Aquatic biodiversity, community composition and ecosystem processes in upper Noatak River basin: Gates of the Arctic Park and Preserve and the Noatak National Preserve, Alaska

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

The primary purpose of this project was to extend the limited base of data and knowledge about the freshwater resources of the Gates of the Arctic Park and Preserve and the Noatak National Preserve. This initiative is part of the National Park Service's (NPS) Inventory and Monitoring program and was intended as an initial effort to be continued as funding allows in future years. The goal of the 2005 effort was to follow up on and test recommendations developed during a scoping workshop organized by the NPS and held in Fairbanks 2-4 June, 2004 to discuss how a freshwater inventory and monitoring initiative in the Arctic National Parks network should be structured.

The 2005 field initiative included landscape and freshwater ecosystem experts from the University of Vermont, the University of Alaska at Fairbanks, the University of Alabama, Utah State University, and the Marine Biological Laboratory. Substantial assistance in preparation and execution of the field work was provided by staff from the NPS Arctic Parks Network (ARCN) in Fairbanks. The field team consisted of 10 members, including one NPS ranger.

The study area for the 2005 effort focused on a portion of the Noatak River from 12-Mile Creek to Lake Matchurak in the western region of the Gates of the Arctic Park and Preserve. The team was deployed from Bettles, Alaska on 13 July and operated continuously in the field until taken out on 26 July 2005. Over the course of the two week field period a total of 20 different stream reaches and 12 lakes were assessed.

The stream assessments included measurements of the physical characteristics of the streams (e.g., width, depth, substrate type and size, stability, and riparian cover). Dissolved oxygen, pH, temperature, and conductivity were measured in the field. Water samples were filtered and preserved for later analysis of phosphate, nitrate plus nitrite, total nitrogen and total phosphorus (by UV/visible spectrometry) and for base cations and metals (by inductively coupled plasma emission spectrometry). Benthic algal biomass was assessed in the field as extractable chlorophyll *a* and samples of benthic algae were saved for later taxonomic identification. Benthic macroinvertebrates were sampled both quantitatively (with a Surber sampler) and qualitatively (with a kick net). Representative specimens of key macroinvertebrates were saved for later taxonomic identification. Fish were assessed through a combination of field observation, trapping (for juveniles and small species), and occasional angling and gill netting. Representative samples of riparian vegetation, macroinvertebrates, and (where present) fish were taken for later analysis of food web structure through isotopic analysis of ^{13}C and ^{15}N.

The lake assessments included detailed bathymetric surveys by GPS-linked sonar depth sounding. Light, temperature, and dissolved oxygen were measured in selected vertical profiles of each lake using an automated sonde. Zooplankton were collected by timed tows with a mesh net. Fish were collected by gill netting and by angling.

All stream and lake sites were documented with digital photography and a GPS location good to 5-10 m accuracy. In addition, a series of photo-transects were obtained for the entire river valley surveyed, for future comparisons.

In general we found that streams in this region are naturally unproductive (oligotrophic) although the specific conductance (electrical conductivity) of the water was relatively high in all but one stream (300-800 µS, except Kamakak Creek = 70 µS). The higher values are much higher than we normally see in Arctic tundra streams on the North Slope (e.g., Kuparuk River = ~30-50 µS). High conductivity occurs due to high dissolved ions in the water. Further analysis of the water samples we collected will be required to determine the origin of the high conductivity in these waters. However, it is likely due to base cations dissolved from the carbonate geology that is prevalent in this area of the Noatak watershed. Algal and macroinvertebrate biomass were low and consistent with expectations for oligotrophic rivers. Tributary streams appeared to have few fish. (It was too early for the summer-run chum salmon known to utilize the Kugrak River.) Sculpin were found in several streams with young of the year salmonids (char or grayling) in some streams. The most productive and diverse stream site was at Kugrak Spring. Aquatic mosses dominated the primary producers at this travertine spring site, though macroinvertebrate biomass and diversity were not greatly different from other streams. Juvenile char were observed at this site.

Lakes were more diverse than the streams. Lake types included glacial-kettle, oxbow and thaw ponds with maximum depths ranging from 0-35 meters. Most survey lakes lacked stream inflows and preliminary observations suggest many of these lakes are primarily fed by groundwater inflows. Depth-specific conductivity gradients observed in some lakes suggest the epilimnion and hypolimnion have different inflow sources. Additionally, chlorophyll concentrations were up to fourteen times higher below the thermocline than concentrations in the epilimnion. Seven of the lakes contained fish, including populations of arctic grayling (*Thymallus arcticus*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), round whitefish (*Prosopium cylindroceum*) and nine-spine stickleback (*Pungitius pungitius*). The highest catch rates for young-of-year arctic grayling occurred in a small pond with a maximum depth of 1 meter, which was dominated by bacterial mats. The highest diversity and catch rates for adult fish occurred in a spring-fed, high-mountain lake with relatively low conductivity. Northern pike were found in large thaw ponds and when present, no other fish were observed. Preliminary observations suggest community and age structure of fish populations strongly influence biomass and diversity of zooplankton and benthic invertebrates; whereas, lake chemistry may play a smaller role.

Comparisons between lakes sampled in both 1973 (Young et al. 1974) and 2005 indicate water clarity was 2.6 times higher during the 2005 survey. In the 2005 survey, ten of twelve lakes were thermally stratified, whereas, only one of forty-seven lakes exhibited thermal stratification during the 1973 survey. In 2005 fish were caught in two lakes where fish were not observed during the 1974 survey (Lake Matchurak and Lake Omelaktivik). During the 1973 survey, Lake Matchurak also lacked a clearly defined outflow to the Noatak River; however, in 2005, we observed a well-defined connection to the Noatak and water clarity in the lake was six times higher than in 1973.

In summary, the research team was able to accomplish all of the proposed objectives for the 2005 field season, due largely to good working conditions and good luck with equipment and supplies. In general, the streams and lakes in this area of the Noatak River are oligotrophic and in good health. Spring streams, seepage lakes, and oxbow sloughs have higher productivity and diversity and should be considered areas of special ecological importance.

Introduction

Context for the expedition within the NPS/I&M

This collaborative project was established to help develop a long-term monitoring program for freshwater resources in the Arctic Network (ARCN) of the National Park Service (NPS) as a part of its national Inventory and Monitoring (I&M) program. The purpose of the I&M Program – established in 1992 – 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." To accomplish this mission the I&M program set out to:

1. provide a consistent database of information about our natural resources, including species diversity, distribution and abundance (Basic Inventories) and
2. determine the current condition of our resources and how they are changing over time (vital signs monitoring).

The I&M Program is vital to fulfilling the NPS's mission of protecting and preserving the natural resources of the national park system unimpaired for the use and enjoyment of current and future generations. The National Park Service Organic Act of 1916, clearly states that NPS lands will be managed:

> "... to promote and regulate the use of the federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as to conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life 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."

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the national park system. The act charges the secretary of the interior to "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System," and to "assure the full and proper utilization of the results of scientific studies for park management decisions." The lack of scientific information about resources under NPS stewardship has been widely acknowledged as inconsistent with NPS goals and standards. In 1992, the National Academy of Science recommended that, "if this agency is to meet the scientific and resource management challenges of the twenty-first century, a fundamental metamorphosis must occur."

Congress reinforced this message in the text of the FY 2000 Appropriations Bill: "The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. 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 from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

The nationwide Natural Resource Challenge program was put in place to revitalize and expand the natural resource program of the National Park Service. This effort increased funding to the I&M Program to facilitate improved baseline and long-term trend data for NPS natural resources. To efficiently and fairly use the funding available for inventories and monitoring, the 270 National Park Service units with significant natural resources managed by the service were organized into 32 biome based networks (ARCN 2004). Four networks were established in Alaska, clustering park units that share similar ecosystems and mandates (Figure 1). These networks have been designed to share expertise and infrastructure for both biological inventories and development of long-term ecological monitoring programs. The Arctic Network (ARCN) is the northern and western most unit in Alaska.

So that the program is highly accessible and useful to park managers, each network was advised to establish a Board of Directors and technical advisory committee to help plan and implement the monitoring program. The ARCN Board of Directors consists of three superintendents representing the park units, the Alaska Regional Inventory and Monitoring (I&M) coordinator, the ARCN I&M coordinator, and the Alaska Regional Science Advisor. The nine-member technical committee consists of the chiefs of resource management from each park unit, two natural resource scientists from each park unit, the ARCN I&M coordinator (chair), the Alaska Region I&M coordinator, and a USGS-Alaska Science Center liaison. Consultation with scientific experts and peer review are also encouraged in the development of the program.

Background planning for the expedition, 2004 Scoping Workshop

The Arctic Network (ARCN)

The ARCN consist of five NPS system units including the Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and the Noatak National Preserve (NOAT). Collectively these units represent approximately 25% of the land area of NPS managed units in the United States. GAAR, KOVA, and NOAT are contiguous and encompass a large expanse of mostly mountainous arctic ecosystems at the northern limit of treeline. Immediately to the west of these units lie CAKR and BELA which border Kotzebue Sound. BELA and CAKR are similar with respect to their coastal resources and strong biogeographic affinities to the Beringian subcontinent—the former land bridge between North America and Asia.

The ARCN park units are not connected to the road system. Much of the ARCN is designated or proposed wilderness. All of the NPS units within the ARCN parks are relatively recent additions to the National Park System. Portions of BELA, CAKR, and GAAR were initially created by presidential proclamation in 1978. All 5 units were re-designated or created with their present boundaries by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. Information about the natural resources in these units is limited because they are remote, relatively inaccessible, and until recently NPS natural resources staffing levels were insufficient to study these units in detail.

From the limited information available, it is clear that the ARCN parks have an extensive and diverse array of freshwater ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, and unique isolated spring systems. There are seven wild and scenic rivers in the ARCN, including: the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyukuk. All of the rivers of the ARCN are free-flowing and run clear most of the year. There are a few glacial streams that originate in the Brooks Range and several spring streams, including tributaries of the Reed River, Kugrak River and Alatna River, although to date, little or no studies have been conducted on them. Much of the land within the ARCN is drained by streams that flow from the uplands into lowland areas, then empty into the Chukchi Sea or coastal lagoons. These lagoons have been a primary fishing ground for native populations for the past 9000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds and terrestrial mammals. There are many lakes in the ARCN. Many of the large deep lakes such as Chandler, Selby, Feniak and Matchurak are renowned for their fisheries resources. These sites are heavily used by both subsistence and sport fishers. One of the largest, Walker Lake was designated a national natural landmarks in April 1968. Thousands of shallow lakes and wetlands are distributed throughout the parks. These ecosystems have diverse geologic origin including countless thaw ponds, kettle lakes, maars and oxbows that provide important rearing areas for fish, macroinvertebrates and waterfowl. There is little or no information on ground water in these parks, although some larger geothermal systems have been studied (e.g. Serpentine Hot Springs).

Goals of the ARCN Monitoring Program

The overall goal of natural resource monitoring in the National Parks is to develop scientifically sound information on the current status and long-term trends of the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. The specific goals of the NPS Vital Signs Monitoring Program are to:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

To achieve the above goals the Arctic Network is following the basic approach to designing a monitoring program laid out in the National Framework. The process involves the following five key steps:

- Define the purpose and scope of the monitoring program.
- Compile and summarize existing data and understanding of park ecosystems.
- Develop conceptual models of relevant ecosystem components.
- Select indicators and specific monitoring objectives for each.
- Determine the appropriate sampling design and sampling protocols.

These five steps were incorporated into a three-phase planning process that was established for the NPS monitoring program. Phase 1 involved defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and determining preliminary monitoring questions. Phase 2 involved refining the conceptual ecosystem models and selecting "vital signs" that will be used as indicators to detect change. Phase 3 of the planning process involves determining the overall sample design for monitoring; developing protocols for monitoring; and production of a data management plan for the network.

This Freshwater Initiative was established to respond to outputs from phase 1 and to provide inputs for phases 2 and 3. Initial planning for the Freshwater Initiative of the ARCN Inventory and Monitoring Program began with a scoping workshop held in Fairbanks, Alaska, 2-4 June 2004. This workshop was the first in a series of three workshops organized to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically-based, management-relevant, and affordable monitoring program for the Arctic Network (ARCN) of Parks. The information gleaned from the Freshwater Workshop was used to provide input for a draft, long-term monitoring plan for the Arctic Network (ARCN). The specific objectives for the 2004 Freshwater Scoping Workshop were:

- review and discuss a conceptual modeling effort
- identify specific monitoring questions for freshwater ecosystems, and
- identify possible sampling methodologies for high priority monitoring questions.

Specific outcomes from the 2004 Freshwater Workshop included a list of potential vital signs for freshwater resources and ideas for protocols that could be used to provide supporting baseline data for the vital signs monitoring program.

The 2005 field workplan

The study area for the 2005 effort focused on a portion of the Noatak River from 12-Mile Creek to Lake Matchurak in the western region of the Gates of the Arctic Park and Preserve. The team was deployed from Bettles, Alaska on 13 July and operated continuously in the field until taken out on 26 July 2005. Over the course of the two week field period a total of 20 different stream reaches and 12 lakes were assessed (Figure 2). We sampled physical, chemical, and biological components of these freshwater ecosystems. We focused on sampling parameters that could be used as indices for monitoring ecosystem change, and that integrated various aspects of ecosystem function. Other documents relevant to this sampling plan included:

- Science Plan entitled "Aquatic Biodiversity, Community Composition and Ecosystem Processes in Gates of the Arctic National Park and Preserve and the Noatak National Preserve"
- The Minimum Requirement Decision entitled "Aquatic Biodiversity, Community Composition and Ecosystem Processes in Gates of the Arctic National Park and Preserve and the Noatak National Preserve"
- Fish Resource Permit Application from the State of Alaska Department of Fish and Game.
- Trip planning maps and other documents produced by Andrew Balser at the University of Alaska – Fairbanks and accessible at http://www.uaf.edu/toolik/gis/TFS_GIS_noatak.html

Background

Literature review

General Setting

The Noatak River and its watershed occupies 6.6 million acres and extends from the Kotzebue Sound through the Arctic foothills of the Brooks Range located in northern Alaska. The headwaters of the Noatak River arise in the Gates of the Arctic Park within the central Brooks Range, a granitic northern extension of the Rocky Mountains, and is fed primarily by snowmelt, with some groundwater and glacial contribution (Elias 1999). The Noatak River is the longest continuous river segment in the U.S. National Wild and Scenic system and the largest mountain-ringed river basin that is virtually unaffected by humans in the United States (Milner 2005).

Due to its complex geology and variety of climate and landscape conditions, the Noatak River basin harbors a wider array of ecosystems than does any other watershed of comparable size in the Arctic region (Jorgenson et al. 2002). The vast and remote nature of the Noatak River basin has left the area and its ecosystems poorly documented from a scientific perspective. There has been little scientific exploration of the Noatak River since the first documented survey in 1885. Aside from a few isolated studies (Smith 1912, Young 1974, O'Brien 1975, Binkley et al. 1994, and Oswald et al. 1999), knowledge of the freshwater ecosystems of the Noatak River basin is limited. The 1973 expedition led by Steve Young was the first "coordinated, interdisciplinary scientific inquiry into the natural environment of a piece of Arctic terrain considerably larger than a number of states in the northeastern United States" (Young 1974). Following this expedition the Noatak watershed was established as a Biosphere Reserve in 1976, a National Monument in 1978, and a National Preserve in 1980 (Jorgenson et al. 2002).

The headwaters of the Noatak River arise near Mount Igikpak in the Schwatka Mountains and the then flow west down three distinct elevation gradients and across a longitudinal profile with six major regions. These six regions were designated by Smith (1913) as Headwater

Mountains, Aniuk Lowlands, Cutler River Upland, Mission Lowland, Zigichuck Hills, and the Coastal Lowland (as reported in Young 1974).

The Noatak River basin has an arctic climate, with long cold winters and short cool summers. Mean temperatures for July and February are approximately 11ºC and -25ºC, respectively (Bartlein et al. 1994). Arctic Alaskan streams display numerous high latitude characteristics that distinguish them from streams of low latitude temperate climates. Evidence shows that high latitude landscapes may serve as sensitive indicators of climate change, in particular, the chemical, biological and physical dynamics of freshwater ecosystems.

The floor of the basin and the surrounding uplands are essentially underlain by continuous permafrost. Arctic streams vary according to the permafrost characteristics and duration of seasonal thaw periods. The streams of the Noatak region begin to freeze in October, with no discharge from the upper basin by later winter. River ice breakup occurs in early May and then rapid streamflow is observed in June due to spring snowmelt (Milner et al. 2002). Ice extension to the substrate of the freshwaters during the Arctic winter creates a limited environment for the benthic macroinvertebrates in which adaptations and physiological tolerances to freezing are critical for survival (Milner et al. 2002).

The last decade (1990-2000) experienced temperatures warmest on record in the last 400 years (Overpeck et al. 1997). This warming event has triggered substantial tree growth in the Noatak Valley allowing for spruce forest to pervade the tundra landscape (Suarez 1999). These changes among others are inevitable given the current warming trends, providing even more rationale for the NPS's Inventory and Monitoring program initiative.

A 1983 NPS report has extensively documented effects of Placer mining and associated settling ponds on aquatic systems throughout GAAR. Placer mining in Mascot Creek has destroyed the riparian vegetation, important for stabilizing banks, providing allocthonous energy inputs and providing critical habitat for invertebrate and populations of arctic grayling, char/dolly varden and whitefish, which as of 1983 could no longer survive in this drainage. Furthermore, large sediment loads and associated contaminants from Mascot Creek flow into Glacier River before joining the North Fork of the Koyokuk where they increase turbidity and temperature, decrease oxygen content, modify flow and channel configuration (decrease channel depth and increase stream width and reduce pool and riffle areas). When settling ponds overflow, these effect can be detected 35 miles downstream of the North Fork of the Koyokuk. Based on siltation estimates from another placer mine, the magnitude of siltation may return to normal levels thirty five years following placer mining; however, complete restoration of channel configuration and biological diversity have not been documented.

Limnology of ARCN Aquatic Resources

Recent summaries of international research clearly document the past and future extent of climate warming in the Arctic (e.g., Chapin et al. 2000, IPCC 2001, US/ARC 2003, ACIA 2004). The ACIA report, for example, reports that in the decades between 1954 and 2003 annual average temperatures in the Arctic rose ~1^{o}C and that average winter temperatures increased 2-4^{o}C. Results from general circulation models (GCMs) differ somewhat regarding future trends, but for the models and scenarios selected for the ACIA report, average annual temperatures in the Arctic are expected to rise a further 3-5^{o}C and winter temperatures may increase by 4-7^{o}C. These models also suggest that the rising temperatures will be accompanied by increased precipitation mostly as rain; 20% more over the Arctic as a whole and up to 30% more in coastal areas during the winter and autumn.

Though Polar regions are particularly sensitive to climate change, the impacts of climate change on aquatic ecosystems and resources in the arctic are relatively poorly understood and may be important (Rouse et al. 1997, Hobbie et al. 1999, Hokinson et al. 1999). Recent studies suggest that the hydrologic regime of arctic watersheds is already responding to climate change (Serreze et al. 2002, Stone et al. 2002, Peterson et al. 2002, McClelland et al. 2004, Wu et al. 2005), resulting in warmer soil and active layer temperatures (Zhang et al. 1997). Modeling exercises suggest that increased air temperatures will increase active layer depths across the Arctic tundra landscape (Anisimov et al. 1997, Hinzman and Kane 1992, Kane et al. 1992, Zhang et al. 2006).

Monitoring key physical, chemical and biological indicators in arctic lakes, streams, and the surrounding landscape may increase our understanding of natural variation in these systems and provide us with information necessary for detecting future changes and establishing thresholds of impairment that affect ecological functioning of and within these ecosystems. To monitor status of aquatic ecosystems, we must first establish relevant baseline indicators and information on the ecological interactions of aquatic organisms and their environment.

With the exception of a few studies, most of which were funded by the National Park Service (O'Brien and Huggins 1974; LaPerriere et al. 1998; LaPerriere 1999; LaPerriere et al. 2003), very few studies have documented the limnology of arctic streams and lakes within the ARCN. There have been a broad range of well funded studies documenting physical, chemical and/or biological characteristics of small thaw ponds and lakes near Point Barrow and lakes and rivers in the upper Kuparuk River Region on the North Slope of the Alaskan Arctic near the Toolik Lake Long Term Ecological Research Site (Toolik LTER). For example, since its establishment as an LTER, researchers have published more than fifty manuscripts on lakes and streams near the Toolik Lake Long Term Ecological Research Site. In contrast, very few studies have documented the limnology of arctic lakes and streams within the ARCN and the majority of these studies have been conducted on a growing core of large, deep lakes within GAAR. To our knowledge, only one study has focused on lakes and streams in both GAAR and NOAT. The majority of these studies were funded by the National Park Service and often conducted by natural resource staff.

Livingstone et al. (1958) reported water transparency (secchi depth), temperature profiles, water chemistry and bathymetric estimates over a three day period in early August 1951 for Chandler Lake, which lies within the boundaries of the more recently established GAAR (see Table C1 for selected results). Twelve years later, in 1973, as part of a larger multidisciplinary study led by Young (1974), O'Brien and Huggins (1974) conducted the most extensive limnological survey ever completed within this region. This limnological survey included estimates of thermal stratification, water transparency, pelagic chlorophyll-a concentrations, major nutrients, cations and anions, and presence of zooplankton, benthic invertebrate and fish taxa (see Table C1-C5 for selected results). Weather during the summer of 1973 was unusually warm and dry during the first month of June, followed by cooler temperatures and very heavy, sometimes torrential downpours during the month of July and the first two weeks of August. The authors suggested that due to the high precipitation lakes and streams were at relatively high levels. During the month of July the mean temperature was 48.3˚F with a maximum mean temperature of 56.8 ˚F and a minimum mean temperature of 39.8˚F. Based on the distribution of terrestrial vegetation and the lack of fruit set by many plants, Young et al. (1974) suggested that air temperatures in this region during the summer of 1973 were likely a few degrees below normal. During this extensive survey, only one of the forty-seven lakes sampled was thermally stratified. These findings were supported by Hobbie (1980) and Livingstone (1963) who suggested arctic lakes do not thermally stratify due to constant wind mixing during the short ice-free season. Ornithologists on this multidisciplinary survey noted that half (67) of the one hundred thirty-three bird species documented during this survey were associated with aquatic habitats.

During the seventies there were very few studies on aquatic ecology within the parks. Studies on Noatak streams included data on benthic invertebrate assemblages collected near the Alaska pipeline prior to its development (Nauman and Kernodle 1977). Other studies conducted within park boundaries during the seventies include surveys of water chemistry and hydrology conducted by USGS (1978-79) and fish conducted by Alaska Division of Fish and Game (1978 and 1979). In an early proposal to Timothy Tilsworth (Associate Professor, Environmental Quality Engineering Program, University of Alaska- Fairbanks) to establish a water quality monitoring program for GAAR, Smith (a student at University of Alaska-Fairbanks) presented an extensive summary of the available water quality information in GAAR (1983). This report has been scanned and is in the ARCN bibliography.

Almost two decades later Swanson (1991) measured conductivity, alkalinity, hardness, water transparency, temperature and dissolved oxygen in nine lakes within the boundaries of GAAR and NOAT. In 1992-93 and 1995, LaPerriere (1999) followed up Swanson's work by collecting a more extensive suite of variables on sixteen lakes within GAAR and NOAT. As far we are aware, there have been no limnological studies of freshwaters within the other ARCN Parks.

Our goal was to develop a protocol and collect baseline data on physical, biological, and chemical parameters potentially important for understanding natural variability and future impairment of lakes and streams in the ARCN. To do this we surveyed lake morphometry, stream geomorphology, water quality and abundance of primary producers, macroinvertebrates and fish in 12 lakes and 21 tributary junctions in the upper Noatak River basin within the Gates of the Arctic National Park and Preserve and the Noatak National Reserve. We then compared these data to historical datasets from Livingstone et al. (1958), O'Brien and Huggins (1974), Swanson (1991) and LaPerriere (1999).

Agency Data

Pre-existing spatial data offering complete coverage for the Upper Noatak Basin (and for the ARCN units in general) are mainly limited to framework data layers provided by federal agencies. Owing to remoteness, these are by necessity relatively coarse scale, especially compared with similar thematic content for lands within the 48 contiguous states. Many other spatially explicit datasets exist which contain information from within these NPS units. However, they are generally limited to specific areas rather than providing synoptic landscape coverage. For a more complete and updated list of these datasets, please see the National Park Service - Alaska Region's GIS data store at http://www.nps.gov/akso/gis/. The only datasets which were available at the time of this study and relevant to these analyses were framework layers described below and in Appendix G.

National Elevation Dataset (NED), US Geological Survey (USGS)

The NED provides synoptic coverage of the United States for elevation/topgraphic data. For Alaska, the NED is offered as a 2 arc-second raster grid in decimal degrees. For practical purposes, most users project this into a conformal or cylindrical format (e.g. ALBERS Alaska, Universal Transverse Mercator), and resample the data to 50m grid cells. Elevations are given in meters, and all data derive from the original USGS quadrangle maps and associated production airphotos. For most of Alaska, these data are current as of the 1950s – 1970s. Initial DEM data were produced from interpolated topographic lines from USGS quadrangles. These tiles were later re-processed and filtered to address quadrangle-specific errors, seam slivers, and other artifacts. The final product is a seamless DEM appropriate for basic hydrologic analysis at coarse to moderate scales. For more information, see http://ned.usgs.gov.

National Hydrography Dataset (NHD), USGS

Like the NED, the NHD is a seamless, re-analyzed national product deriving from original USGS quadrangle information. It is distributed as a geodatabase of vector features, including improved topology, network associations and quantitative and qualitative attributes (e.g. feature dimesions, feature names). In Alaska, these data are equivalent to hydrographic features mapped at 1 : 63,360 scale (inch to the mile) and distributed in decimal degrees. These data are also appropriate for hydrologic analysis at coarse to moderate scales. For more information, see http://nhd.usgs.gov.

Ecological Subsections of Gates of the Arctic National Park and Preserve (EcoSubs), US National Park Service (NPS)

Ecological subsection data were developed for each NPS unit in Alaska, and address landscape-level ecoregion, ecosection and ecosubsection themes at a coarse scale. These data are derived from a combination of remotely sensed sources (primarily Landsat ETM+) and from pre-existing regional-scale and statewide vector datasets. Themes include geology/lithology, dominant land cover type, physiographic region and dominant landforms. Spatial features are very coarse, with units mapped usually at the level of entire tributrary watersheds of primary rivers. These data are appropriate for basic descriptive purposes at moderate scales, and for basic analyses at coarse to regional scales. Stated plans for these data include future enhancement and refinement as a multi-institutional effort. For more information see eco_subs_gaar.htm in Digital Appendix G, or go to http://www.nps.gov/akso/gis/

Landcover for Gates of the Arctic National Park & Preserve, (NPS)

Landcover units were developed using Landsat TM data and standard supervised classification techniques supported by airphotos and field data. This park specific classification includes 30 separate landcover classes, many of which may be logically grouped into more general classes. These landcover data are appropriate for moderate scale analyses (cells from original 28.5m Landsat TM data), but as with all derivatives of remotely sensed data, they are not 100% accurate and suffer from unavoidable confounding factors (differing phenology among mosaicked tiles, shadowing, haze, cloud cover). While it is generally not recommended that the user rely on these data for accurate designations on a pixel-by-pixel basis, the data do support Subwatershed-level analyses on the premise that point-specific errors are generally mitigated by a reasonably high overall accuracy when considering representative areas. Class grouping into more general landcover designations also improves analytical results when general classes are acceptable as variables. For more information see lc_gaar.htm in Digital Appendix G, or go to http://www.nps.gov/akso/gis/.

Remotely Sensed Data

At the time of writing, available remotely sensed data for the Upper Noatak Basin is limited to four primary types: 1) moderate resolution, satellite-based, multi-spectral imagery, 2) moderate resolution, satellite-based, Synthetic Aperture Radar (SAR) data, and 3) historic aerial photographs, and 4) Coarse-resolution satellite-based sensors. The National Park Service Alaska Region is currently engaged in acquisition of high-resolution, satellite-based, multi-spectral data (IKONOS) as part of its BaseCarto program, but these data were not available in time for these analyses.

Landsat TM, ETM+ Imagery

Moderate-resolution, satellite-based multi-spectral data for this area are limited in practical terms to products from the US Landsat program. While data from comparable sensors (e.g. SPOT, IRS) exist as well, they are significantly more expensive and do not offer marked advantages over Landsat data for feature identification, spatial coverage, archive availability or spectral analysis.

Landsat ETM+ data are appropriate for landcover/vegetation and other surficial analyses at moderate scales. In our analyses, they were used to cross-check data from the NPS Landcover dataset, for general vigor (NDVI) comparisons among subwatersheds, and for general reference and logistical planning.

Synthetic Aperture Radar (SAR)

SAR data are available from the archive of the Alaska Satellite Facility at the University of Alaska Fairbanks (http://www.asf.alaska.edu/). These data are primarily limited to C-Band products (ERS-1, ERS-2 & RADARSAT 1 & 2) and L-Band (JERS) data at resolutions of roughly 30m cell sizes. Future data will include ALOS's PALSAR (L_Band, ~10m resolution), which will be entering operational phase in 2007. SAR data and SAR analysis techniques do not presently offer information germane to this study, but may offer significant advantages for analyses on closely related topics in watershed composition, hydrology, and seasonal snowcover/snowpack/snowmelt properties.

