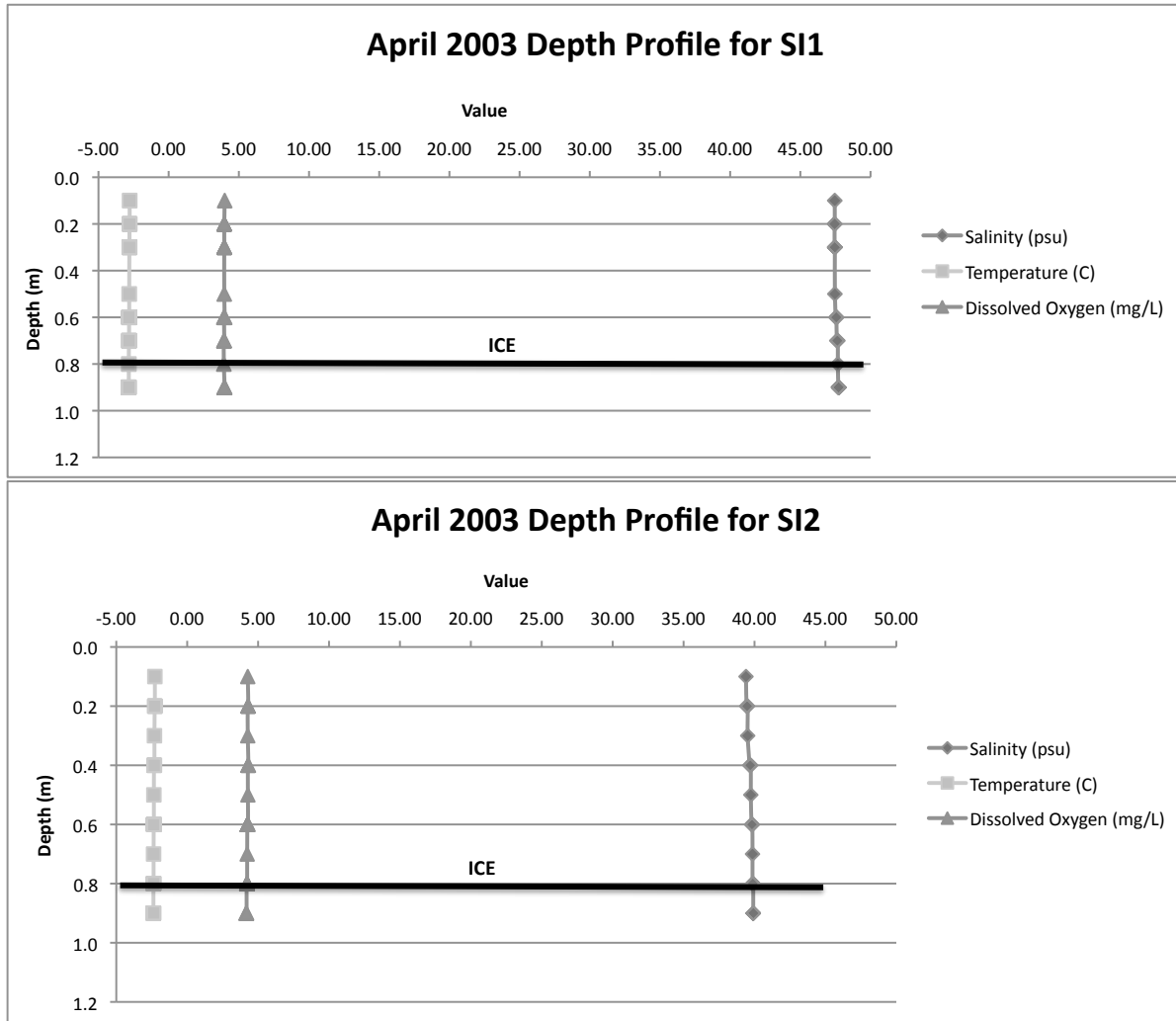


APPENDIX B: DEPTH PROFILES

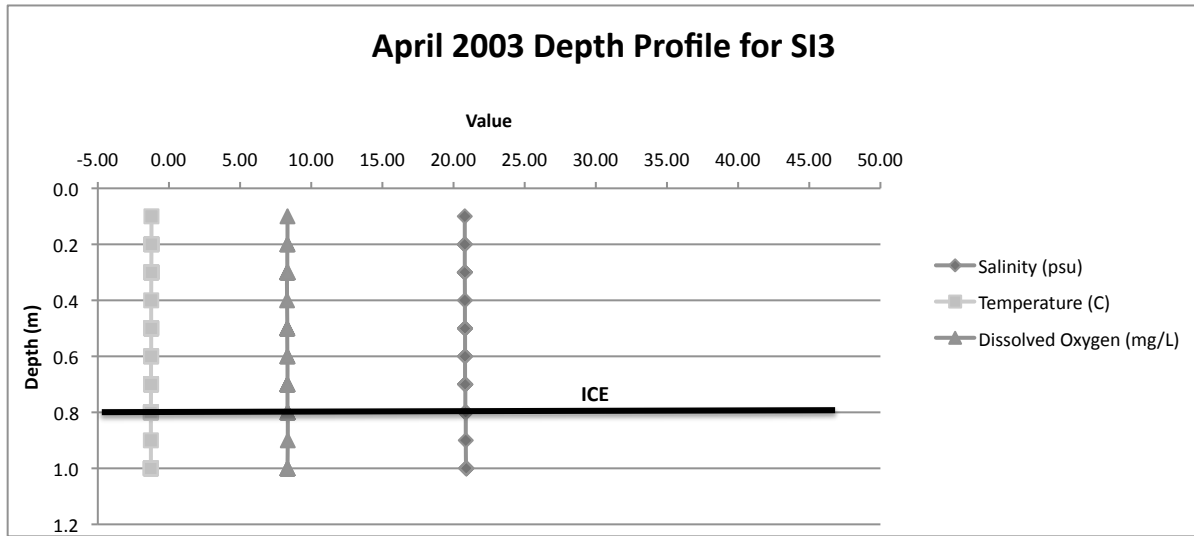


APPENDIX B: DEPTH PROFILES

Sisualik – April 2003

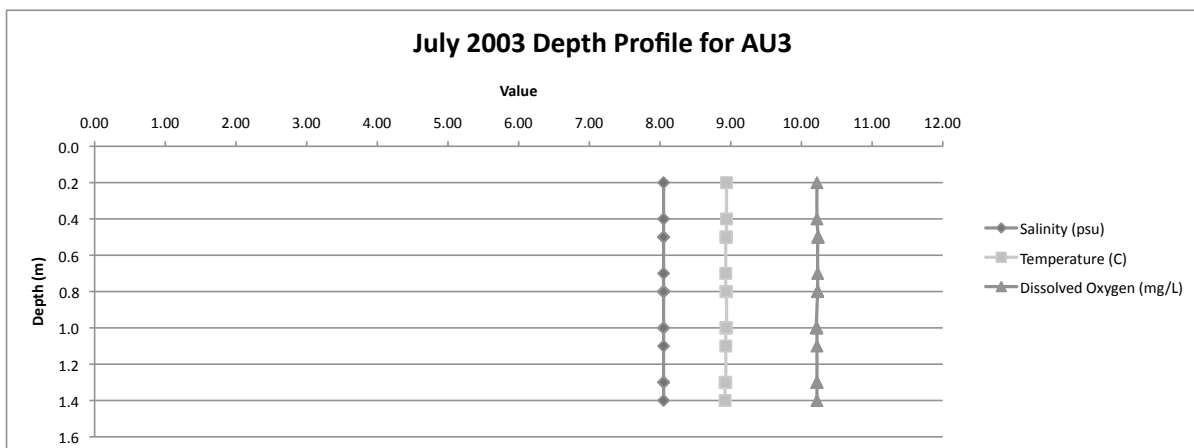
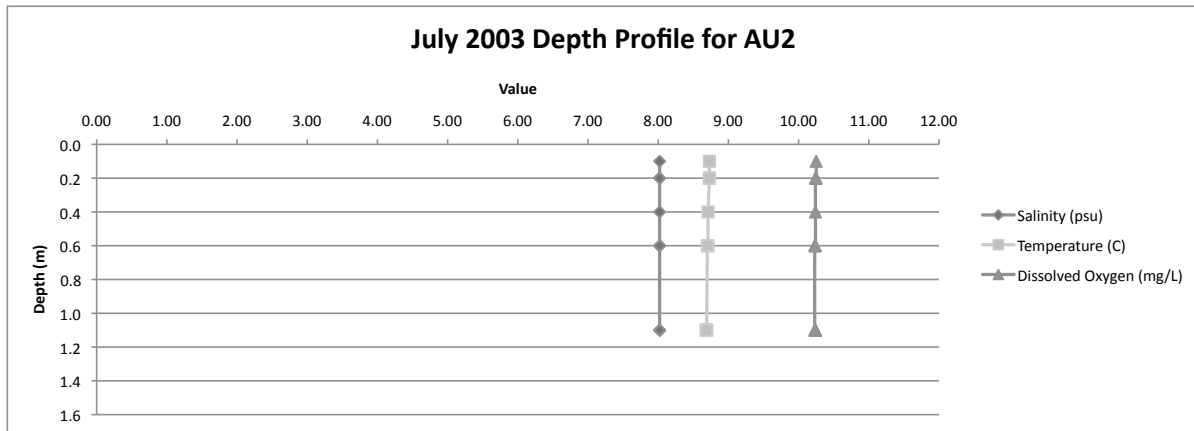
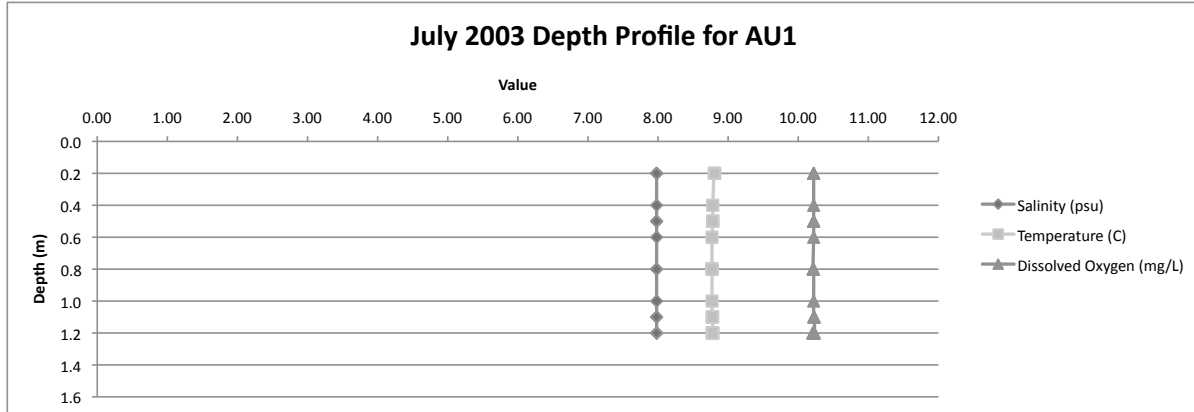


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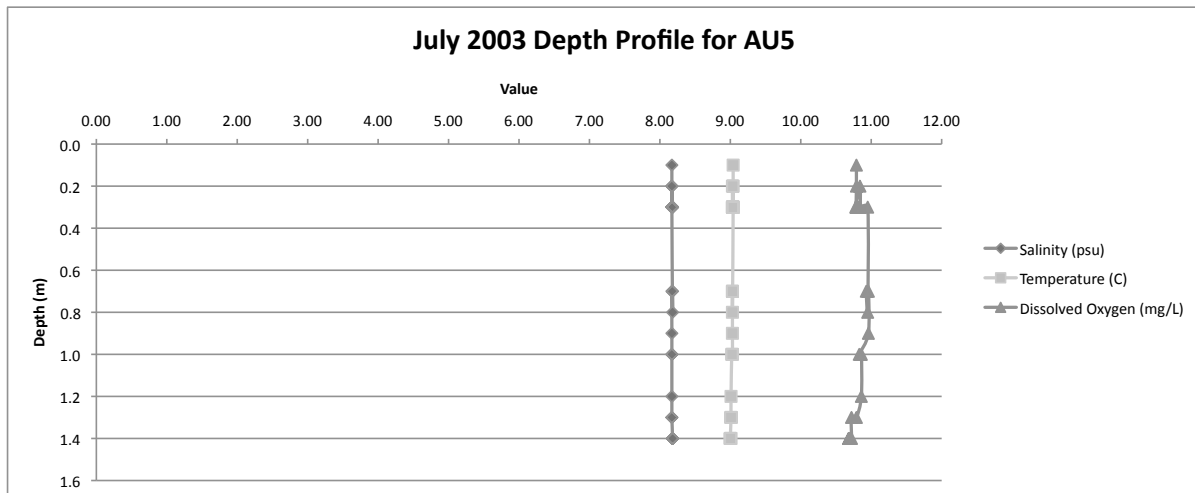
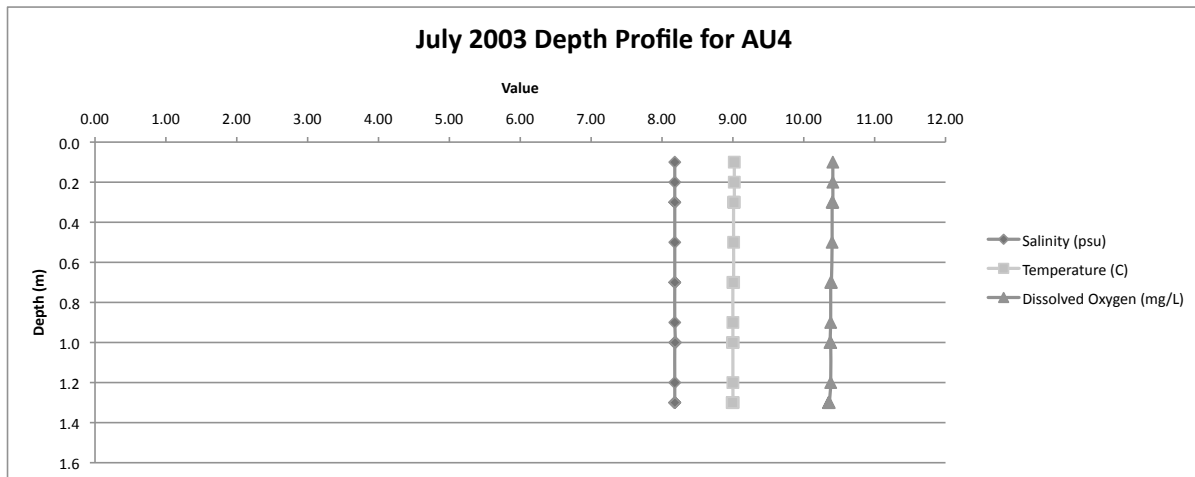


APPENDIX B: DEPTH PROFILES

Akulaaq – July 2003

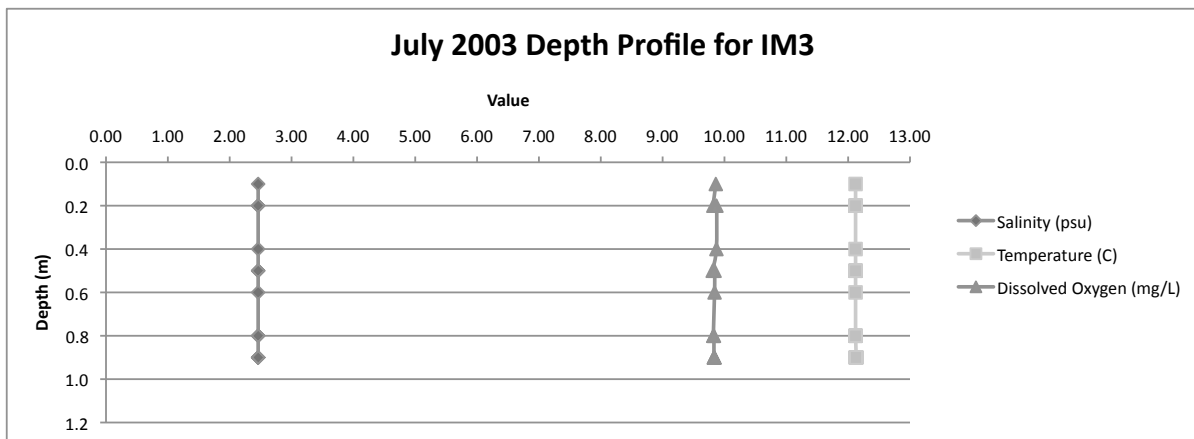
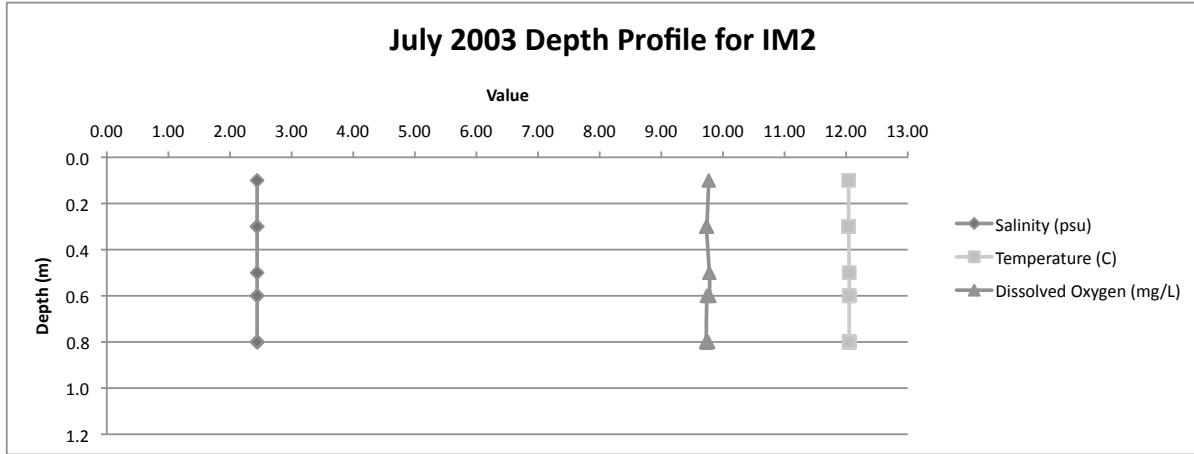