Historic Airphotos

Several sources for historic airphotos from photogrammetric campaigns exist for the Noatak Basin. The best known and most widely used are from the Alaska High Altitude Aerial Photography (AHAP) program. AHAP flew the entire state of Alaska between 1978 and 1986 at roughly 1 : 63,360 scale using 9' format photogrammetric cameras and color-infrared film. Scanned as digitial products, they are appropriate for orthorectification (presuming adequate DEM data, which is not available in the Noatak Basin), and are useful for feature identification, relative vegetative comparisons within-frame, and change detection. Maximum digital resolution based on original film quality is roughly 1.5 ground meters post-rectification. These data are most easily available through the GeoData Center at the University of Alaska Fairbanks.

There are also archives of panchromatic airphotos with similar scale and resolution specifications in agency files throughout the state and federal systems. Most notably, airphotos used by the USGS for initial quadrangle mapping are available, primarily through the USGS. As of writing, methods of data discovery and distribution are changing. For more information, contact the USGS via http://www.usgs.gov/.

Coarse-resolution, Multi-spectral, Satellite-based Imagery

Two platforms offer reliable and archived image data relevant to landscape monitoring within ARCN. The AdVanced High-Resolution Radiometer (AVHRR) is an ongoing program with data archives from 1982. High-resolution in this refers to radiometric rather than spatial resolution. AVHRR covers broad areas multiple times daily in Alaska, and data are easily available through the UAF Geophysical Institute (*http://www.gi.alaska.edu/*). Spatial resolution (1km ground cell) is too coarse for use in this study, but would be entirely appropriate for studies and monitoring that scale up to the ARCN or regional level.

MODIS (MODerate Resolution Imaging Spectroradiometer) is a more recent platform with archives from 2000. The program distributed both multi-spectral data and derived products and scale ranging from 80m ground cells to 500m ground cells. MODIS is most useful in this context as a bridge between scales, most typically between Landsat ETM+ and AVHRR. It is also available from the UAF Geophysical Institute.

1973 Environment of the Noatak Basin Area Sites (Young, 1974)

Much of the data collected in the initial 1973 assessment of the Noatak Basin has direct relevance to results of this study. While GPS and modern mapping and GIS technologies were unavailable at that time, it was possible to reconstruct specific field site locations from that effort using the general maps and descriptive text within the report. Sites relevant to the 2005 Aquatics effort were centered on 1973 Camps V & VI. These sites are included in tabular form in Appendix A, as map features in Appendix F and Digital Appendix F, and as point and line feature classes within the Noatak_Aquatics_2005.mdb GeoDatabase in Digital Appendix G. These locations offer the NPS Inventory & Monitoring Program an opportunity to establish longer term trends in aquatic resources for the Noatak Basin.

Site Descriptions

The Upper Noatak Basin

The Upper Noatak Basin is generally defined from the Noatak River headwaters around the northern and western flanks of Mt. Igikpak, flowing downstream north and then directly west through the narrow Upper Noatak River floodplain to roughly Lakes Isiak, Matchurak and Kavachurak (Map 1, Appendix F & Digital Appendix F). Defined as the Headwater Mountains Province of the Noatak Basin in Young (1974), it includes four generalized EcoSubSections, 1) Upper Noatak Floodplain, 2) Noatak Mountain Valley, 3) Endicott Mountain Non-carbonate and 4) Oyukak Carbonate Mountains.

In general, the Upper Noatak Basin begins with steep peaks, arêtes, horns, spires and cirques with barren rock and talus rubble on slopes up to 60 degrees; all indicative of the area's intensive glacial history (Figures 3a & 3b). These higher elevation zones grade through sparsely vegetated alpine tundra and thin riparian zones. Just upstream of 12-mile slough (maps, Appendix F), the river floodplain begins to broaden, taking on the characteristic 'U' shape of glacial valleys, and to include more depositional material and poorly drained, silty soils. These are primarily alluvial fans near the mainstem Noatak River, which down-cuts and meanders through these alluvial deposits. Typical arctic tundra types, limited shrublands, and small areas of bog and fen vegetation types are present.

Progressing downstream and west, local topography becomes milder with glacially-scoured domes, saddles and smoothed peaks flanking the two mile wide Noatak Valley. This zone supports alpine tundra grading down through moderate slopes and kame terraces to the valley floor (Figures 4a & 4b), where shrub, shrub-tundra, tussock-tundra, bog and fen assemblages are found. Permafrost related features and landforms to include coalescing solifluction lobes, rock glaciers, pingos, and thermokarst features identified as riparian thaw slumps and mid-hillslope active-layer slides are also present. Higher, well-drained, sparsely vegetated hillslopes contain evidence of non-permafrost related landslides, possibly tied to spring run-off or to specific precipitation events.

Near Lake Matchurak, the Noatak Valley widens further, becoming roughly five miles wide as it approaches the Aniuk Lowland in the Middle Noatak Basin (Figures 5a & 5b). This lower portion of the Upper Noatak contains higher proportions of shrubland, and of vegetated landscape in general. Larger lakes also become more common, and evidence of large ice-lenses may be seen along the Noatak river banks.

The Oyukak Carbonate Mountains EcoSubSection includes a strip along much of the southern half of the Upper Noatak Basin. While carbonate lithologies exist within this area (Figure 6), the value of these data at this scale are to alert the user to the presence of carbonate materials within these watersheds; they are explicitly not useful for deriving accurate estimates of total carbonate content of substrate in these areas. In general, these areas are underlain by limestones, shales, dolomites and other sedimentary rock.

Similarly, the Endicott Mountain Noncarbonate EcoSubSection provides a generalized overview of the northern edge of the Upper Noatak Basin. Comprised of noncarbonate sedimentary and conglomerate bedrock, and generally sparsely vegetated, this unit designation also covers much of the western portion of Gates of the Arctic National Park & Preserve.

The Noatak Mountain Valley and Upper Noatak Floodplain EcoSubSections comprise the majority of the Upper Noatak Basin. These generalized classes describe treeless tundra typical of Arctic Alaska, underlain by sedimentary carbonate and noncarbonate rock, with alluvial materials and sandbars in the floodplain proper.

For more information on Ecological Subsections see, http://aknhp.uaa.alaska.edu/pdfs/ecology/GAAR_EcologicalSubs_final.pdf

2005 Aquatic Sites.

Aquatic Field Sites selected for the 2005 fieldwork were generally located on Noatak River tributaries several hundred meters upstream of confluences with the mainstem Noatak River, and at lakes with one mile of the Noatak River. The representative lakes and streams described below are complemented by the complete list of sites in Appendix A, on the maps in Appendix F and Digital Appendix F, and in the Noatak_Aquatics_2005.mdb GeoDatabase in Digital Appendix G. Fully documented, representative ground-photo transects are also included for many of the sites in Appendix E and Digital Appendix E.

Methods

Field Locations

All Field locations (Appendix A, Digital Appendix G) were recorded as waypoints using recreational grade GPS receivers (Garmin eTrex Legend). Waypoints were uploaded into Garmin MapSource 6.0, exported to .mps format in decimal degrees (NAD27), and imported into ESRI ArcView 3.3 using the AV Garmin extension developed by the California Department of Natural Resources. The resulting shapefile was converted to an ESRI Personal GeoDatabase, projected into ALBERS Alaska (NAD27 meters) and edited for attribute content and linked through related tables to field data and landscape metrics derived in post-analysis (Digital Appendix G). Spatial accuracy for these points is to within 15m, which is commensurate with work at each site which was not contained to an area more specific than 15m in radius.

Ground Photo Transects

Ground photo transects were collected at many field sites (provided and fully documented in Appendix E and Digital Appendix E), and are designed to provide a representative view of local and landscape-level characteristics of these sites, and of the Upper Noatak Basin in general. Each photo line was taken at a specific compass bearing, usually beginning with a close-up of the photo point, then broad landscape shots progressively zooming in on distant features. The photos were used in concert with Landsat ETM+ data and the NPS Landcover for GAAR data to a) cross-check land cover classes, and b) condense land cover classes into more generalized categories for subwatershed level analyses.

Land Cover Reclassification

Landcover from the NPS GAAR dataset was condensed from 30 to 8 classes. Some of the 30 classes did not occur in the study area (e.g. coniferous and broadleaf woodland classes), while others were considered more specific than necessary for developing meaningful landscape-level linkages with stream characteristics. Also, generalizing the classification reduces pre-existing errors of misclassification among similar land cover types, and strengthens the validity of simple, statistical relationships among landscape variables and aquatic characteristics. The eight classes used in analysis are shown in Table D.2, Appendix D, with the total area of each class within each subwatershed.

Subwatershed Delineation

Each stream sampling site (Appendix A) was used as the pour point to delineate its associated contributing subwatershed. Artifacts and limitations in the DEM (USGS NED) dictated that the typical method of delineation should be altered to improve results. The pour point in this case was used to select all upstream hydrographic features from the USGS NHD, which were then converted to raster grid format (5m cell size) and applied as a pour point set. The pour point set drove watershed delineation in ArcGIS using the 'fill', 'flowdirection', and 'watershed' functions provided with ArcToolbox Hydrologic tools. Results were visually checked for accuracy, then converted to vector format and included as polygon feature classes within the Personal GeoDatabase (Digital Appendix G).

Calculation of Subwatershed Landscape Parameters

Each subwatershed was used to clip raw and derived data from pre-existing land-level datasets. Each variable was summarized by subwatershed and included in the GeoDatabase in linked tables.

Hydrography

Hydrographic data were summarized from the USGS NHD and are given in Table D.1, Appendix D. Stream order was attributed manually to each stream/stream segment within each subwatershed prior to analysis and included in summary results.

Topography

Derived topographic data (Table D.1) were calculated using the USGS NED, and summarized by subwatershed and included in the GeoDatabase.

Land Cover

Results of the Land Cover Reclassification (Table D.2) were summarized by subwatershed and included in the GeoDatabase.

Statistical Relationships

Summarized landscape data were used as the independent variables against field-measured stream characteristics using SAS 9.1. Univariate and multivariate regressions were run using the 'Fit XY' utility with significant results reported in Table D.4 and Table D.3. Note that analyses were not run for Stream 9 (Kugrak Spring) because it had no relevant landscape parameters since it is a point source. Also, statistics involving nitrates could not be run for Stream 20 since nitrate data for that site were not available.

Streams

Temperature, pH, Dissolved Oxygen, and Electrical Conductivity

Temperature, pH, dissolved oxygen and electrical conductivity were measured at each stream tributary site in situ using a WTW 350i multi meter. Dissolved oxygen and pH probes were calibrated prior to sampling each stream tributary. Electrical conductivity was calibrated once using a calibration cell constant value of 0.475 1/cm.

Nutrients

Water samples were collected and filtered through ashed GF/F filters and preserved with 6N HCl in the field and refrigerated until analyzed. Water samples were analyzed for nitrate, total dissolved nitrogen (TDN) and total dissolved phosphate (TDP), dissolved organic nitrogen (DON), and total particulate nitrogen and total particulate carbon (TPN and TPC). TDN was analyzed on a Shimadzu Total Organic Carbon (TOC) analyzer and TDP was analyzed using acid persulfate digestion and analysis on a Cary spectrophotometer, wavelength 885 nm, 5 cm cell. Nitrates were analyzed by a Lachate autoanalyzer. All calibration standards were acidified to the same pH as samples.

Metals and Cations

Water samples for metals and base cations were filtered (0.45 μm GF/F) and preserved (acidified to pH <2 with nitric acid). Base cations (sodium, calcium, magnesium, and potassium) were analyzed at the University of Vermont by Inductively Coupled Plasma – Optical Emission Spectroscopy. The low-level heavy metal analysis was completed at Severn Trent Laboratories by Inductively Coupled Plasma – Mass Spectroscopy using Analytical Method SW846 6020. Note that the method blanks had analytes detected at concentrations between the method detection limit (MDL) and the reporting limit and were flagged with a "B" qualifier. Any sample associated with a method blank that had the same analyte detected had the result flagged with a "J" qualifier. See Appendix for flagged metal analysis data.

Chlorophyll a

The resulting slurry from the periphyton collection (see Algal section) was sub-sampled for chlorophyll analysis. A 7.82 cm^2 plastic rectangular template was placed on top of each cobble. The area within the template was scrubbed with a wire brush and rinsed with 125 ml of stream water. Ten mls of the slurry was filtered onto a GF/F filter and was extracted in acetone for at least 8 hours time. Extractable chlorophyll *a* was measured using an *Aqua*fluor, a handheld field fluorometer by Turner Designs. The fluorometer was calibrated setting a solid secondary standard that was correlated to a known primary standard and was used daily in the field to check for drift in the instrument.

Algal Taxon

Periphyton was sampled quantitatively by randomly sampling 5 cobbles from riffles along each stream reach. A 7.82 cm^2 plastic rectangular template was placed on top of each cobble. The area within the template was scrubbed with a wire brush and rinsed with 125 ml of stream water. The resulting slurry was subsampled and preserved with Lugol's iodine. Periphyton community structure was determined by counting and identifying a minimum of either 100 algal units or 500 fields of view at 400x magnification using a Palmer-Maloney counting cell. Representative diatom samples from each site were acid-cleansed and mounted in Naphrax® prior to identification. Cell counts were standardized to square meters using the area of the sampling template.

Algal filaments were sampled qualitatively when present. These samples were preserved in Lugol's and identified from wet mounts in the lab. Taxa lists were generated for each study site.

Macroinvertebrate quantitative - Surber

A Surber sampler (area 0.09 m^2, 250-μm Nitex® mesh) was used to collect benthic macroinvertebrates from each stream. Five replicate samples were taken from a minimum of two riffles within each stream reach. Substrate was vigorously disturbed in the sampler frame by hand to a depth of ~10 cm. Cobble and pebble substrate were scrubbed with a brush to remove attached invertebrates and each particle was visually checked before removing from the sampler frame. The substrate was continously disturbed until it yielded little to no fine particulate into the net. The sampler was then removed from the stream and the contents were rinsed to the bottom of the net using a squirt bottle filled with streamwater. At streamside, the contents of the net were then rinsed through a 250-µm standard mesh sieve before being transferred to plastic whirl-paks. If samples were large the contents of the net were placed into a 20-L bucket at streamside and elutriated before pouring through the 250-µm sieve. Samples were preserved with formeldahyde which was added directly to each whirlpak at streamside.

In the laboratory, surber samples were further elutriated to isolate organic materials that were then fractioned into coarse particulate organic matter (CPOM; >1mm) and fine particulate organic matter (FPOM; <1mm >250 µm) using nested sieves. Following removal of macroinvertebrates, samples were dried for a minimum of 48 h at 50ºC, weighed, ashed at 500ºC for 1-2 hours, and then reweighed to determine ash free dry mass (AFDM).

Macroinvertebrates were removed and sorted by eye or low magnification from coarse fractions (>1mm). A dissecting microscope was used for removing and sorting macroinvertebrates from fine fractions (<1mm >250µm). Fine fractions with lots of material were occasionally subsampled (up to 1/16) using a Folsom plankton splitter. Macroinvertebrates were identified to lowest practical taxon (usually genus) according to Merritt and Cummins (1996), Epler (2001), and Smith (2001) and measured (total body length). Taxon-specific length-mass relationships (Rogers et al. 1976, Bottrell et al. 1976, Benke et al. 1999) were used to estimate biomass (dry mass [DM]) based on body length. Macroinvertebrate samples were expressed as biomass (dry mass) and were standardized to g/m^2 for analyses.

Macroinvertebrate qualitative - kicknet

A simple kicknet (1-m^2, 500-µm Nitex® mesh) was used to obtain a qualitative macroinvertebrate sample for isotope analysis. The net was placed in the stream perpendicular to flow and the area upstream from the net was vigorously disturbed by foot. Contents of the net were transferred at streamside to a white plastic picking tray to facilitate removal for later isotope analysis. The process was replicated in several habitats until a representative sample from the stream was obtained.

Fish

Fish were surveyed using 4-5 collapsible minnow traps in each stream. Traps were baited with salmon eggs and left in areas identified as potential fish habitat for 30-60 minutes.

Stable Isotopes: Nitrogen and Carbon

Leaves of the dominant vegetation along the riparian zone of the stream tributaries were collected and placed in manila envelopes. Careful consideration was made to not touch the leaves to avoid interference with natural isotopic signatures of the samples. Qualitative kicknet samples were taken and dominant macroinvertebrates were picked using forceps and a sampling tray and stored in plastic scintillation vials. Sculpin were caught with minnow traps and fin clips were taken for isotope analysis.

Both vegetation and macroinvertebrate samples were dried in the field in the sun when possible. Upon the return to the University of Vermont, samples were dried in a 60ºC oven for 36 hours. Vegetation samples were ground into a fine, homogenous powder using a ball mill and stored in clean, glass vials until analysis. Macroinvertebrate samples were dried in original scint vials and were not homogenized due to the lack of material. Sculpin fins were dried and left whole.

Dried macroinvertebrate and fish sample material (1-2 mg) and dried vegetation sample material (3-5 mg) were packed into 5x9 mm tin capsules for subsequent analysis.

Samples were analyzed for total carbon, total nitrogen, $\delta^{13}C$ and $\delta^{15}N$ content by a continuous flow isotope ratio mass spectrometer (PDZ Europa “20-20”) at the Marine Biological Laboratory at the Ecosystem Center in Woods Hole, Massachusetts.

Lakes

In the upper Noatak River Region, most lakes in mountainous areas were formed by glacial deposits; the majority of lakes in the river valley are oxbow lakes formed by meandering river beds and most lakes on the low-lying coastal plains are thaw lakes formed as permafrost melted over large areas of unconsolidated fine-grained material (Livingstone 1958). From 14-26 July 2005, we assessed physical chemical and biological parameters in twelve lakes near the upper Noatak River from 12-Mile Creek to Lake Matchurak in the western region of the Gates of the Arctic Park and Preserve (Figure 1). Survey lakes were chosen based on lake size, type, and accessibility from the Noatak River, prioritizing lakes sampled during previous surveys (Young et al. 1974, LaPerriere et al. 1995). Eight of the lakes sampled were in the Noatak River Valley and four lakes were at higher elevations (Figure 2).

Lakes were documented with digital photography and a GPS location with 5-10 m accuracy. We identified and recorded riparian and shoreline vegetation. Visual estimates of lake substrates were recorded as an approximation of percent of lake-bottom covered by rocks, sediments and macrophytes. Detailed bathymetric surveys of ten lakes (L1, L2, L4, L5, L6, L7, L8, L9, Matchurak and part of Kipmik) were conducted using a GPS-linked, Garmin-153C echosounder attached to an inflatable kayak which was paddled across lakes along specified transect lines. The echosounder recorded water depth as an algorithm of reflections from the bottom of a 70 kHz pulse of sound (0.4 msec in duration) as the GPS unit recorded the corresponding latitude and longitude. We used GIS ArcMap version 9.0 to create bathymetric maps for four of the deep survey lakes (L4, L5, L6 and L10). Data stored in an .xls file was converted to individual .dbf files and imported into ArcMap version 9.0. Shapefiles were then created from the data for each lake. Lake perimeters were created using heads-up digitizing from a 60 m satellite imagery raster from the Gates of the Artic National Park. The island in L5 was created using the same approach. All Shape files were adjusted to Alaska Albers Equal Area Conic projections, and the datum was transformed into NAD 83. The Inverse Distance Weighting tool was used to create one-meter (L4, L5 and L6) or two-meter (Matchurak) contour lines from depth rasters with a 30-m cell-size.

Vertical profiles of temperature, dissolved oxygen, pH, specific conductivity, penetration of photosynthetically active radiation (PAR), and chlorophyll fluorescence were measured using a Hydrolab Surveyor and Datasonde 4a. Measurements were taken at approximately one-meter intervals from the surface of the lake to the maximum depth (Z) of each lake. Without the aid of polarized sunglasses, we used a 20-cm secchi disc to estimate water transparency on the shaded side of the boat. Being careful not to disturb lake sediments, we used tygon® tubing to collect depth-integrated samples of lake water (0 to 5 m in lakes greater than five meters deep; 0 to Z_{max}-0.5 m in lakes less than five meters deep) for chlorophyll *a*, total nitrogen and total phosphorus analyses. Prior to pouring water into collection bottles, we sieved sample water through an 80-µm sieve to remove macrozooplankton. Water for chlorophyll-a analysis (50 to 100-ml) was filtered through a 1µm, glass-fiber filter (45mm diameter), which was placed in acetone for extraction. Approximately 12 hours later, extracted Chlorophyll-*a* was measured with a Turner Designs Aquafluor field fluorometer and reported as µg chlorophyll-a per liter. Water collected to total nitrogen and phosphorus analysis were stored in polyethylene bottles and preserved with 6N HCl. In the laboratory, nitrogen and phosphorus standards were acidified to the same pH as samples. Particulate phosphorus in samples was digested using an acid-persulfate digestion prior to colorimetric analysis of TP using a Cary spectrophotometer (885 mm wavelength, 5 cm cell). Total nitrogen was analyzed with a Shimadzu TOC analyzer.

Zooplankton were collected from discrete depths using a conical closing net (80 µm-mesh) towed vertically through the water-column near the deepest spot in the lake. Three replicate samples of zooplankton were collected from zero to five meters or the maximum depth, if less than 5m. In lakes greater than 5m, we collected two additional samples from five meters to the maximum depth sampled. Immediately following collection, samples were preserved in Lugol's iodine solution. In the laboratory, zooplankton were identified to lowest practical taxon (*Daphnia middendorffiana, Bosmina sp.*, *Daphnia longiremis*, *Heterocope septentrionalis*, *Cyclops scutifer, Diaptomus pribilofensis and Sida crystalliana*) and ten individuals from each taxa in every sample were measured with an ocular micrometer. For each measured individual, we used taxa-specific, length-mass relationships to estimate biomass (dry body mass in µg) for each individual based on body length (Yurista *et al.* 1999; *D. middendorffiana* and McCauley 1984, all other species; see appendix X for further details). Zooplankton biomass is presented as mean biomass standardized to $\mu g * l^{-1}$ for all zooplankton taxa present in each depth strata (0-5 m and 5-Z m).

In lakes, benthic macroinvertebrates were sampled qualitatively with a sweep net when lake substrates were dominated by macrophytes or cobble and quantitatively with an ekman dredge when sediment was the dominant lake substrate. These samples were sent to a taxonomist, but to date have not been processed. Following sample processing, the data will be analyzed and presented to ARCN in the form of a brief report or as a belated appendix to this report.

- Presence or absence of fish species was assessed using a combination of field observations, gill netting, trapping and angling. As a surrogate for relative abundance, we calculated catch per unit effort (CPUE) for fish caught by angling and gill netting (# of fish caught / effort expended (hrs)).

Results

Streams

Temperature, pH, Dissolved Oxygen, and Electrical Conductivity

Along the main stem and tributary sites temperatures ranged from 7.2 to 15.5 ^{o}C and values of pH were circumneutral ranging from 7.7 to 8.6 (Table B.4). Concentrations of dissolved oxygen were generally supersaturated ranging from 7.6 to 13.3 mg/L and the specific conductance of the stream tributaries ranged from 77 to 811 µS/cm. Stream temperatures ranged from 7.2 to 20.2 ^{o}C over the 2-week period, increasing with each day as we had remarkably warm, sunny weather except for one major rain. The stream pH was circumneutral. The concentration of dissolved oxygen contained in the waters of the Noatak River basin varied considerably and were generally supersaturated. This contrasted the few stream sites assessed in 1974 that showed streams were generally lower than saturation. Electrical conductivity also varied considerably ranging from 77 to 811 µS/cm. There were significant differences in electrical conductivity between carbonate and non-carbonate stream sites suggesting that some aspects of stream chemistry are strongly influenced by differences in geology in this region.

Nutrients

Nutrients collected in the Noatak tributaries during July 2005 were compared to values found on the North Slope in the Kuparuk River between 2000-2004 (Table B.3). Nitrate values were slightly higher in the Noatak tributaries in 2005 when compared to the mean and range of nitrate values in the Kuparuk River. TDN ranged from 5 to 25 micromolar in the Noatak tributaries and there were significant differences detected in nitrate and TDN between carbonate and non-carbonate stream sites in 2005. Comparisons of phosphorus between the Noatak and Kuparuk suggest that the two streams are similar with respect to phosphorus but it should be noted that the values in brackets are soluble reactive phosphorus (SRP) values from the Kuparuk River and that a portion of the TDP is SRP in the Noatak streams (Table B.4.). Benthic TN and TC varied considerably meanwhile sestonic TN/TC observations were quite low.

The nutrient samples from the 2005 survey of the Upper Noatak mainstem and tributaries were analyzed for nitrate (NO_3), total dissolved nitrogen (TDN) and total dissolved phosphorus (TDP). The most notable feature is the very low level of TDP, averaging 0.06 uM (Table B.3). The only exception is the sample from site 12 at 0.44 uM. The levels of TDN are not unusually low with the net result being extremely high ratios of TDN:TDP averaging over 300 (molar ratio). Most of the dissolved nitrogen is present in inorganic form as NO_3 (average 66% omitting S20, Lake Maturak outlet where NO_3 was not detectable and DON was high). The high mean TDN:TDP ratio (315) in these streams indicates that P is the limiting nutrient if and when nutrients limit stream primary productivity or decomposition.

It could be argued that a better indicator of potential nutrient limitation would be the ratio of dissolved inorganic N (DIN) to soluble reactive phosphorus (SRP) because these are more readily available for assimilation. SRP and ammonium were not analyzed in this survey because it was not possible to perform field analyses and the levels are generally so low in arctic streams that preserved samples give unreliable results. However, given the high percentage of nitrate in TDN and the extremely low TDP values it is clear that the inorganic ratio of N:P would also be very high and well above the Redfield ratio of 15:1. For example the NO_3:TDP ratio averages over 100 and this must be an underestimate of the true DIN:SRP ratio because it omits NH_4 which would add a small amount to the available N and SRP is only a fraction of the TDP.

We can characterize the Noatak stream water samples as extremely depleted in P and high in inorganic NO_3 but low in DON relative to TDN. These nutrient chemistry characteristics can be compared with similar analyses from streams on the North Slope of Alaska (Table B. 4). The Upper Noatak streams are distinctly different than tundra streams on the North Slope in several characteristics. They are generally lower in TDP than tundra streams but they differ in N chemistry as well. The upper Noatak streams are lower in DON and higher in NO_3 relative to TDN than North Slope tundra streams. For example, Noatak streams contain about 3 uM DON versus 10 to 20 uM DON in North Slope tundra streams and Noatak streams have 66% of their TDN as NO_3 versus 5 to 10% for tundra streams. These differences reflect the role of terrestrial vegetation and soils in controlling the amounts and forms of N and P inputs to tundra streams. It could be argued that the high % nitrate of TDN in Upper Noatak streams is due to the extreme phosphorus limitation which limits nitrate assimilation by stream biota. This may well be true but the low levels DON are a clear indication of limited interaction with organic soils and vegetation in the Upper Noatak streams.

These differences however do not hold when comparing Noatak streams to mountain streams on the North Slope. Mountain streams on the North Slope have slightly higher levels of TDP than the Upper Noatak streams and also slightly lower levels of TDN. They have similar levels of DON and similar large fractions of their TDN as NO_3. Thus apart from a difference in the TDN:TDP ratio, the Upper Noatak streams have nutrient chemistry similar to mountain streams on the North Slope. In fact, the Noatak stream nutrient chemistries are more similar to mountain, glacial and spring streams on the North Slope than any of these streams are to North Slope tundra streams.

The impact of the differences in TDN:TDP ratios should not be overemphasized because virtually all of the streams both on the North Slope and in the Noatak have ratios indicative of P limitation. If the Upper Noatak streams are in fact best classified as mountain streams, it should be remembered that hydrologic disturbance regimes are likely to be important controls of biotic activity in addition to any control by nutrient limitation.

The 2006 surveys of the Lake Feniak region of the central Noatak should provide an interesting contrast with the Upper Noatak region because a range of streams from tundra-dominated to mountain-dominated were sampled. The expectation is that the tundra dominated streams will have higher levels of DON and lower NO_3 relative to TDN than the streams sampled in 2005. Possibly some of the unique lithologies will yield higher levels of phosphorus but we expect the majority of sites to be low in P. These 2006 samples are currently being analyzed for NO_3, TDN and TDP as well as particulate sestonic P in the Laboratory of the Woods Hole Research Center.

Metals and Cations

Figures B.2 and B.3 show a comparison between base cation and heavy metal values from 2005 to those values reported in the USGS water quality database, which documents water chemistry values from the rivers and streams of the Noatak River basin from 1968 to 2002. The dominant cations for both 2005 and 1978 were calcium (2005 range from 27 mg/L to 86 mg/L and magnesium (2005 range from 6 to 43 mg/L). There were significant differences found between the carbonate and non-carbonate stream sites in 2005, which is not surprising given the dominance of $CaCO_3$ in the carbonate geology. Analysis of metals showed an extremely low level heavy metal content, including many non-detects in the analysis, in which ½ the MDL was used to report (Table B.5). Figure B.3 shows higher heavy metal concentrations detected in the Noatak in 1978 than in 2005.

Chlorophyll a

Chlorophyll *a* values along the Noatak River were exceedingly low (range from 0.0 to 0.3 $\mu g/cm^2$) in comparison to those values found along the Kuparuk River on the North Slope. These results were expected given the lack of a detectable biofilm on the substrate and the ultraoligotrophic nature of the stream tributaries sampled.

Algal Taxon

Algal communities were similar with only 7-12 taxa per stream (Table B.7). Diatoms account for 60-90% of the taxa richness in these headwater streams. The diatom taxa *Achnanthidium* spp., *Cymbella minuta*, and *Hannaea arcus*, as well as the filamentous Cyanobacterium *Phormidium* spp., were present in every site. Diatoms *Fragilaria vaucheriae* and *Gomphonema angustatum* were present in 16 of 17 sites.

Site S9, Kugrak spring, had the highest cell density at 1.41×10^9 cells m^{-2} (Figure B.6; ANOVA $F=5.50$, $p<0.001$). The lowest algal density, 6.36×10^6 cells m^{-2}, occurred in the highly turbid site S13. Cell densities for S9 are similar to algal cell densities for spring streams on the North Slope, however all other sites show densities one to three orders of magnitude lower than headwater mountain streams on the North Slope (S.M. Parker unpublished data).

Low cell densities and relatively small substratum size (median cobble size ranged from 22.6 to 90 mm) suggest that Noatak headwater tributaries may experience high levels of disturbance. Algal taxa common in these streams also suggest disturbance. The diatoms *Achnanthidium* spp. suggest high frequency of disturbance, while *Cymbella minuta*, *Gomphonema angustatum* and *Hannaea arcus* indicate moderate levels of disturbance (Biggs et al. 1998). The Cyanobacteria *Phormidium* spp., found in all 17 sites, is indicative of low resource levels (Wehr and Sheath 2003).

Kugrak spring (S9), however, had high algal cell density, similar to spring-fed streams on the North Slope (S.M. Parker unpublished data). Because these systems are fed by groundwater, stream flow remains constant minimizing bed disturbance allowing more periphytic biomass to accrue, along with greater taxa richness (Parker and Huryn in press). Portage spring (S4) did not show high cell counts, but did contain the diatom *Staurosirella leptostauron*, a colonial species specific to areas of low disturbance.

Invertebrates

The taxonomic richness of benthic macroinvertebrate communities ranged from 17 taxa at S4 (no name creek near Portage Creek) to 6 taxa at S6, S10, S18 and S19. The majority of streams had 10 taxa or less (11 of 17 streams, Table B.8). Several genera of the non-biting midges (Chironomidae) comprised the most widespread taxa (Table b.9), with *Orthocladius* and *Diamesa* occurring in 16 of 17 streams, and *Eukieferiella* and *Tvetenia* occurring in 15 of 17 streams. Other widespread taxa included the stoneflies *Nemoura* (Nemouridae, 14 streams) and *Capnia* (Capniidae, 10 streams) and the mayfly *Baetis* (Baetidae, 10 streams).

Benthic macroinvertebrate abundance ranged from 55,618 individuals/m^2 at S9 (Krugurak Spring) to 72 individuals/m^2 at S19 (no name). The majority of streams had macrovertebrate abundances <1,500 individuals/m^2 (13 out of 17 streams, Tables B.8, B10). Macroinvertebrate biomass showed a similar pattern, with S9 (Krugurak Spring, 2,138 mg dry mass/m^2) and S4 (no name tributary near Portage Creek, 1,200 mg dry mass/m^2) having 1-3 orders of magnitude greater biomass than the remaining streams (Tables B. 10). Most streams (13 of 17 streams) had levels of macroinvertebrate biomass that were lower than 100 mg dry mass/m^2, and biomass at S19 (no name) was essentially undetectable (2 mg dry mass/m^2).

With the exception of Krugurak Spring and S4 (no name creek near Portage Creek), macroinvertebrate community structure and richness were relatively uniform among streams, and consisted of a nucleus of taxa that have been shown to be typical of braided streams of the North Slope of the Brooks Range (Huryn et al. 2005). This nucleus included the mayfly *Baetis*, the stonefly *Nemoura* and the non-biting midge genera *Diamesa*, *Eukieferiella*, *Tvetenia* and *Orthocladius*, (Huryn et al. 2005). Levels of macroinvertebrate abundance and biomass for the majority of streams sampled, although relatively low, were within the range expected for braided, mountain streams of the Brooks Range (Huryn et al. 2005).

The macroinvertebrate communities of S4 and Krugurak Spring were more exceptional. The community of S4 showed relatively high levels of biomass among the streams sampled (at least one order of magnitude greater than all streams except Krugurak Spring). This high biomass was due primarily to high biomass of larvae of the detritivorous crane fly *Tipula* (70% of total biomss) and the detritvorous stonefly *Nemoura* (15% of total biomass, Table B.10). The uniformly straight channel, the dark and angular bed substrata, and the large amounts of organic matter retained within the bed of S4 indicated that, unlike the other streams (with the exception of Krugurak Spring), this stream had relatively stable flows and low levels of bed disturbance. Such relative habitat stability is presumably a factor underlying the high biomass and unusual community characteristics of S4.

Krugurak Spring (S9), which is the outflow of a travertine spring, had a community that was highly unusual, being dominated by larvae of the biting midge *Culicoides*, the crane fly *Limonia*, the midges *Paratrichocladius* and Tanypodinae (genus unknown), and larvae of the microcaddisfly genus *Ochrotrichia*. These taxa were not collected elsewhere during the 2005 survey. *Culicoides*, *Paratrichocladius* and *Ochrotrichia* alone contributed 64% to total biomass at S9. The microcaddisfly genera *Agraylea* and *Oxyethira* have been reported from the Arctic region of the Yukon Territory (Wiggins and Parker 1997) and *Agraylea* has been collected in the vicinity of Toolik Lake on the North Slope of Alaska (A.D. Huryn, unpublished). *Ochrotrichia*, however, has to our knowledge never been reported from the Arctic and the collection at Krugurak Spring may well represent the first record of this genus from this region. The presence of pharate adult males allowed the species to be tentatively identified as *Ochrotrichia logana* (Ross). This species was originally described from Utah and has been reported from the western contiguous United States (AZ, CA, CO, ID, OR, UT, WY, Blickle 1979, Herrmann et al. 1986) and Michigan (http://insects.ummz.lsa.umich.edu/~ethanbr/aim/sp/Trichoptera/sp_tom_hydroptilidae.html).

Fish

Only 2 fish were caught in minnow traps in the study reaches. Slimy sculpin (*Cottus cognatus*) were caught only in S7 (28 mm total length) and S8 (53 mm). Fish densities were likely low due to disturbance and subsequent lack of food resources in these streams.

Stable Isotopes

Figure B.8 provides a summary of the isotopic compositions of the dominant riparian vegetation and key macroinvertebrates found along the Noatak River. The isotope signatures from this preliminary analysis vary significantly within species and across stream sites. This level of variation is unusual and suggests that there are important differences in nutrient sources and (or) processing among these streams. A more detailed analysis of this data and complementary data collected during the 2006 field expedition to Feniak Lake is provided in the separate report by Allen et al. (2010).

Lakes

Lake Morphometry

Pingo Lake (L4), sampled on July 17, 2005, was a relatively large, shallow lake with a mean depth of 3.79 m and a surface area of 3.19 ha (Table C. 1). The hyposgraphic curve produced from interpolation of the acoustic sampling indicated that large proportion of the lake was less than 3 m deep. The small bay on the eastern shore held the deepest part of the lake. The maximum depth recorded was 6.8 m. The western arm of the lake was very shallow with an average depth of less than 2m. Acoustic sampling conducted on July 18, 2005 indicated that Omeltavik Lake (L5) had a surface area of 1260 ha and a mean depth of 3.68 m (Fig. C. 2). A small island was present in the eastern portion of this lake. The deepest part of Ometlavik lake was located near the western shore where maximum observed depths were 7.1 m. The morphometry of Lake 6 was conducted on July 20, 2005 using the echosounder equipped with GPS. Lake 6 was relatively deep considering its small surface area. Acoustic sampling indicated that the surface area was 765 ha, the mean depth 3.64 m, and maximum depth of 8.4 m. Lake Matchurak was a much larger and deeper lake with a mean depth exceeding 9m (Table C. 1, Figure. C. 3). The north arm of the lake was relatively shallow with depths of less than 4 m.

Two basins were evident from acoustic sampling in the open area of the lake. The main basin in the center of the lake had a maximum depth of 18.4 m. A large portion of this basin exceeded 12 m in depth. A smaller basin in the southern portion of the lake surface was the deepest area of the lake with depths exceeding 20 m. The minimum depth along the ridge between the two basins was 6.2 m. Only the southern basin of Kipmik Lake (L12) was sampled before logistical problems prevented further sampling; thus, GPS and depth data for this lake are included in the appendix (table C. 1). Other lakes sampled were relatively uniform and shallow (Table C. 1).

Physical and Chemical Parameters

Mean surface temperature for all lakes was 15.8˚ Celsius, ranging from 10.0˚ (L1, 14 July) to 19.4˚ Celsius (L10, 21 July). Six of the twelve lakes exhibited a thermocline (L4, L6, L7, L8, L11, L12): all four lakes sampled at depths greater than five meters and two of the eight lakes sampled at depths less than five meters. Hypolimnion temperatures ranged from 6.3˚ (L4, 8m, 17 July) to 7.0˚ Celsius (L11, 16m, 24 July and L12, 29m, 26 July). The steepest temperature gradient was in L8, which lies in a steep-sided, basin protected from wind. Surface waters of the two shallowest lakes, L3 and L9, had the lowest dissolved oxygen concentrations (8 mg/l), whereas, surface waters of the two lakes closest to the headwaters had the highest oxygen concentrations (greater than 10 mg/l). Relative to temperature, oxygen concentrations were constant with depth with a few exceptions when the probe may have come into contact with lake sediments.

The hydrogen ion concentration (pH) decreased with depth and ranged from 6.7 in the deep water of L12 to 9.3 in the shallow waters of L2 (Table C. 1). Surface pH was highest in L2 and lowest in L12. Specific conductivity increased with depth in a few lakes (L1, L4 and L8), but remained constant throughout the water column in most lakes. Mean specific conductivity of surface waters was 3.6 µS/cm and ranged from below detection in the deepest lake (L12) to 40.5 µS/cm in the shallowest lake. A mean secchi depth reading for eight of the twelve lakes sampled was 4.5 m. Secchi depth readings for other lakes were greater than the maximum depth sampled.

Mean total nitrogen concentration in the surface waters of all lakes was 34.2 µM/l with the lowest concentrations being in the deepest lakes (L11: 19.1 µM/l, L12: 11.3 µM/l) and the highest concentration of 53.7 µM/l in L4. Mean total phosphorus concentration in the surface waters of all lakes was 0.37 µM/l, ranging from 0.09 (L1) to 0.71 (L10) µM/L. Mean molar ratio of total nitrogen to total phosphorus in the surface waters of all lakes was 93.5, ranging from 50.8 to 147.3. These measurements suggest most lakes were N-limited (>55 indicates N-limitation; see LaPerriere 2003).

Biological Parameters

Mean chlorophyll concentrations in surface waters were 2.2 µg/l, with the lowest concentrations in the surface waters of the deepest lakes (L11: 0.6 µg/l and L12: 0.5 µg/l) to 8.6 µg/l in L3, a shallow high elevation lake. All lakes sampled at depths greater than 5 m exhibited a deep chlorophyll peak with chlorophyll concentrations two (L8) to fourteen (L11) times higher than average concentrations in surface waters.

Mean zooplankton biomass was 86 µg/l, ranging from 198 in a large fishless lake to 4.5 in L9. Tash (1971) found 40 pelagic and littoral zooplankton species in lakes near the confluence of the Kelly and Noatak Rivers. The higher diversity found by Tash (1971) may be associated with the increased habitat diversity associated with sampling near the coast. Similar to the 1973 survey, we also found that *D. longiremis* and *Bosmina* sp. typically co-occurred in these lakes. We also found that fish presence affected total zooplankton biomass.

Catch per unit effort of fish ranged from zero to 13 fish per hour. Five fish species were observed and four fish communities were documented (Table C. 5). Fish catch per unit effort was correlated with total zooplankton biomass.

Landscape analysis

Conductivity

Conductivity (EC µS/cm), showed significant, positive relationships with stream density, total stream length subwatershed area, mean subwatershed slope, and area of barren/unvegetated terrain. Barren area showed the most significant relationship ($r^2 = 0.38$, $p < 0.01$)(Figure D. 6), though all variables had similar values (Table D.4). Multiple regression using all variables except total stream length explained most of the variability in conductivity in the Upper Noatak study area ($r^2 = 0.51$, $p < 0.03$)(Table D.4).

Nitrates

Nitrates (NO_3 µM) were significantly related only to stream density among the variables used in these analyses ($r^2 = 0.22$, $p < 0.05$)(Table D.4). The relationship is strongly negative (slope = -6.47)(Figure D. 7).

Dissolved Organic Nitrogen (DON)

The most significant relationships among DON and landscape variables involve land cover. DON is positively correlated with % vegetated surface ($r^2 = 0.39$, $p < 0.01$)(Table D.4) and even more strongly correlated with % shrub tundra ($r^2 = 0.41$, $p < 0.01$)(Table D.4) Percentage rather than cumulative area is the important consideration, as DON is entirely unrelated to total area of shrub tundra ($r^2 = 0.01$, $p < 0.67$)(Table D.4 (Figure D.5)(Table D.4). DON is also significantly related to mean slope, though less strongly.

Multiple regression reveals that these three variables together explain 46% of DON variability with very high confidence ($p < 0.01$).

Discussion

Streams

At some level, aquatic characteristics at any particular point along a stream are a reflection of conditions in the watershed above it. Parameters measured at these points contain some degree of integration from all landscape influences upstream, though the strength and nature of these relationships varies markedly depending on the parameter, upstream ecosystem processes, and on the relative positioning of the sample point within the watershed (i.e. Is it near the headwaters or part of a much larger catchment?).

The strongest relationships in this study were among abiotic landscape variables and cations within the stream. Conductivity (as an expression of cation concentration) is a function of cation availability within the subwatershed and the degree to which it can be dissolved and incorporated into flowing waters. As a result, stream samples taken from larger watersheds with higher stream density, steeper slopes and presence of cation-rich substrate (carbonate rock in particular) have substantially higher conductivity than samples from streams with opposite characteristics. Denser stream networks situated on steeper slopes have a) better access to substrate per unit area and b) a higher capacity to erode those substrates. Larger watersheds should have higher cation concentrations than smaller ones where other parameters are similar due to the larger overall pool of cations, and the more barren ground within a watershed the more proximal their availability.

Because biotic components in the streams tend not to use or absorb cations, they accumulate regardless of ecosystem processes within the stream or watershed and they tend to be unrelated to the presence or absence particular vegetative land cover types.

Spatial data in Alaska is notoriously coarse in spatial resolution, and geologic data, even surficial geology, is often among the coarsest and least complete thematic data sets for any given area in the state. Even at the level of larger watersheds, it is rare to know anything more than whether carbonate lithologies exist; accurate estimates of area or percentage are very uncommon. In remote areas, presence/absence information itself may be missing. Conductivity as measured from downstream sample points may be of significant use to narrow the knowledge gap; at minimum alerting the investigator to the likely presence of carbonate or ultramafic lithologies within the watershed. Sampling for a suite of specific cations should further narrow the gap, and allow for basic inferences related to ecology within the watershed. Further, these data should help target field and remote sensing work if used as a stratification device.

Arctic and Subarctic ecosystems are frequently nitrogen poor and the Upper Noatak Basin is no exception. The strong, negative relationship between stream density and nitrates suggests that streams in this area are limited by the capacity of the landscape to deliver nitrogen (and other nutrients) to streams. Denser stream networks provide more proximal access to landscape nitrogen pools while sparse stream networks are supported by a higher area of upslope land per unit river length. The lack of relationship between nitrates and vegetated land cover is likely due to the low overall concentrations of nitrogen in the system. While increased vegetation should also mean increased nitrogen fixation, the nitrogen demand of plants would leave very little labile nitrogen in the soil, even in vegetated areas. While there is probably a real relationship concealed in the data, it is likely that there is not enough variability in the very low nitrate concentrations between vegetated and barren surfaces to drive statistically significant relationships in a study at this scale.

The strong correlation between dissolved organic nitrogen (DON) and landscape vegetation is notable but no necessarily surprising. This relationship likely caused by the limited ability of the ecosystem to break down and re-absorb the most recalcitrant compounds deriving from plant decomposition. Even in a low nitrogen environment, many of these compounds may require more investment to break down than their nutrient value would justify. The combined class of Shrub Tundra used in this study contains significant dwarf and shrub birch (*Betula gladulosa, B. nana and B. spp.*) components, and it is possible that papyrific acid in particular comprises a significant proportion of the DON sampled, given the strong relationship between this land cover class and DON.

Phosphorus also tends toward low concentrations in the arctic and the 2005 aquatic data suggest P is extremely low in the Upper Noatak. Significant relationships may exist among landscape variables and P concentrations, but results in these analyses were not considered because more than half of the sample locations had P levels that were below the detection limit of the standard low-level analysis method we employed.

It is worth noting that the earlier limnological survey performed by O'Brien and Huggins (1974) focused primarily on lakes and did not sample any of the locations visited as a part of this 2005 survey. In addition, the streams that were sampled at the camps occupied in 1973 that were most closely associated with our 2005 survey (Camps IV-VI) appear to have been smaller headwater streams and not main tributary junctions. Nevertheless, there is a reasonable correspondence between similar metrics measured in 1973 and 2005. Any differences are more likely to be the result of different weather conditions (very wet in 1973 versus very dry in 2005), different sampling locations, or differences in analytical methods rather than true temporal trends in those metrics.

Overall, landscape-level analysis for aquatic resources should be most helpful in the context of continued resource monitoring and landscape-level change detection. The single time-stamp of this study will be much more meaningful when used with repeated sampling and comparison. In a climate change scenario, many landscape characteristics will change in either a subtle and spatially-even (though significant) way across the landscape, or in very small patches. In either case, these changes would be very difficult to detect through undirected synoptic methods in remote areas like the Noatak Basin. Relating landscape parameters to aquatic point samples should allow less visible but important changes to be more easily detected. In watersheds where measured stream parameters continue to change, or where the relationship between these parameters and landscape variables continues to change, future managers will be able to focus their investigations on these areas, and develop a-priori insights into possible causes.

Lakes

We resurveyed four lakes sampled during a 1973 survey (O'Brien and Huggins 1974) and found different productivity, light availability and thermal patterns compared to those recorded in 1973. During the 1973 survey, one out forty-seven lakes in the Noatak Drainage exhibited well-defined thermal stratification. In our survey, all lakes with depths greater than four meters were thermally stratified, including four lakes that were not thermally stratified when sampled on similar dates in 1973. Thermal patterns observed in 1973 agree with research conducted prior to the warming trends experienced in the arctic over the past few decades: Livingston et al. (1958) indicated thermal stratification in the arctic is rare and Hobbie (1980) indicated arctic lakes that are north of the Brookes Range mix continually during the ice-free season.

Changes in thermal stratification can lead to increased water clarity and declining water column productivity. Mean secchi depths of lakes resurveyed in 2005 were higher than 1973 estimates. Regarding lakes sampled in 1973, O'Brien and Huggins (1974) indicate "even fairly deep lakes had low secchi readings compared to oligotrophic lakes in more temperate regions." In unstratified lakes, a decrease in water clarity may be associated with suspended particles continually mixing from the substrate into the water column during wind events; whereas, in deeper, stratified lakes suspended particles are more likely to settle to and remain in the hypolimnion until seasonal mixing occurs. Although not measured in these studies, the effects of climate warming on lake stratification could affect water-column sedimentation rates, primary and secondary productivity in benthic habitats, energy flow between pelagic and benthic and lake and stream outflow habitats, lake-derived nutrient and sediment output to outflow streams.

Seven of the lakes contained fish, including populations of arctic grayling (*Thymallus arcticus*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), round whitefish (*Prosopium cylindroceum*) and nine-spine stickleback (*Pungitius pungitius*). The highest catch rates were for young-of-year arctic grayling in a small pond (maximum depth = 1.2 m), which was dominated by bacterial mats. The highest diversity and catch rates for adult fish occurred in a spring-fed, high-mountain lake with relatively low conductivity. Northern pike were found in large thaw ponds and when present, no other fish were observed. Preliminary observations suggest community and age structure of fish populations strongly influence biomass and diversity of zooplankton and benthic invertebrates; whereas, lake chemistry may play a smaller role.

In general, lakes in the upper Noatak River Region surveyed during 2005 are thermally stratified and oligotrophic with macroinvertebrate and fish populations similar to those measured on the North Slope, near the Toolik Lake LTER. Spring-fed lakes and oxbow sloughs in this region should be considered areas of special ecological importance, as they tend to have higher productivity and diversity than thaw-lakes and lakes of glacial origin. Comparisons with data from lakes surveyed in 1973 indicate climate plays a large role in lake clarity and thermal stratification and stability, all of which affect lake biology. Future monitoring efforts should continue assessing effects of climate on thermal stability of lakes and begin to evaluate the consequences of changes in thermal stability on stream-lake interactions.

Landscapes

It is widely acknowledged that landscape-level analyses in Alaska would benefit from better and finer topographic data. The push to acquire better DEM data for the state often centers on federal agencies and any role the National Park Service might play in advancing this idea would benefit the Inventory & Monitoring Program directly, as well as numerous agency, public and private initiatives. The need for more accurate and detailed data also applies to other framework layers, most notably geology and landcover.

Data considerations aside, the most important considerations involve expanded sampling to include a greater geographic area and stronger contrasts among landscapes, which should allow for better statistical relationships and a clearer understanding of the interaction between landscape-level characteristics and aquatic ecosystem processes.

Collection of associated, well-documented ground photos and GPS locations was pivotal to successful landscape-level analysis. They further provide irreplaceable legacy information to drive accurate and meaningful future comparisons and monitoring. In particular, all GPS data should include full documentation for features relevant at accuracies better than 10-15m. Receiver, software, spatial units, datum and reference frame, point collection method and contact information for the investigator can be the difference between a plausible change detection analysis and complete uncertainty. In this study, locations were not specific enough to cause great concern regarding accuracy, but we have included an appropriate metadata file (Appendix A and Digital Appendix G) in hopes of promoting consistent GPS metadata use.

Repeat sampling of aquatic resources and continued updating of landscape datasets will also be critical to resource monitoring. Results from an ongoing extension of this aquatic research will help drive protocol development for these activities.

Conclusions

General

Climate change and the subsequent effects on the distribution of permafrost and the hydrologic regime in the arctic may lead to more rapid changes in the size, abundance or distribution of aquatic resources on the arctic landscape. For these reasons and for general management needs, the National Park Service (NPS) funded the Arctic Network (ARCN) to establish a long-term Inventory and Monitoring program that includes as assessment of freshwater ecosystems. Through a series of workshops in 2003 a combination of NPS staff and science experts identified a list of "vital signs" and associated indicators that could be used to assess and subsequently monitor the health or condition of the parks. Indicators suggested for freshwater vital signs included water quality and chemistry, physical characterization, riparian vegetation, epilithon, bryophytes, macroinvertebrates, benthic microbial communities, and fish. These indicators were chosen because they represent important physical, chemical and biological elements of the freshwater ecosystems and because they will probably change if the freshwater resources in the parks are stressed at some point in the future.

Lakes and streams are good choices as vital signs in the ARCN for a variety of reasons. First, they are abundant; the ARCN area contains well over 25,000 shallow lakes and ponds. In addition, lakes and rivers are useful vital signs because they are self-contained and responsive to changes in their environments. They are natural laboratories where ecological interactions of organisms and their environment can be easily tracked. They are relatively easy to sample, have distinct boundaries (as compared to other ecosystem types), and provide relatively easy opportunities for field experiments. Working in an ecosystem where changes are easy to track will enhance the ability to document trends and to provide early warnings of impending threats.

Streams and lakes provide a diverse array of ecological functions. The interactions of physical, biological and chemical components of a streams and lakes, such as soils, water, plants and animals, enable the ecosystem to perform vital functions such as water storage; storm protection and flood mitigation; shoreline stabilization and erosion control; groundwater recharge; groundwater discharge; water purification through retention of nutrients, sediments, and pollutants; and stabilization of local climate conditions, particularly rainfall and temperature (Mitsch and Gosselink, 1986; Hauer and Lamberti, 2006). Besides serving many ecological functions, lakes and rivers provide a variety of ecological benefits related to biological diversity and provide the resources that many plants and animals depend on for survival. They provide critical habitat for aquatic primary producers and primary consumers like macroinvertebrates, which fuel many secondary consumers such as birds and fish. Streams and lakes in the ARCN are particularly important to the people who hunt and trap within the boundaries of the parks. These people rely on streams and lakes for harvesting subsistence resources such as moose, waterfowl, and furbearers. Because of their remoteness, modern protected status, and the resulting relative lack of human influence on them, the lakes and stream ecosystems of the ARCN parks also have enormous value as references of background conditions for monitoring efforts on other high latitude regions.

ARCN expects the freshwater monitoring program to provide broad-based, scientific information that can be used to make sound management decisions and support research, education, and public awareness regarding the parks, as required by the NPS Inventory and Monitoring program. The field work undertaken in this study was devised to test a field sampling strategy and a set of protocols that we thought could form the basis for future monitoring of freshwater resources in ARCN. This was the first year of what we expected to be a 3 year effort to test different approaches and protocols at several different locations in the Noatak River network.

Specific

The field sampling strategy we employed in 2005 was to float a long section of the upper Noatak River between Seven Mile Slough and Matchurak Lake and to intensively sample every major tributary junction we encountered for an array of indicators that we thought might be sensitive to change in the future. Water quality monitoring programs typically emphasize measurements of physical and chemical properties of water. These properties are usually sensitive indicators of environmental change – natural and anthropogenic – because water in streams and lakes carries with it the chemical signature of the watershed through which it flows. However, this sensitivity presents a challenge as well, because the physical and chemical properties of water can change rapidly in response to annual, seasonal, and even shorter events (e.g. dry summers, intense snowmelt, or large storm events). In addition, it is not always clear which properties of water should be measured; the contaminants or human modifications may not be known, present, or easily detected by current technologies.

For these reasons most aquatic monitoring programs include physical, chemical and biological indicators that integrate the effects of rapidly changing water quality properties over time and space. For these reasons we carefully selected a suite of indicators that we thought would be responsive to change over a range of temporal and spatial scales. These indicators included: 1) physical characterization of streams and lake geomorphology, 3) physical and chemical properties of water and 3) biological assessments including epilithon, riparian vegetation, bryophytes, macroinvertebrates, and fish. The specific metrics we chose are ones that we have used in studies of other rivers on the North Slope of Alaska, primarily in association with Arctic LTER program at the Toolik Field Station. Furthermore, these same metrics would likely be regarded by most limnologists as logical first choices to characterize lakes and rivers. Thus, we have some confidence that the metrics used in this study are at least a reasonable set that balances information return versus effort and cost to obtain the samples and data.

We are less convinced that the sampling strategy we used in 2005 should be employed in the future. Our original rationale for this strategy was that sampling at large tributary junctions to the Noatak River would provide a coarse but integrated assessment of the entire watershed upstream of the sampling point. By sampling each tributary we would essentially be "sampling" the entire basin. This type of sampling framework is routinely employed in more developed areas where different watersheds may have significantly different proportions of agriculture, industry, urban development, forests, and wetlands. These vastly different land uses and land covers can significantly alter water quality and thus exert important influences on stream and lake ecosystems.

However, we concluded that this sampling strategy might not suit the requirements of the ARCN Freshwater Vital Signs monitoring program. While the landscape in the Noatak River basin is quite diverse, at a coarse scale of resolution the entire region is rather homogeneous and is clearly pristine. While there are extremes in elevation from high mountain peaks to low valley bottoms, a complex array of vegetation types, and diverse geological characteristics ranging from non-carbonate to carbonate to mafic, this diverse array of characteristics is more or less evenly distributed across the landscape. As a consequence, large watersheds all tend to have high mountains in the headwaters and wide floodplain valleys near the main stem of the Noatak River. The complex vegetation matrix is also somewhat evenly distributed across the landscape. And though geology tends to differ a bit at coarse scales, the geology is sufficiently complex that the only useful discriminating characteristic we could identify was carbonate versus non-carbonate geology.

Furthermore, the entire area is some of the most pristine landscape in the world. Productivity across this landscape is low relative to temperate or tropical standards but is generally limited by the availability of nutrients that are naturally supplied a very low rates. Thus, it is not surprising that "leakage" of nutrients from terrestrial to aquatic ecosystems is low. As a consequence a single molecule of nitrogen or phosphorus, for example, will be recycled many times as it moves through a river and lake network (i.e., it spirals rapidly). Effectively this means that the limited productivity in aquatic systems effectively resets nutrient conditions to very low levels, probably numerous times, as water moves from headwaters to a tributary junction. In other words, tributary junctions are likely to be biogeochemically disconnected from sites further upstream in the river network, so that headwaters have little influence on downstream sites.

The fact that these watersheds appear to be in pristine conditions is, of course, a good thing. However, from a monitoring perspective it presents a challenge. If aquatic nutrients, productivity, and diversity are low everywhere then there is no basis for extrapolation of data collected in one place to estimate whether conditions might be changing in another place that has not yet been measured; i.e., there is no way to extrapolate. As a consequence, it would be necessary to measure everything, everywhere to have some assurance that conditions were not changing. This is not a practicable solution.