APPENDIX B: DEPTH PROFILES



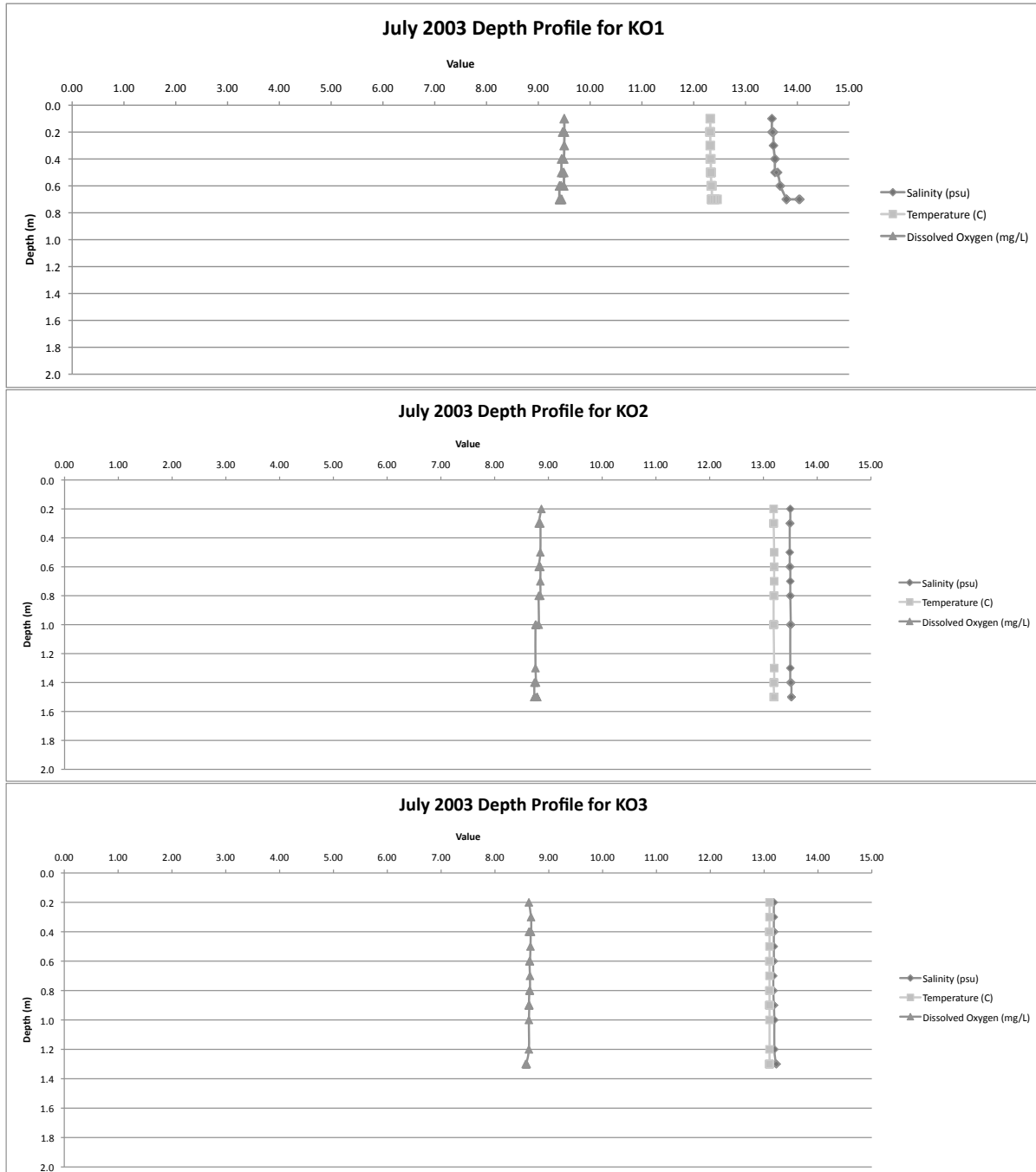
APPENDIX B: DEPTH PROFILES

Imik – July 2003



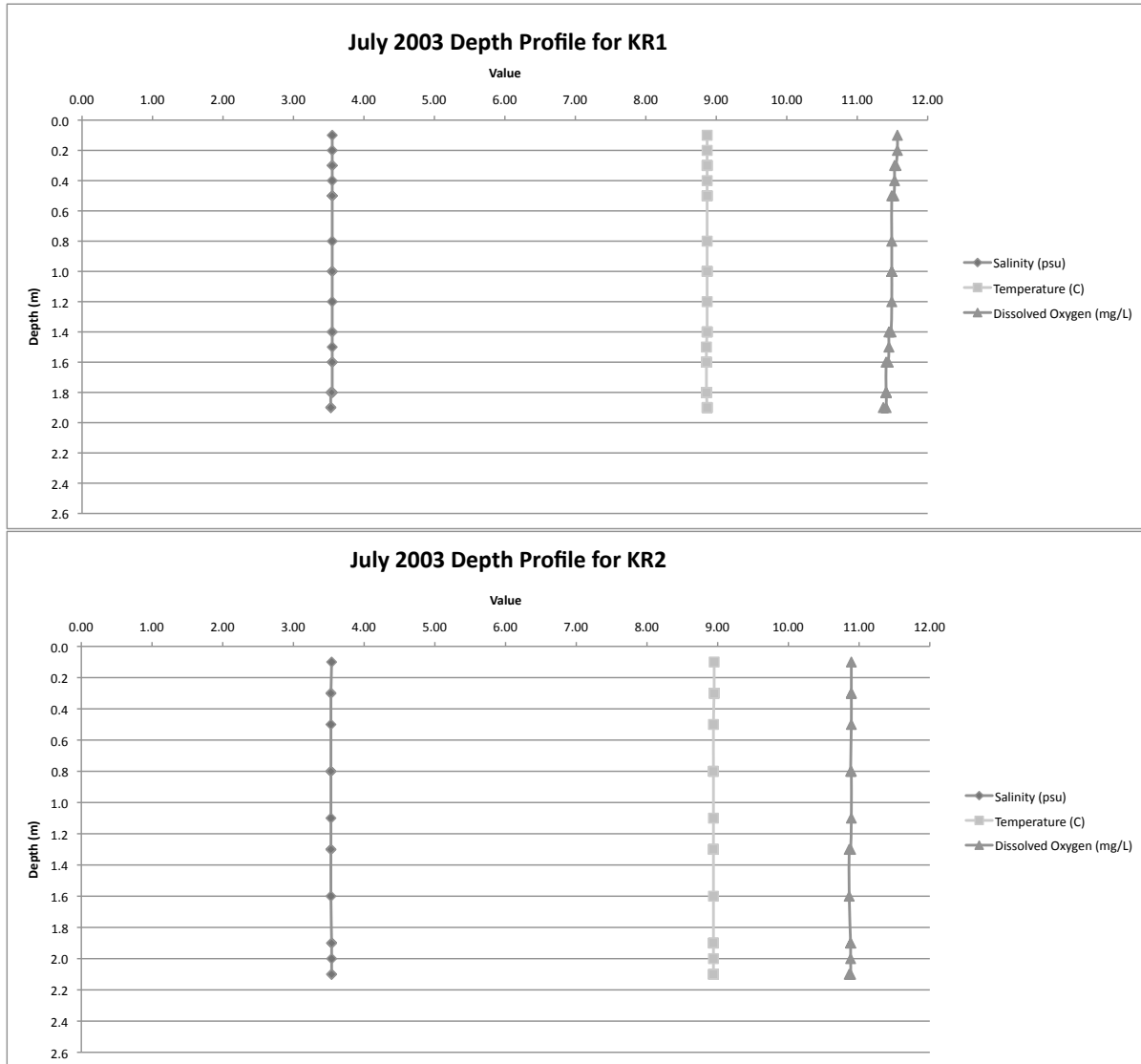
APPENDIX B: DEPTH PROFILES

Kotlik – July 2003



APPENDIX B: DEPTH PROFILES

Krusenstern – July 2003



APPENDIX B: DEPTH PROFILES

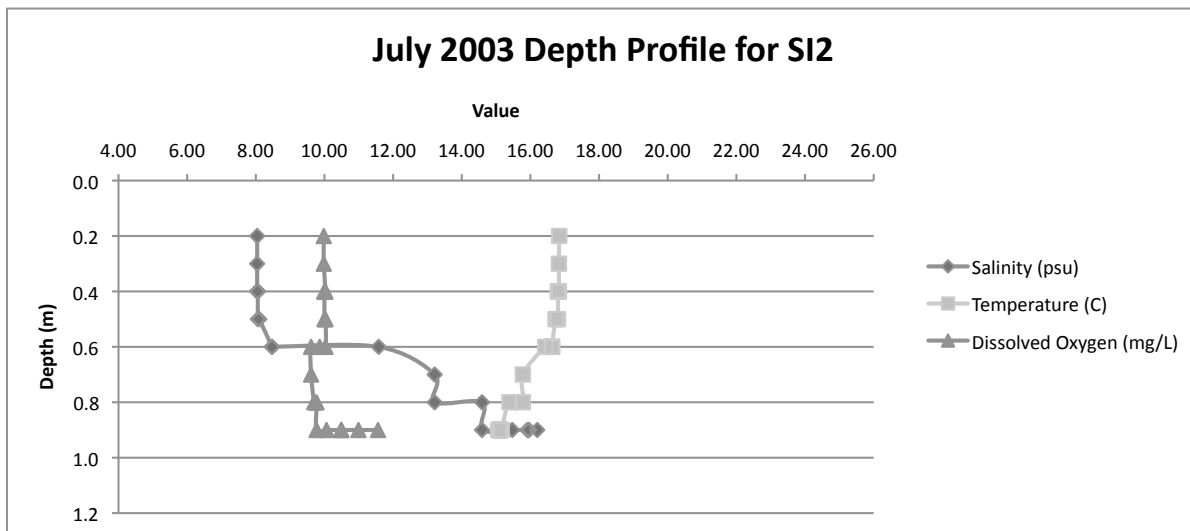
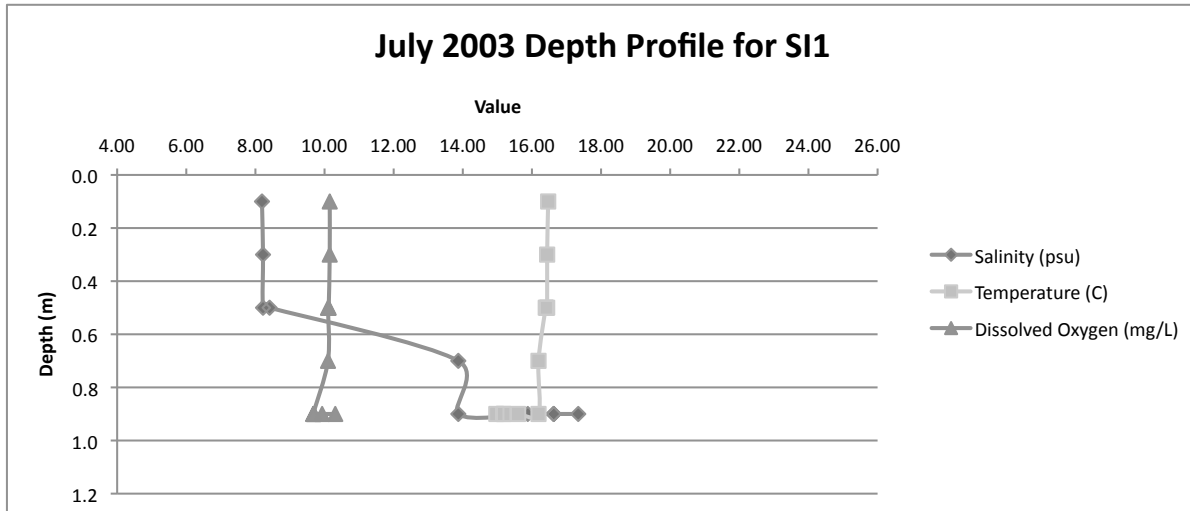


APPENDIX B: DEPTH PROFILES



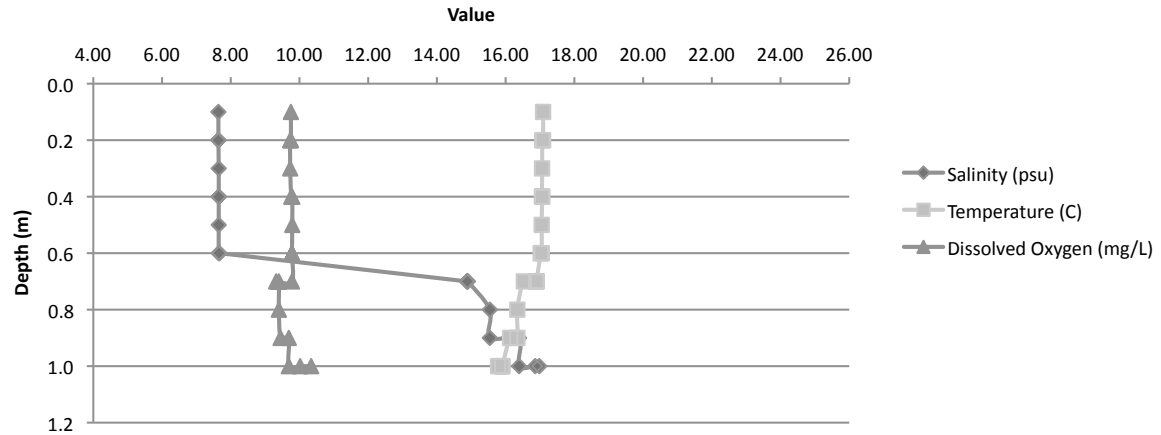
APPENDIX B: DEPTH PROFILES

Sisualik – July 2003

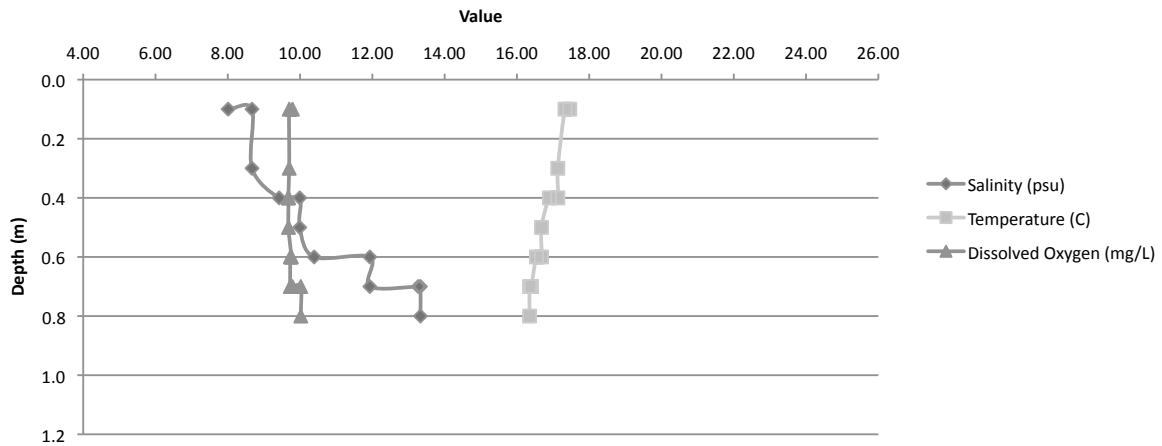


APPENDIX B: DEPTH PROFILES

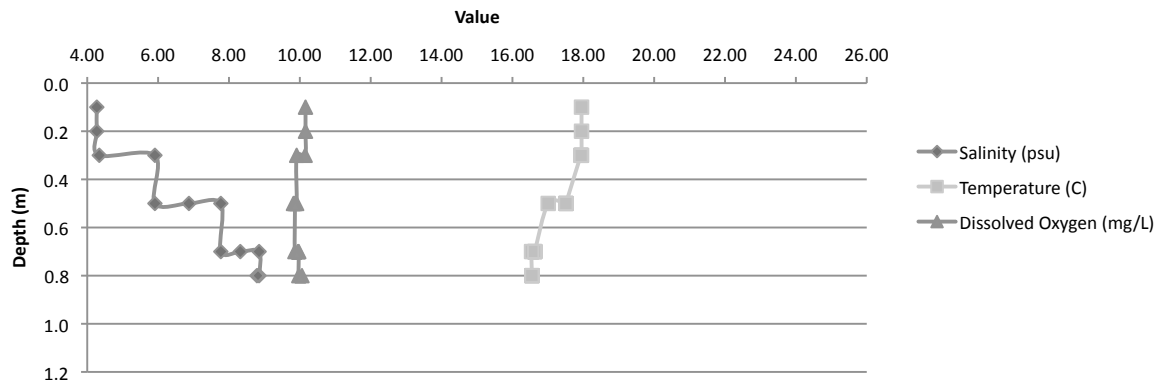
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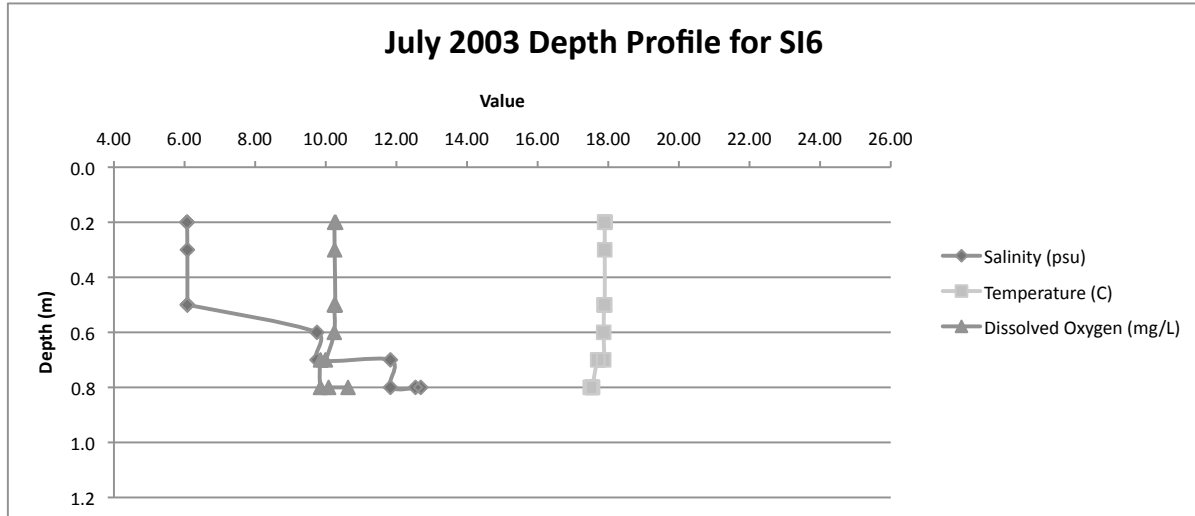
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July 2003 Depth Profile for SI5

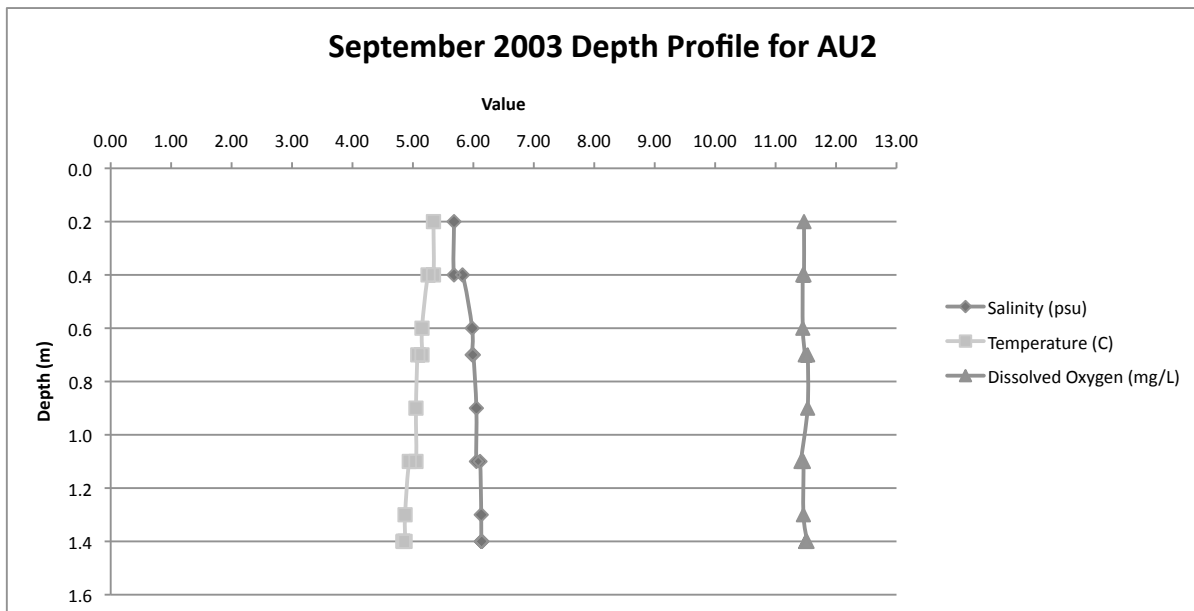
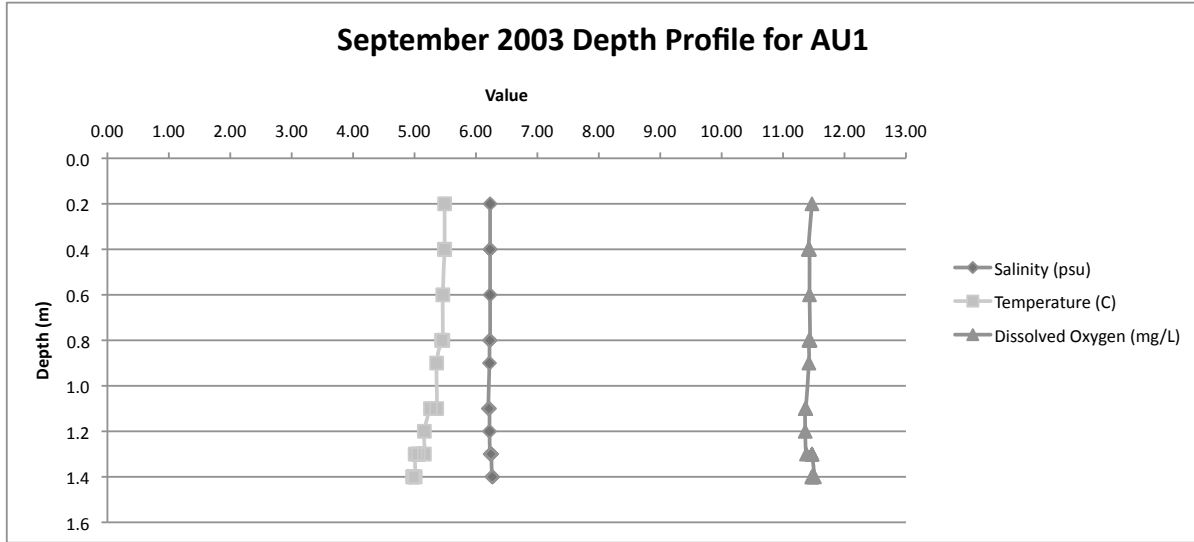


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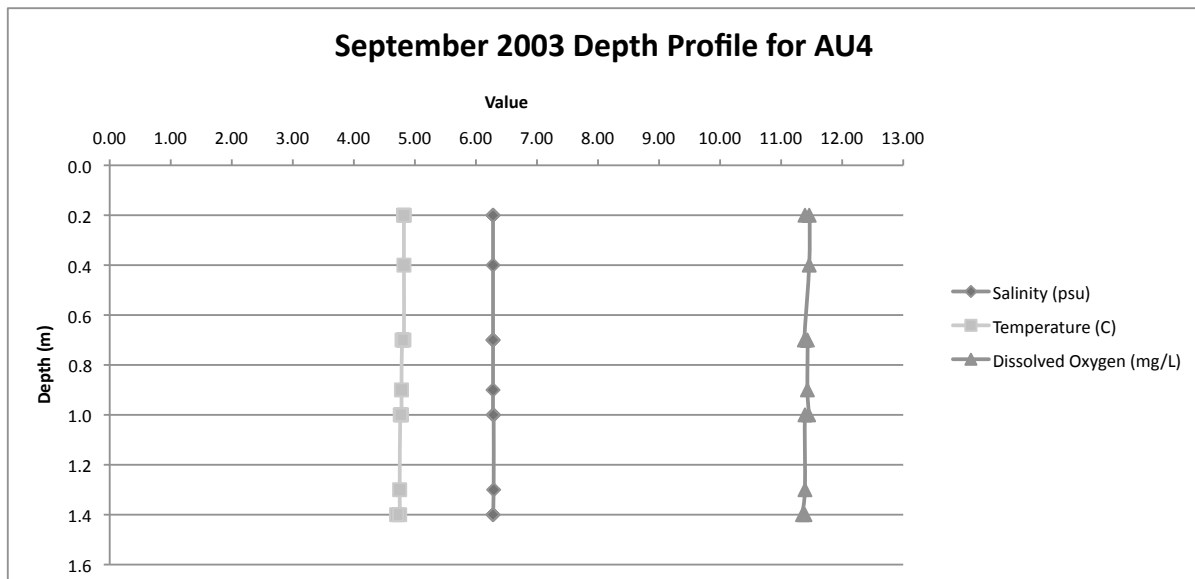
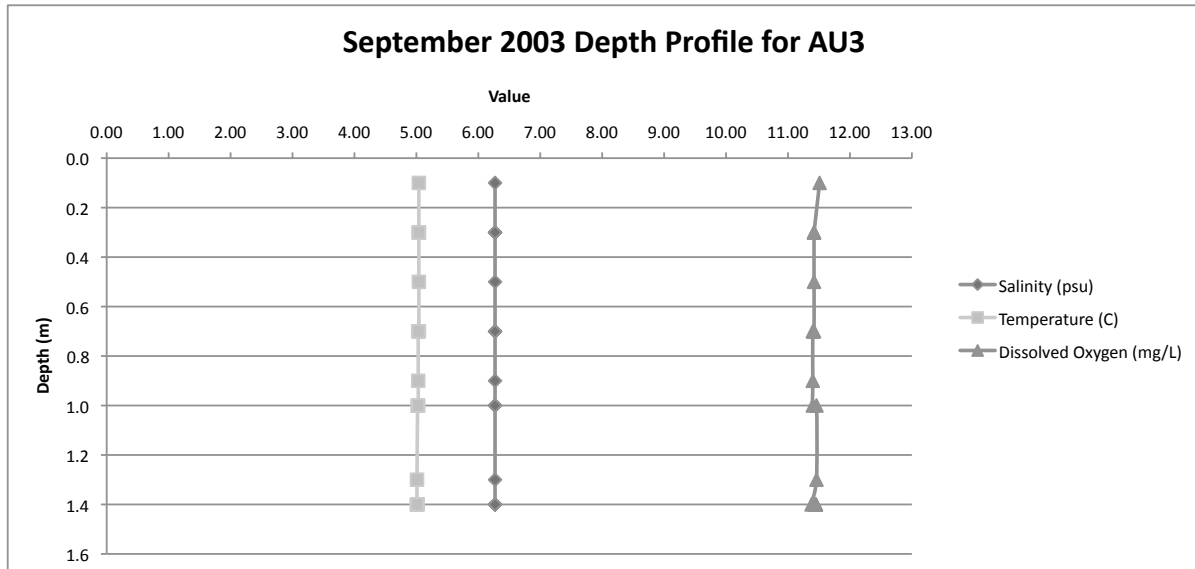