We think that a useful alternative would be to sample individual stream networks that arise from a uniform geology. A limited set of places could be identified that represented the major combinations of topography, geology, and plant communities. As these factors are closely associated, the total number of sampling sites required will likely be less than the product of all possible categories of these factors; e.g., lowland, mafic, wet sedge meadows are unlikely to be a large part of the landscape.

With the landscape stratified in this way it would be easier to extrapolate across the entire ARCN park system. If the complete set of strata represent a major portion of the ARCN environment, then sampling a representative selection of each strata type should provide useful information about most of the ARCN environment. This is an efficient sampling strategy that should minimize effort and cost. The “ecoregions” approach employed by Jorgensen et al. (XX) in other projects supported by ARCN would be ideal to identify and define strata.

We think it would be useful to stratify first on the basis of geology. Geology is immutable; it will not change in the future. Most other factors that might be interesting as either strata characteristics or indicators (e.g., vegetation, hydrology, nutrients, etc.) are subject to change in the future. Thus, by creating primary strata that are defined by geology and secondary strata that are defined by vegetation, it should be possible to create a limited number of strata that could be used to select benchmark streams to sample. Over long periods of time vegetation within a strata might change, which could redefine the strata class of some sampling points. But this is one probable consequence of change that would be interesting and useful to follow. Furthermore, if there are a sufficient number of replicate sampling sites across all strata then hopefully all strata will remain represented in the monitoring program. If there is an indication that a strata class might disappear from the monitoring network, new sites could be established to fill the gap. However, it might also be the case that this strata class is no longer important; e.g., a particular geology-topography-vegetation strata class is no longer an important component of the parks. In either case, some form of adaptive management could address this circumstance.

The fieldwork we proposed to do in 2006 in the vicinity of Feniak Lake, was designed to employ this geology-based sampling strategy while using essentially the same metrics and protocols employed in this study. Results from that effort are reported by Flinn el al. (2009).

Acknowledgements

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Appendices

Introduction figures.

Figure 1. The Arctic Network of Parks (ARCN) in the National Park Service Inventory & Monitoring Program (map courtesy of ARCN).

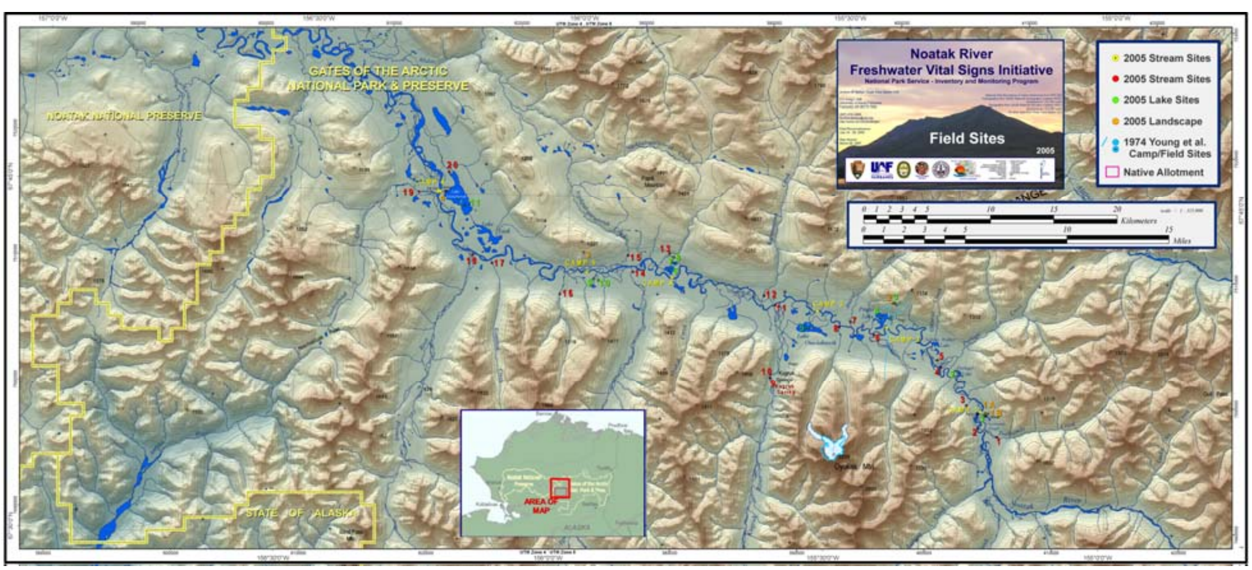


Figure 2. Aquatic Biodiversity,Community Composition and Ecosystem Processes: 2005 Field Sites. For full-size thematic maps please see Appendix F.


Figures 3a and 3b. 3a: Mt. Igikpak looking east with the Arrigetch Peaks in the extreme background to the left. Note the sharp arêtes and spires throughout the photo, and that Mt. Igikpak is almost a horn. 3b. Noatak River Headwaters. Note the mixture of rock types, steep slopes, talus and sparse vegetation. (Photos by Andrew Balser, 2006)


Figures 4a and 4b. 4a: 2005 Stream 5 (Portage Creek) looking northeast upstream. The Noatak Valley widens to two miles in this area, shrub, shrub tundra and tussock-tundra are prevalent, and topographic relief is milder. 4b: The Upper Noatak Valley looking south over Pingo Lake (2005 Lake 4, 1973 Camp VI Lake 1). Note the meandering Noatak mainstem and mosaic of floodplain vegetation in the valley below. The two small lakes adjacent to Pingo Lake are 1973 Camp VI Lakes 1 & 2. The 1973 Camp VI Vegetation transect runs from roughly the point of this photograph across the valley and up the opposite slope on the southern side. 2005 Stream 6 is visible at the confluence on the far side of the Noatak River. (Photos by Andrew Balser, 2005)

Figures 5a and 5b. 5a: Foothills east of Lake Matchurak near the downstream end of the Upper Noatak Basin. Note the milder topography, the prevalence of shrubs, and the hillslope failures (possibly active-layer slides) in the foreground. 5b: The western bank of Lake Matchurak (2005 Lake 11, 1973 Camp VI Lake 4). Note the thick birch-willow scrub in the foreground. (Photos by Andrew Balser, 2005)

Figure 6. The Kugrak River Valley. The Kugrak River, within the Oyukak Carbonate Mountains EcoSubSection, is a major tributary of the Noatak River containing significant carbonate lithologies in the Upper Noatak Basin. In this view, looking north,substantial limestone outcrops are prominent, and the Noatak River is visible in the extreme distance. Kugrak Springs (2005 Stream 9) is located at the edge of the photo at the last visible bend in the Kugrak River. Omelaktavik Lake (2005 Lake 5, 1973 Camp VI Lake 5) is visible in the distance as well. (Photo by Andrew Balser, 2006).

Appendix A. Field Site Locations

Table A.1. Noatak 2005 Aquatic Site Locations and Descriptions. Geographic coordinates in decimal degrees, North American Datum of 1927 (NAD27).

Name	Feature	Data Name	Year	Latitude N	Longitude W	Source
Camp 1	Camp	BC1A	2005	67.602851	155.230362	gps
Camp 2	Camp	BC2A	2005	67.662290	155.407158	Gps
Camp 3	Camp	BC3A	2005	67.673304	155.535881	Gps
Camp 4	Camp	BC4A	2005	67.694252	155.806564	Gps
Camp 5	Camp	BC5A	2005	67.696652	155.964267	Gps
Camp 6	Camp	BC6A	2005	67.751381	156.243057	Gps
Camp V	Camp	FC736X	1973	67.969064	156.168078	1974 Young et al.
Camp VI	Camp	FC735X	1973	67.670353	155.403754	1974 Young et al.
Fg1a	Photo Transect	FG1A	2005	67.601845	155.221763	Gps
Fg1b	Photo Transect	FG1B	2005	67.601636	155.216218	Gps
Fg2a	Photo Transect	FG2A	2005	67.679931	155.396062	Gps
Fg3a	Photo Transect	FG3A	2005	67.710410	155.971223	Gps
Fg4a	Photo Transect	FG4A	2005	67.751182	156.232080	Gps
fl12a	Photo Transect	FG19A	2005	67.957632	156.160607	Gps
fl1a	Photo Transect	FG9A	2005	67.601148	155.223856	Gps
fl1b	Photo Transect	FG10B	2005	67.601166	155.221290	Gps
fl7a	Photo Transect	FG16A	2005	67.703280	155.802626	Gps
fl8a	Photo Transect	FG17A	2005	67.708302	155.807010	Gps
fl9a	Photo Transect	FG18A	2005	67.692054	155.949294	Gps
Fs3a	Photo Transect	FG14A	2005	67.607177	155.256367	Gps
Fs4a	Photo Transect	FG13A	2005	67.634378	155.305058	Gps
Fs5a	Photo Transect	FG12A	2005	67.639582	155.311419	Gps
Fs7a	Photo Transect	FG15A	2005	67.665876	155.473555	Gps
Fs8a	Photo Transect	FG11A	2005	67.624292	155.619704	Gps
Camp V Lake 1	Lake	FL7351X	1973	67.956760	156.132967	1974 Young et al.
Camp V Lake 2	Lake	FL7352X	1973	67.973365	156.202527	1974 Young et al.
Camp V Lake 3	Lake	FL7353X	1973	67.983379	156.207012	1974 Young et al.
Camp VI Lake 1	Lake	FL7361X	1973	67.670361	155.411614	1974 Young et al.
Camp VI Lake 2	Lake	FL7362X	1973	67.668506	155.400284	1974 Young et al.
Camp VI Lake 3	Lake	FL7363X	1973	67.670248	155.398883	1974 Young et al.
Camp VI Lake 5	Lake	FL7365X	1973	67.660007	155.550215	1974 Young et al.
Camp VI Lake 5	Lake	FL7365X	1973	67.660007	155.550215	1974 Young et al.
Camp VI Lake 6	Lake	FL7366X	1973	67.678980	155.389626	1974 Young et al.
Lake 1	Lake	FL1X	2005	67.600456	155.220855	USGS_map
Lake 2	Lake	FL2X	2005	67.631565	155.272967	USGS_map
Lake 3	Lake	FL3X	2005	67.679821	155.391587	USGS_map
Lake 4	Lake	FL4X	2005	67.669904	155.417855	USGS_map
Lake 5	Lake	FL5X	2005	67.661230	155.555787	USGS_map
Lake 6	Lake	FL6X	2005	67.699799	155.810438	USGS_map
Lake 7	Lake	FL7X	2005	67.704679	155.802993	USGS_map
Lake 8	Lake	FL8X	2005	67.708715	155.804276	USGS_map
Lake 9	Lake	FL9X	2005	67.691393	155.950638	USGS_map
Lake 10	Lake	FL10X	2005	67.690582	155.942236	USGS_map
Lake 11	Lake	FL11X	2005	67.750383	156.220967	USGS_map

Name	Feature	Data Name	Year	Latitude N	Longitude W	Source
Lake 12	Lake	FL12X	2005	67.956088	156.149586	USGS_map
Stream 1	Stream	BS1A	2005	67.584953	155.199020	Gps
Stream 2	Stream	BS2A	2005	67.591049	155.234787	Gps
Stream 3	Stream	BS3A	2005	67.607269	155.256500	Gps
Stream 4	Stream	BS4A	2005	67.634368	155.305054	Gps
Stream 5	Stream	BS5A	2005	67.639649	155.311401	Gps
Stream 6	Stream	BS6A	2005	67.656852	155.429871	Gps
Stream 7	Stream	BS7A	2005	67.665878	155.473556	Gps
Stream 8	Stream	BS8A	2005	67.661949	155.494873	Gps
Stream 9	Stream	BS9A	2005	67.624283	155.619690	Gps
Stream 10	Stream	BS10A	2005	67.624283	155.619934	Gps
Stream 11	Stream	BS11A	2005	67.676636	155.613937	Gps
Stream 12	Stream	BS12A	2005	67.683113	155.634872	Gps
Stream 13	Stream	BS13A	2005	67.711098	155.811859	Gps
Stream 14	Stream	BS14A	2005	67.697403	155.878998	Gps
Stream 15	Stream	BS15A	2005	67.709069	155.888855	Gps
Stream 16	Stream	BS16A	2005	67.680420	156.013138	Gps
Stream 17	Stream	BS17A	2005	67.700837	156.140320	Gps
Stream 18	Stream	BS18A	2005	67.706185	156.176605	Gps
Stream 19	Stream	BS19A	2005	67.750320	156.280090	Gps
Stream 20	Stream	BS20A	2005	67.765236	156.225433	Gps
12-Mile Slough	Other	BO2A	2005	67.599567	155.220371	Gps
PORTAGE	Other	BO4A	2005	67.639214	155.308212	Gps
Pull-out	Other	BO6A	2005	67.751404	156.230331	Gps
Put-In	Other	BO5A	2005	67.601433	155.235532	Gps
Camp V Midas Creek	Stream	FS7351X	1973	67.943854	156.032015	1974 Young et al.

Figure A.1. GPS Metadata Form

GPS Data Collection Documentation (Metadata)

Toolik Field Station GIS
IAB, 311 Irving I
University of Alaska Fairbanks
Fairbanks, AK 99775-7000
(907) 474-2466
Andrew.Balser@uaf.edu

Basis of Bearings and Coordinates

Linear unit: Meters

Geodetic datum: NAD27 — Epoch: n/a

Vertical datum: NGVD29

Coordinate System: ALBERS Alaska (Lambert's Conformal Conic)

Feature Description: 2005 Aquatics Sites - Stream Sampling, Camps, Landscape

Rover File Name: noatak_complete.gdb — Base File Name: n/a

Field Technician(who collected data): Andrew Balser

PI Name: Andrew Balser

GPS Reciever: Recreational Grade Rover

Antenna: Trimble TSC1 w/2m cable

GPS & Mapping Software: Garmin Mapsource — v 6.0 w/ Garmin eTrex

Mapping Conditions: July 14 - 26, 2005 - generally good weather
valley conditions with moderate obstruction from valley walls north & south

Mapping Process:

GPS Quality Settings:

- HDOP - 1 - 6
- SNR - n/a
- Satellite Elevation Mask - n/a
- Logging Rate - single fix - 1 obs

Andrew Balser

Post-Processing Technician: Andrew Balser

GPS Data Processing:
Garmin eTrex Legend - waypoint collection
Upload to Garmin MapSource
Export in lat/long decimal degrees NAD27, .mps format
Import to ArcView 3.3 using AV Garmin (CA Dept. of Nat. Res. extension script)
convert to geodatabase feature class in ArcGIS 9.0
project into ALBERS Alaska NAD27
append to Noatak_2005_Aquatics.gdb

Appendix B. Stream data

Table B. 1. Comparison of general stream characteristics between 2005 and 1974.

Metric	Noatak 2005		*Noatak 1974	
	Mean	Range	Mean	Range
Width (m)	10	2.5 - 25	N/A	N/A
Depth (cm)	24	13 - 40	N/A	N/A
D50	54	22.6 - 90	N/A	N/A
Temp. (ºC)	12.2	7.2 - 20.2	N/A	N/A
pH	8.3	7.7 - 8.6	7.4	7.0 -7.5
DO (mg/L)	10.2	7.6 - 13.3	6.8	5.7 - 7.5
EC (µS/cm)	416	77 - 811	199	44 - 623

*Young et al. 1974

Table B. 2. Comparison of nutrient chemistry between Noatak 2005 tributaries and North Slope stream data.

Metric	Noatak 2005		North Slope	
	Mean	Range	Mean	Range
Nitrate (µM)	7.1	3.7 - 9.9	3.0*	0.98-6.43*
TDN (µM)	10.7	5.1 - 24.5	N/A	N/A
TDP [SRP] (µM)	0.07	0.01-0.44	[0.04]*	[0.025-0.058]*
Benthic TN (mg/L)	3.1	0.8-19.2	N/A	N/A
Benthic TC (mg/L)	10.8	1.9-14.6	N/A	N/A
Sestonic TN (mg/L)	0.06	0.01-0.33	N/A	N/A
Sestonic TC (mg/L)	0.65	0.1-2.9	N/A	N/A
CHL *a* (µg/cm2)	0.04	0.0 - 0.3	0.28**	0.08-0.69**

*LTER Toolik Lake Research Station data (2000-2004)

**LTER Toolik Lake Research Station data (June/July 2004)

Table B 3. Nutrients in the Noatak River stream tributaries by lithology

Stream Type	n	Total CHLa (µg/cm2)	*Nitrate (µM)	**TDN (µM)
Non-Carbonate	12	0.02 (0.02)	7.92 (1.32)	12.88 (4.48)
Carbonate	7	0.03 (0.05)	6.03 (1.72)	7.74 (1.72)
Kugrak Spring	1	0.30	5.30	5.63
		TDP (µM)	TDN:TDP	TDN-NO3 (DON)
Non-Carbonate	12	0.09 (0.12)	281.01 (234.98)	3.90 (2.97)
Carbonate	7	0.03 (0.01)	403.96 (423.99)	1.70 (0.55)
Kugrak Spring	1	0.05	117.09	0.33
		TPN benthic (µg/L)	TPN seston (µg/L)	TPC benthic (µg/L)
Non-Carbonate	12	4705.6 (8115)	72.85 (104.67)	9932.2 (4660.2)
Carbonate	7	990.25 (221.80)	18.63 (12.9)	11926.25 (2195.38)
Kugrak Spring	1	N/A	25.42	N/A
		TPC seston (µg/L)	C:N benthic	C:N seston
Non-Carbonate	12	735.30 (900.58)	10.76 (6.41)	13.65 (4.54)
Carbonate	7	518.05 (590.21)	14.43 (3.66)	26.7 (14.16)
Kugrak Spring	1	378.74	N/A	17.4

*Significant differences between non-carbonate and carbonate stream types, (T-test, $p = 0.014$, $\alpha = 0.05$)

**Significant differences between non-carbonate and carbonate stream types (Mann-Whitney, $p = 0.008$, α = 0

Table B 4. NOATAK 2005 vs North Slope nutrients. Comparisons of the stream nutrient chemistry of the Upper Noatak with North Slope streams. The streams column includes the sampling years and the numbers of streams sampled except for the Kuparuk where n = samples taken over the season. Tabled values are arithmetic means. Values are uM and ratios are molar.

STREAMS	Nitrate	DON	TDN	NO_3 as % of TDN	TDP	TDN/TDP
Upper Noatak 2005 n= 20	7.1	2.9	10.6	66%	0.07	315
Kuparuk River 1980 n= 30-34	1.5	18.5	20.0	8%	0.26	49
North Slope Survey 1997-2000						
9 springs	3.5	2.5	5.9	58%	0.19	31
8 mountain	4.5	2.7	6.3	71%	0.25	25
6 glacier	5.3	0.4	5.1	100%	0.45	11
6 tundra	0.7	12.3	13.1	5.6%	0.30	44
North Slope Survey 2004-2005						
8 springs	5.2	3.0	8.2	65%	0.10	120
3 mountain	5.2	1.1	6.3	80%	0.06	102
4 glacier	14.4	1.0	15.2	92%	0.28	78
5 tundra	1.6	16.4	17.9	9.4%	0.29	81

Table B. 5. General chemistry of Noatak River stream tributaries by lithology.

Stream Type	n	pH	DO mg/l	*EC (µS/cm)	Temperature ºC
Non-Carbonate Sites Mean (SE)	12	8.32 (0.13)	10.50 (1.50)	335.5 (120.54)	11.58 (3.40)
Carbonate Sites Mean (SE)	7	8.36 (0.03)	10.06 (0.85)	527.57 (162.57)	12.99 (1.79)
Kugrak Spring Site	1	7.682	7.64	605	13.5

*Significant differences between non-carbonate and carbonate stream types (T-test, $p = 0.009$, $\alpha = 0.05$)

Table B. 6. Heavy metals in Noatak River stream tributaries by lithology.

Stream Type	n	Iron (µg/L)	Lead (µg/L)	Nickel (µg/L)
Non-Carbonate	12	66.87 (111.31)	0.35 (1.12)	0.79 (0.59)
Carbonate	7	25.64 (12.14)	0.17 (0.41)	6.46 (7.64)
Kugrak Spring	1	16.40	0.10	0.32
		Silicon (µg/L)	Zinc (µg/L)	Chromium (µg/L)
Non-Carbonate	12	1119.5 (228.33)	8.33 (6.93)	3.62 (1.97)
Carbonate	7	1088.14 (221.42)	13.33 (11.76)	3.19 (0.41)
Kugrak Spring	1	3450.00	9.50	3.30
		Cadmium (µg/L)	Copper (µg/L)	Aluminum (µg/L)
Non-Carbonate	12	0.38 (1.00)	0.74 (0.51)	18.73 (31.55)
Carbonate	7	0.06 (0.07)	0.62 (0.48)	30.16 (26.80)
Kugrak Spring	1	0.04	0.95	6.90

Table B. 7. Periphyton taxa list for upper Noatak tributary streams (D=diatom, G=Chlorophyta, C=Cyanobacteria).

	S1	S3	S4	S5	S6	S7	S8	S9	S11	S12	S13	S14	S15	S16	S17	S18	S19
Achnanthidium spp. (D)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cocconeis placentula (D)				+	+	+	+	+	+		+		+				
Cymbella minuta (D)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Diatoma heimale (D)	+		+			+		+	+	+		+	+			+	+
Eunotia sp. (D)			+	+				+			+						
Fragilaria vaucheriae (D)	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
Gomphonema angustatum (D)	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
Hannaea arcus (D)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Meridion circulare (D)			+			+		+		+	+		+	+			
Navicula radiosa (D)		+		+		+	+	+	+	+	+			+		+	
Nitschia sp. (D)								+	+								
Staurosirella leptostauron (D)			+														
Synedra ulna (D)	+		+	+				+	+		+		+		+	+	+
Tabellaria flocculosa (D)				+			+	+									
Oscillatoria sp. (G)	+						+	+	+	+			+			+	+
Zygnema sp. (G)			+		+		+									+	
Chamaesiphon sp. (C)	+	+	+	+	+	+	+	+	+			+	+	+	+	+	
Phormidium sp. (C)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table B. 8. Rank of streams based on macroinvertebrate taxon richness (left, number of taxa per stream), abundance (number of individuals per m^2), and biomass (mg dry mass per m^2). Streams are tributaries of the Noatak River, Gates of the Arctic National Park, Alaska.

Stream	no. taxa/stream	Stream	#/m^2	Stream	mg/m^2
S4	17	S9	55618	S9	2138
S5	16	S4	4609	S4	1200
S15	14	S8	2270	S15	121
S8	12	S16	1560	S8	113
S9	12	S7	1255	S16	91
S13	12	S14	1137	S7	76
S1	10	S1	1133	S14	71
S2	10	S10	678	S10	53
S14	10	S17	660	S1	52
S16	10	S15	570	S13	37
S17	8	S2	456	S17	33
S7	7	S5	359	S2	33
S12	7	S12	316	S5	28
S6	6	S13	276	S12	15
S10	6	S6	219	S18	13
S18	6	S18	183	S6	8
S19	6	S19	72	S19	2

Table B 9. Rank of streams based on taxonomic richness of benthic macroinvertebrates. Streams are tributaries of the Noatak River, Gates of the Arctic National Park, Alaska.

Class/Order	Family	Subfamily	Genus	# streams present
Diptera	Chironomidae	Orthocladiinae	*Orthocladius*	16
Diptera	Chironomidae	Diamesinae	*Diamesa*	16
Diptera	Chironomidae	Orthocladiinae	*Eukieferiella*	15
Diptera	Chironomidae	Orthocladiinae	*Tvetenia*	15
Plecoptera	Nemouridae		*Nemoura*	14
Oligochaeta				10
Ephemeroptera	Baetidae		*Baetis*	10
Plecoptera	Capniidae		*Capnia*	10
Diptera	Tipulidae		*Tipula*	7
Diptera	Chironomidae	Orthocladiinae	Orthocladiinae A	6
Ephemeroptera	Baetidae		*Acentrella*	5
Diptera	Empididae		*Clinocera*	5
Diptera	Tipulidae		*Dicranota*	4
Acarina				4
Ephemeroptera	Heptageniidae		*Cinygmula*	3
Diptera	Simuliidae		*Gymnopais*	3
Diptera	Chironomidae	Orthocladiinae	*Cricotopus*	3
Diptera	Chironomidae	Orthocladiinae	*Diplocladius*	3
Diptera	Chironomidae	Orthocladiinae	*Metriocnemus*	3
Turbellaria				2
Diptera	Simuliidae		*Simulium*	2
Diptera	Chironomidae	Orthocladiinae	*Corynoneura*	2
Diptera	Chironomidae	Diamesinae	*Syndiamesa*	2
Plecoptera	Perlodidae		*Arcynopteryx*	1
Diptera	Ceratopogonidae		*Culicoides*	1
Diptera	Tipulidae		*Limonia*	1
Diptera	Simuliidae		*Stegopterna*	1
Diptera	Chironomidae	Orthocladiinae	*Paratrichocladius*	1
Diptera	Chironomidae	Chironominae	Tanytarsini A	1
Diptera	Chironomidae	Diamesinae	*Pseudokieferiella*	1
Diptera	Chironomidae	Tanypodinae	Tanypodinae A	1
Trichoptera	Hydroptilidae		*Ochrotrichia*	1

Table B. 10. Mean abundance (individuals/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream.

				Streams					
Class/Order	Family	Subfamily	Genus	S1	S2	S4	S5	S6	S7
Oligochaeta				*	39	1460	65	*	*
Turbellaria				*	*	*	*	*	*
Ephemeroptera	Baetidae		*Baetis*	4	*	4	14	4	22
"	"		*Acentrella*	*	*	395	4	*	*
"	Heptageniidae		*Cinygmula*	*	*	*	*	*	*
Plecoptera	Capniidae		*Capnia*	36	*	54	18	*	14
"	Nemouridae		*Nemoura*	68	7	1499	39	*	39
"	Perlodidae		*Arcynopteryx*	*	*	*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	*	*	*	*	*	*
"	Tipulidae		*Dicranota*	*	*	*	4	*	*
"	"		*Tipula*	*	*	29	*	*	*
"	"		*Limonia*	*	*	*	*	*	*
"	Empididae		*Clinocera*	14	7	*	4	*	*
"	Simuliidae		*Gymnopais*	4	39	*	*	*	*
"	"		*Simulium*	*	*	29	*	*	*
"	"		*Stegopterna*	*	*	*	*	*	*
"	Chironomidae	Orthocladiinae	*Corynoneura*	*	*	25	*	*	*
"	"	"	*Cricotopus*	*	4	18	4	*	*
"	"	"	*Diplocladius*	*	*	190	11	*	*
"	"	"	*Eukieferiella*	14	32	47	4	7	47
"	"	"	Orthocladiinae A	32	*	*	4	11	0
"	"	"	*Orthocladius*	161	29	283	75	54	208
"	"	"	*Tvetenia*	344	86	520	47	29	147
"	"	"	*Paratrichocladius*	*	*	*	*	*	*
"	"	"	*Metriocnemus*	*	*	11	4	*	*
"	"	Chironominae	Tanytarsini A	*	*	4	*	*	*
"	"	Diamesinae	*Diamesa*	456	204	39	54	115	778
"	"	"	*Pseudokieferiella*	*	7	*	*	*	*
"	"	"	*Syndiamesa*	*	*	*	11	*	*
"	"	Tanypodinae	Tanypodinae A	*	*	*	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	*	*	*	*	*	*
Acarina				*	*	4	*	*	*

Table B. 10, continued. Mean abundance (individuals/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream.

				Stream					
Class/Order	Family	Subfamily	Genus	S8	S9	S10	S12	S13	S14
Oligochaeta				29	6460	*	18	14	11
Turbellaria				*	29	*	*	4	*
Ephemeroptera	Baetidae		*Baetis*	*	*	*	*	39	4
"	"		*Acentrella*	4	*	*	*	4	*
"	Heptageniidae		*Cinygmula*	*	*	*	*	11	*
Plecoptera	Capniidae		*Capnia*	154	*	*	*	14	*
"	Nemouridae		*Nemoura*	990	9010	14	54	36	11
"	Perlodidae		*Arcynopteryx*	4	*	*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	*	1732	*	*	*	*
"	Tipulidae		*Dicranota*	7	*	*	14	*	*
"	"		*Tipula*	32	*	*	14	4	4
"	"		*Limonia*	*	14	*	*	*	*
"	Empididae		*Clinocera*	*	*	14	*	*	4
"	Simuliidae		*Gymnopais*	*	*	*	*	*	*
"	"		*Simulium*	*	*	*	*	*	*
"	"		*Stegopterna*	*	*	*	*	*	*
"	Chironomidae	Orthocladiinae	*Corynoneura*	*	86	*	*	*	*
"	"	"	*Cricotopus*	*	*	*	*	*	*
"	"	"	*Diplocladius*	4	*	*	*	*	*
"	"	"	*Eukieferiella*	57	25383	7	*	7	*
"	"	"	Orthocladiinae A	*	*	*	*	*	29
"	"	"	*Orthocladius*	104	*	179	97	65	384
"	"	"	*Tvetenia*	703	*	204	*	18	301
"	"	"	*Paratrichocladius*	*	2295	*	*	*	*
"	"	"	*Metriocnemus*	*	2295	*	*	*	*
"	"	Chironominae	Tanytarsini A	*	*	*	*	*	*
"	"	Diamesinae	*Diamesa*	183	*	258	104	61	319
"	"	"	*Pseudokieferiella*	*	*	*	*	*	*
"	"	"	*Syndiamesa*	*	*	*	*	*	72
"	"	Tanypodinae	Tanypodinae A	*	7	*	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	*	7467	*	*	*	*
Acarina				*	839	*	14	*	*

Table B. 10, continued. Mean abundance (individuals/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream.

				Stream				
Class/Order	Family	Subfamily	Genus	S15	S16	S17	S18	S19
Oligochaeta				11	22	*	*	*
Turbellaria				*	*	*	*	*
Ephemeroptera	Baetidae		*Baetis*	72	*	4	4	*
"	"		*Acentrella*	25	*	*	*	*
"	Heptageniidae		*Cinygmula*	93	*	*	*	18
Plecoptera	Capniidae		*Capnia*	47	75	75	11	*
"	Nemouridae		*Nemoura*	32	75	4	*	*
"	Perlodidae		*Arcynopteryx*	*	*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	*	*	*	*	*
"	Tipulidae		*Dicranota*	*	14	*	*	*
"	"		*Tipula*	4	*	*	*	4
"	"		*Limonia*	*	*	*	*	*
"	Empididae		*Clinocera*	*	*	*	*	*
"	Simuliidae		*Gymnopais*	*	11	*	*	*
"	"		*Simulium*	50	*	*	*	*
"	"		*Stegopterna*	4	*	*	*	*
"	Chironomidae	Orthocladiinae	*Corynoneura*	*	*	*	*	*
"	"	"	*Cricotopus*	*	*	*	*	*
"	"	"	*Diplocladius*	*	*	*	*	*
"	"	"	*Eukieferiella*	61	18	14	61	4
"	"	"	Orthocladiinae A	*	47	43	*	*
"	"	"	*Orthocladius*	79	57	54	14	22
"	"	"	*Tvetenia*	18	115	25	29	7
"	"	"	*Paratrichocladius*	*	*	*	*	*
"	"	"	*Metriocnemus*	*	*	*	*	*
"	"	Chironominae	Tanytarsini A	*	*	*	*	*
"	"	Diamesinae	*Diamesa*	68	1126	441	65	18
"	"	"	*Pseudokieferiella*	*	*	*	*	*
"	"	"	*Syndiamesa*	*	*	*	*	*
"	"	Tanypodinae	Tanypodinae A	*	*	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	*	*	*	*	*
Acarina				7	*	*	*	*

Table B 11. Mean biomass (mg dry mass/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream. "0.0" indicates biomass was less than 0.1 mg dry mass/m^2.

				Stream					
Class/Order	Family	Subfamily	Genus	S1	S2	S4	S5	S6	S7
Oligochaeta				*	0.6	52.9	4.2	*	*
Turbellaria				*	*	*	*	*	*
Ephemeroptera	Baetidae		*Baetis*	0.3	*	2.3	5.3	1.0	16.0
"	"		*Acentrella*	*	*	66.3	1.0	*	*
"	Heptageniidae		*Cinygmula*	*	*	*	*	*	*
Plecoptera	Capniidae		*Capnia*	2.9	*	9.1	0.4	*	2.5
"	Nemouridae		*Nemoura*	5.6	1.4	175.0	3.1	*	3.8
"	Perlodidae		*Arcynopteryx*	*	*	*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	*	*	*	*	*	*
"	Tipulidae		*Dicranota*	*	*	*	0.2	*	*
"	"		*Tipula*	*	*	839.9	*	*	*
"	"		*Limonia*	*	*	*	*	*	*
"	Empididae		*Clinocera*	2.7	4.8	*	0.1	*	*
"	Simuliidae		*Gymnopais*	0.2	6.1	*	*	*	*
"	"		*Simulium*	*	*	3.9	*	*	*
"	"		*Stegopterna*	*	*	*	*	*	*
"	Chironomidae	Orthocladiinae	*Corynoneura*	*	*	0.1	*	*	*
"	"	"	*Cricotopus*	*	4.6	5.0	1.0	*	*
"	"	"	*Diplocladius*	*	*	1.8	0.4	*	*
"	"	"	*Eukieferiella*	0.5	1.6	2.2	0.0	0.2	0.4
"	"	"	Orthocladiinae A	2.3	*	*	0.3	0.4	*
"	"	"	*Orthocladius*	11.9	1.2	16.8	2.8	2.2	8.3
"	"	"	*Tvetenia*	14.4	2.2	16.9	2.6	1.6	14.5
"	"	"	*Paratrichocladius*	*	*	*	*	*	*
"	"	"	*Metriocnemus*	*	*	5.0	4.6	*	*
"	"	Chironominae	Tanytarsini A	*	*	1.0	*	*	*
"	"	Diamesinae	*Diamesa*	11.6	10.3	1.8	2.1	2.2	30.5
"	"	"	*Pseudokieferiella*	*	0.2	*	*	*	*
"	"	"	*Syndiamesa*	*	*	*	0.3	*	*
"	"	Tanypodinae	Tanypodinae A	*	*	*	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	*	*	*	*	*	*
Acarina				*	*	0.0	*	*	*

Table B. 11, continued. Mean biomass (mg dry mass/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream. "0.0" indicates biomass was less than 0.1 mg dry mass/m^2.

				Stream					
Class/Order	Family	Subfamily	Genus	S9	S10	S12	S13	S14	S15
Oligochaeta				133.3	*	0.9	0.3	2.7	1.6
Turbellaria				1.9	*	*	0.2	*	*
Ephemeroptera	Baetidae		*Baetis*	*	*	*	22.8	2.3	47.4
"	"		*Acentrella*	*	*	*	0.3	*	9.0
"	Heptageniidae		*Cinygmula*	*	*	*	0.3	*	25.1
Plecoptera	Capniidae		*Capnia*	*	*	*	4.0	*	6.4
"	Nemouridae		*Nemoura*	298.7	0.6	3.4	3.8	1.8	2.3
"	Perlodidae		*Arcynopteryx*	*	*	*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	469.5	*	*	*	*	*
"	Tipulidae		*Dicranota*	*	*	0.8	*	*	*
"	"		*Tipula*	*	*	1.8	0.8	15.3	0.2
"	"		*Limonia*	25.6		*	*	0.0	*
"	Empididae		*Clinocera*	*	4.8	*	*	0.7	*
"	Simuliidae		*Gymnopais*	*	*	*	*	*	*
"	"		*Simulium*	*	*	*	*	*	16.2
"	"		*Stegopterna*	*	*	*	*	*	0.5
"	Chironomidae	Orthocladiinae	*Corynoneura*	0.4	*	*	*	*	*
"	"	"	*Cricotopus*	*	*	*	*	*	*
"	"	"	*Diplocladius*	*	*	*	*	*	*
"	"	"	*Eukieferiella*	256.6	0.2	*	0.1	*	2.6
"	"	"	Orthocladiinae A	*	*	*	*	0.3	*
"	"	"	*Orthocladius*	*	12.8	3.7	2.2	16.0	3.3
"	"	"	*Tvetenia*	*	17.4	*	0.5	15.7	1.1
"	"	"	*Paratrichocladius*	755.7	*	*	*	*	*
"	"	"	*Metriocnemus*	*	*	*	*	*	*
"	"	Chironominae	Tanytarsini A	*	*	*	*	*	*
"	"	Diamesinae	*Diamesa*	*	17.4	4.1	2.0	11.7	4.6
"	"	"	*Pseudokieferiella*	*	*	*	*	*	*
"	"	"	*Syndiamesa*	*	*	*	*	4.4	*
"	"	Tanypodinae	Tanypodinae A	37.9	*	*	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	139.2	*	*	*	*	*
Acarina				19.0	*	0.1	*	*	1.0

Table B. 11, continued. Mean biomass (mg dry mass/m^2) for benthic macroinvertebrates in tributaries of the Noatak River, Gates of the Arctic National Park, Alaska. Asterisks indicate absence of taxon from stream. “0.0” indicates biomass was less than 0.1 mg dry mass/m^2.

				Stream		
Class/Order	Family	Subfamily	Genus	S17	S18	S19
Oligochaeta				*	*	*
Turbellaria				*	*	*
Ephemeroptera	Baetidae		*Baetis*	4.4	1.0	*
"	"		*Acentrella*	*	*	*
"	Heptageniidae		*Cinygmula*	*	*	0.2
Plecoptera	Capniidae		*Capnia*	1.7	4.4	*
"	Nemouridae		*Nemoura*	0.4	*	*
"	Perlodidae		*Arcynopteryx*	*	*	*
Diptera	Ceratopogonidae		*Culicoides*	*	*	*
"	Tipulidae		*Dicranota*	*	*	*
"	"		*Tipula*	*	*	0.2
"	"		*Limonia*	*	*	*
"	Empididae		*Clinocera*	*	*	*
"	Simuliidae		*Gymnopais*	*	*	*
"	"		*Simulium*	*	*	*
"	"		*Stegopterna*	*	*	*
"	Chironomidae	Orthocladiinae	*Corynoneura*	*	*	*
"	"	"	*Cricotopus*	*	*	*
"	"	"	*Diplocladius*	*	*	*
"	"	"	*Eukieferiella*	0.0	0.9	*
"	"	"	Orthocladiinae A	3.3	*	*
"	"	"	*Orthocladius*	1.7	0.5	0.6
"	"	"	*Tvetenia*	1.9	2.5	0.2
"	"	"	*Paratrichocladius*	*	*	*
"	"	"	*Metriocnemus*	*	*	*
"	"	Chironominae	Tanytarsini A	*	*	*
"	"	Diamesinae	*Diamesa*	19.7	4.2	0.4
"	"	"	*Pseudokieferiella*	*	*	*
"	"	"	*Syndiamesa*	*	*	*
"	"	Tanypodinae	Tanypodinae A	*	*	*
Trichoptera	Hydroptilidae		*Ochrotrichia*	*	*	*
Acarina				*	*	*

Figure B 2. Base cations from tributaries in the Noatak National Preserve in 2005 and 1978

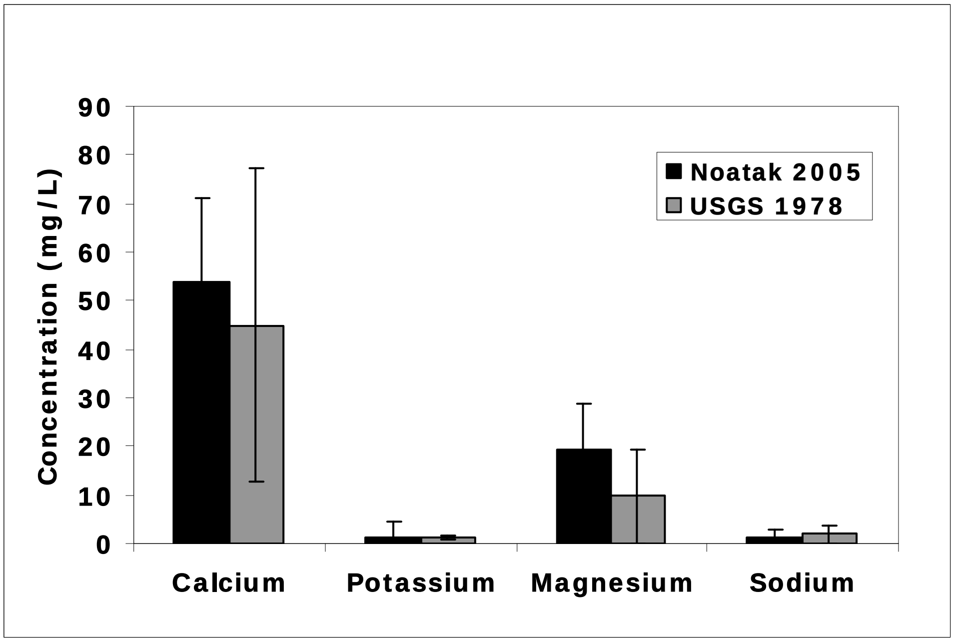


Figure B 3. Heavy metals from tributaries in the Noatak National Preserve in 2005 and 1978

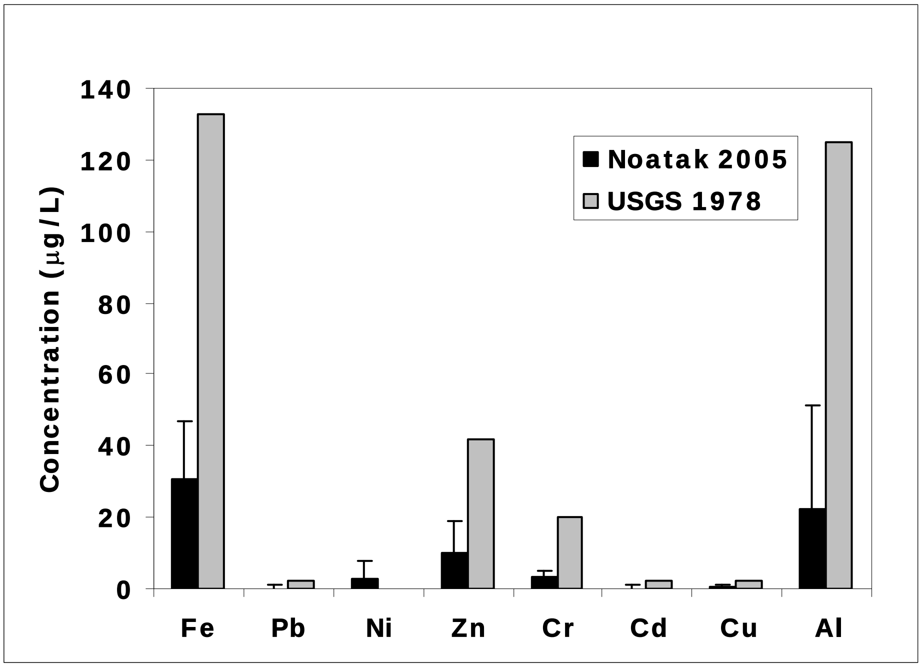


Figure B 4. Comparison of dissolved organic nitrogen (DON) and nitrate (NO_3) in the Alaskan arctic and tributaries on the North Slope.

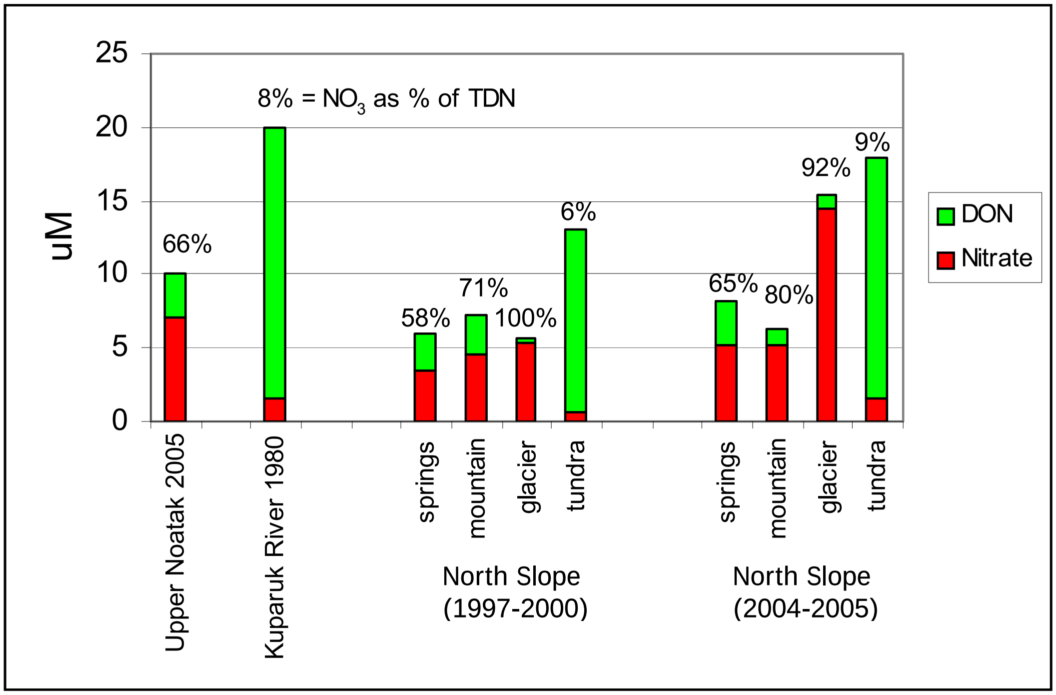


Figure B 5. Comparison of phosphorus from tributaries in the Noatak National Preserve in 2005 and 1978

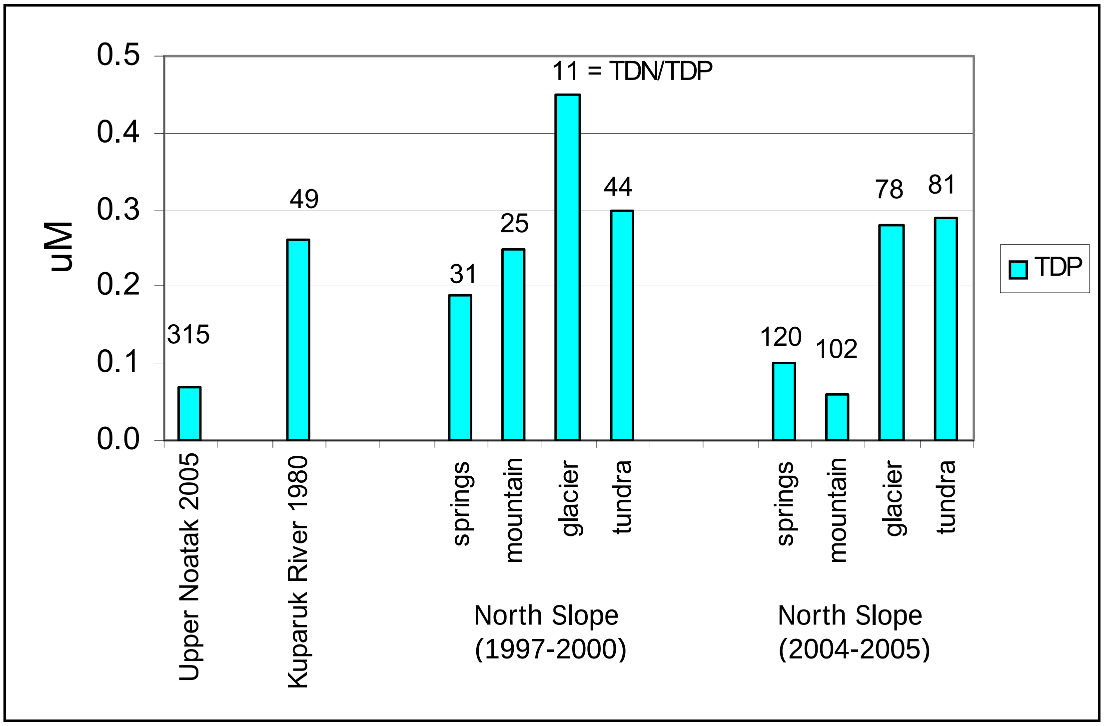


Figure B 6. Algal cell counts per area stream bottom (mean ± 1SE). Dominant Species - Diatoms: *Achnanthidium* spp., *Cymbella minuta*, *Hannaea arcus*, *Fragilaria vaucheriae* and *Gomphonema angustatum*, Cyanobacterium: *Phormidium* spp. ANOVA for differences among sites is significant a p<0.001 (F=5.50)

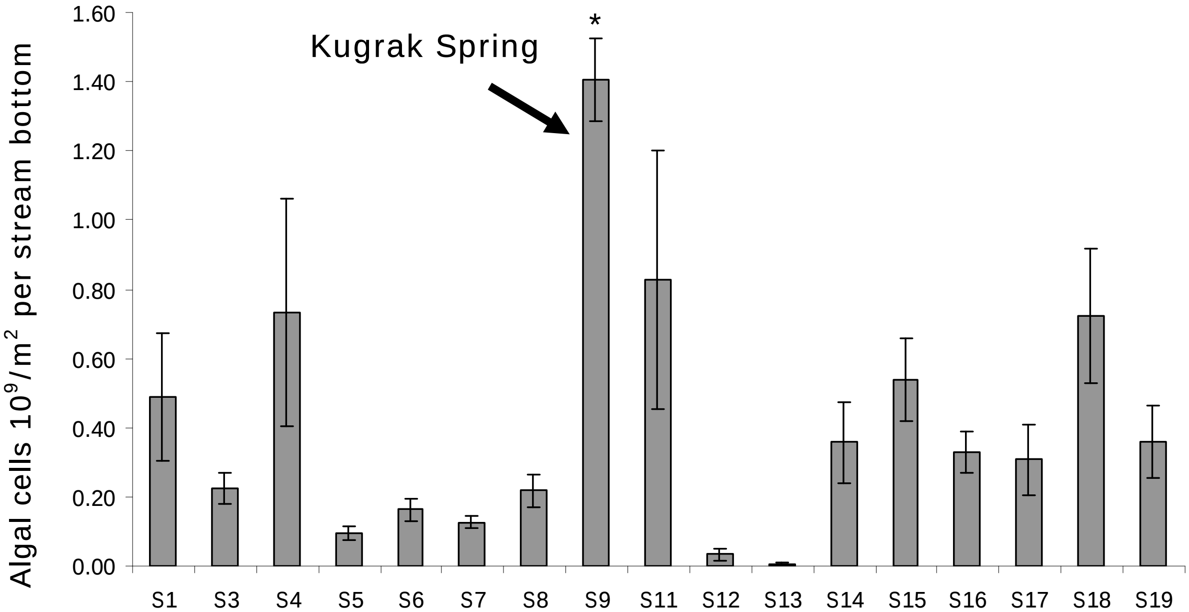


Figure B 7. Non-metric multidimensional scaling analysis of the invertebrate community data from the Noatak tributaries sampled in 2005 compared to streams sampled on the North Slope (Huryn, unpublished data).

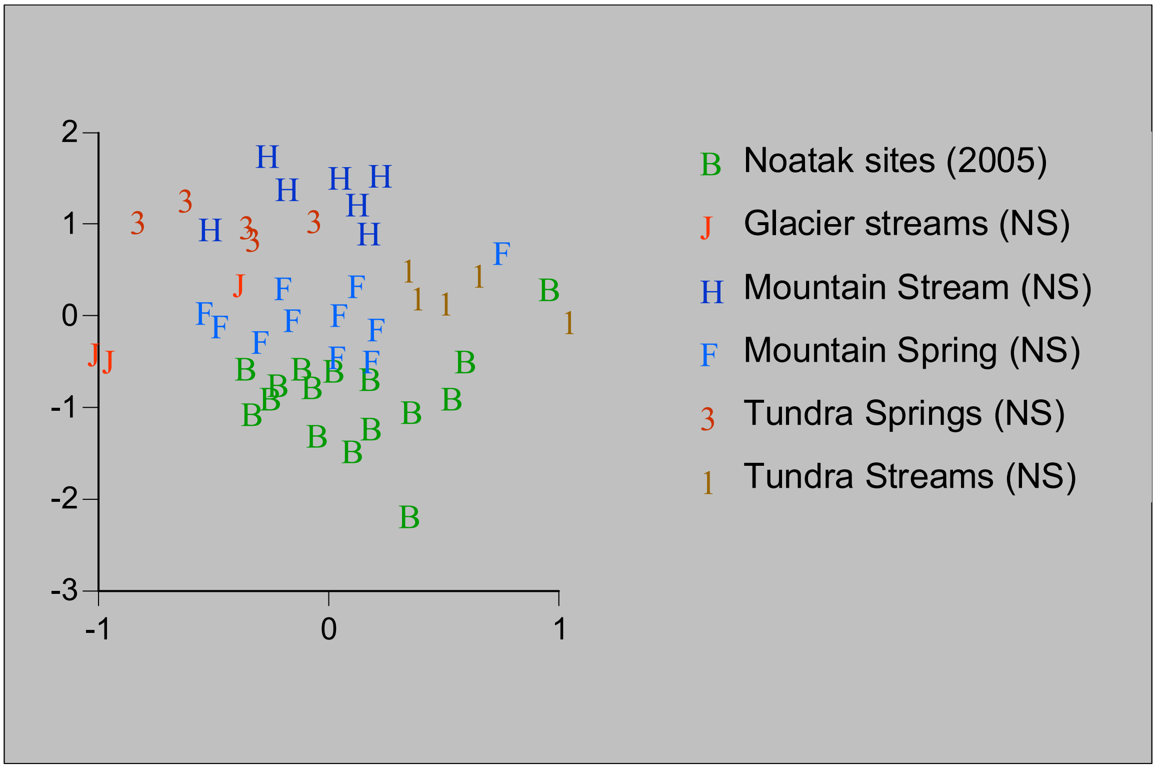
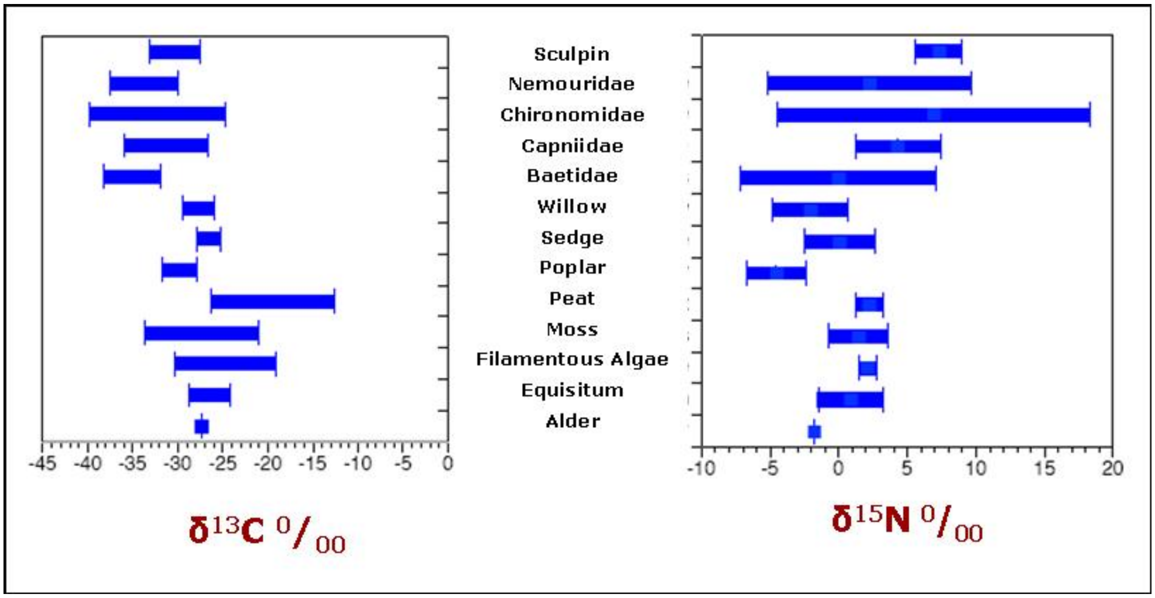


Figure B 8. Ranges of isotopic compositions of dominant vegetation and dominant macroinvertebrates along the Noatak River.



Appendix C. Lake data

Table C 1. -- Morphometry of twelve survey lakes. Elevation was estimated from GPS readings and USGS contour maps. Surface areas were estimated from GPS linked sonar readings, USGS maps ("*") and/or data from La Perriere et al. ("", 2003). Maximum depths were estimated from GPS linked sonar readings or maximum sampling depth documented during our 2005 survey ("*").**

Lake	Elevation (m)	Surface Area (Ha)	Volume ($1000\ m^3$)	Depth (m) Mean	Depth (m) Maximum
1 (12-Mile Slough)	572	7*	--	--	3.0*
2 (Portage)	570	19*	--	--	6.8*
3 (Mountain-Top)	1089	3*	--	--	2.0*
4 (Pingo)	540	96	957	3.19	8.8
		101*	--	--	8.0*
		70**	--	--	--
5 (Omeltavik)	540	126	1260	3.68	7.7*
		122*	--	--	--
6 (unnamed)	525	77	765	3.64	8.9*
		53*	--	--	--
7 (unnamed)	530	11*	--	--	5.2*
8 (unnamed)	582	3*	--	--	5.6*
9 (YOY-lake)*	520	0.4*	--	--	1.1*
10 (unnamed)	520	1*	--	--	2.1*
11 (Matchurak)	502	353	88500	9.4	20.3
		350*	--	--	25*
		280**	35000	12.5	25**
12 (Kipmik)	740	290**	25000	8.6	45**

Table C 2. Total phosphorus (TP), total nitrogen (TN), TN:TP and chlorophyll-a (Chl-a) from an integrated sample of the epilimnion of lakes located in the upper Noatak River basin. Estimates of water clarity (secchi depths) are from 2005 survey, 1993-1995 Survey (LaPerriere 2003) and 1973 survey (O' Brien and Huggins 1974). Bold type indicates water quality parameters considered oligotrophic according to trophic boundaries recommended by Nürnberg 1996 (see Table 3).