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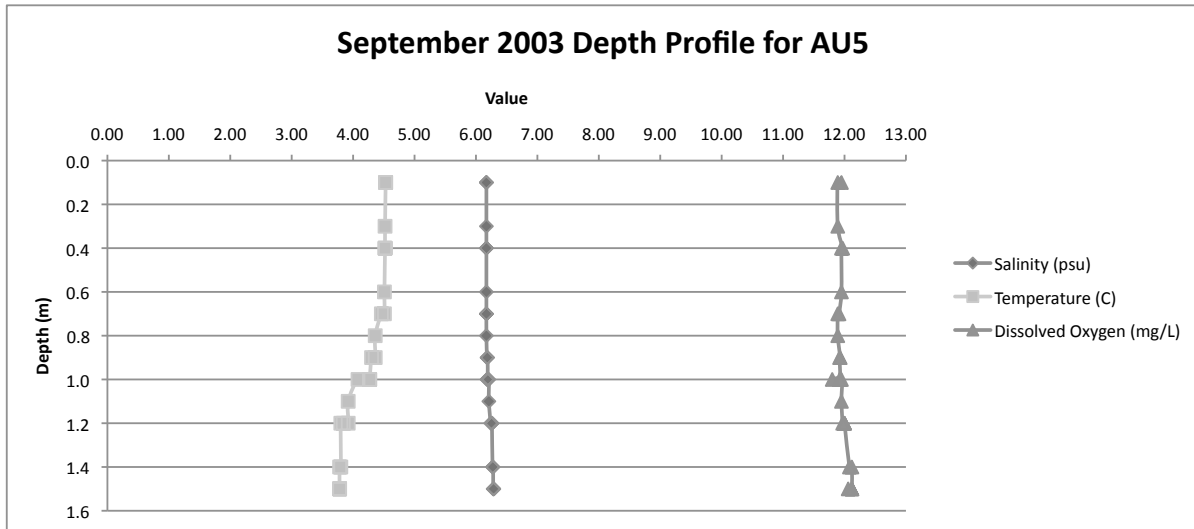
Akulaaq – September 2003



APPENDIX B: DEPTH PROFILES

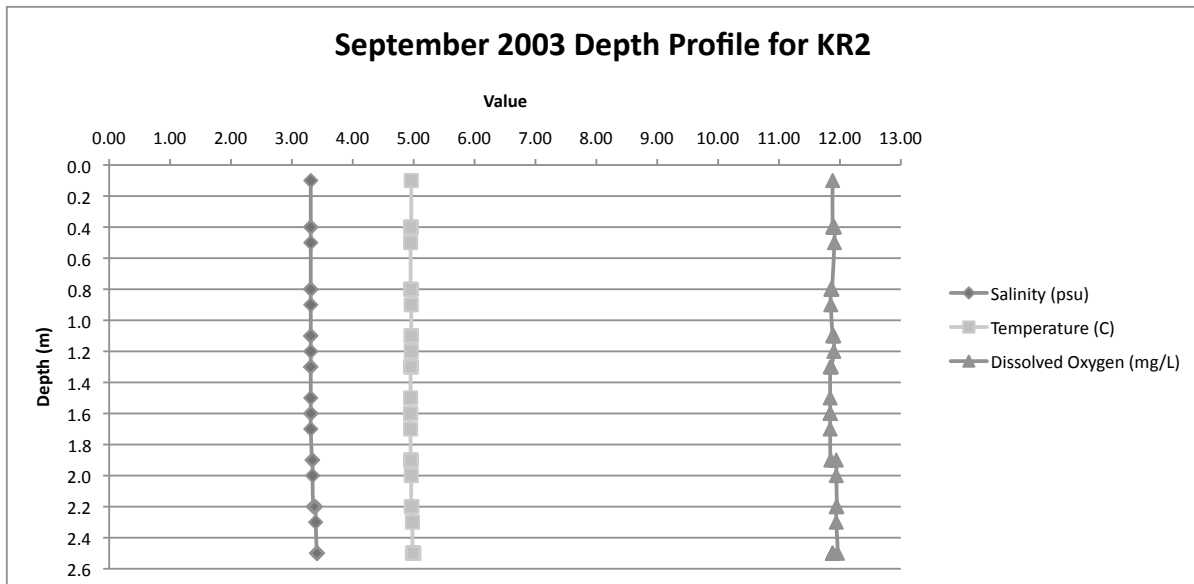
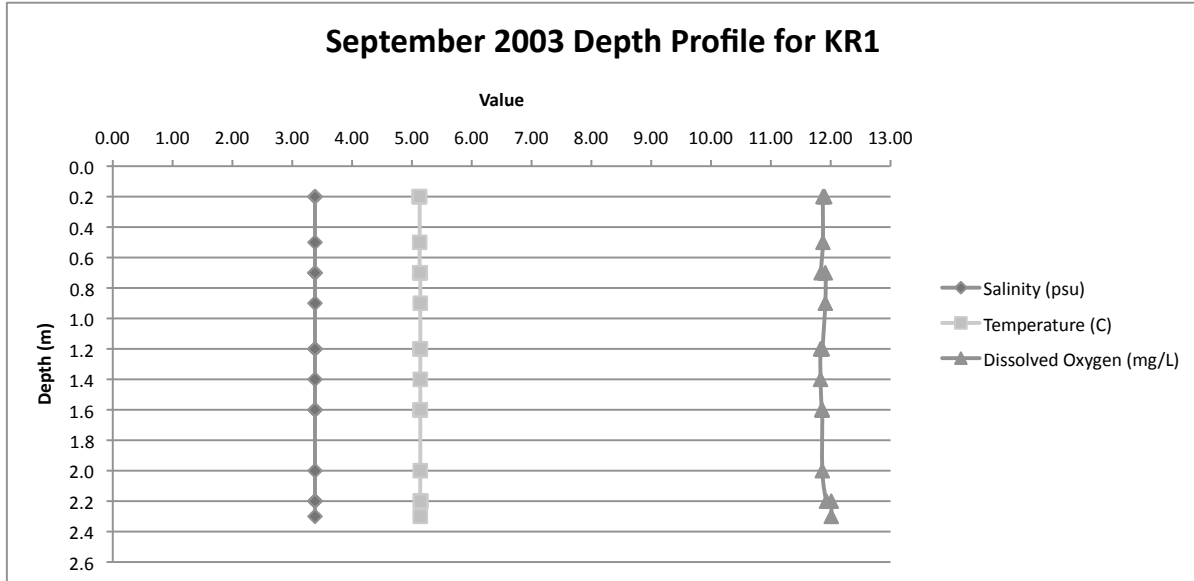


APPENDIX B: DEPTH PROFILES

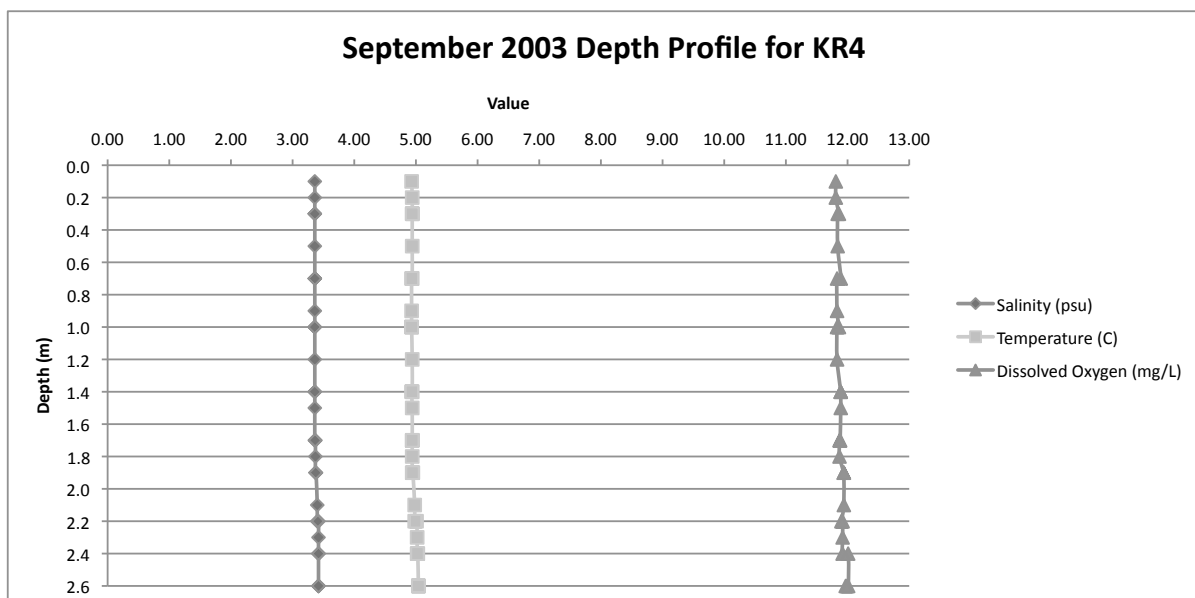
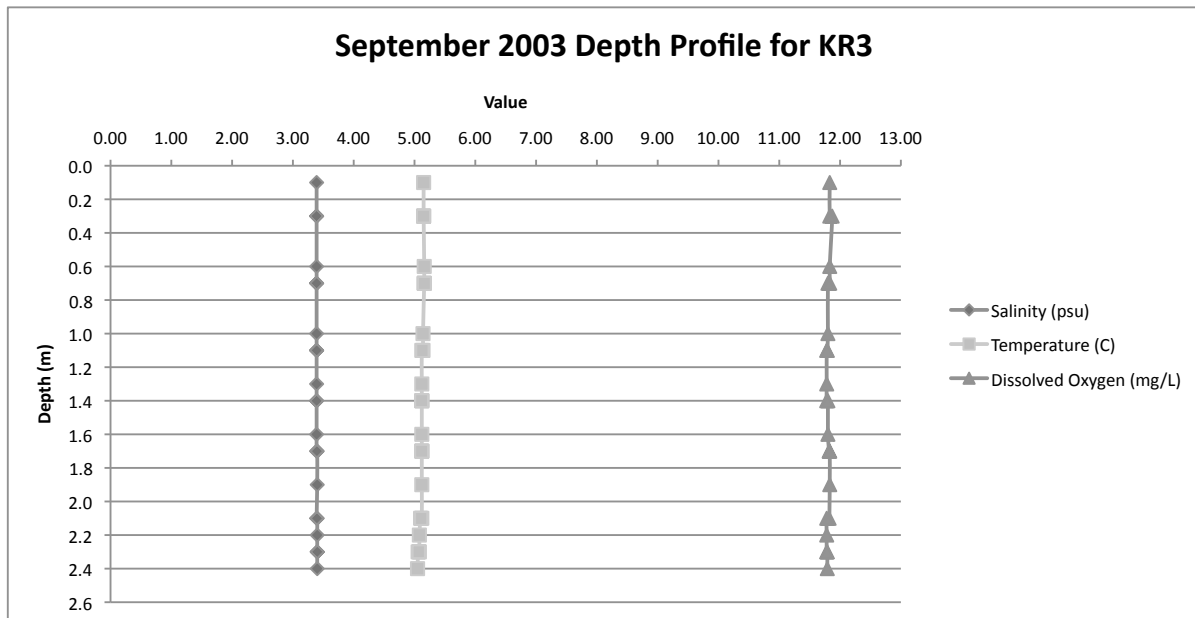


APPENDIX B: DEPTH PROFILES

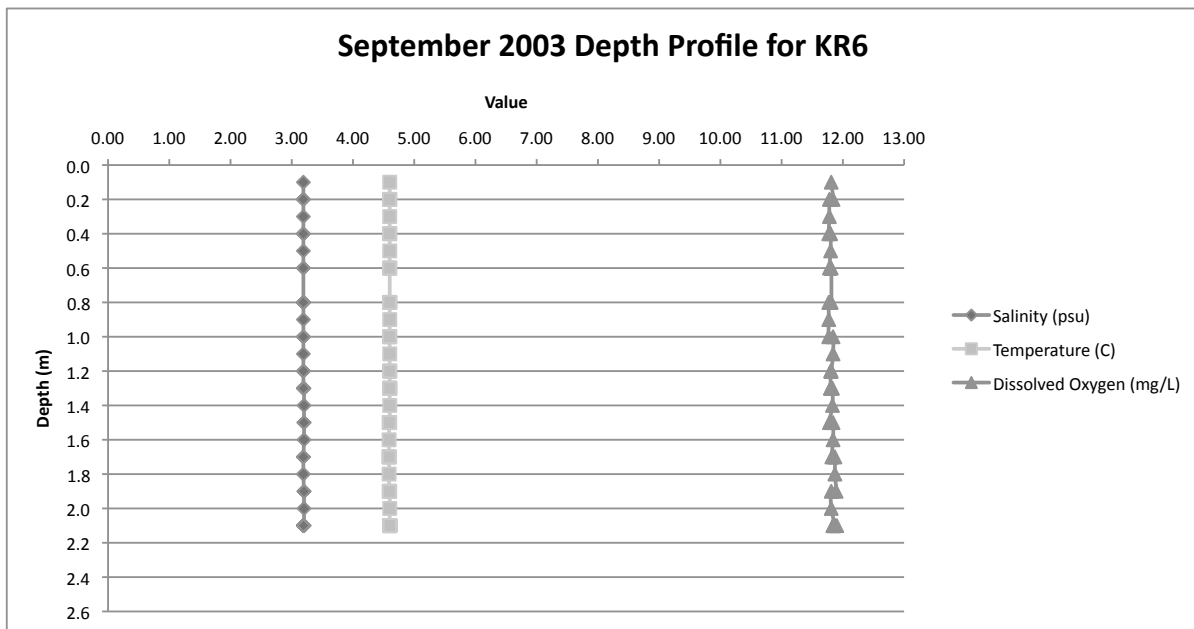
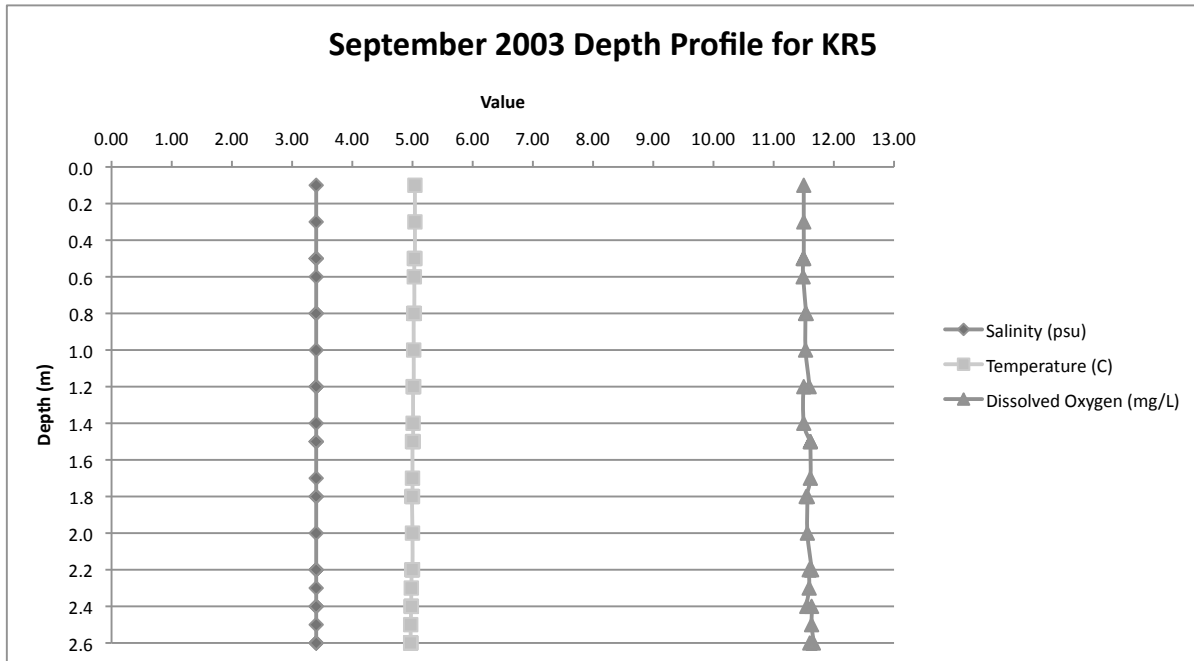
Krusenstern – September 2003



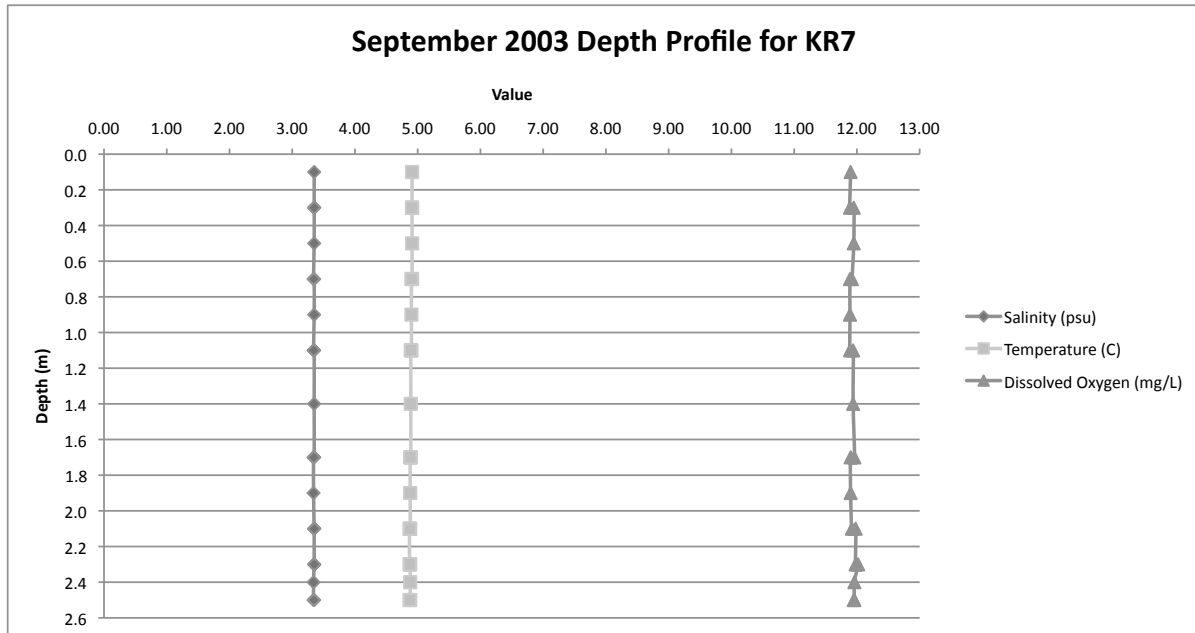
APPENDIX B: DEPTH PROFILES



APPENDIX B: DEPTH PROFILES

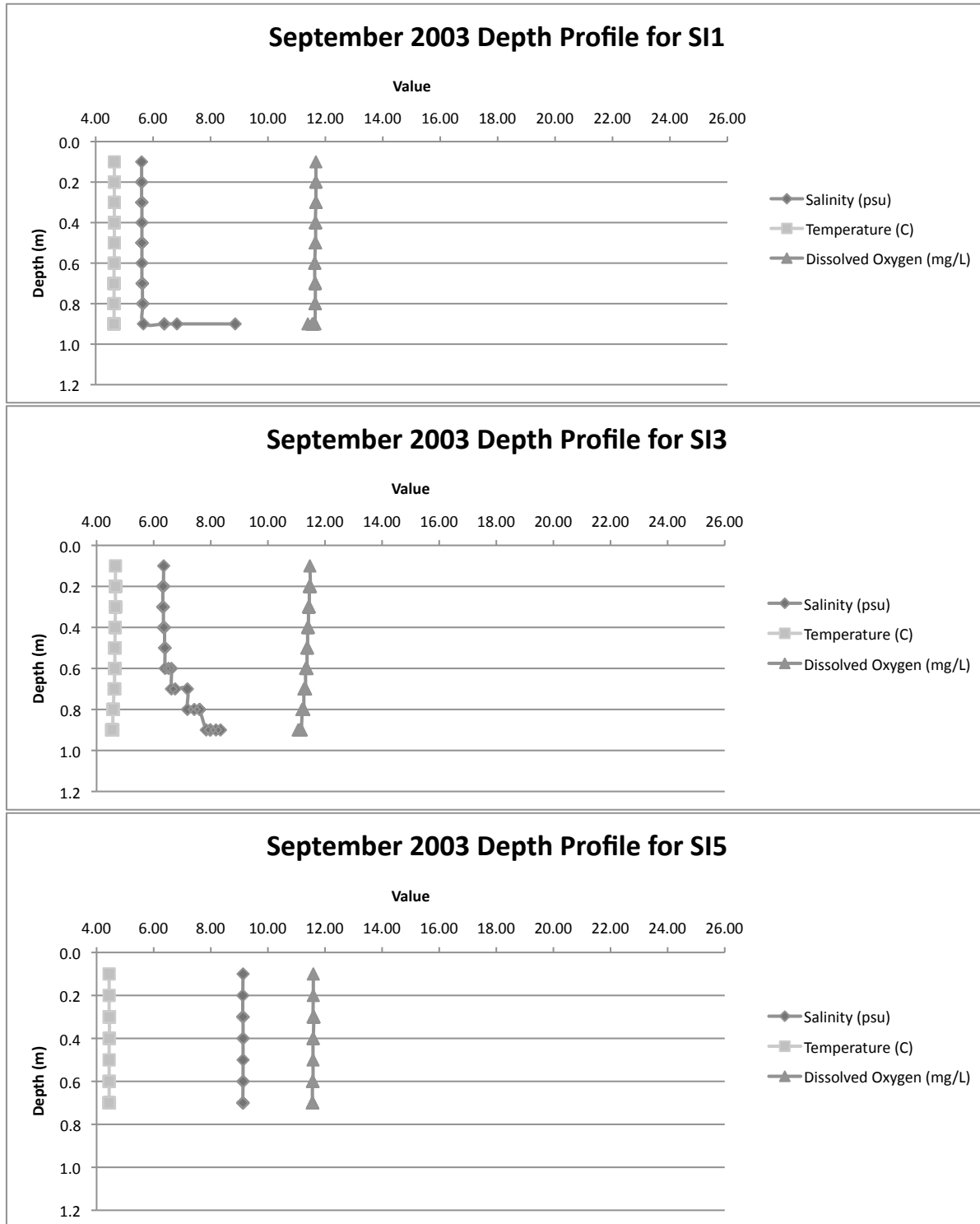


APPENDIX B: DEPTH PROFILES



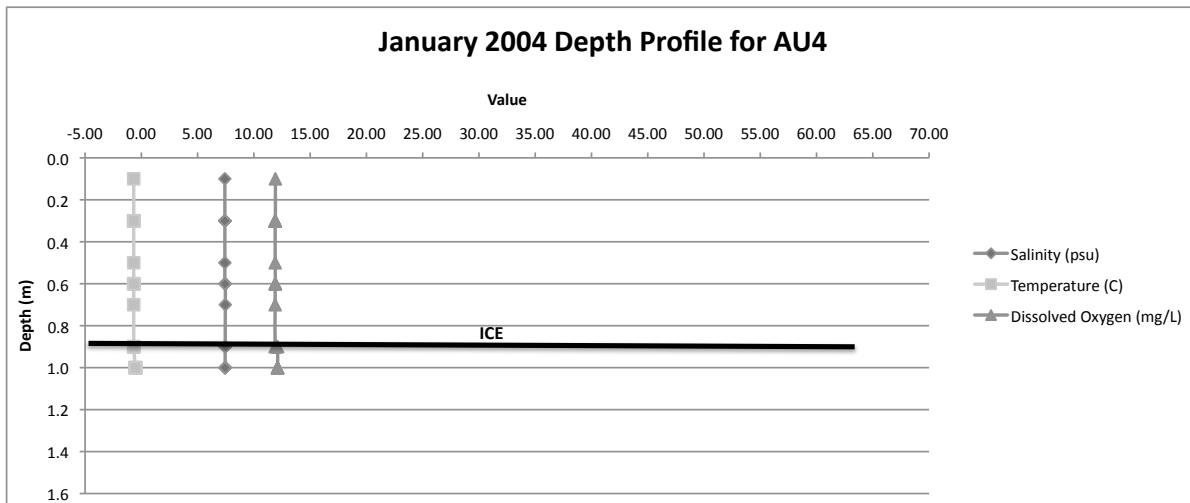
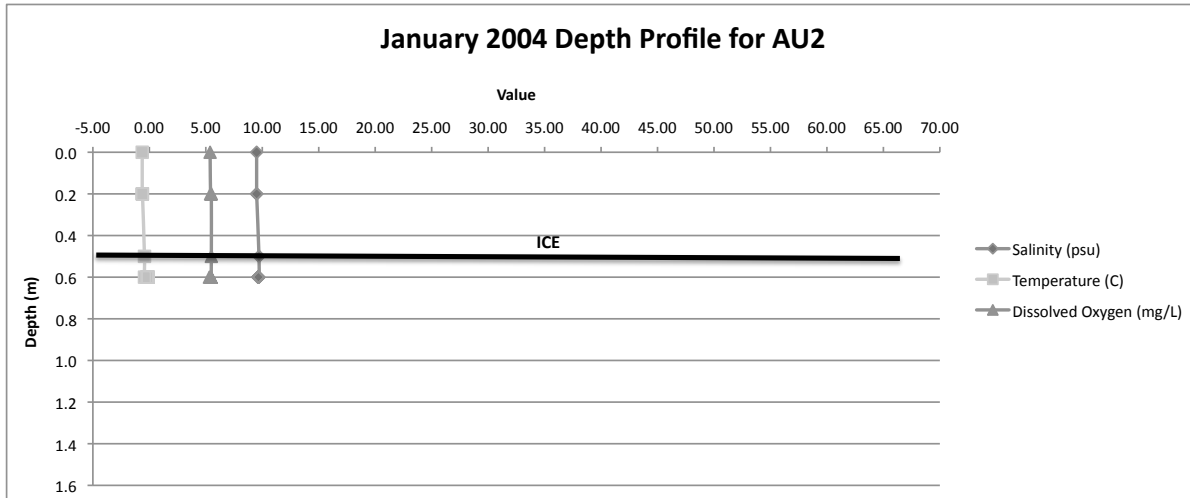
APPENDIX B: DEPTH PROFILES