Lake	Sampling Date	TN (µmols)	1973 (1-2m)	TP (µmols)	1973	TN:TP	Chl-a (µg/L)	Sechi Depth (m) 2005	1993-95	1972
L1 - 12 Mile	14-Jul-05			0.090			**1.4**	>2.8		
L2 – Portage	15-Jul-05	25.41		0.340		75	**1.4**	**>4.2**		
L3 - Mtn-Top	16-Jul-05		31.4				*12.4*	>2		
L4 – Pingo	17-Jul-05	*53.24*	45.7	0.477		112	6.3	3		*1.8*
L5 – Omeltavik	18-Jul-05	28.80		0.464		62	**1.1**	3		2.5
L6	20-Jul-05	37.96		**0.258**		147	**0.2**	**4**		
L7	20-Jul-05	*52.08*		0.492		106	**2.0**	~3?		
L8	20-Jul-05	*53.67*					**1.0**	2.5		
L9	21-Jul-05	**24.34**		**0.213**		114	**0.1**	>1.2		
L10	21-Jul-05	35.92		0.707		51	**1.0**	>2.5		
L11 - Matchurak	24-Jul-05	**19.71**		**0.194**		101	na	**10**		*1.6*
L12 - Kipmik	26-Jul-05	**11.30**		0.495		73	**0.9**	**6**		4.0

Table C 3. Recommended trophic thresholds for nutrient and chlorophyll concentrations, Secchi transparency, and hyplimnetic oxygen demand from Nürnberg (1996).

Boundary	TP (ug/L)	TN (ug/L)	Chl a (ug/L)	Secchi (m)	Hypolimnetic O2 demand (mg m^{-2} d^{-1})
Oligotrophic	< 10	< 350	< 3.5	< 4	< 252
Mesotrophic	10-30	350-650	3.5-9	4-2	252-398
Eutrophic	30-100	650-1200	9-25	2-1	398-550
Hypereutrophic	> 100	> 1200	> 25	> 1	> 550

Table C 4. Pearson Correlation Coefficients relating landscape and morphometric variables (surface area (SA), maximum depth (Z_MAX), elevation (ALT)) to Chemical (total nitrogen (TN), Total Phosphorus (TP), TN:TP, pH, Dissolved Oxygen (DO), Specific Conductivity (SP_COND), Salinity (SALIN), Physical (PAR), and biological variables (chlorophyll (CHL) and zooplankton biomass) measured the epilimnion of twelve study lakes. Below the correlation coefficient is the p-value (Prob > |r| under H0: Rho=0) and the number of observations.

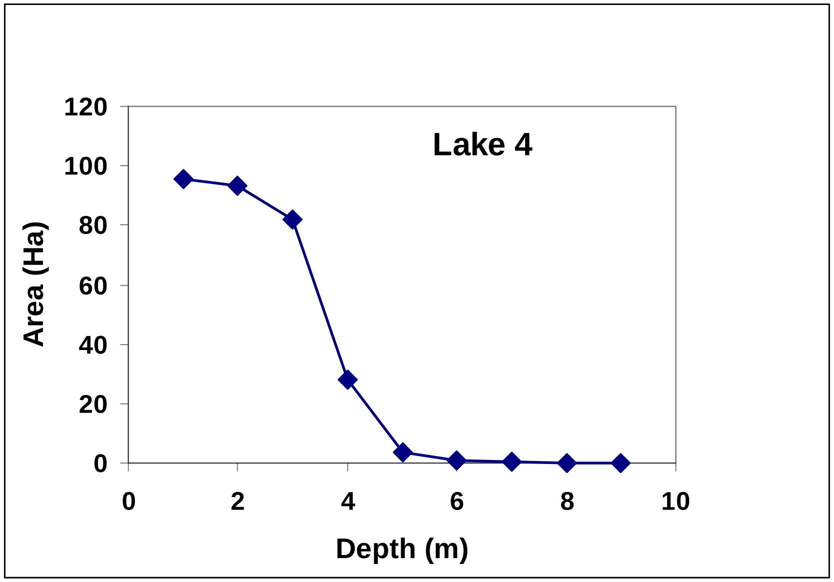
	SA (Ha)	Z_MAX (m)	ALT (m)
TN	-0.59587 0.0691 10	-0.61188 0.0601 10	-0.38459 0.2725 10
TP	-0.10306 0.7769 10	0.07724 0.8320 10	0.17050 0.6377 10
TN:TP	-0.25873 0.5014 9	-0.49482 0.1757 9	-0.66822 0.0491 9
SECCHI	0.92009 0.0033 7	0.65606 0.1095 7	0.02266 0.9615 7
TEMP	0.27197 0.3925 12	0.24860 0.4359 12	0.01045 0.9743 12
Ph	0.19815 0.5592 11	0.17297 0.6110 11	0.00280 0.9935 11
DO	0.26509 0.4050 12	0.27581 0.3855 12	-0.02876 0.9293 12
SP_COND	-0.41801 0.1763 12	-0.49784 0.0995 12	-0.14259 0.6584 12
SALIN	-0.32605 0.3010 12	-0.37389 0.2312 12	-0.15643 0.6273 12
PAR	0.25237 0.4287 12	0.23526 0.4617 12	-0.15618 0.6279 12
CHL	-0.43211 0.1844 11	-0.39516 0.2290 11	0.78291 0.0044 11
PEAK_CHL/EPI_CHL	0.86772 0.0005 11	0.60853 0.0470 11	-0.19627 0.5630 11
Cyclops	0.45433 0.1379 12	0.21718 0.4977 12	-0.26537 0.4045 12
Daphnia middendorfianna	0.34701 0.3602 9	0.46148 0.2112 9	0.01380 0.9719 9
Diaptomus pribilofensis	-0.27661 0.3841 12	-0.27757 0.3824 12	0.10245 0.7514 12

Heterocope septentrionalis	-0.24972 0.5170 9	-0.36728 0.3309 9	0.09145 0.8150 9
Nauplii	-0.39774 0.2004 12	-0.36322 0.2458 12	-0.15694 0.6262 12
Total	-0.39272 0.2067 12	-0.38325 0.2188 12	-0.06524 0.8404 12

Table C 5. Fish species captured or observed in twelve study lakes. Fish were captured by angling, gill net, sweep net or sculpin traps. An '*" indicates when fish were observed, only.

Lake	Arctic Grayling	Lake Trout	Round White Fish	Northern Pike	9-Spine Stickleback	Slimy Sculpin	Arctic Char / Dolly Varden
L1 - 12 Mile	X						
L2 - Portage	X		X				
L3 - Mtn-Top							
L4 - Pingo							
L5 - Omeltavik				X			
L6				X			
L7							
L8							
L9	X						
L10							
L11 Macharak		X	X		X		
L12 - Kipmik	X *		X				X *

Figure C 1. a) Hypsographic curve and b) bathymetric map for L4. Lake area at each one-meter depth contour was plotted from interpolation of GPS referenced acoustic depth measurements. Depth contours were plotted from interpolation of echosounding 18 July 2005. Note, small deep hole located in the eastern arm of the lake with depths of 5-7 m.



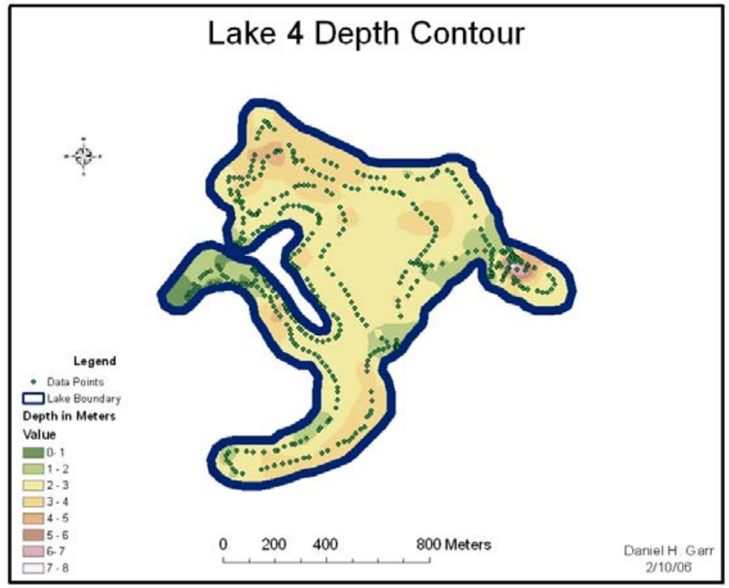
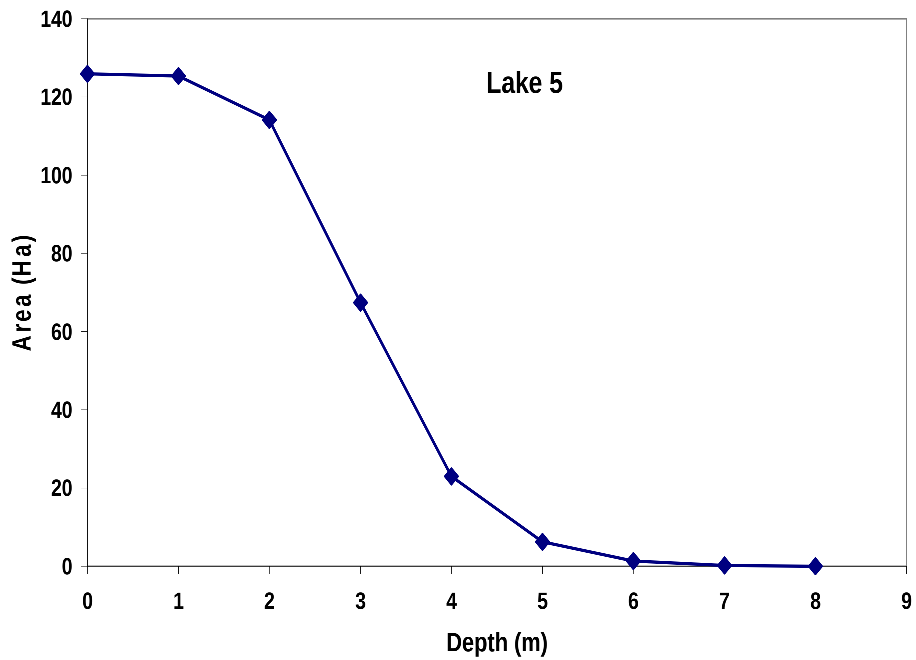


Figure C 2. Top. Hypsographic curve for Lake 5: the lake area at each one-meter depth contour was plotted from interpolation of GPS referenced acoustic depth measurements. b). Bathymetric map of Lake 5. Depth contours were plotted from interpolation of echosounding on 18 July 2005. Note island in center of lake in white.



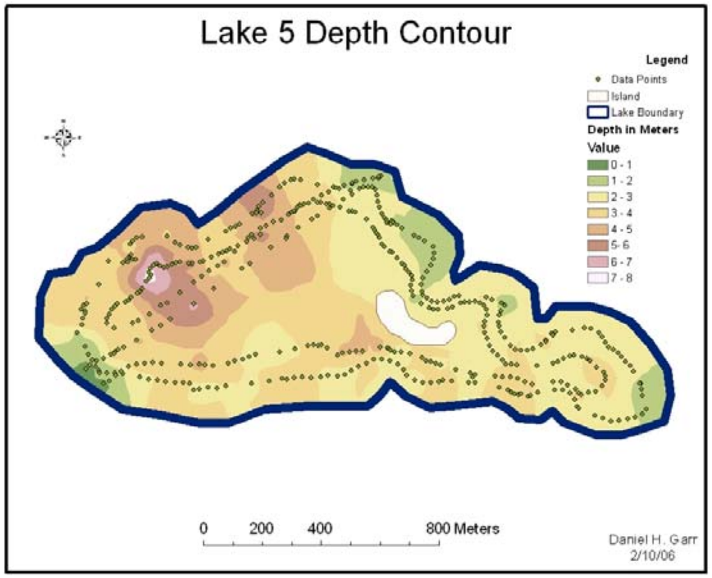


Figure C 3. Top. Hypsographic curve for Lake 6: the lake area at each one-meter depth contour was plotted from interpolation of GPS referenced acoustic depth measurements. b). Bathymetric map of Lake 6. Depth contours were plotted from interpolation of echosounding on 19 July 2005. Note deep spot at north end of lake in white.

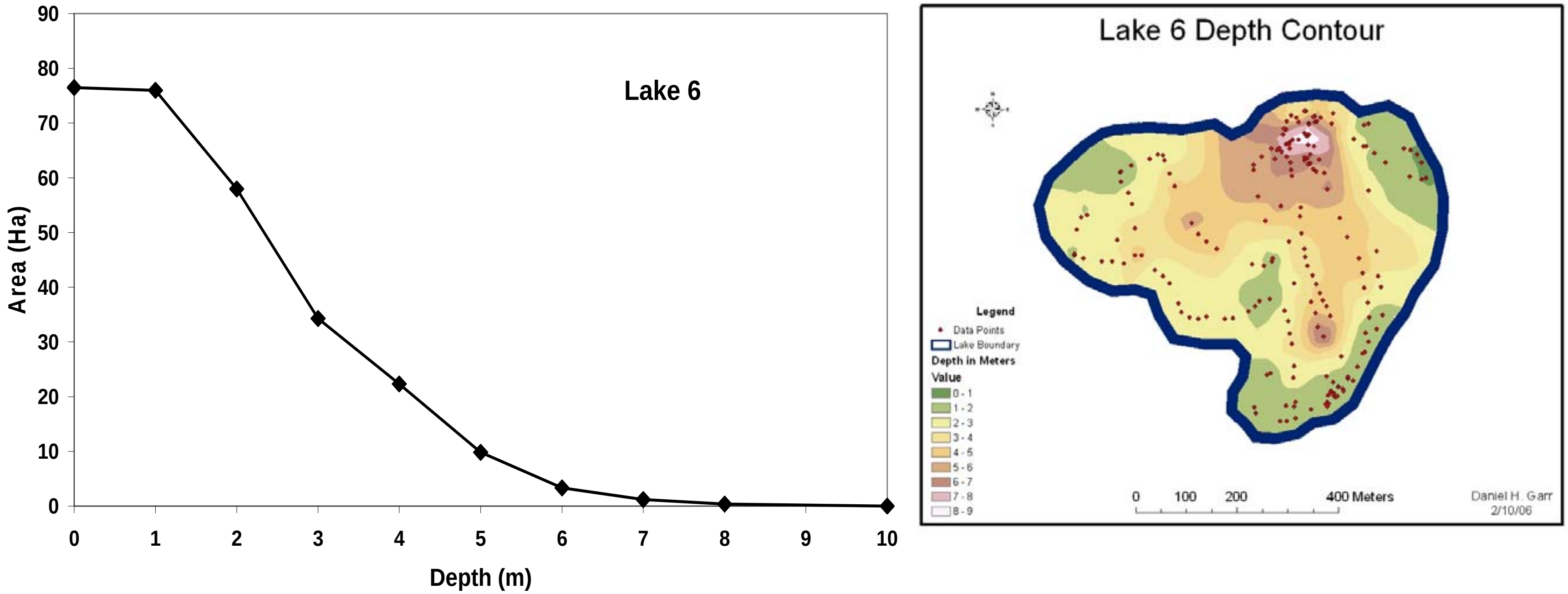
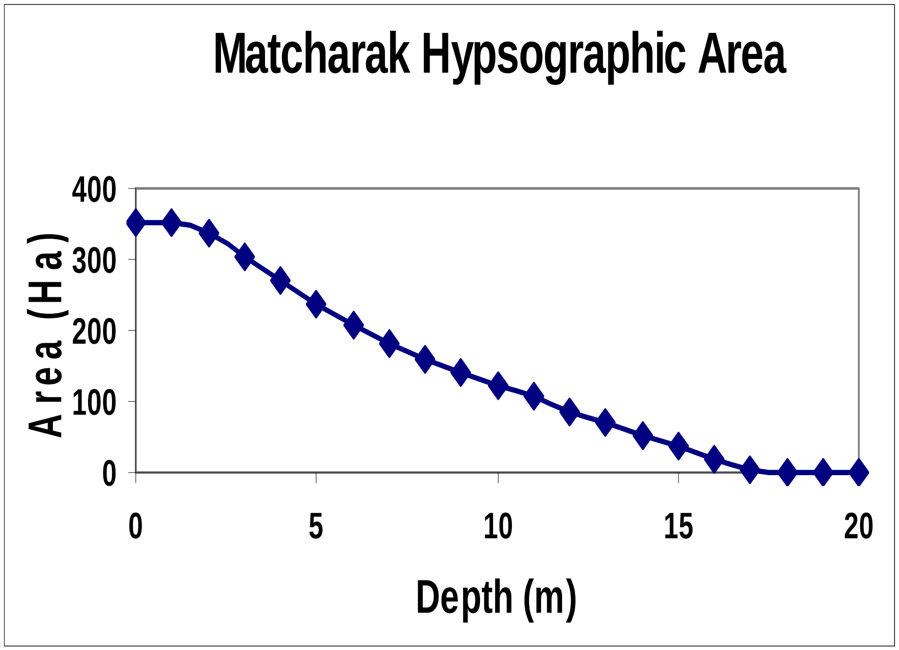


Figure C 4. Top. Hypsographic curve for Matchurak: the lake area at each one-meter depth contour was plotted from interpolation of GPS referenced acoustic depth measurements. b). Bathymetric map of Matchurak. Depth contours were plotted from interpolation of echosounding on 26 July 2005. Note the shallow north arm and the two central basins.



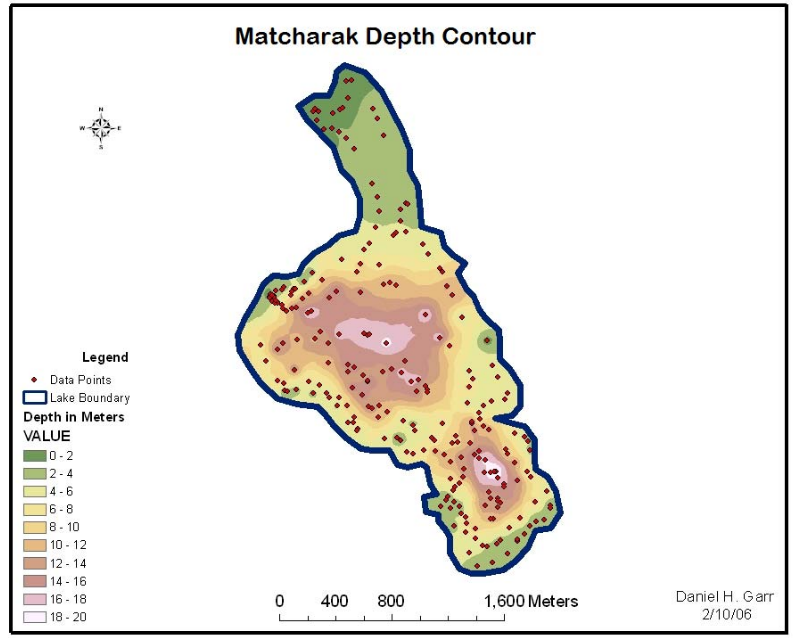


Figure C 5. Vertical profile of temperature, pH and dissolved oxygen measured at the deepest point in twelve lakes using a hydrolab. The X-axis is depth in meters.

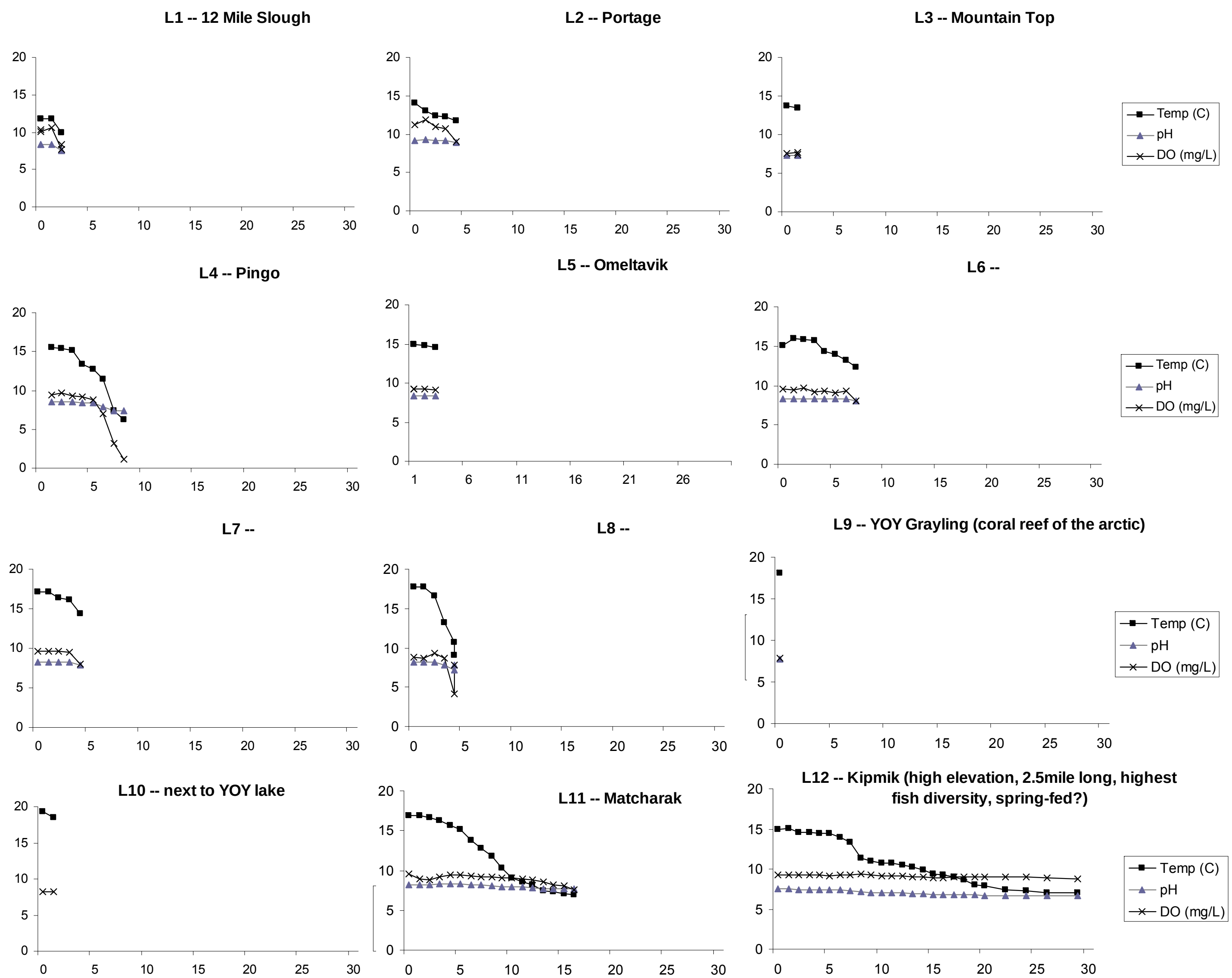


Figure C 6. Vertical profile of specific conductivity and salinity measured at the deepest point in twelve lakes using a hydrolab. The X-axis is depth in meters.

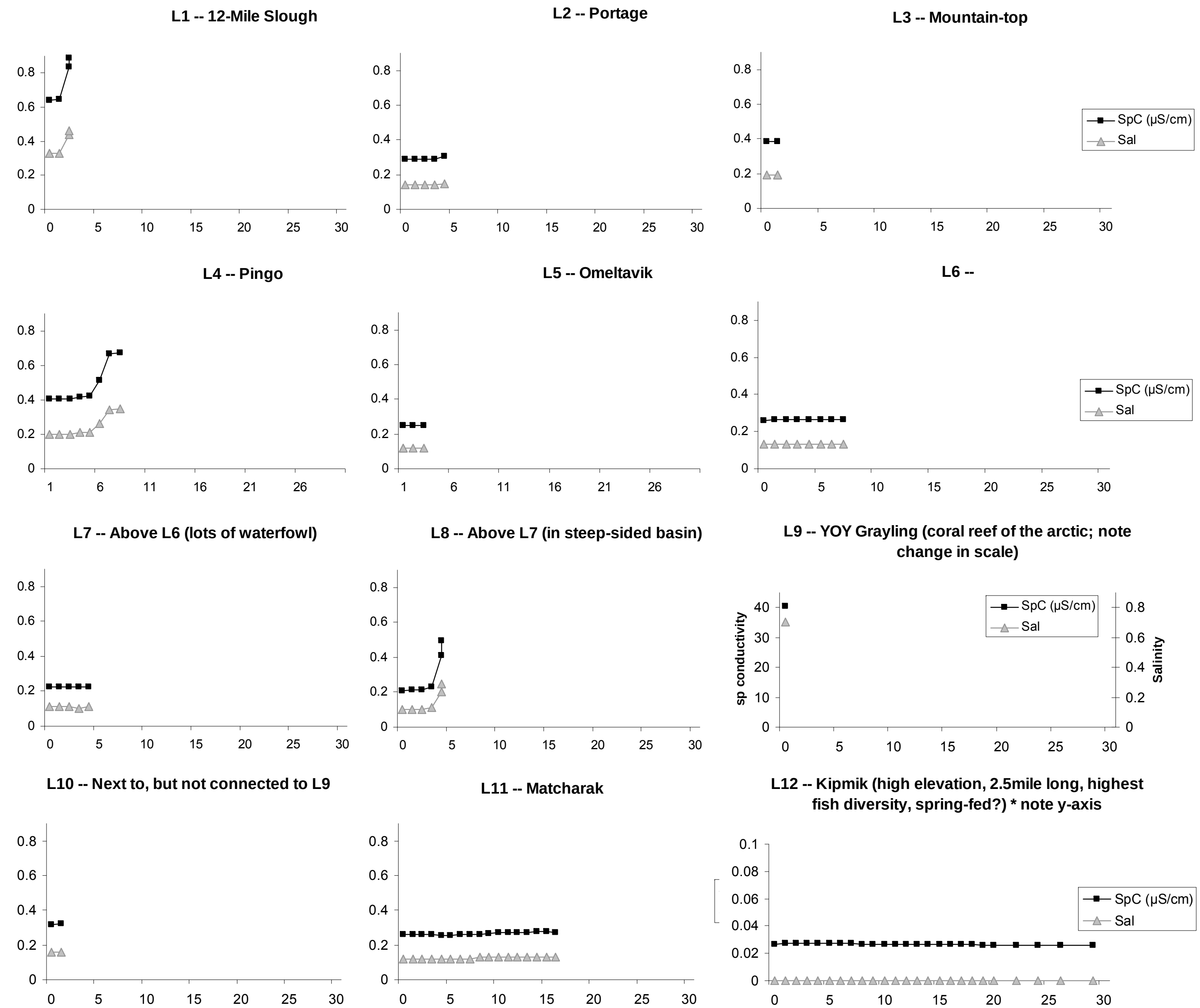


Figure C 7. Vertical profile of water-column chlorophyll-a measured at the deepest point in twelve lakes using a hydrolab (■) and an integrated sample of chlorophyll-a in the epilimnion measured using a fluorometer (X). The X-axis is depth in meters.

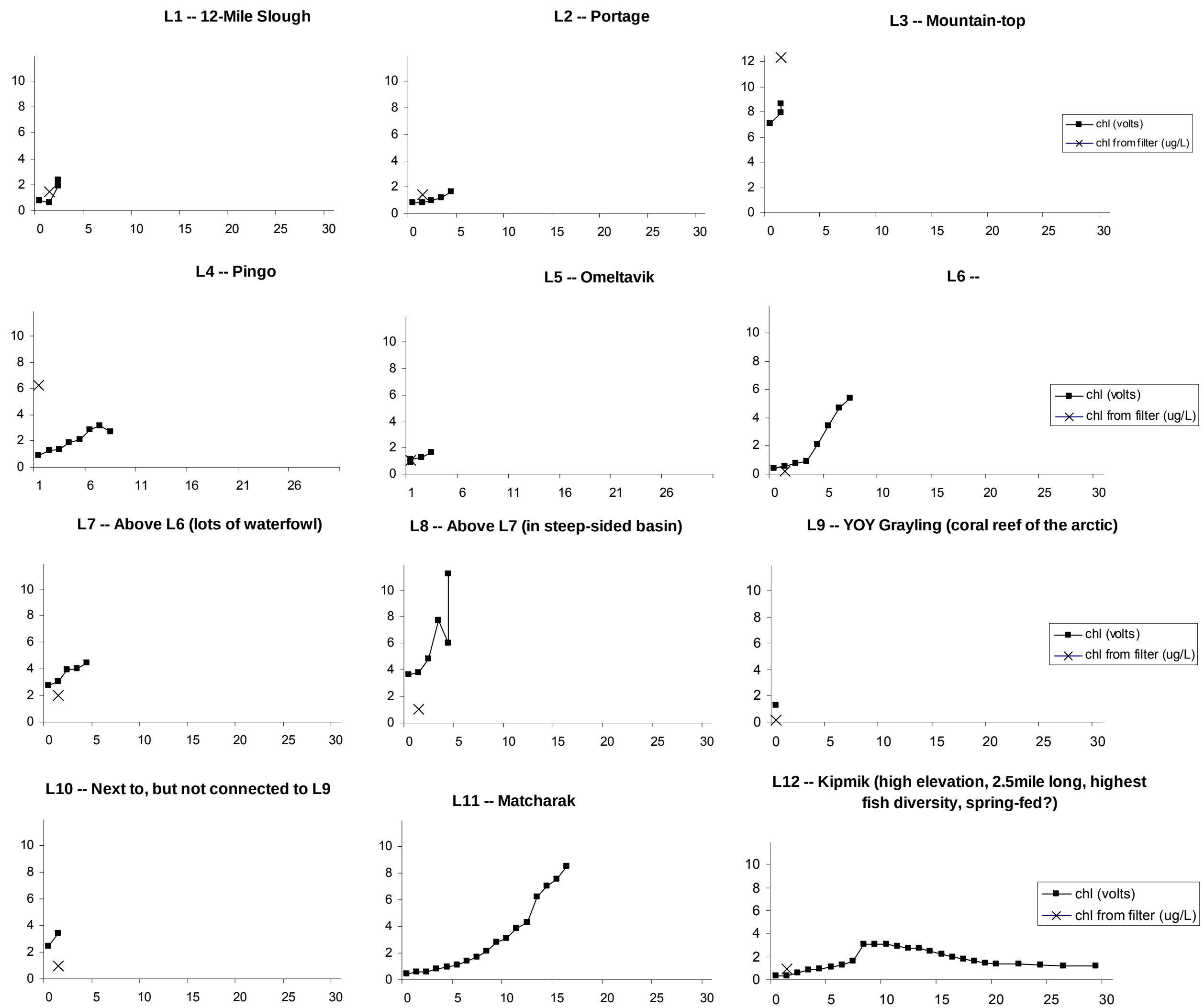


Figure C 8. Photosynthetically Active Radiation (PAR, µmol s^{-1} m^{-2}) in twelve study lakes.