Sisualik – September 2003



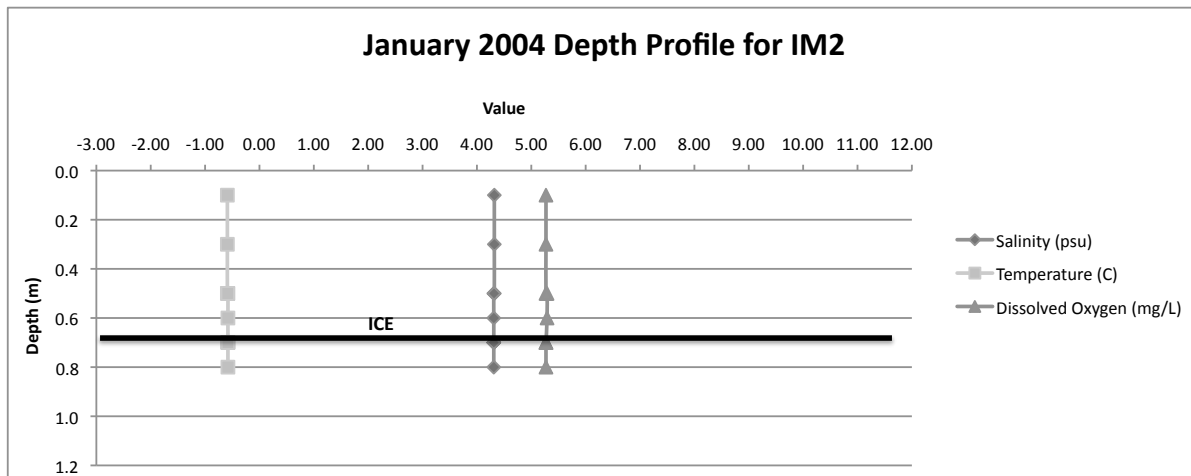
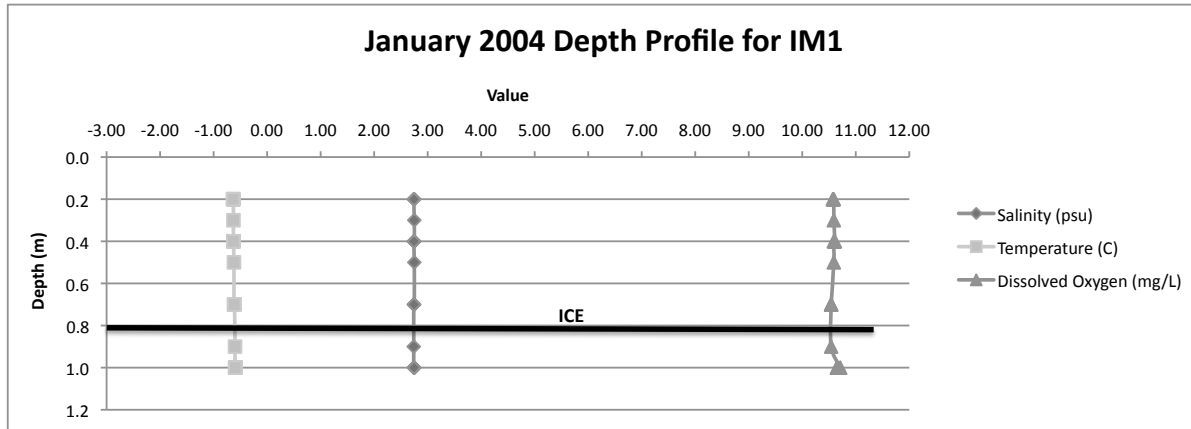
APPENDIX B: DEPTH PROFILES

Akulaaq – January 2004



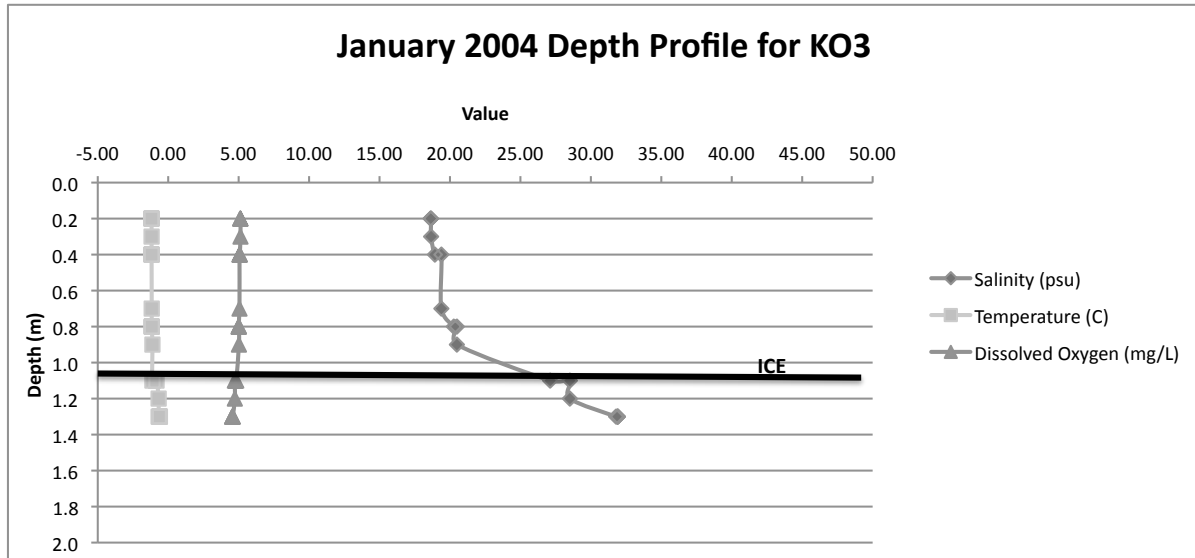
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Imik – January 2004



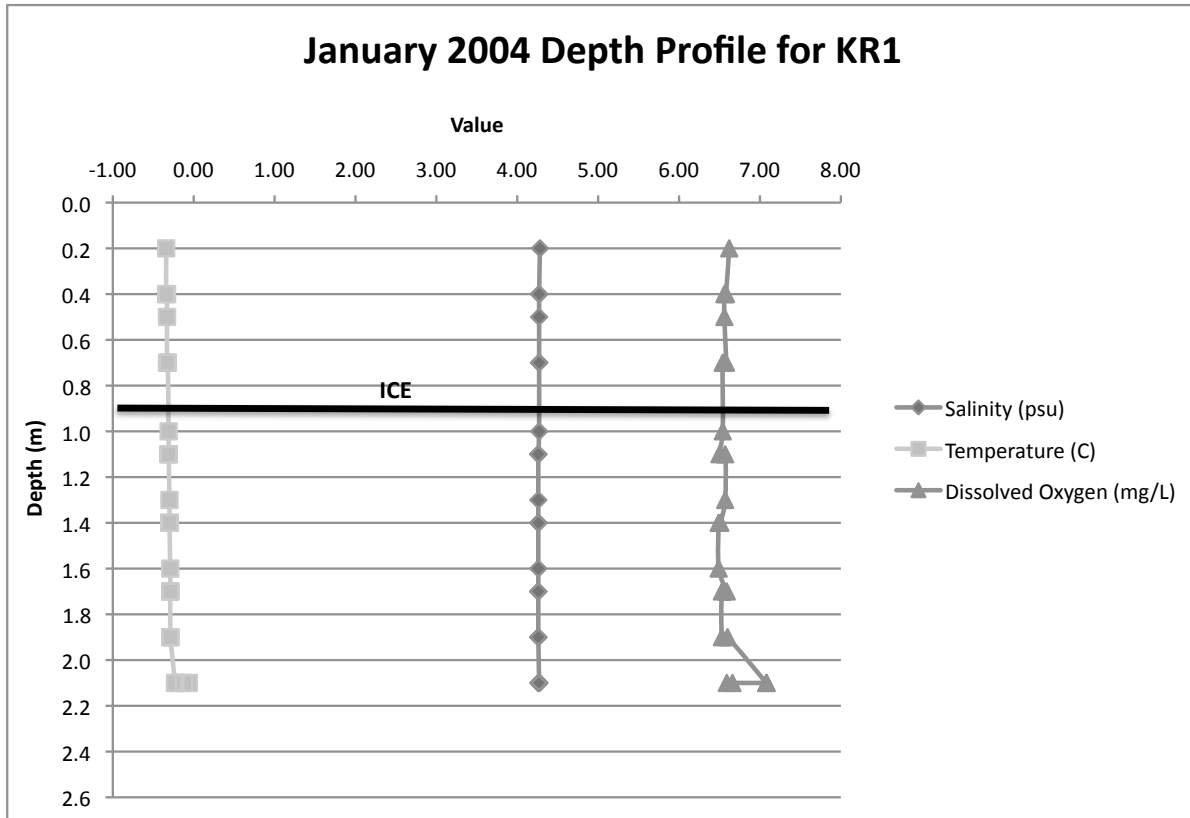
APPENDIX B: DEPTH PROFILES

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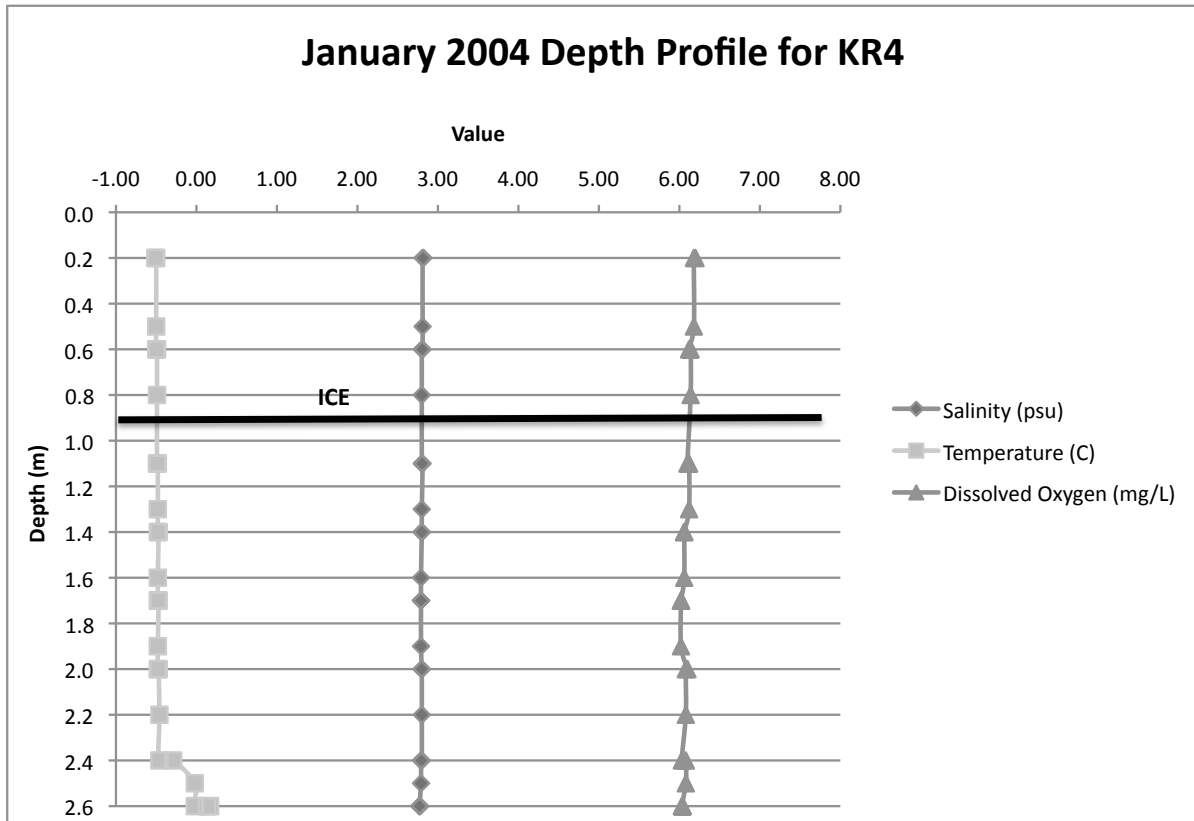


APPENDIX B: DEPTH PROFILES

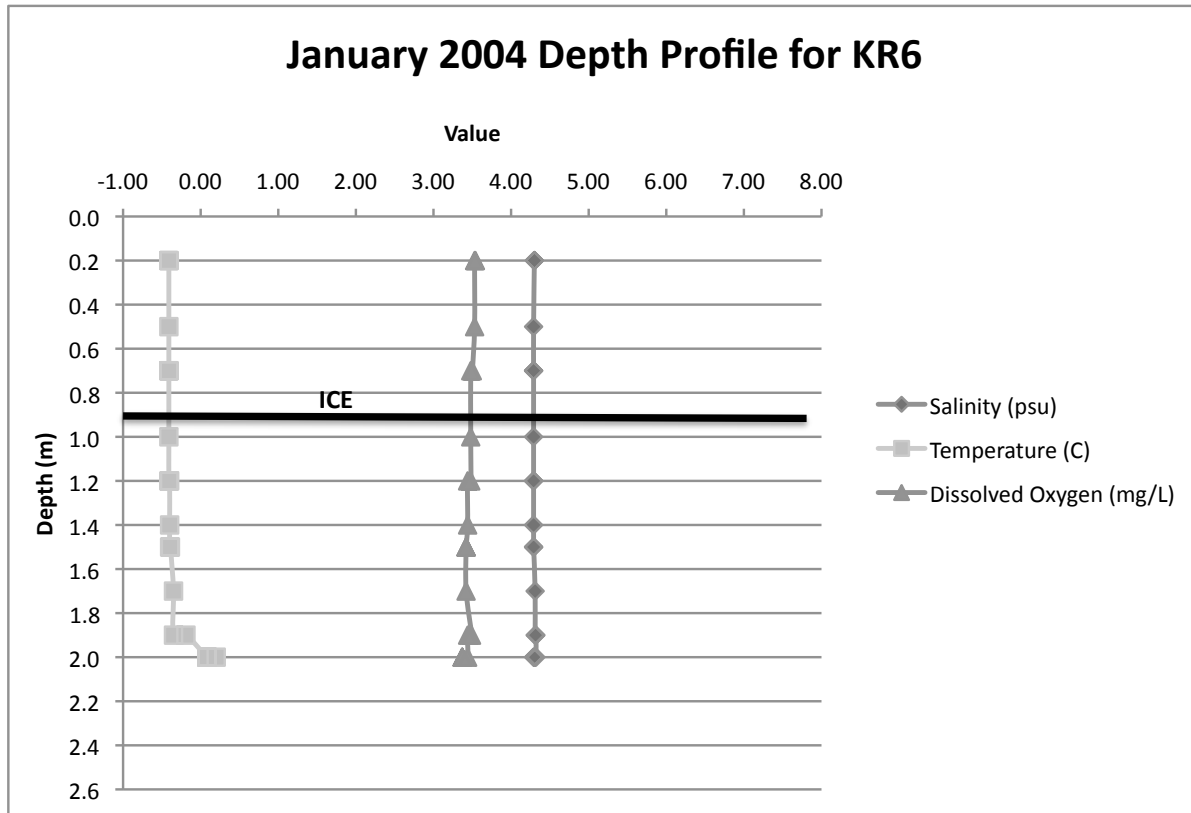
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APPENDIX B: DEPTH PROFILES

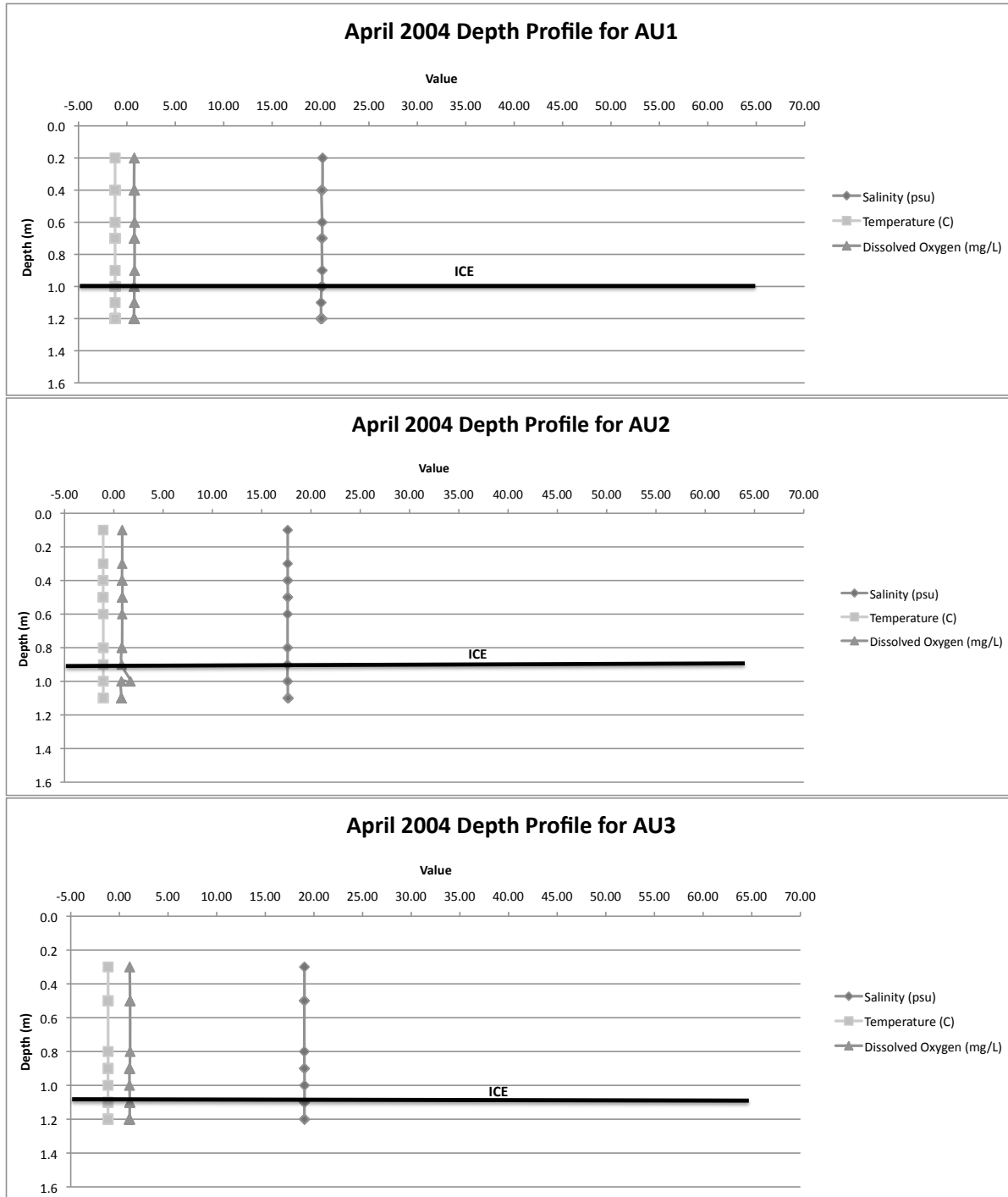


APPENDIX B: DEPTH PROFILES

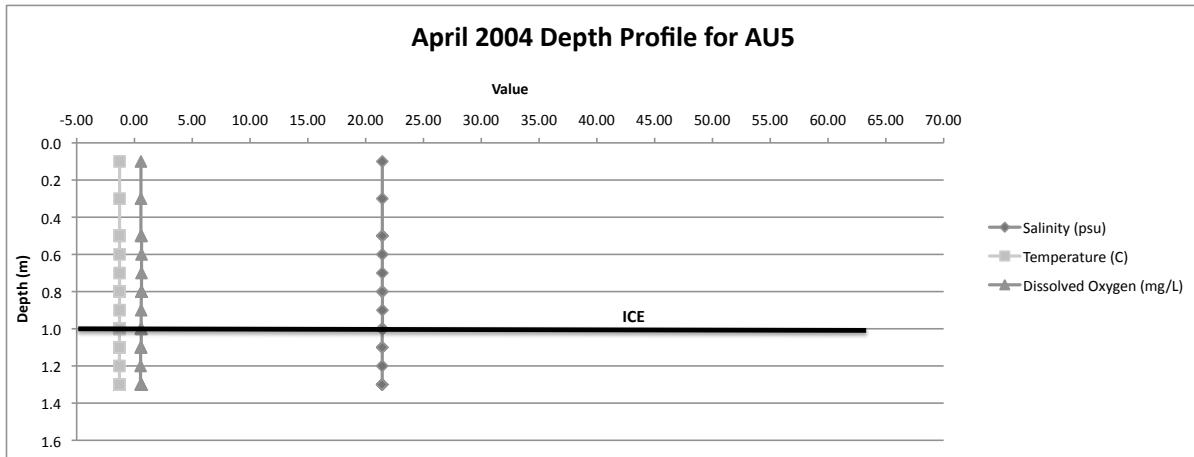
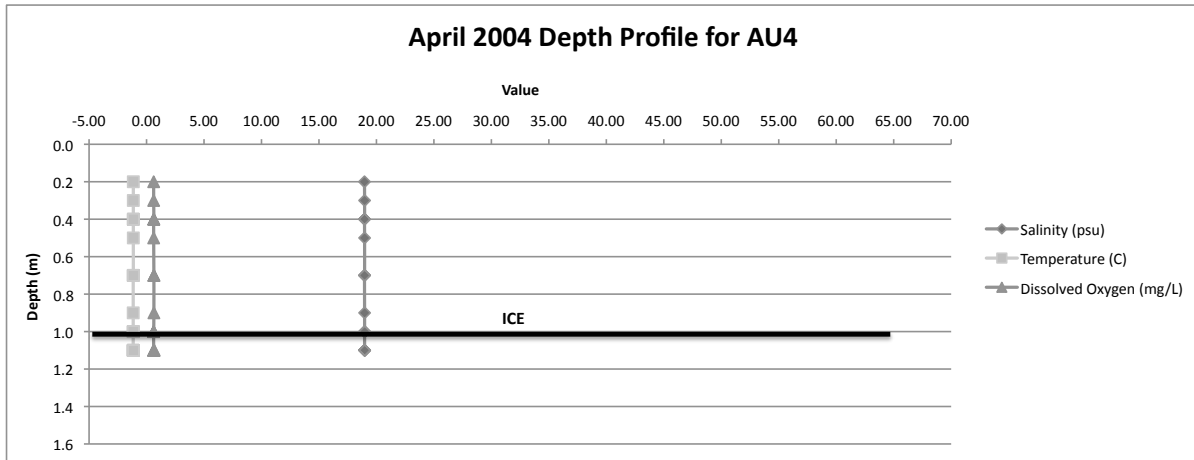