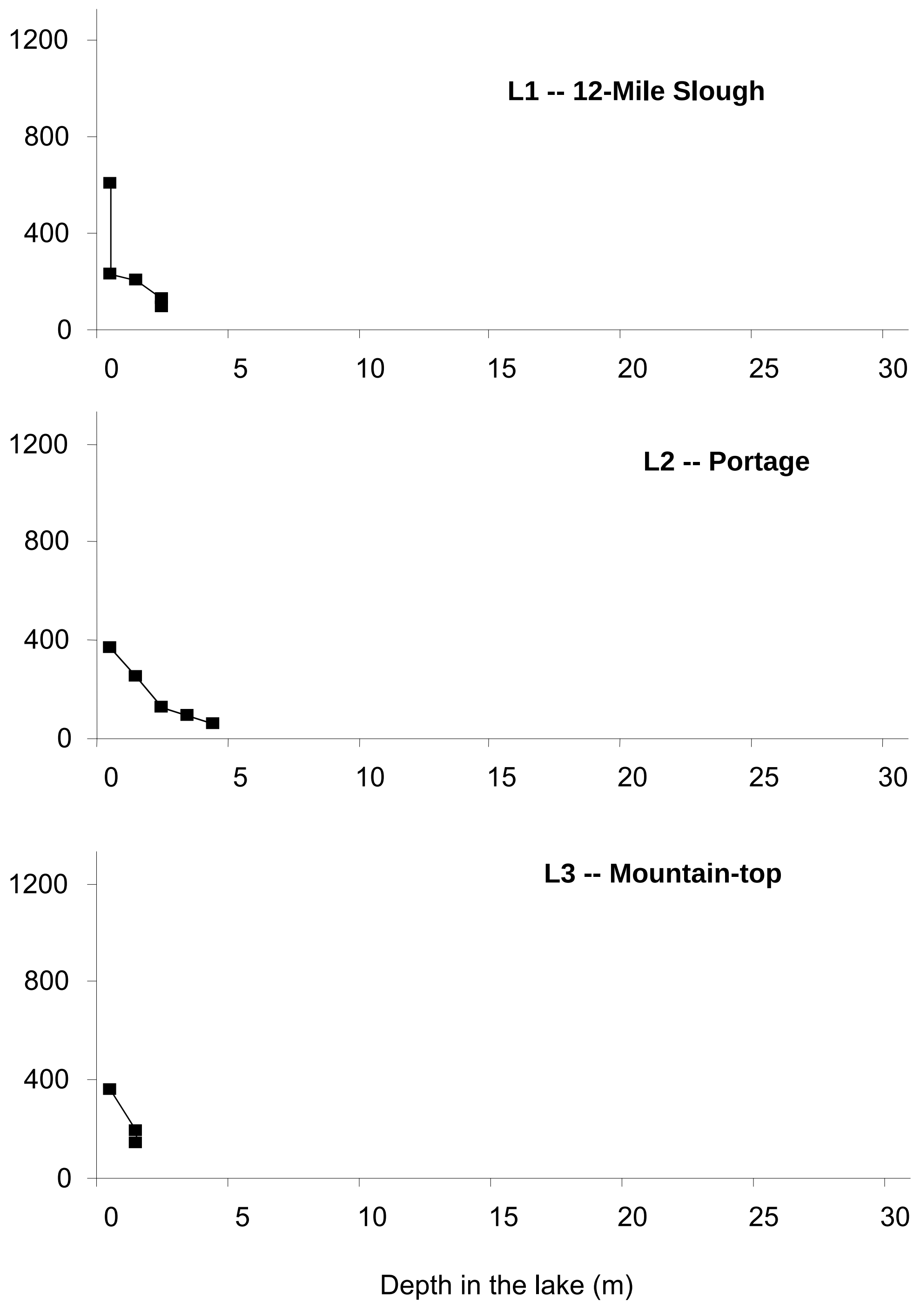


Figure C 9. Macro-zooplankton density (mean + standard error; n=3) in twelve study lakes.

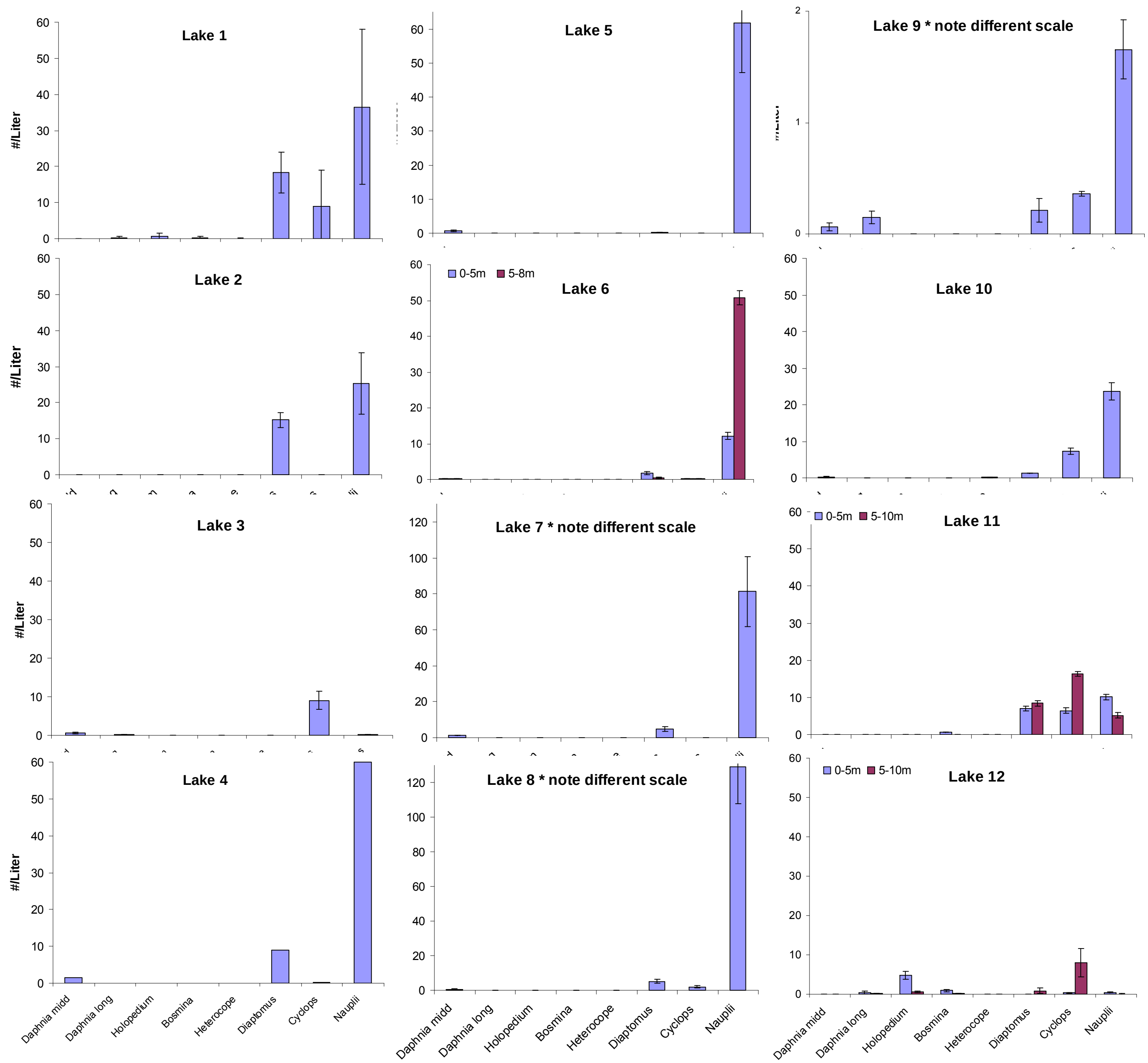


Figure C 10. Mean macro-zooplankton density in twelve study lakes.

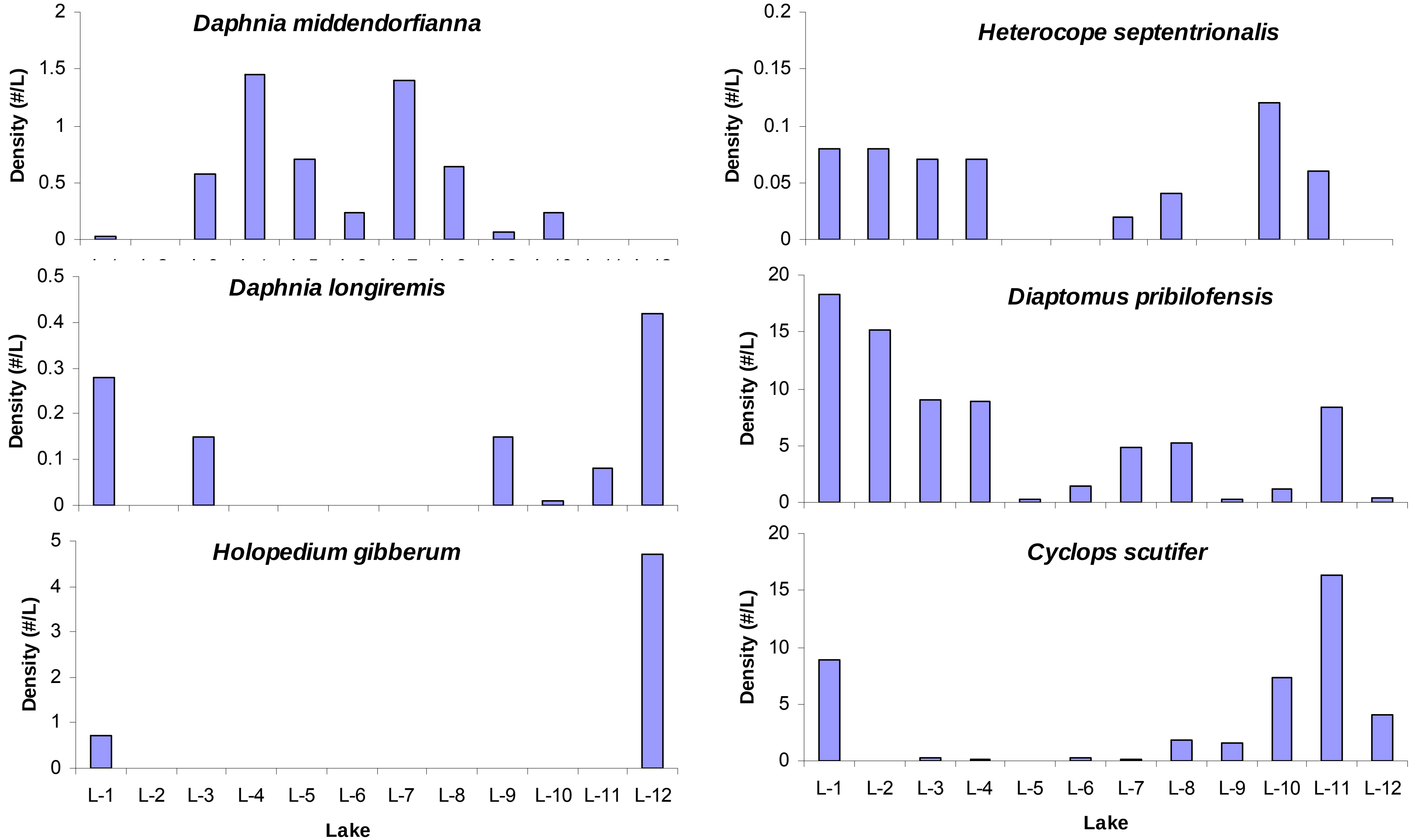
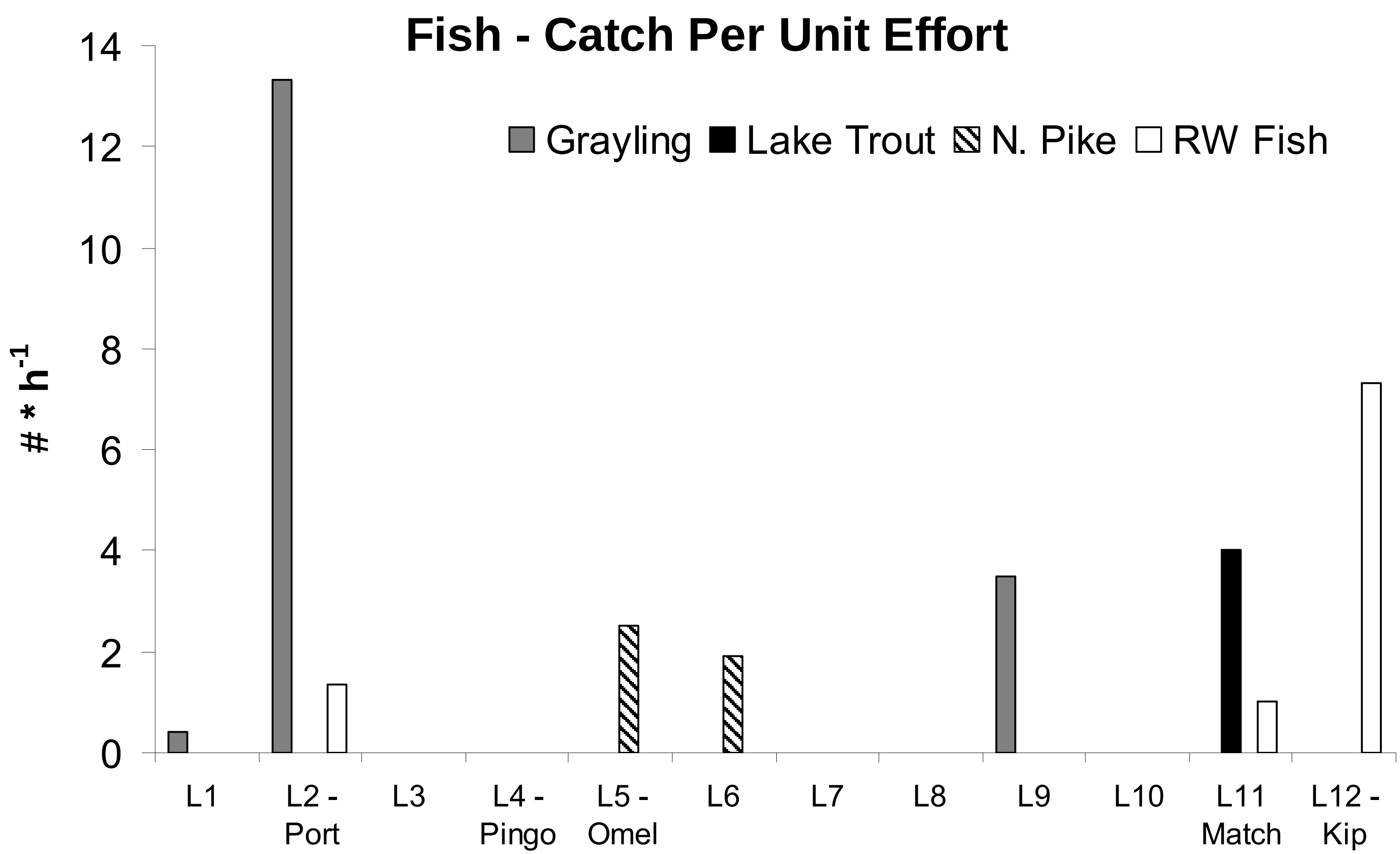


Figure C 11. Catch per unit effort (# fish caught / hours angling or gillnetting) for arctic grayling, lake trout, northern pike and round white fish captured in twelve study lakes.



Appendix D. Landscape Data

Table D.1. Physical Landscape Characteristics by Subwatershed. Each subwatershed delineated with USGS National Elevation Dataset (NED) at 1:63,360 scale using ArcGIS 9.0, and using each stream sample point as the 'pour point'.

Name	Kilometers of Stream					Stream Density	Avg. Segment	Confluences	Area	Slope (degrees)		
	Total	1st Order	2nd Order	3rd Order	4th Order	km/km^2	meters		km^2	mean	max	std
Stream 1	434	246	77	95	17	0.70	526	707	622	38	75	22
Stream 2	55	38	5	12	0	0.66	1128	48	83	28	56	16
Stream 3	4	4	0	0	0	0.67	4358	2	6	31	59	17
Stream 4	82	40	22	10	10	0.58	1029	77	142	27	53	16
Stream 5	82	40	22	10	10	0.58	1029	77	142	27	53	16
Stream 6	35	16	19	0	0	0.61	833	39	57	30	60	18
Stream 7	59	34	21	4	0	0.62	1369	50	95	28	55	16
Stream 8	15	12	3	0	0	0.45	1171	19	33	28	55	16
Stream 10	195	103	29	21	43	0.68	723	220	286	33	65	19
Stream 11	217	106	29	21	62	0.72	578	261	303	33	65	19
Stream 12	75	46	17	12	0	0.61	1437	54	123	27	53	16
Stream 13	12	9	4	0	0	0.43	2483	6	28	23	47	14
Stream 14	213	107	32	74	0	0.70	591	283	304	33	65	19
Stream 15	70	34	24	11	0	0.59	749	90	118	24	47	14
Stream 16	11	9	2	0	0	0.33	1627	8	33	25	53	15
Stream 17	13	13	0	0	0	0.28	13095	2	47	26	52	15
Stream 18	174	87	19	68	0	0.58	714	187	298	35	69	20
Stream 19	62	35	5	21	0	0.56	739	70	110	33	66	19
Stream 20	28	19	10	0	0	0.50	949	33	56	25	49	14

Table D.2. Land Cover Characteristics by Subwatershed. Each subwatershed delineated with USGS National Elevation Dataset (NED) at 1 : 63,360 scale using ArcGIS 9.0, and using each stream sample point as the 'pour point'. Land Cover data condensed from classes in NPS Land Cover Dataset for Gates of the Arctic National Park, 1999.

Name	Landcover (km^2)							
	Tall Shrubs	Shrub Tundra	Sparse	Herbaceous	Barren	Water	Snow/Ice	Indeterminate
Stream 1	51	76	210	32	223	1	12	17
Stream 2	7	9	26	4	34	0	0	3
Stream 3	0	0	2	0	3	0	0	0
Stream 4	16	24	60	10	31	0	0	1
Stream 5	16	24	60	10	31	0	0	1
Stream 6	3	4	14	3	29	0	1	5
Stream 7	11	22	28	6	26	0	0	2
Stream 8	2	3	13	2	10	0	2	1
Stream 10	12	26	72	13	147	0	5	12
Stream 11	14	28	76	15	153	1	5	12
Stream 12	6	26	45	10	34	0	0	3
Stream 13	1	7	14	3	3	0	0	0
Stream 14	24	43	91	18	112	2	3	11
Stream 15	7	34	51	14	12	0	0	0
Stream 16	2	4	15	2	10	0	0	0
Stream 17	2	4	18	2	18	0	0	1
Stream 18	16	38	95	17	119	0	3	11
Stream 19	4	17	44	2	26	0	0	16
Stream 20	3	19	20	7	3	5	0	0

Table D.3. Significant Relationships Among Landscape Parameters and Stream Characteristics

Stream characteristic	Landscape parameter	p	intercept	slope	R^2	obs.
Conductivity			Linear Regression			
EC (µS/cm)	Stream Density (km/km^2)	0.0074	-44.3061	789.2939	0.3525	19
	Total Stream Length (km)	0.0112	322.891	0.8628	0.3227	19
	Subwatershed Area (km^2)	0.0168	317.494	0.58441	0.2925	19
	Mean Subwatershed Slope (deg.)	0.0056	-302.835	24.31924	0.3716	19
	Barren Area (km^2)	0.0048	320.999	1.5837	0.3823	19
			Multiple Regression			
	Model	0.0295	8.8335		0.5138	19
	Stream Density (km/km^2)			457.678		
	Subwatershed Area (km^2)			0.7654		
	Mean Subwatershed Slope (deg.)			4.4919		
	Barren Area (km^2)			2.584		
Nitrates			Linear Regression			
NO_3 (µM)	Stream Density (km/km^2)	0.0479	10.91104	-6.47875	0.2229	18
Dissolved Organic Nitrogen			Linear Regression			
DON (TDN-NO_3)	Mean Subwatershed Slope (deg.)	0.0288	12.48394	-0.32113	0.265	18
	Vegetated Percentage	0.0054	-3.5768	0.1069	0.393	18
	Shrub Tundra Percentage	0.0044	-0.5325	0.2502	0.4069	18
	Shrub Tundra Area (km^2)	0.676	3.356	0.0143	0.0112	18
			Multiple Regression			
	Model	0.0097	5.085		0.4609	18
	Mean Subwatershed Slope (deg.)			0.1662		
	Shrub Tundra Percentage			0.199		

Table D.4. Significant Relationships Among Landscape Parameters and Stream Characteristics

Stream characteristic	Landscape parameter	p	intercept	slope	r^2	obs.
Conductivity		Linear Regression				
EC (µS/cm)	Stream Density (km/km^2)	0.0074	-44.3061	789.2939	0.3525	19
	Total Stream Length (km)	0.0112	322.891	0.8628	0.3227	19
	Subwatershed Area (km^2)	0.0168	317.494	0.58441	0.2925	19
	Mean Subwatershed Slope (deg.)	0.0056	-302.835	24.31924	0.3716	19
	Barren Area (km^2)	0.0048	320.999	1.5837	0.3823	19
		Multiple Regression				
	Model	0.0295	8.8335		0.5138	19
	Stream Density (km/km^2)			457.678		
	Subwatershed Area (km^2)			0.7654		
	Mean Subwatershed Slope (deg.)			4.4919		
	Barren Area (km^2)			2.584		
Nitrates		Linear Regression				
NO_3 (µM)	Stream Density (km/km^2)	0.0479	10.91104	-6.47875	0.2229	18
Dissolved Organic Nitrogen		Linear Regression				
DON (TDN-NO_3)	Mean Subwatershed Slope (deg.)	0.0288	12.48394	-0.32113	0.265	18
	Vegetated Percentage	0.0054	-3.5768	0.1069	0.393	18
	Shrub Tundra Percentage	0.0044	-0.5325	0.2502	0.4069	18
	Shrub Tundra Area (km^2)	0.676	3.356	0.0143	0.0112	18
		Multiple Regression				
	Model	0.0097	5.085		0.4609	18
	Mean Subwatershed Slope (deg.)			0.1662		
	Shrub Tundra Percentage			0.199		