APPENDIX B: DEPTH PROFILES

Akulaaq – April 2004

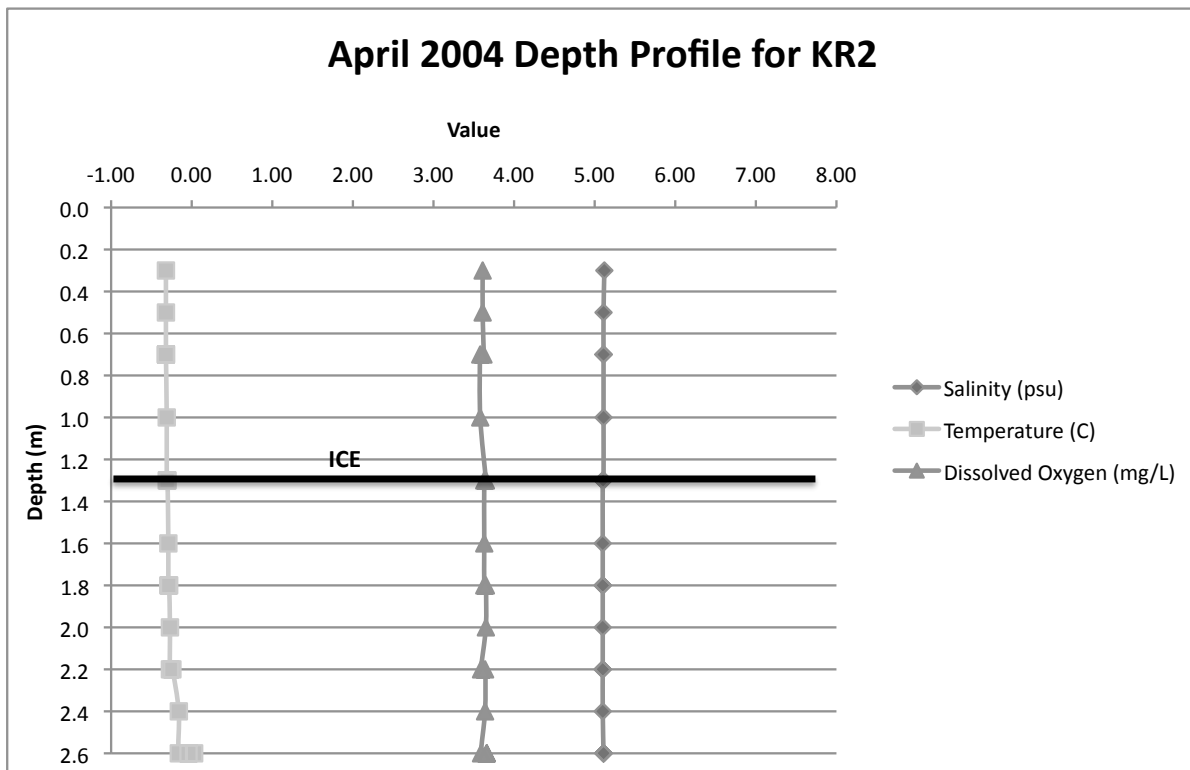
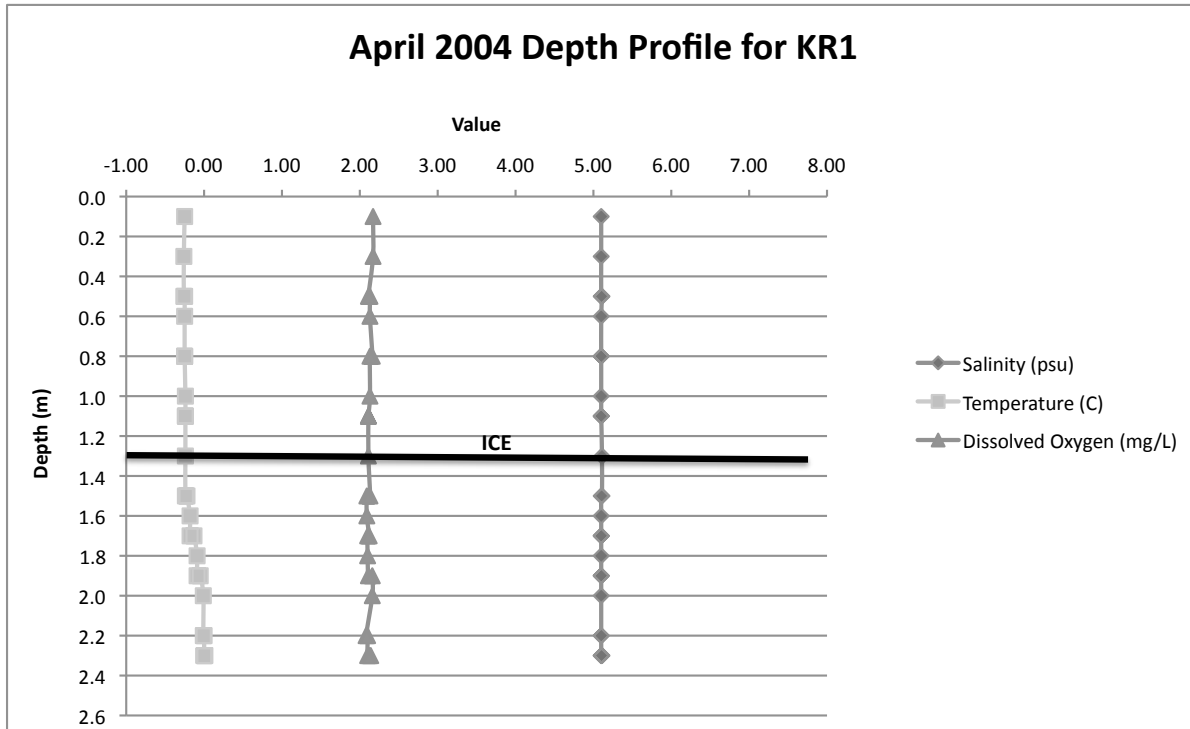


APPENDIX B: DEPTH PROFILES

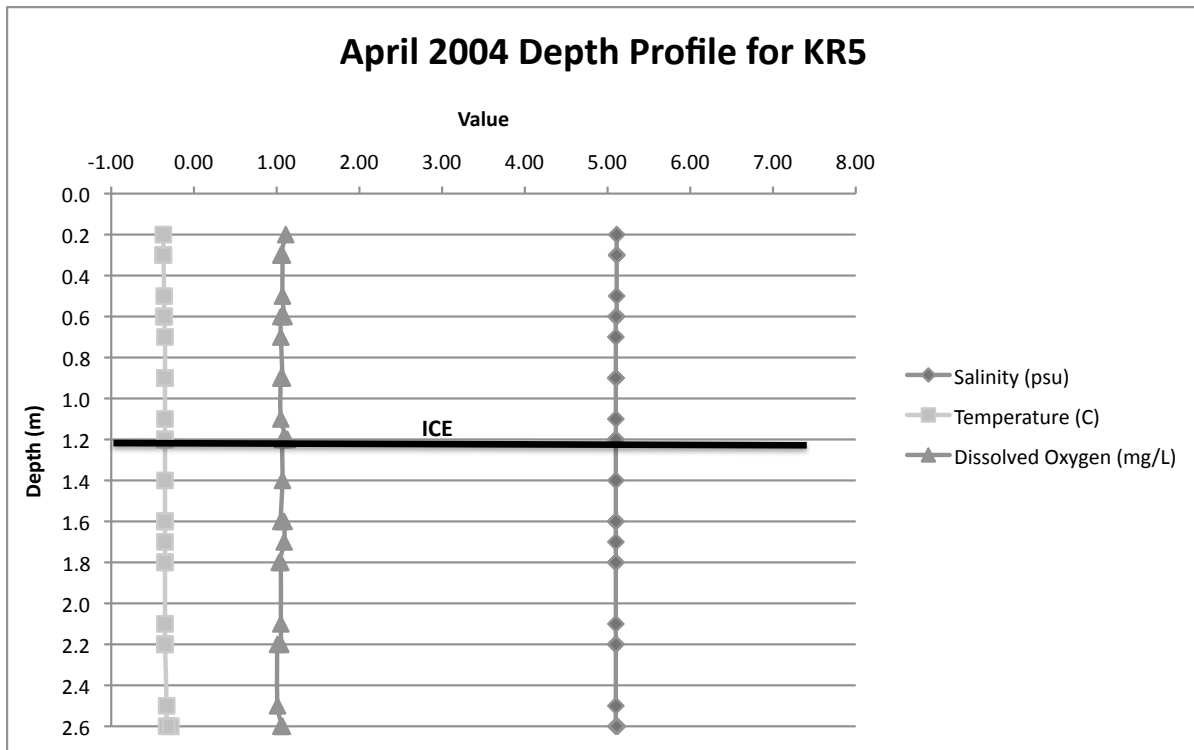
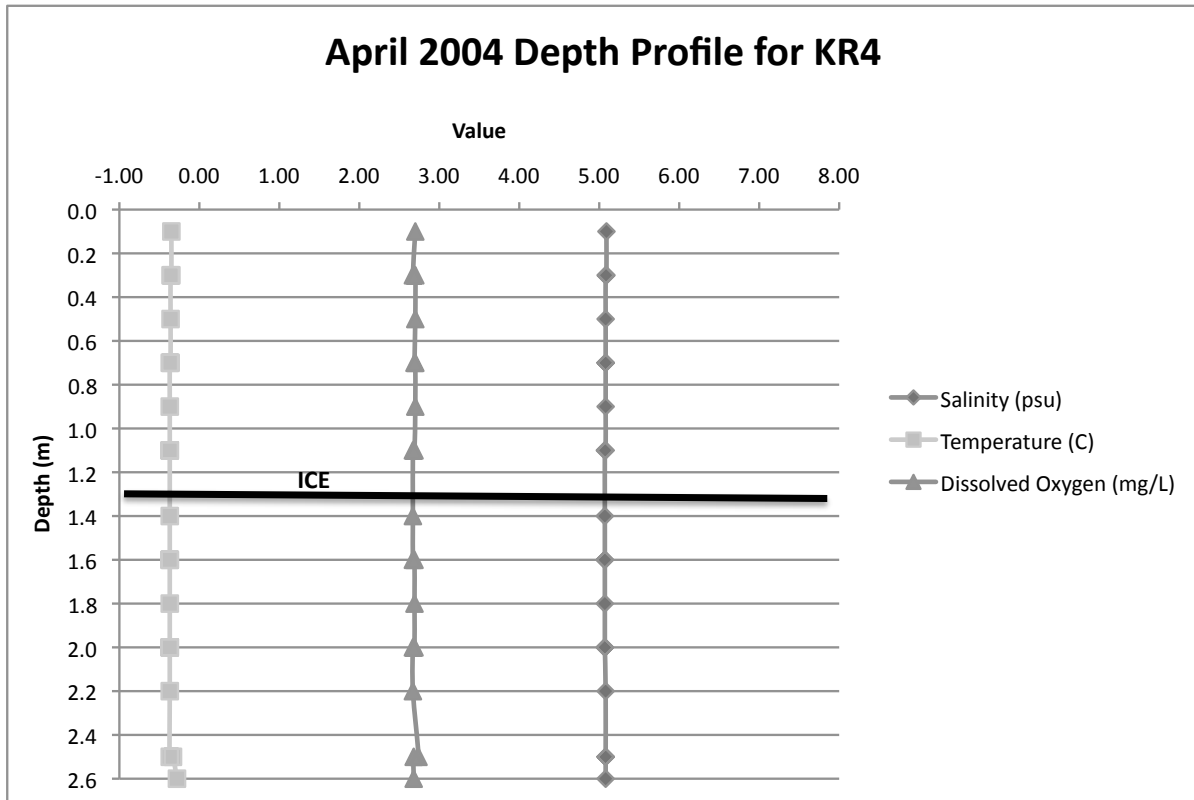


APPENDIX B: DEPTH PROFILES

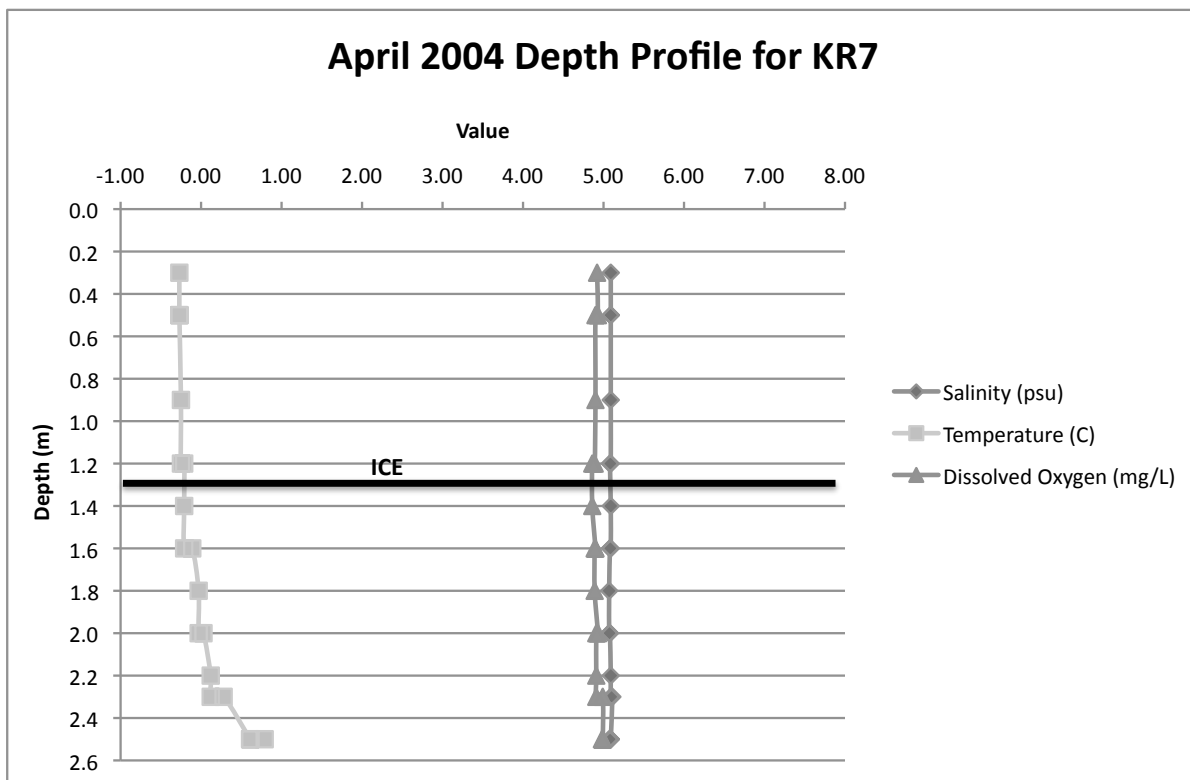
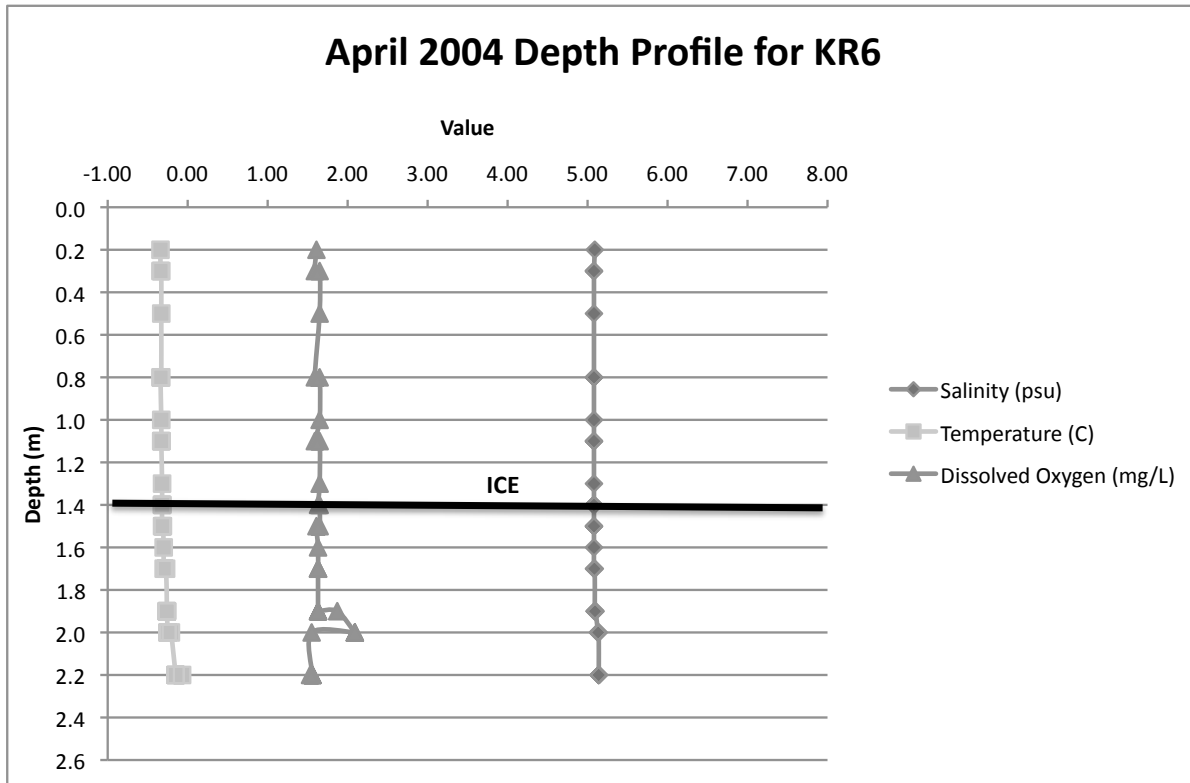
Krusenstern – April 2004



APPENDIX B: DEPTH PROFILES

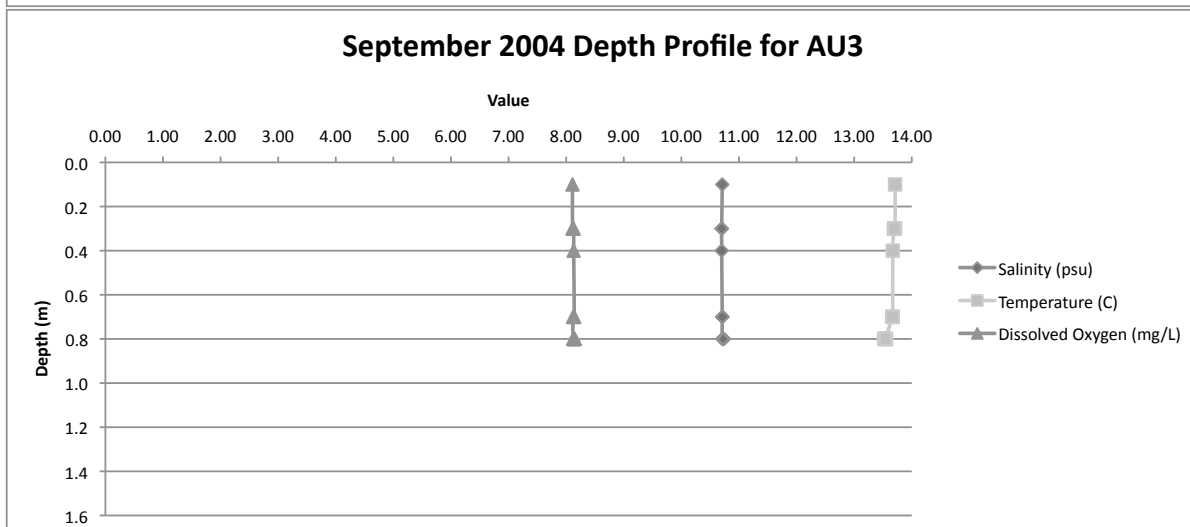
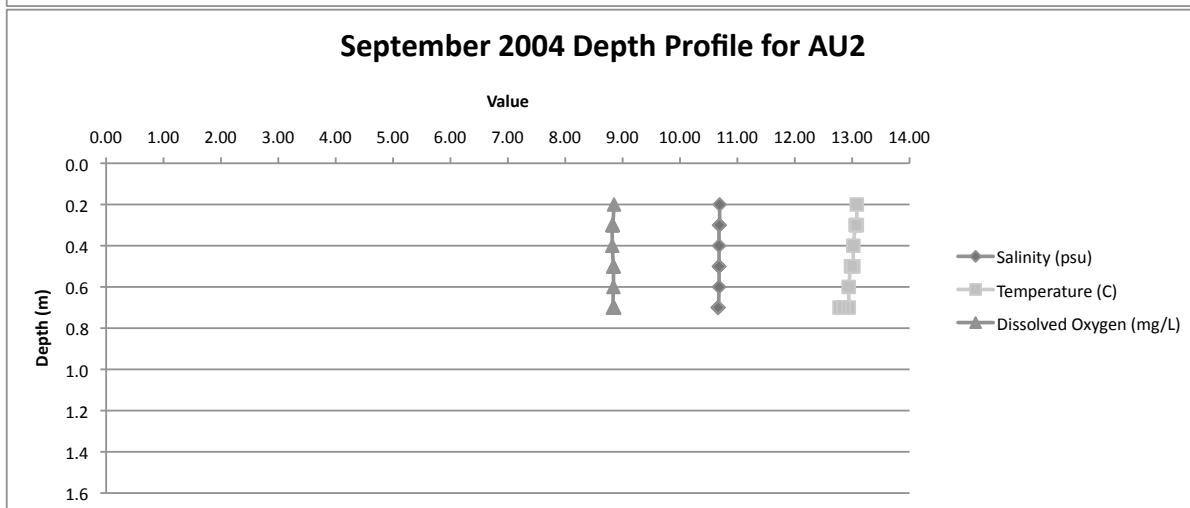
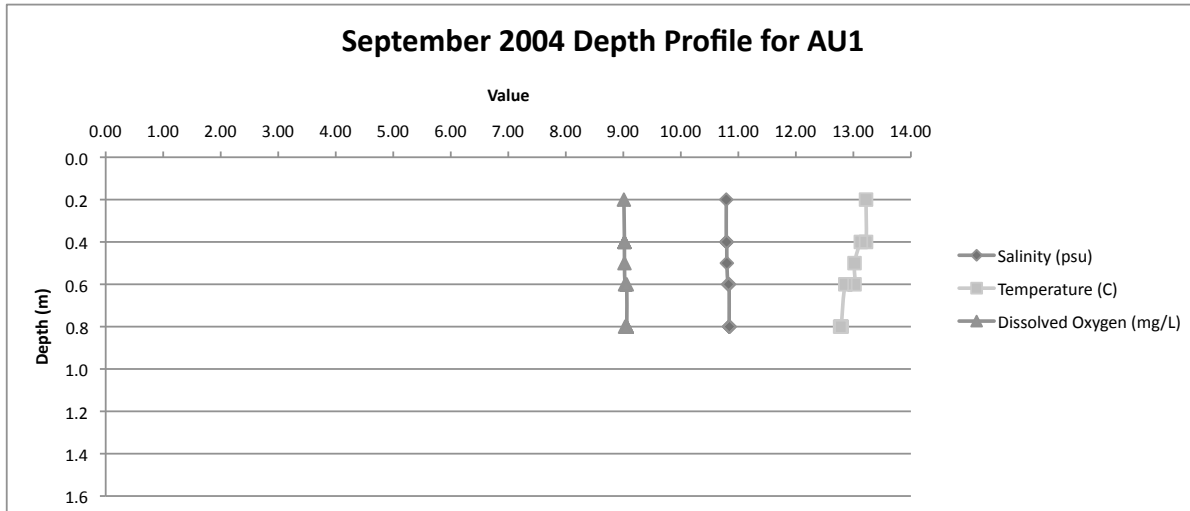


APPENDIX B: DEPTH PROFILES

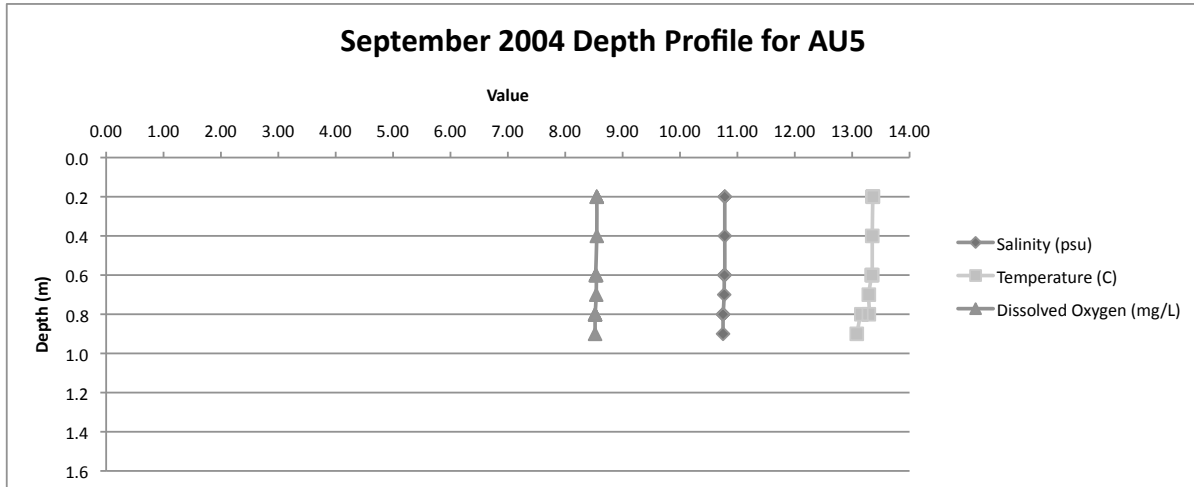
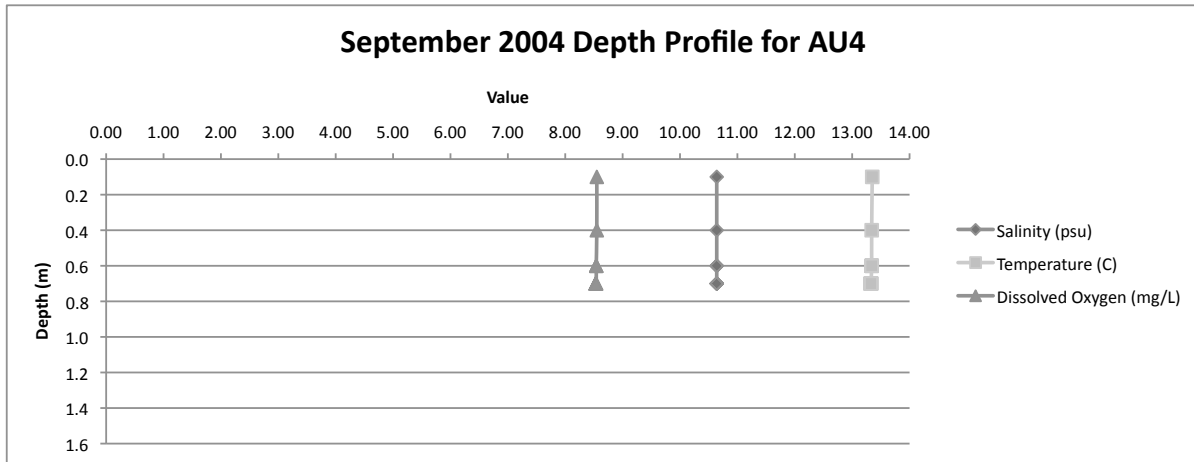


APPENDIX B: DEPTH PROFILES

Akulaaq – September 2004

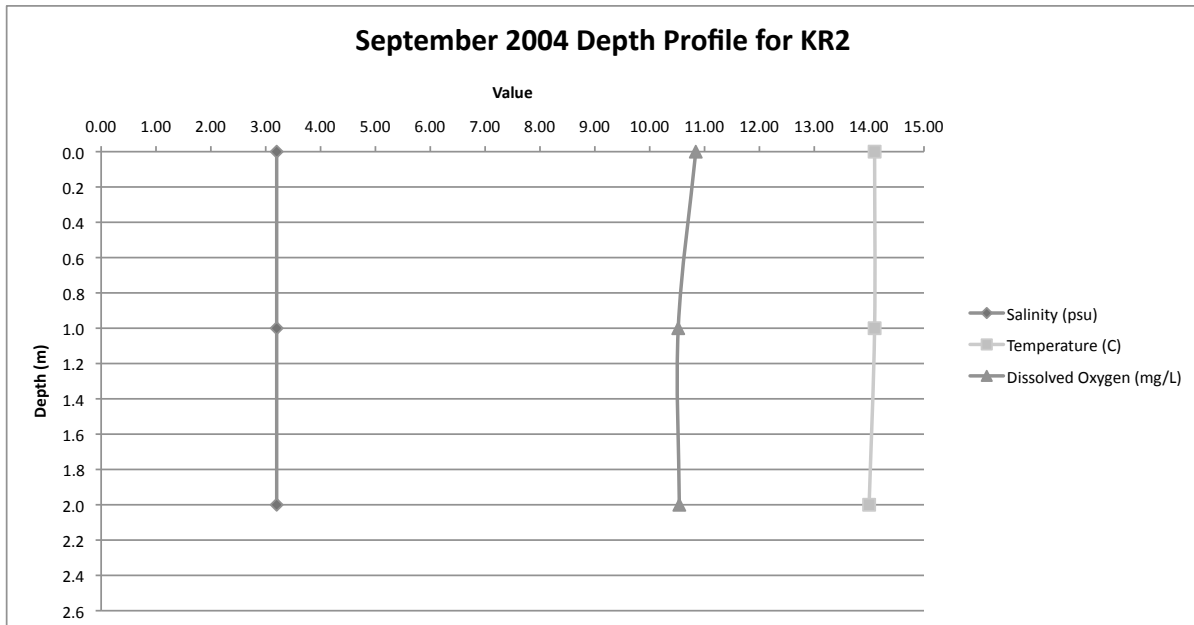
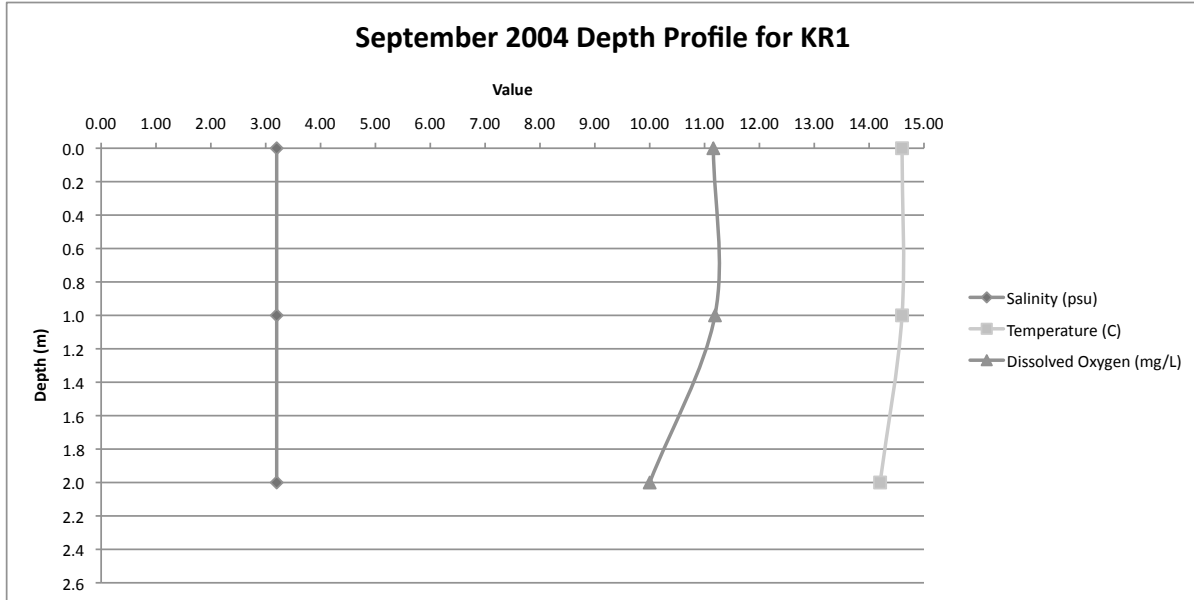


APPENDIX B: DEPTH PROFILES

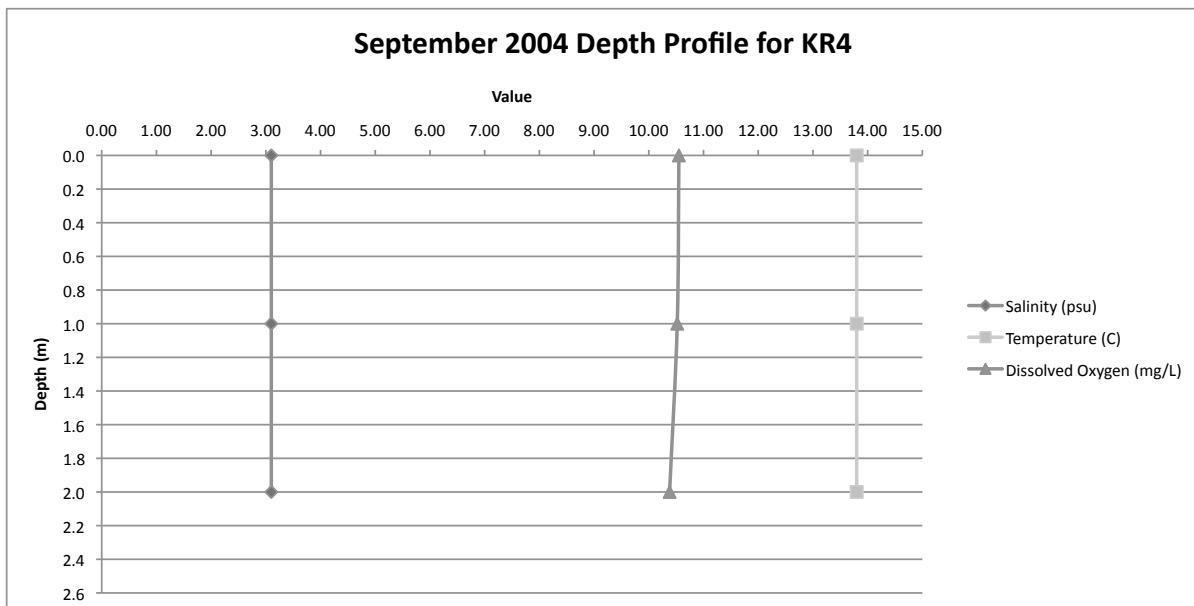
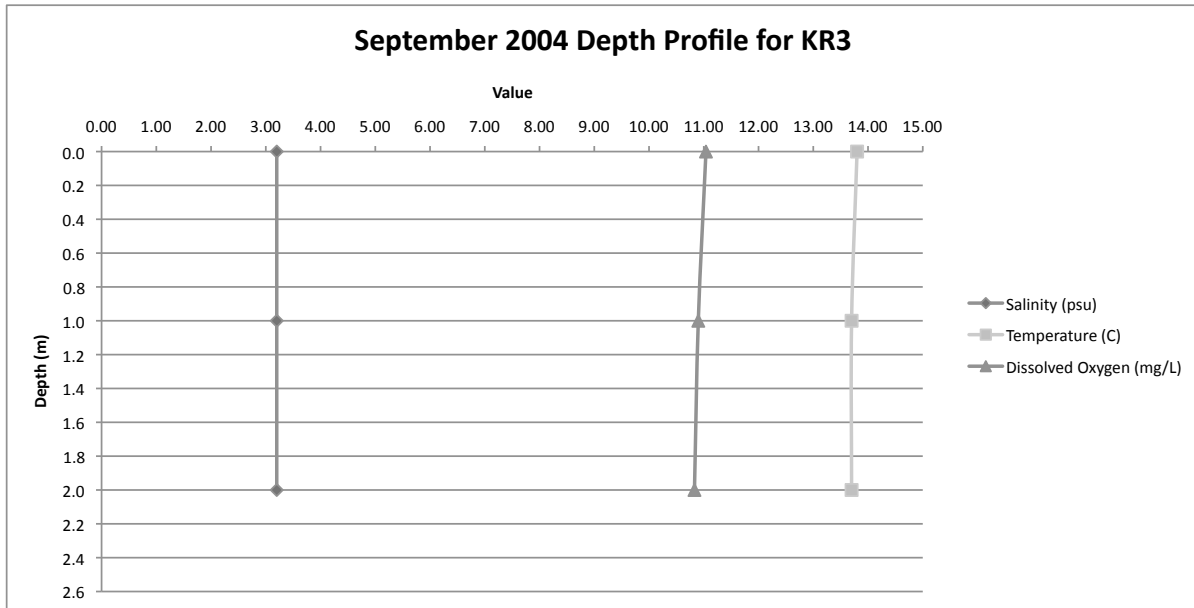


APPENDIX B: DEPTH PROFILES

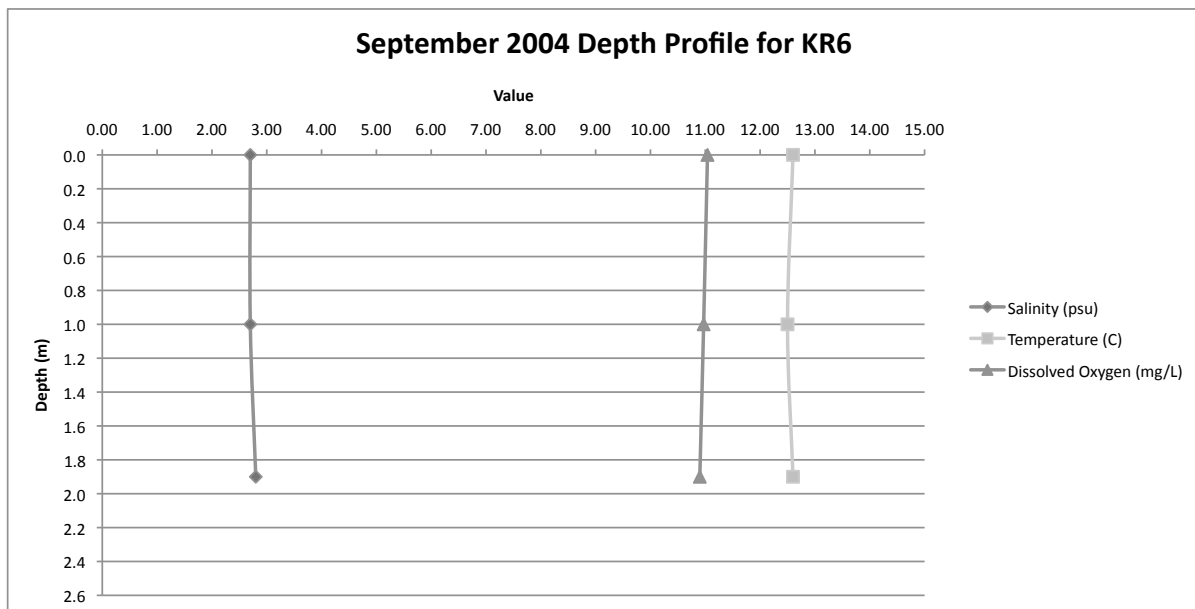
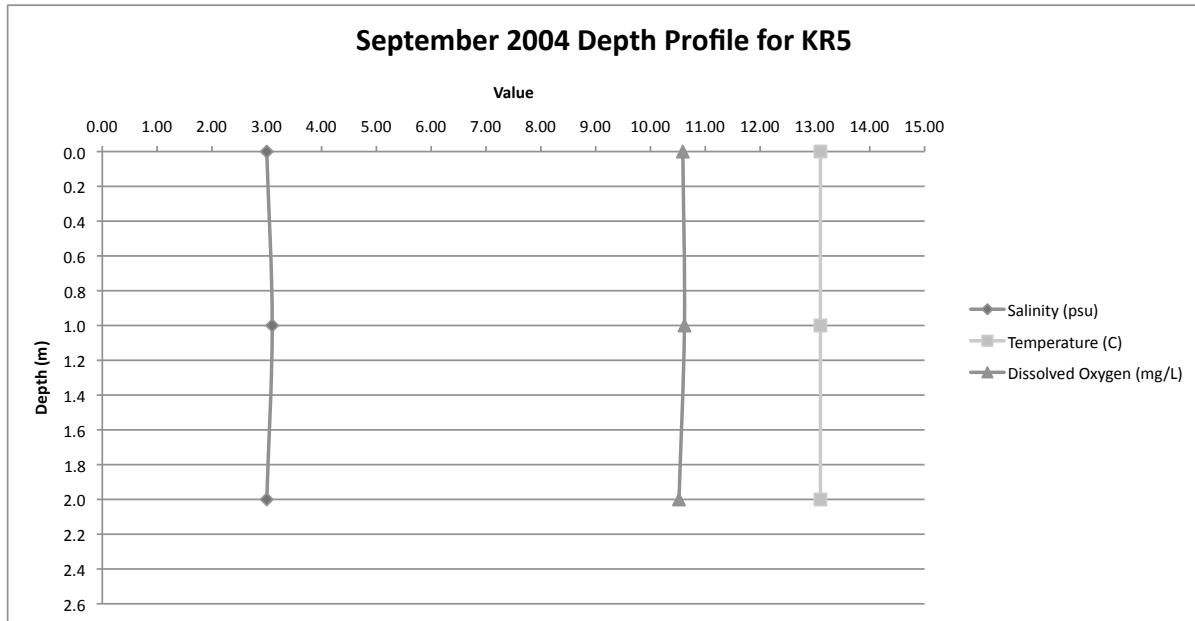
Krusenstern – September 2004