Figure D.1. Subwatershed Mean Slope vs. Conductivity

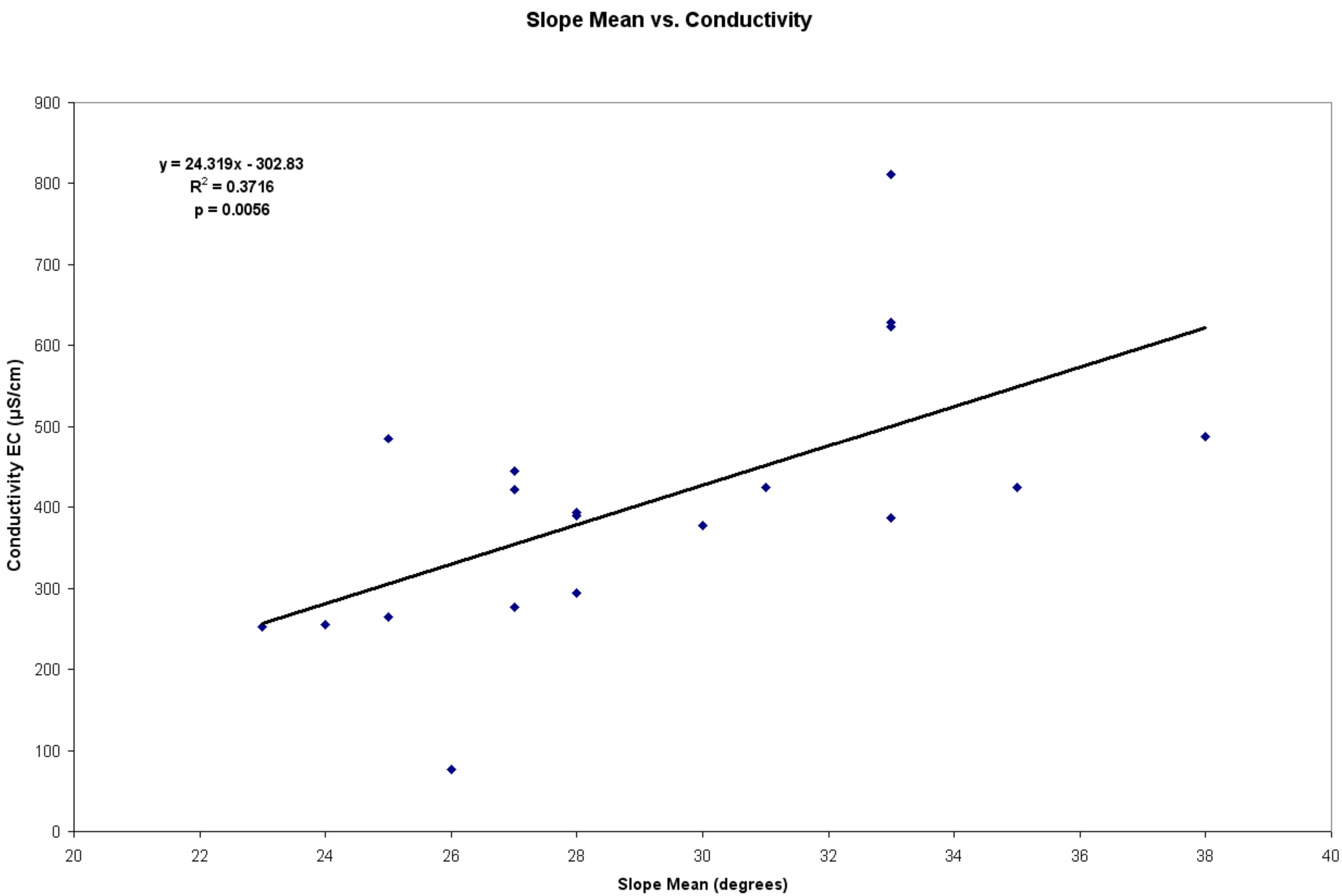


Figure D.2. Subwatershed Stream Density vs. Conductivity

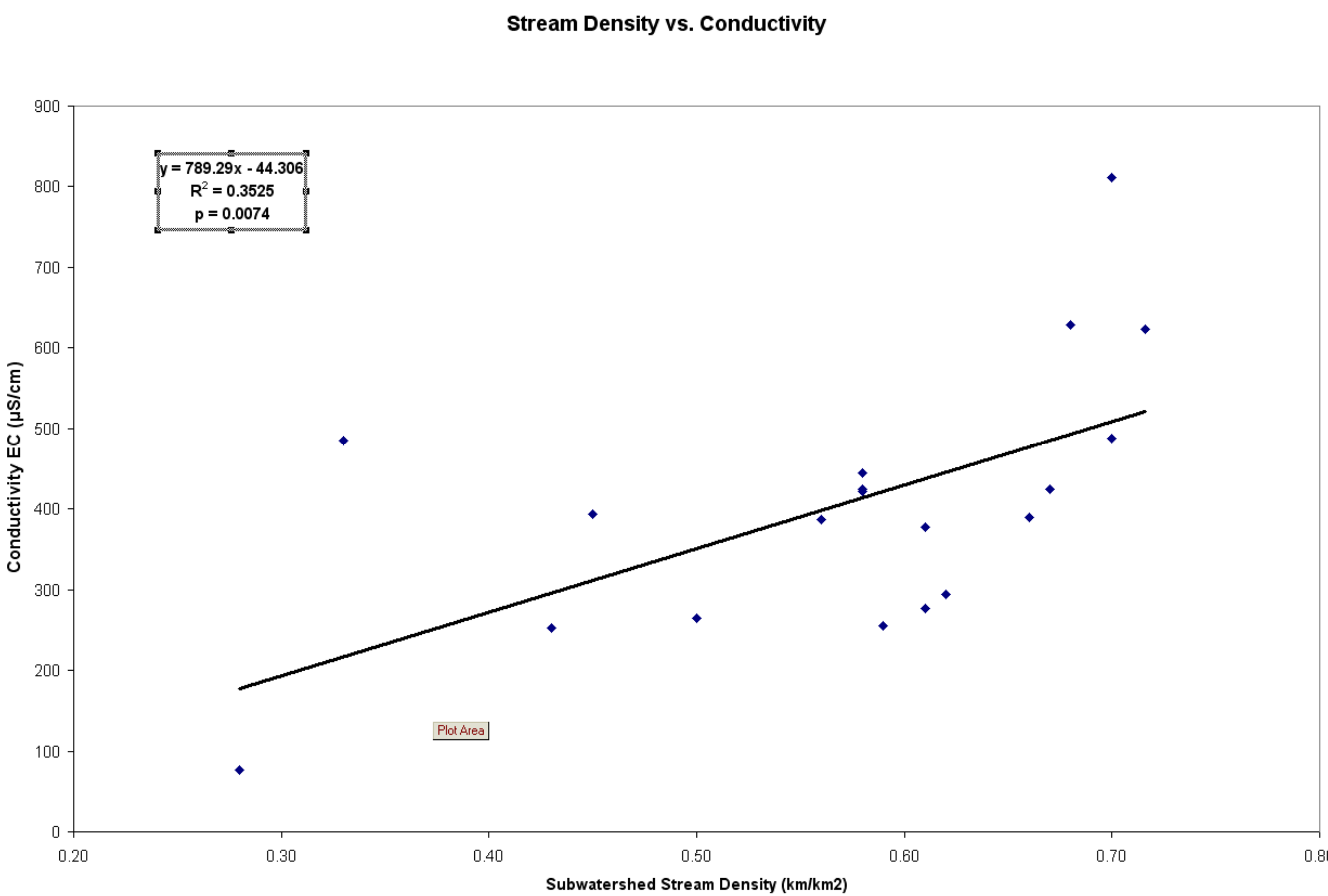


Figure D.3. Subwatershed Stream Density vs. Nitrates

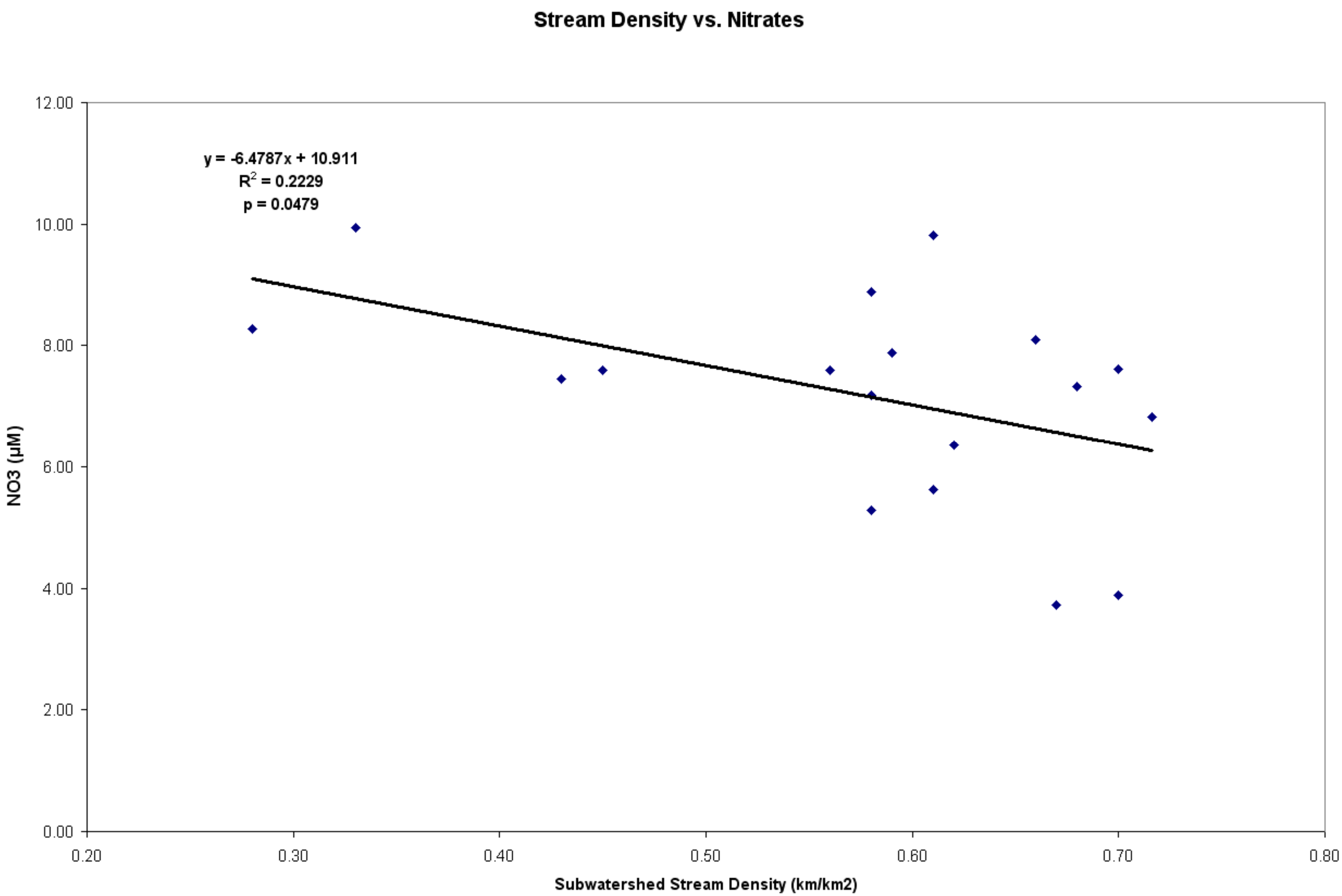


Figure D.4. Subwatershed Shrub Tundra Percentage vs. Dissolved Organic Nitrogen

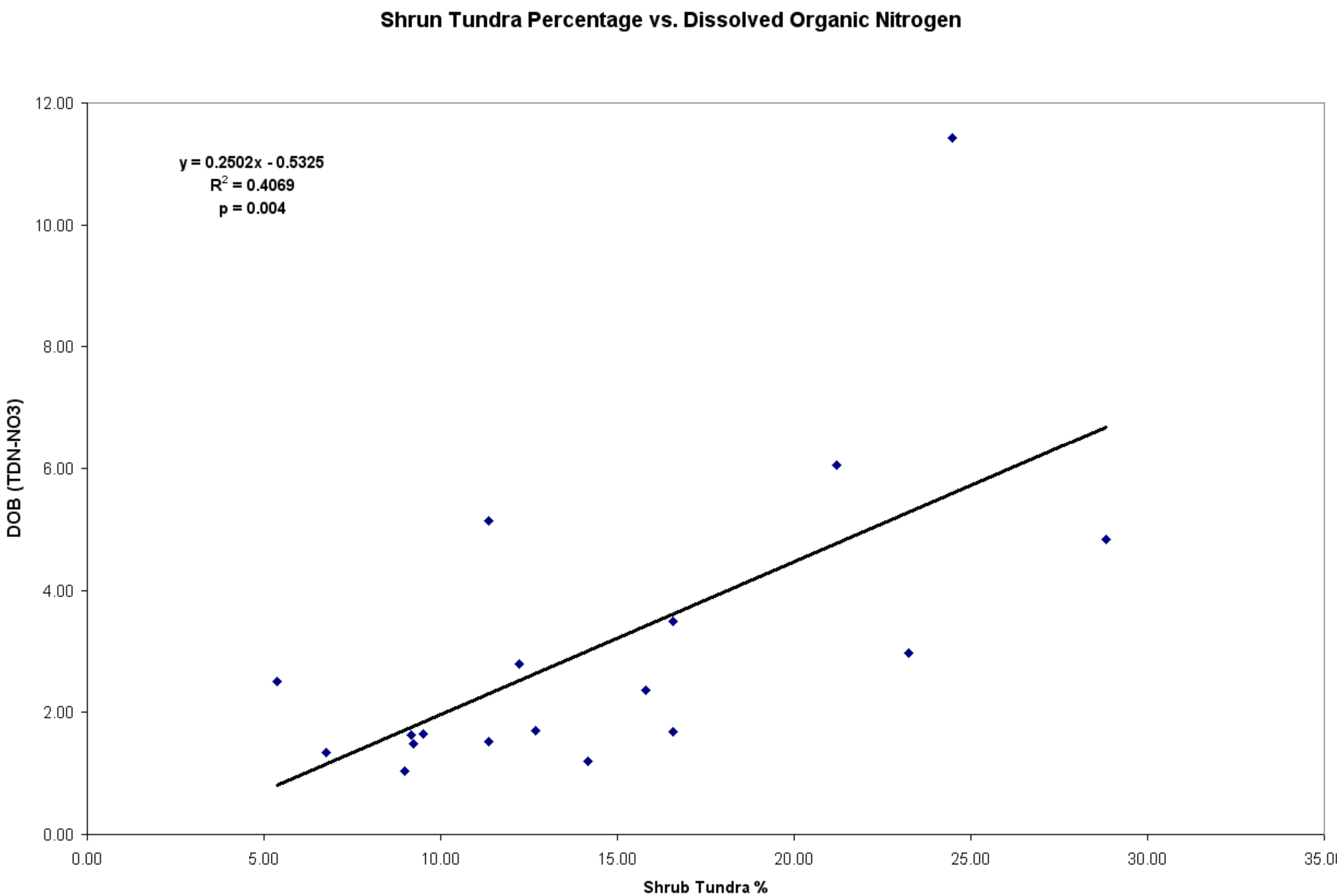


Figure D.5. Subwatershed Shrub Tundra Area vs. Dissolved Organic Nitrogen

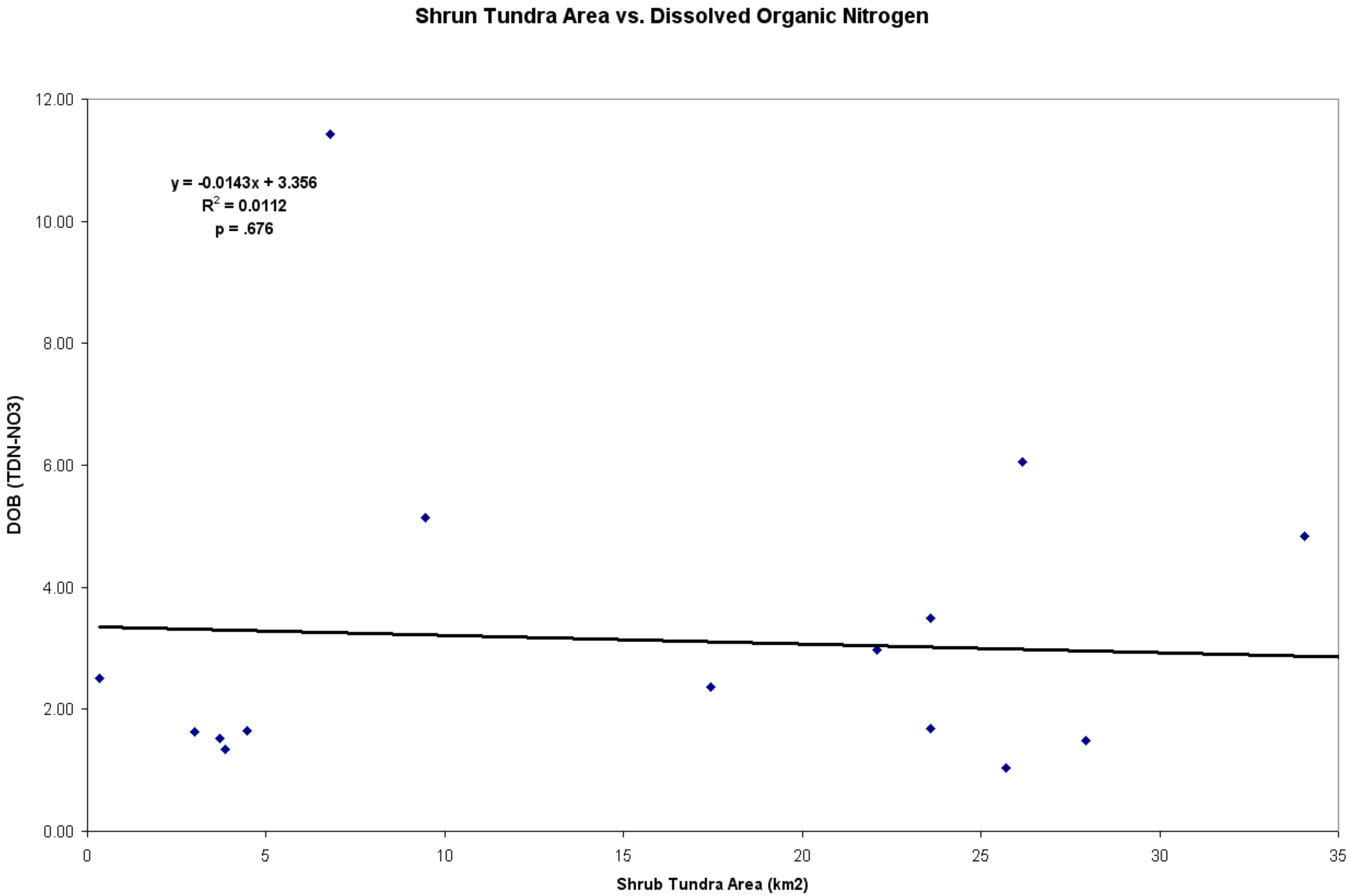


Figure D.6. Barren Area vs. Conductivity

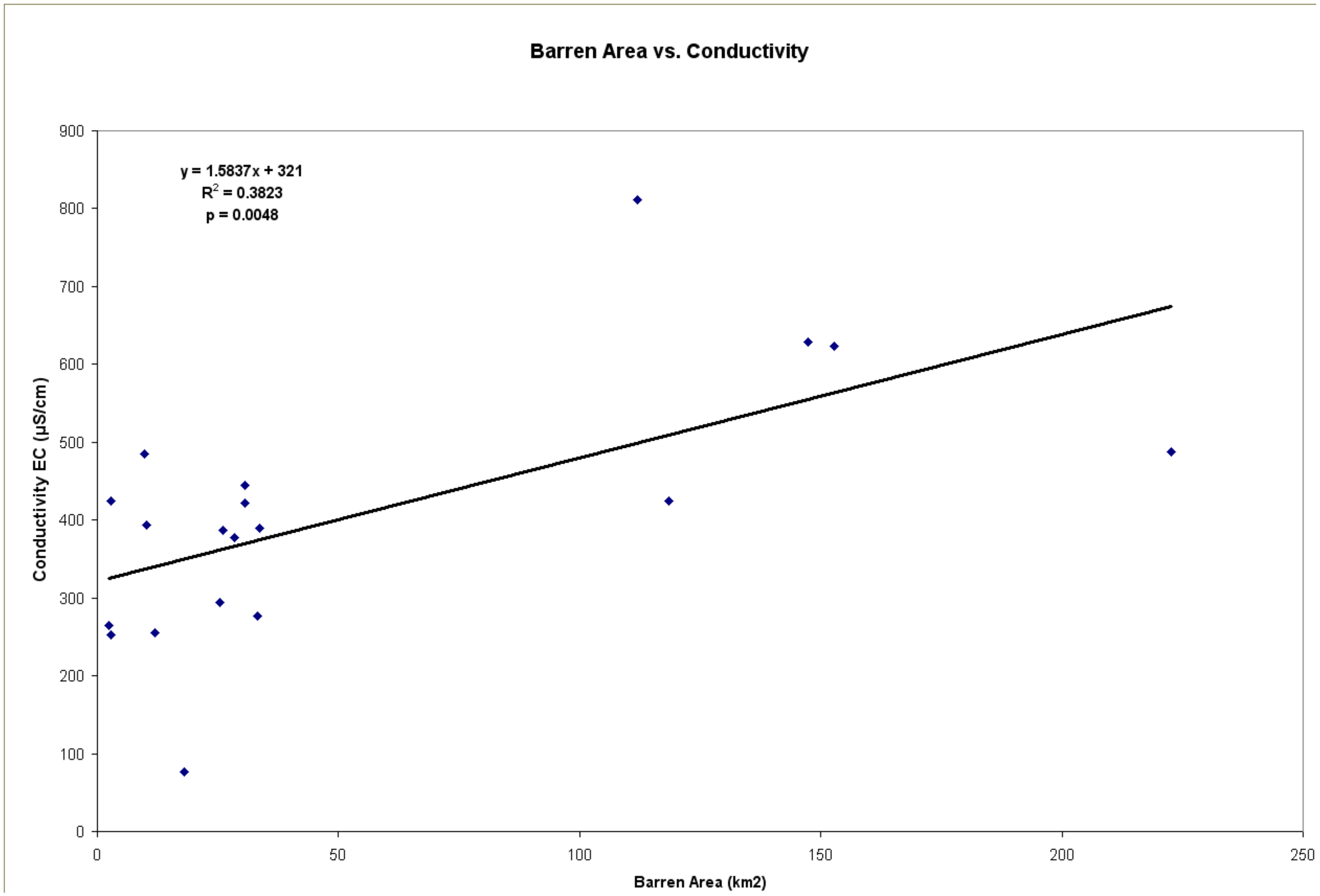
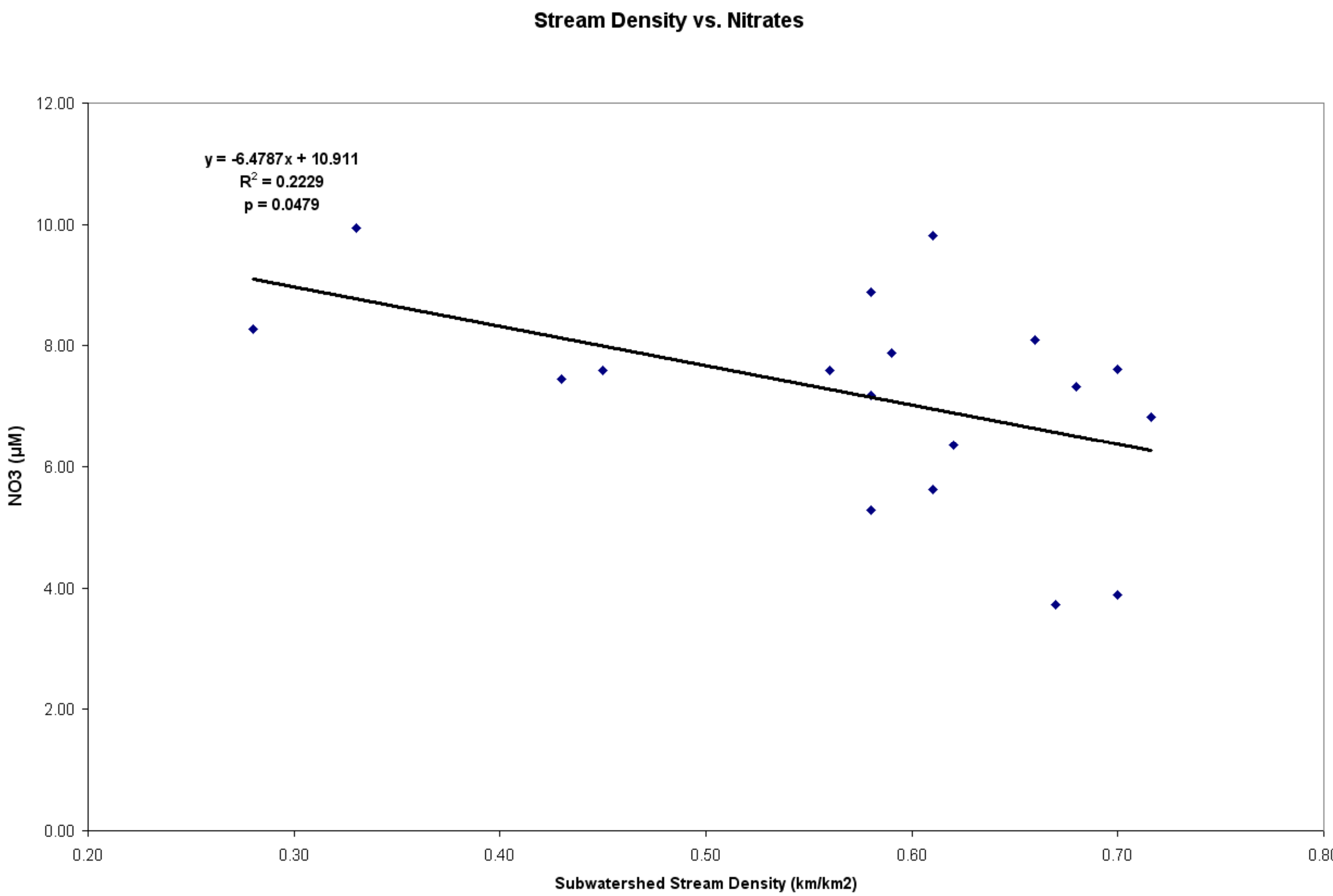


Figure D. 7. Subwatershed Stream Density vs. Nitrates



Appendix E. Ground Photo Transect Data

All ground photo transects are included in digital Appendix E. They are organized in separate folders by Site (Table E.1), and presented as contrast-adjusted jpg files, accessed through an index web page (index.htm) for each site. These online directories will remain available for an indefinite period at http://www.uaf.edu/toolik/gis/noatak/photos/lines. The National Park Service will retain these photos in archive, and may post them separately. The 'contact sheet' indices, organized by site and included as figures within this appendix, are intended as simple hard-copy references to provide the reader an indication of the content within each frame. They are not intended to provide the full level of information and detail available within each photograph.

Table E.1. Ground Photo Transects. All photographs and metadata included in digital Appendix E. Photos taken and catalogued by Andrew W. Balser

Site	Date	Coordinates (UTM meters, NAD27)	Bearing (degrees True)	Line	Frame Nos.
FL1A	7/14/2005	405452E, 7499911N, zone 5	135	A	1
FL1A	7/14/2005	405452E, 7499911N, zone 5	225	B	1
FL1B	7/14/2005	405556E, 7499901N, zone 5	240	A	1-4
FL1B	7/14/2005	405556E, 7499901N, zone 5	60	B	5-7
FG1B	7/14/2005	405792E, 7499958N, zone 5	225	A	1-8
FG1B	7/14/2005	405792E, 7499958N, zone 5	82	B	9-13
FS3A	7/15/2005	404191E, 7500636N, zone 5	60	A	8-16
FS3A	7/15/2005	404191E, 7500636N, zone 5	148	B	17-18
FS3A	7/15/2005	404191E, 7500636N, zone 5	240	C	19-22
FS3A	7/15/2005	404191E, 7500636N, zone 5	329	D	23-24
FS3A	7/15/2005	404191E, 7500636N, zone 5	24	E	25-29
FS3A	7/15/2005	404191E, 7500636N, zone 5	102	F	30-33
FS4A	7/15/2005	402133E, 7503734N, zone 5	73	A	1-5
FS4A	7/15/2005	402133E, 7503734N, zone 5	220	B	6-9
FS4A	7/15/2005	402133E, 7503734N, zone 5	240	C	10-12
FS4A	7/15/2005	402133E, 7503734N, zone 5	25	D	13-15
FS5A	7/15/2005	401883E, 7504327N, zone 5	90	A	1-5
FS5A	7/15/2005	401883E, 7504327N, zone 5	30	B	6-7
FS5A	7/15/2005	401883E, 7504327N, zone 5	176	C	8-10
FG2A	7/16/2005	398466E, 7508963N, zone 5	360	A	1-5
FG2A	7/16/2005	398466E, 7508963N, zone 5	64	B	6-8
FG2A	7/16/2005	398466E, 7508963N, zone 5	185	C	9-18
FG2A	7/16/2005	398466E, 7508963N, zone 5	145	D	19-24
FG2A	7/16/2005	398466E, 7508963N, zone 5	227	E	25-31
FG2A	7/16/2005	398466E, 7508963N, zone 5	255	F	32-35
FS7A	7/17/2005	395122E, 7507525N, zone 5	2	A	1-4
FS7A	7/17/2005	395122E, 7507525N, zone 5	45	B	5-8
FS7A	7/17/2005	395122E, 7507525N, zone 5	191	C	9-11
FS7A	7/17/2005	395122E, 7507525N, zone 5	227	D	12-14
FS8A	7/18/2005	388740E, 7503152N, zone 5	250	A	1-3
FS8A	7/18/2005	388740E, 7503152N, zone 5	185	B	4-5

Site	Date	Coordinates (UTM meters, NAD27)	Bearing (degrees True)	Line	Frame Nos.
FS8A	7/18/2005	388740E, 7503152N, zone 5	130	C	6-8
FL7A	7/20/2005	381366E, 7512283N, zone 5	46	A	1-5
FL7A	7/20/2005	381366E, 7512283N, zone 5	2	B	6-9
FL7A	7/20/2005	381366E, 7512283N, zone 5	310	C	10-11
FL7A	7/20/2005	381366E, 7512283N, zone 5	107	D	12-13
FL8A	7/20/2005	381206E, 7512851N, zone 5	68	A	1-5
FL8A	7/20/2005	381206E, 7512851N, zone 5	111	B	6-8
FL8A	7/20/2005	381206E, 7512851N, zone 5	133	C	9-11
FL8A	7/20/2005	381206E, 7512851N, zone 5	360	D	12-15
FL8A	7/20/2005	381206E, 7512851N, zone 5	305	E	16-18
FL8A	7/20/2005	381206E, 7512851N, zone 5	183	F	19-25
FL8A	7/20/2005	381206E, 7512851N, zone 5	142	G	26-28
FL8A	7/20/2005	381206E, 7512851N, zone 5	229	H	29-33
FL9A	7/21/2005	375103E, 7511322N, zone 5	177	A	1-3
FL9A	7/21/2005	375103E, 7511322N, zone 5	142	B	4-6
FL9A	7/21/2005	375103E, 7511322N, zone 5	109	C	7-9
FL9A	7/21/2005	375103E, 7511322N, zone 5	60	D	10-12
FL9A	7/21/2005	375103E, 7511322N, zone 5	34	E	13-15
FL9A	7/21/2005	375103E, 7511322N, zone 5	2	F	16-18
FL9A	7/21/2005	375103E, 7511322N, zone 5	320	G	19-22
FL9A	7/21/2005	375103E, 7511322N, zone 5	300	H	23-25
FL9A	7/21/2005	375103E, 7511322N, zone 5	249	I	26-28
FL9A	7/21/2005	375103E, 7511322N, zone 5	228	J	29-32
FL9A	7/21/2005	375103E, 7511322N, zone 5	panorama	PAN	33-54
FG3A	7/22/2005	374274E, 7513413N, zone 5	250	A	1-4
FG3A	7/22/2005	374274E, 7513413N, zone 5	224	B	5-10
FG3A	7/22/2005	374274E, 7513413N, zone 5	186	C	11-18
FG3A	7/22/2005	374274E, 7513413N, zone 5	144	D	19-24
FG3A	7/22/2005	374274E, 7513413N, zone 5	130	E	25-29
FG4A	7/24/2005	616927E, 7517555N, zone 4	173	A	1-4
FG4A	7/24/2005	616927E, 7517555N, zone 4	60	B	5-8
FG4A	7/24/2005	616927E, 7517555N, zone 4	19	C	9-12
FG4A	7/24/2005	616927E, 7517555N, zone 4	284	D	13-18
FG4A	7/24/2005	616927E, 7517555N, zone 4	96	E	19-22
FG4A	7/24/2005	616927E, 7517555N, zone 4	panorama	PAN	23-32
FL12A	7/26/2005	618887E, 7540689N, zone 4	general	GEN	1-7
FL12A	7/26/2005	618887E, 7540689N, zone 4	29	A	8-11
FL12A	7/26/2005	618887E, 7540689N, zone 4	295	B	12-15
FL12A	7/26/2005	618887E, 7540689N, zone 4	200	C	16-18
FL12A	7/26/2005	618887E, 7540689N, zone 4	general	GEN	19-21

Appendix G. GeoData

Table G.1. Primary Landscape and Spatial Datasets. These are only the most critical datasets for the landscape-level analyses. Many other datasets relevant to Gates of the Arctic National Park & Preserve and to the Noatak River basin are available, primarily through the National Park Service's GIS Data Store for the Alaska Region (http://www.nps.gov/akso/gis/). Data currency and availability frequently change; source websites should be checked for updated information prior to performing further analyses.

Dataset	Source	Scale	Year	Type	Themes	Metadata Digital Appendix G	Data File
2005 Aquatics Sites	Andrew W. Balser	n/a	2007	Geodatabase	Locations field measurements landscape metrics sources dates	Noatak_Aquatics_2005.htm	Noatak_Aquatics_2005.mdb (Digital Appendix G)
2005 Aquatics Ground Photo Lines	Andrew W. Balser	n/a	2007	Photographs	Landscape Landcover Aquatic features	photo_metadata.txt	Folders by Site (Digital Appendix E)
National Elevation Dataset (NED)	US Geological Survey	63,360	1999	Raster Grid	topography in meters 50m cell size	NED.htm	http://ned.usgs.gov/
National Hydrography Dataset (NHD)	US Geological Survey	63,360	n/a	Geodatabase	Hydrography Names Metrics	NHD.htm	http://nhd.usgs.gov/
Ecological Subsections Gates of the Arctic National Park & Preserve	US National Park Service	>250,000	2001	Shapefile	coarse scale landforms geology landcover	eco_subs_gaar.htm	http://www.nps.gov/akso/gis/
Landcover of Gates of the Arctic National park & Preserve	US National Park Service	~63,360	1999	Raster Grid	Landcover	Lc_gaar.htm	http://www.nps.gov/akso/gis/ (Digital Appendix G)