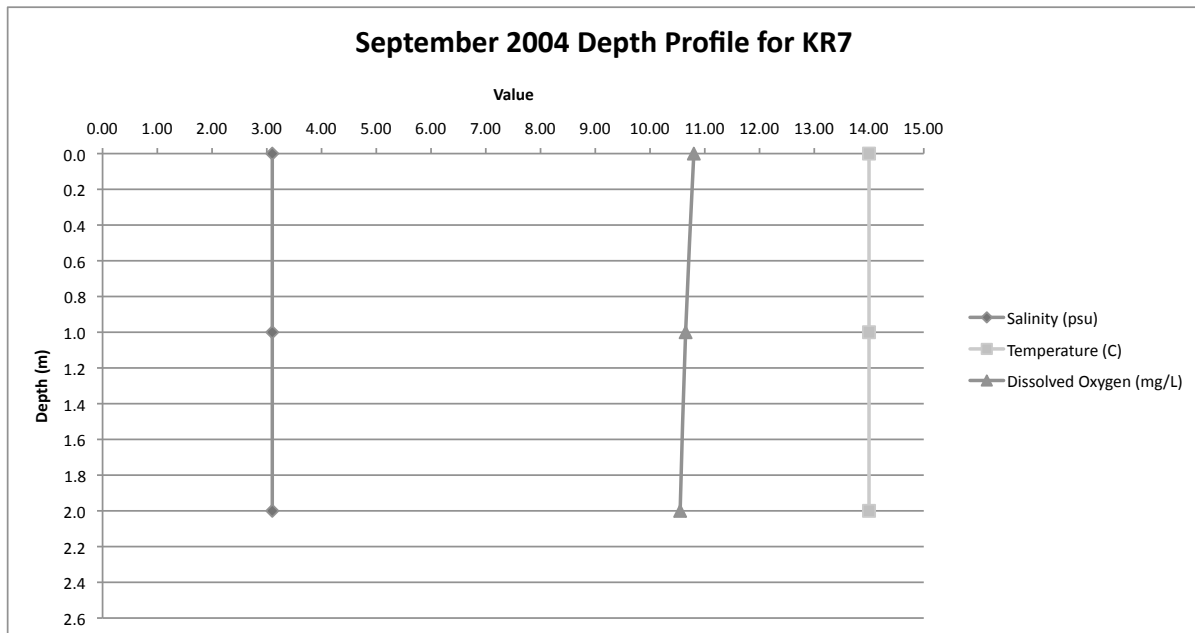
APPENDIX B: DEPTH PROFILES



APPENDIX B: DEPTH PROFILES



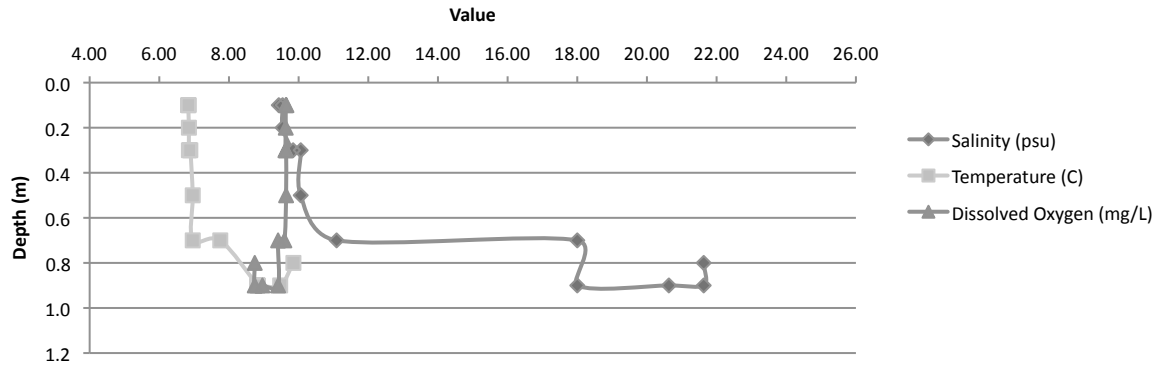
APPENDIX B: DEPTH PROFILES



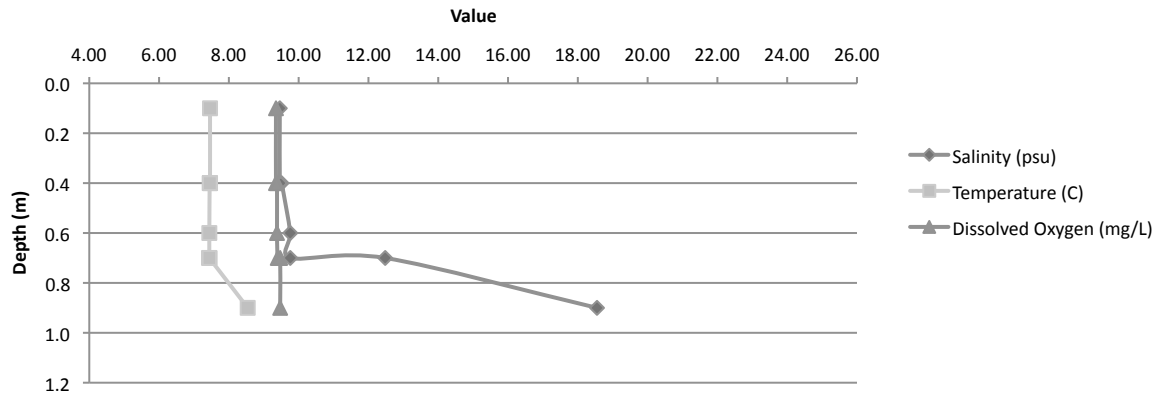
APPENDIX B: DEPTH PROFILES

Sisualik – September 2004

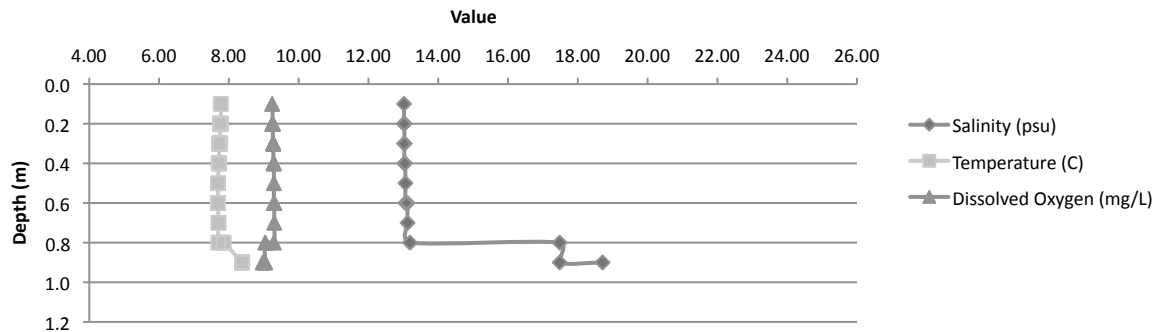
September 2004 Depth Profile for SI1



September 2004 Depth Profile for SI2

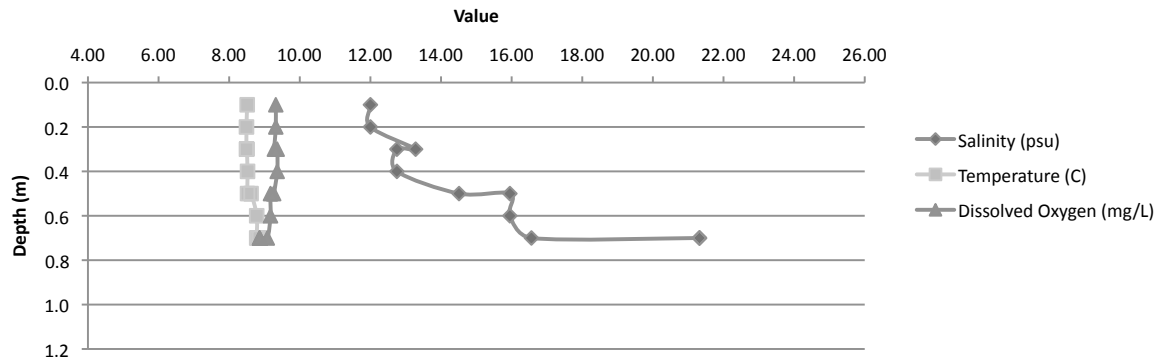


September 2004 Depth Profile for SI3

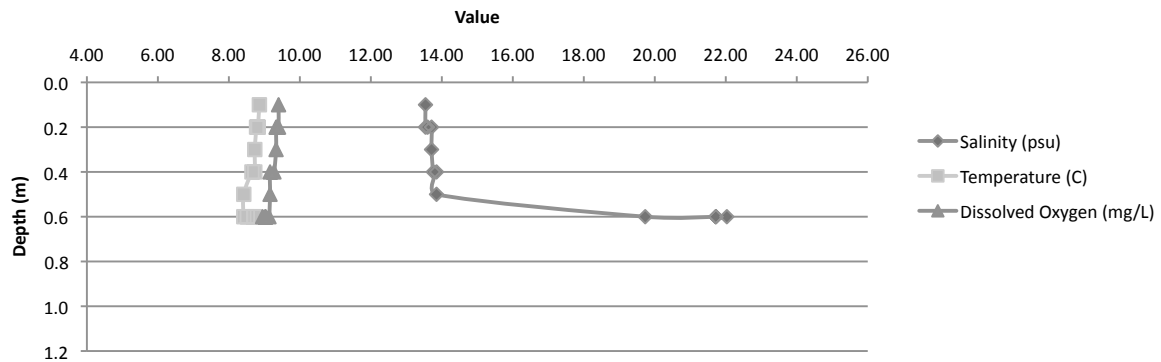


APPENDIX B: DEPTH PROFILES

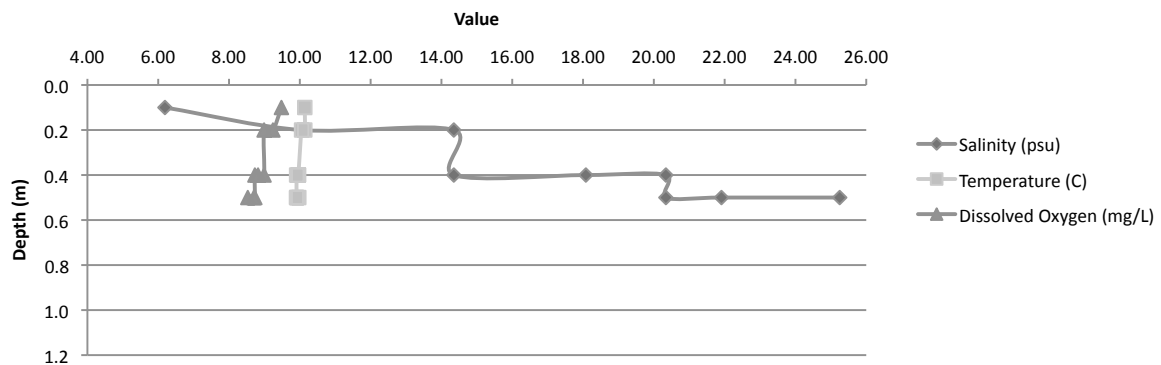
September 2004 Depth Profile for SI4



September 2004 Depth Profile for SI5



September 2004 Depth Profile for SI6



APPENDIX C: STATION PHYSICOCHEMICAL MEANS / LAGOON

Table C. Mean and standard deviation (± 1) for each sampling station in five CAKR lagoons during the seven sampling periods between January 2003 – September 2004. Means during ice-covered sampling periods were calculated using all available depth measurements taken under the ice and surface means during open water periods were calculated using all available depth measurements to a depth of 0.5 m.

Date	Lagoon	Station	Mean		
			Salinity (psu)	Dissolved Oxygen (mg/L)	Water Temperature (°C)
January 2003	Akulaaq	AU1	41.2 $\pm$ 0.0	2.8 $\pm$ 0.0	-2.5 $\pm$ 0.0
		AU2	37.3 $\pm$ 0.2	1.6 $\pm$ 0.0	-2.3 $\pm$ 0.0
		AU3	31.9 $\pm$ 0.0	4.0 $\pm$ 0.0	-2.5 $\pm$ 0.0
		AU4	37.5 $\pm$ 1.3	2.8 $\pm$ 0.0	-2.4 $\pm$ 0.0
		AU5	32.2 $\pm$ 0.0	4.2 $\pm$ 0.0	-2.5 $\pm$ 0.0
	Imik	IM1	6.7 $\pm$ 0.1	8.5 $\pm$ 0.0	-0.5 $\pm$ 0.0
	Kotlik	KO1	13.6 $\pm$ 0.7	8.8 $\pm$ 0.0	-1.2 $\pm$ 0.0
		KO2	18.0 $\pm$ 0.1	9.9 $\pm$ 0.0	-1.2 $\pm$ 0.0
	Krusenstern	KR1	5.1 $\pm$ 0.1	9.8 $\pm$ 0.1	-0.1 $\pm$ 0.2
		KR2	5.0 $\pm$ 0.0	9.7 $\pm$ 0.1	-0.3 $\pm$ 0.1
		KR3	5.0 $\pm$ 0.0	8.6 $\pm$ 0.3	-0.4 $\pm$ 0.1
		KR4	5.0 $\pm$ 0.1	6.8 $\pm$ 0.0	-0.3 $\pm$ 0.1
		KR5	5.0 $\pm$ 0.1	6.4 $\pm$ 0.0	-0.3 $\pm$ 0.1
		KR6	5.1 $\pm$ 0.0	6.6 $\pm$ 0.0	-0.4 $\pm$ 0.1
		KR7	5.0 $\pm$ 0.1	7.0 $\pm$ 0.1	0.0 $\pm$ 0.3
	Sisualik	SI1	34.4 $\pm$ 0.6	9.2 $\pm$ 0.0	-1.9 $\pm$ 0.0
		SI2	29.4 $\pm$ 0.1	8.0 $\pm$ 0.0	-1.8 $\pm$ 0.0
		SI3	21.2 $\pm$ 0.1	9.1 $\pm$ 0.1	-1.7 $\pm$ 0.0
		SI4	FROZEN TO THE BOTTOM		
		SI5			
		SI6			
April 2003	Akulaaq	AU1	62.0 $\pm$ 0.2	4.0 $\pm$ 0.1	-3.6 $\pm$ 0.1
		AU2	59.4 $\pm$ 0.1	7.2 $\pm$ 0.0	-3.6 $\pm$ 0.0
		AU3	64.5 $\pm$ 0.1	6.7 $\pm$ 0.4	-3.8 $\pm$ 0.0
		AU4	61.9 $\pm$ 0.0	4.6 $\pm$ 0.2	-3.7 $\pm$ 0.0
		AU5	62.6 $\pm$ 0.1	3.9 $\pm$ 0.0	-3.7 $\pm$ 0.0
	Kotlik	KO1	3.2 $\pm$ 0.1	14.0 $\pm$ 0.1	-0.2 $\pm$ 0.0
		KO2	24.3 $\pm$ 0.2	6.7 $\pm$ 1.4	-1.0 $\pm$ 0.2
		KO3	8.5 $\pm$ 10.6	10.7 $\pm$ 0.8	0.5 $\pm$ 0.1
	Krusenstern	KR1	6.1 $\pm$ 1.7	11.2 $\pm$ 1.6	0.2 $\pm$ 0.3
		KR2	6.8 $\pm$ 0.1	6.9 $\pm$ 1.7	-0.4 $\pm$ 0.1
		KR3	6.8 $\pm$ 0.2	10.9 $\pm$ 1.5	-0.3 $\pm$ 0.2
		KR5	6.2 $\pm$ 0.8	10.3 $\pm$ 2.7	0.2 $\pm$ 0.1
		KR6	6.5 $\pm$ 0.0	8.9 $\pm$ 2.0	-0.1 $\pm$ 0.3
	Sisualik	SI1	47.7 $\pm$ 0.0	4.0 $\pm$ 0.0	-2.8 $\pm$ 0.0
		SI2	39.9 $\pm$ 0.0	4.2 $\pm$ 0.0	-2.4 $\pm$ 0.0
		SI3	20.9 $\pm$ 0.0	8.3 $\pm$ 0.0	-1.3 $\pm$ 0.0
		SI4	FROZEN TO THE BOTTOM		
		SI5			
		SI6			

APPENDIX C: STATION PHYSICOCHEMICAL MEANS / LAGOON

Date	Lagoon	Station	Mean		
			Salinity (psu)	Dissolved Oxygen (mg/L)	Water Temperature (°C)
July 2003	Akulaaq	AU1	8.0 ± 0.0	10.2 ± 0.0	8.8 ± 0.0
		AU2	8.0 ± 0.0	10.2 ± 0.0	8.7 ± 0.0
		AU3	8.1 ± 0.0	10.2 ± 0.0	8.9 ± 0.0
		AU4	8.2 ± 0.0	10.4 ± 0.0	9.0 ± 0.0
		AU5	8.2 ± 0.0	10.8 ± 0.0	9.0 ± 0.0
	Imik	IM2	2.4 ± 0.0	9.8 ± 0.0	12.0 ± 0.0
		IM3	2.5 ± 0.0	9.8 ± 0.0	12.1 ± 0.0
	Kotlik	KO1	13.5 ± 0.0	9.5 ± 0.0	12.3 ± 0.0
		KO2	13.5 ± 0.0	8.8 ± 0.0	13.2 ± 0.0
		KO3	13.2 ± 0.0	8.7 ± 0.0	13.1 ± 0.0
	Krusenstern	KR1	3.6 ± 0.0	11.6 ± 0.1	8.9 ± 0.0
		KR2	3.5 ± 0.0	10.9 ± 0.0	9.0 ± 0.1
		KR3	3.5 ± 0.0	11.0 ± 0.0	8.9 ± 0.0
		KR4	3.6 ± 0.0	11.1 ± 0.0	9.0 ± 0.1
		KR5	3.6 ± 0.0	11.0 ± 0.1	8.9 ± 0.0
		KR6	3.6 ± 0.0	10.9 ± 0.0	8.8 ± 0.0
		KR7	3.5 ± 0.0	10.8 ± 0.0	8.9 ± 0.0
	Sisualik	SI1	8.2 ± 0.0	10.1 ± 0.0	16.5 ± 0.0
		SI2	8.0 ± 0.0	10.0 ± 0.0	16.8 ± 0.0
		SI3	7.6 ± 0.0	9.8 ± 0.0	17.1 ± 0.0
		SI4	9.0 ± 0.9	9.7 ± 0.1	17.1 ± 0.3
		SI5	4.7 ± 0.8	10.1 ± 0.1	17.8 ± 0.2
		SI6	6.1 ± 0.0	10.3 ± 0.0	17.9 ± 0.0
September 2003	Akulaaq	AU1	6.2 ± 0.0	11.4 ± 0.0	5.5 ± 0.0
		AU2	5.8 ± 0.1	11.5 ± 0.0	5.3 ± 0.1
		AU3	6.3 ± 0.0	11.4 ± 0.0	5.0 ± 0.0
		AU4	6.3 ± 0.0	11.4 ± 0.0	4.8 ± 0.0
		AU5	6.2 ± 0.0	11.9 ± 0.0	4.5 ± 0.0
	Krusenstern	KR1	3.4 ± 0.0	11.9 ± 0.0	5.1 ± 0.0
		KR2	3.3 ± 0.0	11.9 ± 0.0	5.0 ± 0.0
		KR3	3.4 ± 0.0	11.8 ± 0.0	5.2 ± 0.0
		KR4	3.4 ± 0.0	11.8 ± 0.0	4.9 ± 0.0
		KR5	3.4 ± 0.0	11.5 ± 0.0	5.0 ± 0.0
		KR6	3.2 ± 0.0	11.8 ± 0.0	4.6 ± 0.0
		KR7	3.4 ± 0.0	12.0 ± 0.1	4.9 ± 0.0
	Sisualik	SI1	5.6 ± 0.0	11.7 ± 0.0	4.7 ± 0.0
		SI3	6.3 ± 0.0	11.4 ± 0.0	4.7 ± 0.0
		SI5	9.1 ± 0.0	11.6 ± 0.0	4.4 ± 0.0
January 2004	Akulaaq	AU2	9.7 ± 0.1	5.5 ± 0.0	-0.4 ± 0.1
		AU4	7.4 ± 0.0	12.1 ± 0.1	-0.6 ± 0.1
	Imik	IM1	2.7 ± 0.0	10.6 ± 0.1	-0.6 ± 0.0
		IM2	4.3 ± 0.0	5.3 ± 0.0	-0.6 ± 0.0
	Kotlik	KO3	29.6 ± 2.2	4.7 ± 0.1	-0.8 ± 0.2
	Krusenstern	KR1	4.3 ± 0.0	6.6 ± 0.2	-0.3 ± 0.0
		KR4	2.8 ± 0.0	6.1 ± 0.1	-0.4 ± 0.2
		KR6	4.3 ± 0.0	3.4 ± 0.1	-0.3 ± 0.2
	Sisualik	ALL SITES FROZEN TO THE BOTTOM			
April 2004	Akulaaq	AU1	20.1 ± 0.1	0.7 ± 0.0	-1.2 ± 0.0
		AU2	17.6 ± 0.0	1.0 ± 0.5	-1.1 ± 0.0
		AU3	19.0 ± 0.0	1.1 ± 0.0	-1.2 ± 0.0
		AU4	19.0 ± 0.0	0.6 ± 0.0	-1.2 ± 0.0
		AU5	21.4 ± 0.0	0.6 ± 0.0	-1.3 ± 0.0
	Imik	ALL SITES FROZEN TO THE BOTTOM			

APPENDIX C: STATION PHYSICOCHEMICAL MEANS / LAGOON

Date	Lagoon	Station	Mean		
			Salinity (psu)	Dissolved Oxygen (mg/L)	Water Temperature (°C)
April 2004 (Cont.)	Kotlik	KO2	49.1 ± 0.3	2.5 ± 0.0	-2.6 ± 0.3
	Krusenstern	KR1	5.1 ± 0.0	2.1 ± 0.0	-0.1 ± 0.1
		KR2	5.1 ± 0.0	3.6 ± 0.0	-0.3 ± 0.0
		KR3	5.1 ± 0.0	3.0 ± 0.0	-0.3 ± 0.0
		KR4	5.1 ± 0.0	2.7 ± 0.0	-0.4 ± 0.0
		KR5	5.1 ± 0.0	1.1 ± 0.0	-0.4 ± 0.0
		KR6	5.1 ± 0.0	1.7 ± 0.2	-0.3 ± 0.0
		KR7	5.1 ± 0.0	4.9 ± 0.0	0.1 ± 0.3
	Sisualik	ALL SITES FROZEN TO THE BOTTOM			
September 2004	Akulaaq	AU1	10.8 ± 0.0	9.0 ± 0.0	13.1 ± 0.1
		AU2	10.7 ± 0.0	8.8 ± 0.0	13.1 ± 0.0
		AU3	10.7 ± 0.0	8.1 ± 0.0	13.7 ± 0.0
		AU4	10.6 ± 0.0	8.5 ± 0.0	13.3 ± 0.0
		AU5	10.8 ± 0.0	8.5 ± 0.0	13.4 ± 0.0
	Krusenstern	KR1	3.2 ± 0.0	11.2 ± 0.0	14.6 ± 0.0
		KR2	3.2 ± 0.0	10.7 ± 0.2	14.1 ± 0.0
		KR3	3.2 ± 0.0	11.0 ± 0.1	13.8 ± 0.1
		KR4	3.1 ± 0.0	10.6 ± 0.1	13.8 ± 0.0
		KR5	3.1 ± 0.1	10.6 ± 0.0	13.1 ± 0.0
		KR6	2.7 ± 0.0	11.0 ± 0.0	12.6 ± 0.1
		KR7	3.1 ± 0.0	10.8 ± 0.1	14.0 ± 0.0
	Sisualik	SI1	9.7 ± 0.3	9.6 ± 0.0	6.9 ± 0.1
		SI2	9.5 ± 0.0	9.4 ± 0.0	7.5 ± 0.0
		SI3	13.0 ± 0.0	9.3 ± 0.0	7.7 ± 0.0
		SI4	12.9 ± 1.0	9.3 ± 0.0	8.5 ± 0.0
		SI5	13.7 ± 0.1	9.3 ± 0.1	8.7 ± 0.2
		SI6	12.7 ± 6.1	9.1 ± 0.3	10.0 ± 0.1

APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON

Table D. Kruskal-Wallis mean ranks and significance for physicochemical parameters at all sampling stations in Akulaaq Lagoon between January 2003 and September 2004. Groups based on station number. * significant value ($p < 0.05$)

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
January 2003	Salinity (psu)	1	5	17.00	16.726	4	0.002*
		2	4	10.50			
		3	4	2.50			
		4	3	11.67			
		5	3	6.00	16.395	4	0.003*
		Total	19				
		1	5	8.50			
		2	4	2.50			
	DO (mg/L)	3	4	14.50	17.224	4	0.002*
		4	3	8.50			
		5	3	18.00			
		Total	19				
	Water Temperature (°C)	1	5	7.50	16.576	4	0.002*
		2	4	17.50			
		3	4	8.63			
		4	3	14.00			
		5	3	2.00	16.576	4	0.002*
		Total	19				
April 2003	Salinity (psu)	1	4	8.50	16.576	4	0.002*
		2	3	2.00			
		3	4	17.50			
		4	4	6.50			
		5	4	13.50	16.576	4	0.002*
		Total	19				

APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
April 2003 (Cont.)	DO (mg/L)	1	4	6.50	17.381	4	0.002*
		2	3	18.00			
		3	4	14.50			
		4	4	10.50			
		5	4	2.50			
		Total	19				
	Water Temperature (°C)	1	4	15.25	16.001	4	0.003*
		2	3	17.00			
		3	4	2.50			
		4	4	8.13			
		5	4	8.88			
		Total	19				
July 2003	Salinity (psu)	1	4	2.50	18.448	4	0.001*
		2	4	6.50			
		3	4	10.50			
		4	4	17.38			
		5	4	15.63			
		Total	20				
	DO (mg/L)	1	4	3.00	17.295	4	0.002*
		2	4	9.25			
		3	4	7.25			
		4	4	14.50			
		5	4	18.50			
		Total	20				
	Water Temperature (°C)	1	4	6.50	18.263	4	0.001*
		2	4	2.50			
		3	4	10.50			
		4	4	14.88			
		5	4	18.13			
		Total	20				

APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
September 2003	Salinity (psu)	1	4	10.50	18.867	4	0.001*
		2	4	2.50			
		3	4	14.50			
		4	4	18.50			
		5	4	6.50	10.999	4	0.027*
		Total	20				
		1	4	8.00			
		2	4	11.75			
	DO (mg/L)	3	4	7.75	18.693	4	0.001*
		4	4	6.50			
		5	4	18.50			
		Total	20				
	Water Temperature (°C)	1	4	18.50	4.755	1	0.029*
		2	4	14.50			
		3	4	10.50			
		4	4	6.50			
January 2004	Salinity (psu)	5	4	2.50	4.582	1	0.032*
		Total	20				
		2	3	6.00			
		4	4	2.50			
	DO (mg/L)	Total	7		4.755	1	0.029*
		2	3	2.00			
		4	4	5.50			
		Total	7				
	Water Temperature (°C)	2	3	6.00	4.755	1	0.029*
		4	4	2.50			
		Total	7				

APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
April 2004	Salinity (psu)	1	3	14.00	17.599	4	0.001*
		2	4	2.50			
		3	4	10.50			
		4	4	6.50			
	DO (mg/L)	5	4	17.50	16.664	4	0.002*
		Total	19				
		1	3	10.00			
		2	4	14.50			
	Water Temperature (°C)	3	4	16.50	17.902	4	0.001*
		4	4	6.50			
		5	4	2.50			
		Total	19				
September 2004	Salinity (psu)	1	3	6.00	19.616	4	0.001*
		2	4	17.50			
		3	4	9.50			
		4	4	13.50			
	DO (mg/L)	5	4	2.50	18.743	4	0.001*
		Total	21				
		1	4	19.50			
		2	5	7.00			
		3	4	11.50			
		4	4	2.50			
		5	4	15.50			
		Total	21				

APPENDIX D: KRUSKAL-WALLIS RESULTS FOR AKULAAQ LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
September 2004 (Cont.)	Water Temperature (°C)	1	4	6.50	18.470	4	0.001*
		2	5	3.80			
		3	4	19.50			
		4	4	11.75			
		5	4	15.25			
		Total	21				

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Table E. Kruskal-Wallis mean ranks and significance for physicochemical parameters at all sampling stations in Krusenstern Lagoon between January 2003 and September 2004. Groups based on station number. * significant value ($p < 0.05$)

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
January 2003	Salinity (psu)	1 2 3 4 5 6 7 Total	12 14 11 12 13 8 13 83	71.88 44.89 25.41 24.21 52.04 66.75 16.50	55.983	6	0.001*
	DO (mg/L)	1 2 3 4 5 6 7 Total	12 14 11 12 13 8 13 83	72.96 68.39 52.00 27.50 7.00 17.50 40.00	78.617	6	0.001*
	Water Temperature (°C)	1 2 3 4 5 6 7 Total	12 14 11 12 13 8 13 83	63.88 43.07 34.68 25.54 29.77 23.56 65.62	37.279	6	0.001*

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
April 2003	Salinity (psu)	1	7	26.64	20.124	4	0.001*
		2	8	33.00			
		3	10	29.65			
		5	10	13.20			
	DO (mg/L)	6	9	12.33	16.706	4	0.002*
		Total	44				
		1	7	30.57			
		2	8	8.38			
	Water Temperature (°C)	3	10	28.95	28.965	4	0.001*
		5	10	25.75			
		6	9	18.00			
		Total	44				
	Salinity (psu)	1	6	20.00	31.214	6	0.001*
		2	4	8.00			
		3	4	11.00			
		4	5	20.00			
July 2003		5	4	23.75			
		6	5	31.00			
		7	5	3.00			
		Total	33				

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
July 2003 (Cont.)	DO (mg/L)	1	6	30.50	31.448	6	0.001*
		2	4	7.50			
		3	4	19.50			
		4	5	25.00			
		5	4	17.50			
		6	5	12.00			
		7	5	3.00			
		Total	33				
	Water Temperature (°C)	1	6	13.00	31.528	6	0.001*
		2	4	29.38			
		3	4	13.00			
		4	5	28.70			
		5	4	22.50			
		6	5	3.00			
		7	5	13.00			
		Total	33				
September 2003	Salinity (psu)	1	5	22.00	33.000	6	0.001*
		2	5	8.00			
		3	5	27.00			
		4	5	17.00			
		5	5	32.00			
		6	5	3.00			
		7	4	12.50			
		Total	34				

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
September 2003 (Cont.)	DO (mg/L)	1 2 3 4 5 6 7 Total	5 5 5 5 5 5 4 34	24.40 27.10 15.30 15.00 3.00 9.70 30.63	28.423	6	0.001*
	Water Temperature (°C)	1 2 3 4 5 6 7 Total	5 5 5 5 5 5 4 34	27.00 17.00 32.00 12.00 22.00 3.00 7.50	32.639	6	0.001*
	Salinity (psu)	1 4 6 Total	8 11 7 26	15.50 6.00 23.00	22.516	2	0.001*
January 2004	DO (mg/L)	1 4 6 Total	8 11 7 26	22.50 13.00 4.00	21.983	2	0.001*
	Water Temperature (°C)	1 4 6 Total	8 11 7 26	19.50 8.55 14.43	9.868	2	0.001*

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
April 2004	Salinity (psu)	1	9	37.78	35.118	6	0.001*
		2	7	38.57			
		3	5	12.50			
		4	7	7.36			
		5	9	35.00			
		6	7	24.64			
		7	7	16.36			
		Total	51				
	DO (mg/L)	1	9	20.83	21.983	2	0.001*
		2	7	41.00			
		3	5	35.00			
		4	7	29.00			
		5	9	5.00			
		6	7	13.21			
		7	7	48.00			
		Total	51				
	Water Temperature (°C)	1	9	40.89	42.021	6	0.001*
		2	7	30.43			
		3	5	18.80			
		4	7	7.00			
		5	9	11.22			
		6	7	27.29			
		7	7	44.29			
		Total	51				

APPENDIX E: KRUSKAL-WALLIS RESULTS FOR KRUSENSTERN LAGOON

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
September 2004	Salinity (psu)	1	2	11.50	12.707	6	0.048*
		2	2	11.50			
		3	2	11.50			
		4	2	6.00			
		5	2	4.50			
		6	2	1.50			
		7	2	6.00			
		Total	14				
	DO (mg/L)	1	2	13.50	11.393	6	0.077
		2	2	4.75			
		3	2	10.25			
		4	2	2.25			
		5	2	4.50			
		6	2	10.75			
		7	2	6.50			
		Total	14				
	Water Temperature (°C)	1	2	13.50	12.855	6	0.045*
		2	2	11.50			
		3	2	6.00			
		4	2	7.00			
		5	2	3.50			
		6	2	1.50			
		7	2	9.50			
		Total	14				

APPENDIX F: KRUSKAL-WALLIS RESULTS FOR SISUALIK

Table F. Kruskal-Wallis mean ranks and significance for physicochemical parameters at all sampling stations in Sisualik between January 2003 and September 2004. Groups based on station number. * significant value ($p < 0.05$)

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
January 2003	Salinity (psu)	1	5	12.00	11.597	2	0.003*
		2	4	7.50			
		3	5	3.00			
		Total	14				
	DO (mg/L)	1	5	11.30	9.895	2	0.007*
		2	4	2.50			
		3	5	7.70			
		Total	14				
	Water Temperature (°C)	1	5	3.00	11.805	2	0.003*
		2	4	7.50			
		3	5	12.00			
		Total	14				
April 2003	Salinity (psu)	1	3	8.00	7.513	2	0.023*
		2	3	5.00			
		3	3	2.00			
		Total	9				
	DO (mg/L)	1	3	2.00	7.322	2	0.026*
		2	3	5.00			
		3	3	8.00			
		Total	9				
	Water Temperature (°C)	1	3	2.00	7.784	2	0.020*
		2	3	5.00			
		3	3	8.00			
		Total	9				

APPENDIX F: KRUSKAL-WALLIS RESULTS FOR SISUALIK

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
July 2003	Salinity (psu)	1	3	21.00	22.098	5	0.001*
		2	5	17.00			
		3	5	11.00			
		4	4	21.50			
	DO (mg/L)	5	4	2.50	21.483	5	0.001*
		6	4	6.50			
		Total	25				
		1	3	17.33			
	Water Temperature (°C)	2	5	13.00	21.090	5	0.001*
		3	5	6.10			
		4	4	3.63			
		5	4	17.25			
	Salinity (psu)	6	4	23.50	12.750	2	0.002*
		Total	25				
		1	3	2.00			
		2	5	7.00			
September 2003	DO (mg/L)	3	5	12.00	12.704	2	0.002*
		4	4	13.00			
		5	4	22.50			
		6	4	20.50			
	Salinity (psu)	Total	25		12.750	2	0.002*
		1	5	3.00			
		3	5	8.00			
		5	5	13.00			
	DO (mg/L)	Total	15		12.704	2	0.002*
		1	5	13.00			
		3	5	3.00			
		5	5	8.00			
	Water Temperature (°C)	Total	15		12.704	2	0.002*
		1	5	13.00			
		3	5	3.00			
		5	5	8.00			

APPENDIX F: KRUSKAL-WALLIS RESULTS FOR SISUALIK

Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
September 2003 (Cont.)	Water Temperature (°C)	1	5	9.50	10.822	2	0.004*
		3	5	11.50			
		5	5	3.00			
		Total	15				
September 2004	Salinity (psu)	1	4	6.00	13.852	5	0.017*
		2	3	4.00			
		3	5	15.00			
		4	5	15.20			
		5	5	21.00			
		6	4	14.75			
		Total	26				
	DO (mg/L)	1	4	24.50	13.952	5	0.016*
		2	3	17.33			
		3	5	8.40			
		4	5	12.40			
		5	5	13.50			
		6	4	7.38			
		Total	26				
	Water Temperature (°C)	1	4	2.50	23.655	5	0.001*
		2	3	6.00			
		3	5	10.00			
		4	5	16.00			
		5	5	19.00			
		6	4	24.50			
		Total	26				

APPENDIX G: STATION MEAN ALGAL BIOMASS / LAGOON

Table G. Station mean and standard deviation (± 1) for January 2003, April 2003 and September 2004 algal biomass. The mean at each station was calculated by averaging three subsamples taken from a 1 L Niskin bottle. In ice-covered periods, the sample was collected just beneath the ice; in open water periods, the sample was collected ≈ 0.5 m below the surface.

<i>Date</i>	<i>Lagoon</i>	<i>Station</i>	<i>Mean Chlorophyll a ($\mu\text{g/L}$)</i>	<i>Mean Phaeophytin ($\mu\text{g/L}$)</i>
January 2003	Akulaaq	AU1	0.34 ± 0.04	0.65 ± 0.04
		AU2	0.14 ± 0.04	0.48 ± 0.19
		AU3	0.47 ± 0.05	0.97 ± 0.06
		AU4	1.95 ± 0.04	2.64 ± 0.00
		AU5	0.08 ± 0.08	0.16 ± 0.15
	Imik	IM1	1.67 ± 0.15	3.34 ± 0.17
	Kotlik	KO1	0.09 ± 0.01	0.20 ± 0.02
		KO2	0.10 ± 0.00	0.24 ± 0.09
	Krusenstern	KR1	0.68 ± 0.50	0.86 ± 0.64
		KR2	1.06 ± 0.53	0.91 ± 0.65
		KR3	1.93 ± 0.74	2.19 ± 1.24
		KR4	1.02 ± 0.77	1.14 ± 0.97
		KR5	0.69 ± 0.21	0.83 ± 0.27
		KR6	0.80 ± 0.12	0.80 ± 0.18
		KR7	0.72 ± 0.16	0.60 ± 0.14
	Sisualik	SI1	0.08 ± 0.05	0.17 ± 0.07
		SI2	0.56 ± 0.24	1.13 ± 0.57
		SI3	0.55 ± 0.12	0.60 ± 0.12
April 2003	Akulaaq	AU1	16.89 ± 2.71	13.77 ± 3.12
		AU2	1.24 ± 0.76	3.34 ± 1.56
		AU3	0.51 ± 0.04	0.40 ± 0.07
		AU4	0.75 ± 0.46	0.95 ± 0.33
		AU5	1.99 ± 0.70	1.13 ± 0.36
	Kotlik	KO1	1.35 ± 0.07	1.13 ± 0.55
		KO2	0.46 ± 0.27	0.31 ± 0.11
		KO3	2.11 ± 0.53	0.58 ± 0.23
	Krusenstern	KR2	38.81 ± 6.38	22.49 ± 1.85
		KR3	38.07 ± 11.27	33.15 ± 11.62
		KR4	22.76 ± 2.20	13.21 ± 1.93
		KR5	23.75 ± 0.77	15.63 ± 3.22
		KR6	20.71 ± 3.23	19.83 ± 2.63
		KR7	33.61 ± 7.16	34.61 ± 11.53
	Sisualik	SI1	6.34 ± 2.93	7.67 ± 3.61
		SI2	7.70 ± 1.29	10.16 ± 1.44
		SI3	3.87 ± 1.52	3.00 ± 0.83
September 2004	Akulaaq	AU1	1.34 ± 0.48	0.95 ± 0.10
		AU2	1.73 ± 0.43	0.84 ± 0.22
		AU3	3.18 ± 1.14	1.54 ± 0.71
		AU4	1.49 ± 0.24	0.64 ± 0.09
		AU5	1.07 ± 0.81	0.79 ± 0.10
	Krusenstern	KR1	2.44 ± 1.21	0.61 ± 0.35
		KR2	4.65 ± 1.14	0.59 ± 0.21
		KR3	9.92 ± 2.39	1.80 ± 0.63
		KR4	10.30 ± 8.10	2.77 ± 2.65
		KR5	6.41 ± 3.04	0.97 ± 0.96
		KR6	6.28 ± 1.59	1.50 ± 0.51
		KR7	5.21 ± 0.93	0.78 ± 0.09

APPENDIX H: MEAN RELATIVE ABUNDANCE OF ZOOPLANKTON / LAGOON

Table H. Mean relative abundance and standard deviation (± 1) for the most dominant zooplankton collected in five coastal lagoons in CAKR in January 2003, July 2003, September 2003, and September 2004. +only one sample collected, no mean or standard deviation

Date	Lagoon	Station	Relative Abundance	
			Copepods (ind/m ³)	Cladocerans (ind/m ³)
January 2003	Krusenstern	KR1+	45+	0
	Sisualik	SI1+	136+	0
July 2003	Akulaaq	AU1	27224 $\pm$ 2414	1715 $\pm$ 1220
		AU2	32333 $\pm$ 9665	1206 $\pm$ 231
		AU3	30618 $\pm$ 9640	3153 $\pm$ 1251
		AU4	23481 $\pm$ 7174	3257 $\pm$ 1885
		Lagoon	28414 $\pm$ 3914	2333 $\pm$ 1029
	Imik	IM2	1074 $\pm$ 199	8754 $\pm$ 2188
		IM3	1379 $\pm$ 566	2405 $\pm$ 637
		Lagoon	1227 $\pm$ 216	5579 $\pm$ 4489
	Kotlik	KO1	12278 $\pm$ 1546	0
		KO2	9507 $\pm$ 2483	0
		KO3	7101 $\pm$ 2522	0
		Lagoon	9628 $\pm$ 2591	0
	Krusenstern	KR1	1659 $\pm$ 653	0
		KR2+	500+	0
		KR3	1448 $\pm$ 477	0
		KR4	2272 $\pm$ 449	0
		KR5	1780 $\pm$ 564	0
		KR6	1134 $\pm$ 736	0
		KR7	819 $\pm$ 152	0
		Lagoon	1373 $\pm$ 604	0
	Sisualik	SI1	1981 $\pm$ 743	0
		SI2	4103 $\pm$ 4810	0
		SI3	414 $\pm$ 541	0
		SI4	318 $\pm$ 279	0
		SI5	279 $\pm$ 119	0
		SI6	159 $\pm$ 119	0
		Lagoon	1209 $\pm$ 1572	0
September 2003	Akulaaq	AU1	14006 $\pm$ 990	3042 $\pm$ 1521
		AU2	14908 $\pm$ 3115	1038 $\pm$ 409
		AU3	12380 $\pm$ 1023	2535 $\pm$ 3069
		AU4	8970 $\pm$ 1023	2114 $\pm$ 1091
		AU5	11006 $\pm$ 3650	1627 $\pm$ 828
		Lagoon	12254 $\pm$ 2370	2071 $\pm$ 778
	Krusenstern	KR1	97 $\pm$ 83	0
		KR2	115 $\pm$ 51	0
		KR3	133 $\pm$ 93	0
		KR4	73 $\pm$ 49	12 $\pm$ 12
		KR5	49 $\pm$ 24	0
		KR6	91 $\pm$ 30	45 $\pm$ 30
		KR7	76 $\pm$ 13	25 $\pm$ 13
		Lagoon	91 $\pm$ 28	12 $\pm$ 18

APPENDIX H: MEAN RELATIVE ABUNDANCE OF ZOOPLANKTON / LAGOON

<i>Date</i>	<i>Lagoon</i>	<i>Station</i>	<i>Relative Abundance</i>	
			<i>Copepods (ind/m³)</i>	<i>Cladocerans (ind/m³)</i>
September 2003 (Cont.)	Sisualik	SI1	601 ± 248	0
		SI3	743 ± 141	0
		SI5	546 ± 318	0
		Lagoon	630 ± 102	0
September 2004	Akulaaq	AU1	80 ± 119	0
		AU2	6988 ± 11732	3592 ± 5093
		AU3	318 ± 199	0
		AU4	91 ± 45	45 ± 45
		AU5	32 ± 32	0
		Lagoon	1502 ± 3069	728 ± 1602
	Krusenstern	KR1	95 ± 64	0
		KR2	143 ± 64	0
		KR3	127 ± 80	0
		KR4	95 ± 48	0
		KR5	175 ± 191	0
		KR6	34 ± 17	0
		KR7	95 ± 32	0
		Lagoon	109 ± 45	0
	Sisualik	SI1	3714 ± 1415	0
		SI2	2087 ± 672	0
		SI3	1061 ± 389	0
		SI4	364 ± 45	0
		SI5	2706 ± 2653	0
		SI6	1528 ± 573	0
		Lagoon	1910 ± 1198	0

APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON

Table I. Kruskal-Wallis mean ranks and significance for most abundant zooplankton at sampling stations in Akulaaq, Krusenstern, and Sisualik in July 2003, September 2003, and September 2004. Groups based on station number. *significant value ($p < 0.05$); + no sample collected

Lagoon	Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
Akulaaq	July 2003	Cladocerans	1	3	4.50	5.978	3	0.113
			2	3	3.50			
			3	3	8.67			
			4	3	9.33			
			5	+	-			
			Total	12				
	September 2003	Copepods	1	3	6.00	1.981	3	0.576
			2	3	7.67			
			3	3	8.00			
			4	3	4.33			
			5	+	-			
			Total	12				
	September 2003	Cladocerans	1	3	8.33	2.077	4	0.722
			2	3	4.33			
			3	2	7.00			
			4	2	8.50			
			5	3	7.33			
			Total	13				
	September 2003	Copepods	1	3	3.67	7.527	4	0.111
			2	3	11.00			
			3	2	9.00			
			4	2	3.50			
			5	3	7.33			
			Total	13				

APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON

Lagoon	Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
Akulaaq (Cont.)	September 2004	Cladocerans	1	3	5.50	4.757	4	0.313
			2	2	9.75			
			3	3	7.50	4.757	4	0.313
			4	3	10.00			
			5	3	5.50			
			Total	14				
		Copepods	1	3	6.50	6.465	4	0.167
			2	3	10.50			
			3	3	12.17	6.465	4	0.167
			4	3	6.67			
			5	3	4.17			
			Total	15				
Krusenstem	July 2003	Cladocerans	1	3	11.00	0.000	6	1.000
			2	3	11.00			
			3	3	11.00	0.000	6	1.000
			4	3	11.00			
			5	3	11.00			
			6	3	11.00	0.000	6	1.000
			7	3	11.00			
			Total	21	11.00			
		Copepods	1	3	10.67	11.573	6	0.072
			2	1	2.00			
			3	3	10.00	11.573	6	0.072
			4	3	16.33			
			5	2	13.00			
			6	3	5.33	11.573	6	0.072
			7	3	5.33			
			Total	18				

APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON

Lagoon	Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
Krusenstern (Cont.)	September 2003	Cladocerans	1	3	9.50	4.460	6	0.615
			2	3	9.50			
			3	3	9.50			
			4	3	12.67			
			5	3	9.50			
			6	3	13.33			
			7	3	13.00			
			Total	21				
	September 2004	Cladocerans	1	3	9.67	6.437	6	0.376
			2	3	16.00			
			3	3	15.33			
			4	3	8.17			
			5	3	6.00			
			6	3	9.83			
			7	3	12.00			
			Total	21				
	September 2004	Copepods	1	3	9.67	6.437	6	0.376
			2	3	16.00			
			3	3	15.33			
			4	3	8.17			
			5	3	6.00			
			6	3	9.83			
			7	3	12.00			
			Total	21				
	September 2004	Cladocerans	1	3	11.00	0.000	6	1.000
			2	3	11.00			
			3	3	11.00			
			4	3	11.00			
			5	3	11.00			
			6	3	11.00			
			7	3	11.00			
			Total	21				

APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON

Lagoon	Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
Krusenstern (Cont.)	September 2004 (Cont.)	Copepods	1	2	8.75	5.242	6	0.513
			2	2	13.00			
			3	3	11.50			
			4	3	9.50			
			5	3	10.67			
			6	2	2.25			
			7	3	9.33			
			Total	18				
Sisualik	July 2003	Cladocerans	1	3	9.50	0.000	5	1.000
			2	3	9.50			
			3	3	9.50			
			4	3	9.50			
			5	3	9.50			
			6	3	9.50			
			Total	18				
		Copepods	1	2	15.00	10.260	5	0.068
			2	3	14.67			
			3	3	6.67			
			4	3	7.67			
			5	3	7.67			
			6	3	4.33			
			Total	17				

APPENDIX I: KRUSKAL-WALLIS RESULTS FOR ZOOPLANKTON

Lagoon	Date	Parameter	Station Number	N	Mean Rank	X ²	df	p-value
Sisualik (Cont.)	September 2003	Cladocerans	1	3	9.50	0.000	5	1.000
			2	3	9.50			
			3	3	9.50			
			4	3	9.50			
			5	3	9.50			
			6	3	9.50			
			Total	18				
	September 2004	Copepods	1	3	5.17	2.980	2	0.225
			2	+	-			
			3	3	6.83			
			4	+	-			
			5	3	3.00			
			6	+	-			
			Total	9				
	September 2004	Cladocerans	1	3	9.50	0.000	5	1.000
			2	3	9.50			
			3	3	9.50			
			4	3	9.50			
			5	3	9.50			
			6	3	9.50			
			Total	18				
	September 2004	Copepods	1	3	14.33	10.429	5	0.064
			2	3	10.67			
			3	3	7.00			
			4	2	1.50			
			5	3	8.50			
			6	2	5.75			
			Total	16				